Essays on Macroeconomics

by

Xiaodan Gao

B.A., Zhejiang University, 2006
M.A., The University of British Columbia, 2007

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Abstract

This dissertation studies two important topics in macroeconomics. The first topic is on the corporate cash hoarding. The first two chapters analyze the cash-inventory tradeoff from two different but complementary perspectives and shed light on the causes of cash hoarding. The second topic is international business cycles. A new feature of capital market is introduced into a standard international business cycle model to account for the disconnect between theory and data.

The first chapter proposes an explanation for the joint dynamics of cash and inventory — the adoption of the Just-in-Time (JIT) system. I start by demonstrating the importance of JIT in shaping corporate cash. I then develop a dynamic stochastic model to analyze the mechanisms and quantify their impacts. In the model, both cash and inventory can serve as working capital. As firms switch over from the traditional operating system (Just-in-Case, JIC) to JIT, they allocate the resources freed up from inventory to cash, in order to ensure smooth transactions with suppliers. On average, this switchover accounts for 45% and 69% of the observed cash increase and inventory decline respectively.

The second chapter provides a complementary explanation for the cash-inventory joint dynamics. It models inventory as a reversible store of liquidity and studies the tradeoff between cash and inventory when a firm manages its liquidity needs. I argue that two key determinants of a firm's resource allocation decision are its market power and its exposure to risk. In the model, firms with lower market power and firms operating in riskier environments rely more heavily on cash rather than inventory. Model implications are supported by data.

The third chapter studies the role of limited asset market participation (LAMP) in explaining international business cycles. We show that when LAMP is introduced into an otherwise standard model of international business cycles, the performance of the model improves significantly, especially in matching cross-country correlations. To perform formal evaluation of the models we develop a novel statistical procedure that adapts the statistical framework of Vuong (1989) to DSGE models. Using this methodology, we show that the improvements brought out by LAMP are statistically significant.

Preface

The third chapter of this dissertation is a joint work with two members of my committee: Viktoria Hnatkovska and Vadim Marmer. As part of the training and under the supervision of both, I was involved in each stage of the project: collecting and managing data, constructing and numerically solving models, implementing statistical procedures to compare model performance and writing a subsection of the manuscript.

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The second person I owe a tremendous amount of gratitude to is my co-supervisor **Professor Viktoria Hnatkovska**. She fundamentally influences my views on macroeconomics, which is much richer, deeper and more interesting than simply deriving Euler equations and implementing computational algorithms. Her open-mindedness and unconditional support provide me with a high degree of freedom to choose my own research topics and help me discover my true research interests. I also appreciate her and Professor Vadim Marmer offering the opportunity to work with them on a project (the third chapter) and receive rigorous training in writing papers. Viktoria is a great supervisor. I remember those days when she asked me to write Euler equations on the whiteboard in her office and helped me develop intuition behind those mathematical symbols. All the training prepares me better for the job market. I am indebted to her for her guidance, time and patience.

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Another person I would like to extend my deepest and heartfelt thank-you to is **Professor Hiroyuki Kasahara**. Although not serving on my dissertation committee, Hiro is always available for questions. His thoughtful and detailed comments help to shape my research ideas and guide the work towards a more interesting and promising direction.

Big thanks to my colleagues at UBC as well: especially, **Haimin Zhang** for providing delicious food when my research crowd outs time spent in cooking and for sharing the joy and dividing the sorrow over the course of the past six years; **Andrew Hill** for his irresistible sense of humour — often appropriate sarcastic responses and timely self-deprecation, and his kindness in helping me with empirical questions; **Lori Timmins** for comforting me whenever I was sad and for delivering happy hours with Britney Spears' music; and **David Freeman** for his always serious and sincere suggestions whenever needed and for his help during the first year of the program. Having awesome colleagues like them makes the office full of fun and working more enjoyable.

I also wish to take this opportunity to thank my **family**. I thank my parents for their unconditional love and endless support, for trusting in me and all my decisions, and for tolerating my occasional mood swings and stubborn mind. I also greatly appreciate the warm hospitality from my grandparents, aunts, uncles and cousins. They make Vancouver my second home.

Lastly, I would like to thank NUS for offering me an exciting job and giving the whole six years a happy ending.

The completion of this dissertation is a long journey, filled with frustration, depression, tears and joy. It witnesses my growing up and getting stronger. It brings with a sense of closure, but more importantly, a feeling of a brand new start with new hopes and dreams.

Dedication

To my always encouraging parents;

to myself;

and to my half-gone youth.

Chapter 1

Corporate Cash Hoarding: The Role of Just-in-Time Adoption

1.1 Introduction

The build-up of the cash reserve in the U.S. corporate sector has captured considerable attention from academic researchers, policy makers and financial practitioners over the past few years, and has become one of the most hotly debated issues during the recent economic recession.[1] It raises concerns about resource misallocation from high productivity assets (physical capital) to low productivity assets (cash) in the corporate sector. This paper aims to understand the causes behind the rise in corporate cash holdings.

In this paper, I propose an explanation motivated by the simultaneous changes in cash and inventory in the data. As shown in Figure 1.1, for publicly traded U.S. firms, the average cash-to-asset ratio increased from 9.2% in the 1970s to 23.3% in 2011, and the inventory-to-asset ratio decreased from 24.3% to 10.1%. Despite the striking changes in both, the sum of these two ratios was relatively stable over the past thirty years. The substantial reduction in inventory is most commonly attributed to the widespread adoption of Just-in-Time (JIT) logistics since the early 1980s. Prior to the introduction of JIT, U.S. firms operated using the Just-in-Case (JIC) system which suggests that inventory be held for every possible eventuality. By contrast, JIT aims to eliminate buffer inventory in the production process. In light of the two facts described above: (i) the similar magnitude of the cash and inventory changes, and (ii) a significant inventory reduction as a result of JIT adoption, this study investigates the role of JIT in explaining

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[1] See, for instance, "Companies' cash piles: Show us the money", The Economist, July 1, 2010. It states that "if cautious firms pile up more savings, the prospects for recovery are poor". See also, "Corporate savings: dead money", The Economist, November 3, 2012.

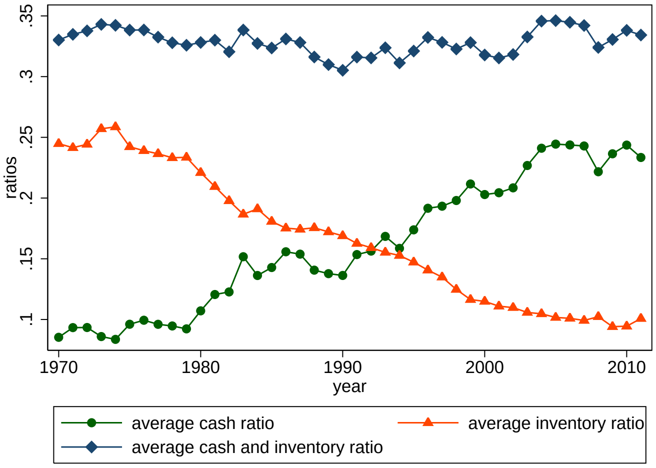

Figure 1.1: Average Cash and Inventory Ratio from 1970 to 2011 in the U.S.. The figure plots the average cash-to-asset ratio, average inventory-to-asset ratio and sum of those two ratios over time. The sample includes all Compustat firm-year observations from 1970 to 2011 with positive total assets and sales for U.S. manufacturing firms. Both cash and inventory ratios are winsorized between zero and one.

the observed cash increase.

I start by providing evidence that JIT implementation plays a role in shaping corporate cash policy. First, I use firm-level panel analysis to show that a one percentage point drop in inventory ratio is related to a 0.73 percentage point rise in cash, and that the change in inventory holdings is the most important factor associated with the (explained) cash increase. Second, with a sample of JIT adopters and their counterparts, I find that a firm's cash saving behavior in the post-adoption period is statistically different from that in the pre-adoption period. Implementing JIT leads firms to progressively accumulate cash. On average, firms increase their cash holdings by over six percentage points after ten years of implementation. Lastly, I show that the same patterns as those in Figure 1 are also found in Japan, UK and France.

After demonstrating the importance of JIT in understanding the increase in corporate cash holdings, I develop a model to explore the channels through which JIT implementation impacts cash and inventory. I then quantify their contributions. To keep the model tractable, I focus on input inventory only.[2]

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[2] When looking at the components of overall inventory, [25] find that the significant

In the model, a firm purchases material inputs for production. It holds cash to facilitate transactions with suppliers and holds inventory to economize on fixed adjustment costs and to avoid stockouts.[3]

More specifically, each period, the firm makes decisions on inventory adjustment, material input use, fixed capital investment, cash savings and dividend distributions. It faces productivity uncertainty and capital market frictions modelled by costly equity issuance, and is required to pay upon receipt of materials ordered. There are two operating systems with respect to inventory management — JIC and JIT. Under the JIC system, there is a lag between material orders and delivery. Although the firm adjusts its material input stock before production, new orders are unavailable for current period production. As a result, the firm adjusts inventory to anticipate future demand and carries inventory forward to avoid a stockout. By contrast, JIT allows the firm to respond contemporaneously to unexpected events. By adopting JIT, the firm adjusts inventory holdings with full information about the state of the economy and receives new purchases before production starts. Therefore, under the JIT system, the stockout motive for holding inventory is absent.

How does JIT adoption influence a firm's cash policy? Under JIT, the firm needs to pay for input purchases before current-period cash flow is available. The firm therefore has only two channels to finance its input purchases: internal cash balance and costly external financing.[4] To avoid

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decline in inventory in U.S. publicly traded firms over the 1981-2000 period was mainly driven by declines in material inventory and work-in-process inventory. Accordingly, I model input inventory only for tractability.

[3] In the model, I assume that both material inventory and work-in-progress inventory are inputs purchased from suppliers and JIT is narrowly defined as JIT-purchasing. In reality, work-in-process inventory are produced within firm due to production inefficiency. However, my story can also be applied to work-in-progress inventory and my results remain unchanged, if I model material inventory and work-in-process inventory separately and consider JIT-manufacturing. This is because, as firms switch over from JIC-manufacturing (production takes time and firms have to first transform materials into work-in-progress products and then transform those half-finished products into finished products) to JIT-manufacturing (firms can directly transform materials into finished products), they eliminate work-in-progress inventory but increase their material inventory. I illustrate and prove this statement in Appendix A.4. Therefore, implementing JIT-purchasing is a must for implementing JIT-manufacturing, otherwise firms simply shift resources from work-in-process inventory to material inventory, and the aim of getting rid of inventory is unaccomplished. Once firms implement JIT-purchasing, all material inventory would be replaced by cash, as shown in this paper.

[4] Here, costly external financing can be debt financing, equity financing, line of credit from banks, or short-term credit from suppliers, although in my structural model costly external financing takes the form of equity issuance.

raising expensive external funds, the firm preserves financial flexibility by building up its cash stock ([12]). In other words, to reduce costly inventory holdings (the objective of adopting JIT), the firm holds cash to fund its day-to-day operations.[5] As a result, cash replaces inventory as the main component of a firm's working capital.

My model delivers a negative cash-inventory correlation of similar magnitude to that found in the data. It predicts that if all firms in the economy switch from JIC to JIT, the average cash ratio will rise by 10.4 percentage points, while the inventory ratio will decline by 11.6 percentage points. Taking into account the fact that around two-thirds of U.S. manufacturers have adopted JIT by 2008, I find that the average cash and inventory ratios change by 6.9 and 7.1 percentage points respectively. That is, 45 percent of the observed cash increase and 69 percent of the inventory reduction are attributable to the JIT adoption. Results are quantitatively very similar after controlling for self-selection bias. Hence, almost half of the corporate cash increase can be rationalized by the adoption of JIT.

Previous studies typically view the increase in firms' idiosyncratic risk as the main driver behind the observed cash increase (see for example, [11]).[6] I use my model to investigate whether this explanation is sufficiently strong to quantitatively account for the trend. I find that firms would raise their cash ratios by just 0.8 percentage points if risk doubled. This result indicates that the considerable increase in corporate cash is better explained by the transaction motive for cash saving stemming from JIT adoption, rather than the precautionary motive linked with the increased idiosyncratic risk.

I also use my structural model to explore whether the adoption of JIT increases firm value, and to examine how firm characteristics generate heterogeneity in the benefits from JIT adoption. These analyses respond to the mixed empirical evidence on the association between JIT adoption and firm performance.[7] My results suggest that all firms benefit from implementing JIT, and smaller firms gain more relative to the larger. On average, implementing JIT increases firm value by 47.4% in the long run.

My work fits into three broad streams of literature. First, it contributes

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[5] According to [78], taking into account service costs, storage costs and risk costs, inventory carrying costs are 19%-43% of total inventory.

[6] The rise in the average firm-level volatility is well documented in the literature. See for example, [22], [31], and [56].

[7] [10] compare a sample of adopter and non-adopters over the period 1985 to 1989 and conclude that on average there is no significant positive effects of JIT on short-term return on assets. [54] and [60], on the contrary, find that firms adopting JIT outperform their matched non-adopters, in terms of earnings per share and profit margin.

to the cash literature by helping understand the reasons behind the significant rise in corporate cash over the past thirty years.[8] It explores the role of JIT and finds that it can explain over half of the trend. [11] also highlight the change in inventory as an important factor in understanding cash hoarding. However, their study does not explore the drivers behind the negative correlation between cash and inventory. This paper proposes a channel through which cash and inventory behave in a way that is consistent with the empirical evidence.

Second, this paper complements recent cash studies by modelling cash as a source of working capital. There are a number of structural cash models focusing on the non-operational use of cash. In those studies, cash is modelled as a precautionary hedge against future uncertainty. In my model, cash serves two motives: non-operational use (precautionary savings) and operational use (working capital). When operating under the JIT system, firms hold cash not only to finance future capital investment, but also to purchase production inputs and facilitate operations. This is consistent with the survey evidence that a large portion of corporate cash savings is held for operational purposes (see [65]). Accordingly, it is of great importance to model operational cash.

Lastly, this paper adds to the JIT literature by relating it with firms' financial policies. To the best of my knowledge, no previous work on JIT links it with cash management. This is despite abundant evidence that JIT is an efficient approach to reduce inventory and therefore lower costs by freeing funds tied up in buffer stocks. How do firms allocate those released funds from inventory? My model suggests that firms choose to augment their cash stocks to maintain smooth operations. In addition, my work provides a structural framework to quantitatively evaluate the impact of JIT on firm performance. The advantages of this exercise relative to previous reduced-form empirical studies are twofold: (i) it can isolate other unobserved factors which possibly affect firm performance along with JIT, and (ii) it can help understand whether firms with heterogenous characteristics benefit differently from JIT implementation, particularly for firms of different sizes.

The remainder of the paper is organized as follows. Section 2 provides evidence that JIT implementation plays a role in shaping corporate cash policy. In Section 3, I develop a dynamic stochastic model in which a firm manages its cash, inventory and capital. Section 4 derives analytical solutions

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[8] There is a number of papers examining the cash hoarding behaviour of U.S. firms. An incomplete list includes [11], [71], [82], [5] and [19].

of a simplified model to highlight the intuition behind the inventory-cash substitution. Section 5 describes the calibration of model parameters and presents simulation results to evaluate the role of JIT in explaining corporate cash hoarding and in improving firm performance. Section 6 concludes and discusses policy implications.

1.2 Empirical Evidence

In this section, I use firm-level data to present empirical evidence regarding the effect of JIT adoption on firms' cash management. I start by showing the negative relationship between inventory and cash and estimating the fraction of the increased cash holdings associated with the reduced inventory. This in turn helps to infer the impact of implementing JIT on cash balance, given its role in eliminating inventory. I then focus on a sample of JIT adopters and non-adopters to directly investigate the difference between their pre-adoption and post-adoption cash saving behavior. At last, I show that similar patterns plotted in Figure 1 are also found in Japan, Germany and France.

1.2.1 Just-in-Time (JIT) Philosophy

Before showing the evidence of the importance of JIT in explaining the rise in cash holdings, I give a brief introduction to the JIT philosophy.

JIT is a philosophy of efficiency improvement, emphasizing the performance of activities based on immediate needs. Narrowly defined, it strives to eliminate excess inventory resulting from overproduction and waiting. JIT philosophy can be applied to both the purchasing stage and the production stage. JIT purchasing involves the speedy delivery of materials from suppliers once they are ordered, and the requirement for purchasing comes from manufacturing process. JIT manufacturing involves the production of goods to meet current needs, rather than anticipate future demand. JIT purchasing is a must for firms that implement JIT manufacturing. A delay in material delivery will affect the entire production process.

JIT strategy was first adopted by the Toyota manufacturing plants and then attracted a large number of followers in Japan by the mid 1970s. With Japanese manufacturing firms achieving high levels of international competitiveness in the early 1980s, JIT started capturing considerable attention in the U.S., and has been gradually adopted since then. Prior to the introduction of JIT, U.S. firms believed in Just-in-Case (JIC) philosophy. They held buffer stocks at every stage in the production process in order to meet unexpected demand fluctuations or production problems.

1.2.2 Cash and Inventory

Stimulated by the time-series patterns of the cash and inventory ratios illustrated in Figure 1, the first question I set out to answer is how important inventory is as an element linking with cash hoarding, after controlling for other factors that are usually taken into account to explain cash.

To answer this question, I use the baseline cash regression in [11] and make three changes to it. First, I separate inventory holdings from net working capital, in order to explicitly gauge the importance of the former. Second, I replace industry level risk with firm specific risk and control for industry fixed effects, so that I can use within-industry variations to identify the effect of risk on cash holdings. Lastly, I include cohort dummies which are constructed based on firms' IPO listing dates as well as time dummies. The cohort fixed effects are motivated by the fact documented in [11] that most recent listed companies on average hold more cash than older cohorts, and the year fixed effects are used to capture the common macroeconomic shocks across firms. The cash regression is therefore specified as follows,

$$\begin{aligned} cash = \alpha_0 + \alpha_1\, firm\ size + \alpha_2\, risk + \alpha_3\, inventory + \alpha_4' X + \sum industry \\ + \sum year + \sum cohort + \epsilon_1. \end{aligned} \tag{1.1}$$

In this regression, cash is the ratio of cash and short-term investments to total asset; firm size is defined as the natural logarithm of total asset; risk is computed as the standard deviation of annual operating cash flow to total asset for the previous five years; and inventory is measured as the ratio of inventory to total asset. Other explanatory variables X include market-to-book ratio, firm's operating cash flows, working capital net of cash and inventory, capital investment, and so forth. A detailed description of these covariates is provided in Appendix A.1.

The sample is constructed from Compustat Industrial Annual files, constituting an unbalanced panel of manufacturing firms (SIC 2000-3999) that covers 1980 to 2006.[9] To control for the outliers in the sample, I delete firms

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[9] I use a pre-crisis sample to ensure that estimation results are not driven by the Great Recession. I also run the same cash regression for wholesale and retail trade (SIC 5000-5999) and services (7000-8999). Results are presented in Appendix A.2.

with negative total assets and negative sales, and winsorize continuous variables. Leverage, cash, and inventory ratios are winsorized between zero and one. R&D, acquisition and capital investment ratios are winsorized at the top and bottom 1%. Cash flow ratio and net working capital are winsorized at the bottom 1%, and market-to-book ratio is winsorized at the top 1%. Table 1.1 reports descriptive statistics for these variables, which have similar characteristics to those in prior studies.[10]

Table 1.1: Summary Statistics

Table 1.1 presents descriptive statistics for the variables used in the estimation, and reports the mean, median, standard deviation, 25th and 75th percentile, and number of observations of each variable for manufacturing. The sample is constructed from Compustat Annual Industrial files over the period 1980-2006. A detailed definition of variables is provided in Appendix A.1.

Variables	Mean	Median	Std. Dev.	25%	75%	Obs.
Cash	0.19	0.08	0.24	0.02	0.27	78055
Inventory	0.19	0.17	0.14	0.08	0.27	78006
Size	4.23	4.10	2.54	2.50	5.87	78055
Risk	0.11	0.04	0.22	0.02	0.10	53646
Market-to-Book	2.28	1.20	3.60	0.78	2.18	67494
Cash flow	-0.12	0.06	0.62	-0.06	0.12	78055
Net working capital	-0.14	-0.04	0.50	-0.14	0.04	77288
Capital investment	0.06	0.04	0.06	0.02	0.07	77154
Leverage	0.26	0.21	0.25	0.05	0.38	77921
R&D	0.13	0.05	0.21	0.02	0.13	54216
Dividend dummy	0.31	0	0.46	0	1	78180
Acquisition	0.02	0	0.05	0	0	74801

Table 1.2 summarizes the estimation results of regression (1.1) and its alternative specifications. Column (1) reports the pooled OLS regression results controlling for 3-digit SIC industry fixed effects, year fixed effects and cohort fixed effects, whereas columns (2)-(4) re-estimate regression (1.1) with 4-digit SIC industry dummy variables, and firm fixed effects respectively.

The variable of particular interest here is the inventory ratio. According to Column (1), a 1 percentage point decrease in inventory is correlated with a 0.69 percentage point increase in a firm's cash holdings, which is statistically

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[10] See, for instance, [71].

Table 1.2: The Regression Results on Corporate Cash Holdings

Table 1.2 reports the estimation results of the cash regressions on firms' characteristics, including firm size, risk, market-to-book ratio, cash flow, inventory, and other commonly-included control variables. Industry, cohort and year fixed effects are included in the regressions. The heteroskedasticity-consistent standard errors reported in parenthesis account for possible correlation within a firm cluster. Significance levels are indicated by *, **, and *** for 10%, 5%, and 1%, respectively. Column (5) shows the average changes for each explanatory variable and Column (6) reports the predicted changes in cash holdings by each explanatory variable, according to the regression estimates in Column (4).

Variables	(1) Pooled OLS	(2) Pooled OLS	(3) Fixed Effect	(4) Fixed Effect	(5) Δ in Each Variable	(6) Explained Δ in cash	(7) Explained Fraction
Inventory	**-0.6928*****	**-0.6894*****	**-0.7417*****	**-0.7299*****	-0.1002	**0.0731**	64.5%
	(0.0210)	(0.0201)	(0.0137)	(0.0134)		(0.0013)	
Size	-0.0101***	-0.0107***		-0.0059***	1.104	-0.0065	-5.74%
	(0.0008)	(0.0012)		(0.0018)		(0.0020)	
Market-to-book	0.0067***	0.0067***		0.0047***	1.364	0.0063	5.56%
	(0.0008)	(0.0008)		(0.0006)		(0.0008)	
Risk	0.0627**	0.0604***		0.0589***	0.104	0.0061	5.54%
	(0.0114)	(0.0111)		(0.0089)		(0.0009)	
Cash flow	0.0361***	0.0333***		0.0174***	-0.2456	-0.0043	-3.80%
	(0.0058)	(0.0056)		(0.0047)		(0.0012)	
Net working capital	-0.0096	-0.0077		-0.0340***	-0.1235	0.0042	3.71%
	(0.0067)	(0.0067)		(0.0052)		(0.0006)	
Capital investment	-0.7484***	-0.7330***		-0.4033***	-0.0265	0.0107	9.45%
	(0.0305)	(0.0307)		(0.0183)		(0.0005)	
Leverage	-0.2497***	-0.2409***		-0.1908***	-0.0191	0.0036	3.18%
	(0.0105)	(0.0105)		(0.0068)		(0.0001)	
R&D	0.1397***	0.1160***		-0.1160***	0.0797	-0.0092	-8.12%
	(0.0185)	(0.0182)		(0.0139)		(0.0011)	
Dividend	-0.0291***	-0.0253***		0.0077***	-0.1464	-0.0011	-0.97%
	(0.0047)	(0.0045)		(0.0025)		(0.0004)	
Acquisition	-0.3894***	-0.3767***		-0.2571***	0.0054	-0.0014	-1.24%
	(0.0190)	(0.0189)		(0.0124)		(0.0001)	
Industry FE (3-digit)	Yes						
Industry FE (4-digit)		Yes					
Firm FE			Yes	Yes			
Year FE	Yes	Yes	Yes	Yes			
Cohort dummy	Yes	Yes					
Observations	32,939	32,939	32,939	32,939			
R-squared	0.572	0.585	0.770	0.799			

and economically significant. The coefficients of other independent variables are consistent with those estimated in [11]. Larger firms, either because of economies of scale for transaction purposes or because of having easier access to external capital, hold less cash. Firms facing higher risks tend to save more cash because of precautionary motives. Firms expecting more future investment opportunities, proxied by market-to-book ratio and R&D spending, accumulate more cash. Also, paying off debt, investing in capital and distributing dividends consume cash. Results are robust with respect to different specifications and regression methodologies. Columns (2)-(4) show quantitatively similar results to column (1). In particular, the coefficient on inventory ratio varies within a fairly narrow interval [-0.69,-0.74].

To assess the importance of inventory, I estimate how much of the explained cash increase is associated with the changes in each explanatory variable over the past thirty years. I first compute the average value of each independent variable in 1980s and 2000s respectively. The differences between those two periods are the overtime changes of every firm characteristic, which are reported in Column (5). Then the product of the changes and their corresponding coefficients reported in Column (4) gives us the contribution of each factor to the increase in the predicted cash. Results are summarized in Column (6) and (7). We can see that the most important factor related to the increased cash holdings is the decline in inventory, which accounts for 7.31 percentage points increase, or 64.5% of the observed cash increase. This result echoes the finding in [11].

1.2.3 Cash and JIT

I showed above that the inventory and cash ratios are negatively correlated and the decline in inventory is the primary driver behind the increase in cash holdings. Given the role of JIT playing in reducing inventory, we can infer its importance in understanding cash hoarding behavior. In this subsection, I provide direct evidence with a sample of JIT adopters and non-adopters. I examine the impact of JIT on corporate cash holdings by employing a difference-in-differences (DID) approach. The identification comes from the differences between pre-adoption and post-adoption, within-firm differences of JIT adopters and non-adopters.

The initial JIT adopter sample, along with the information on the adoption year for each firm, is kindly provided by the authors of [60].[11] Of the 201 adopters, 14 firms are no longer available on Compustat; of the remaining 187 firms, I drop 18 non-manufacturing firms. My final sample therefore includes 169 JIT adopters.[12] I then pool these adopter with non-adopters from Compustat Industrial Annual files and extract financial data for each firm.

Table 1.3 presents the summary statistics for the relevant variables of the adopters. Relative to the average firm as shown in Table 1, adopters hold a similar level of inventory but less cash. They are larger in size, face lower cash flow risks and have lower market-to-book ratios. They also have healthier operating cash flows, higher net working capital and lower leverage ratios. In terms of expenses, adopters spend a similar rate on physical capital and acquisition, invest less in R&D and pay out more dividends.

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[11] Please refer to [60] for the detailed sample selection and screening procedures.

[12] The description of the JIT adopter sample is provided in Appendix A.3.

Table 1.3: Summary Statistics for 169 JIT Adopters

Table 1.3 presents descriptive statistics for a sample of 169 JIT adopters, and reports the mean, median, standard deviation, 25th and 75th percentile, and number of observations of each variable used in the cash and inventory regressions. The sample covers the period 1980-2006. Detailed information about the adopters is provided in Appendix A.3.

Variables	Mean	Median	Std. Dev.	25%	75%	Obs.
Cash	0.10	0.06	0.11	0.02	0.13	3314
Inventory	0.20	0.18	0.10	0.13	0.25	3314
Size	6.33	6.26	1.97	4.84	7.71	3314
Risk	0.04	0.24	0.06	0.01	0.04	3207
Market-to-Book	1.30	1.03	0.98	0.77	1.52	3265
Cash flow	0.09	0.10	0.12	0.06	0.14	3314
Net working capital	-0.01	-0.01	0.11	-0.06	0.05	3265
Capital investment	0.06	0.05	0.04	0.03	0.08	3281
Leverage	0.21	0.20	0.15	0.10	0.30	3309
R&D	0.05	0.04	0.06	0.02	0.07	2821
Dividend dummy	0.71	1	0.45	0	1	3314
Acquisition	0.02	0	0.05	0	0.01	3105

1.2.3.1 Sample Validation

Before analyzing the effect of JIT on cash holdings, I validate the adopter sample by examining whether adopters manage their inventory in a way consistent with JIT philosophy. To this end, I consider the following specification,

$$inventory_{i,t} = \beta_0 + \beta_1 \, D_{i,t} + \beta_2' \, X_{i,t} + \gamma_i + \sigma_t + \epsilon_{i,t}, \tag{1.2}$$

where $D_{i,t}$ is the dummy variable, taking the value one if firm i at time t implements JIT and zero otherwise, $X_{i,t}$ are the control variables similar to those included in the cash regression, and γ_i and σ_t are firm fixed effects and year fixed effects, respectively. I identify β_1, the average effect of JIT on inventory holdings, by assuming that (1) all the unobserved heterogeneity that leads to the correlation between adopting JIT and the error terms is captured by firm fixed effects, and that (2) the changes of the dependent variable due to changes in the macroeconomic environment are captured by year fixed effects, which are common to firms in both the treated and the control groups.

The estimation results for regression model (1.2) with the sample constructed from Compustat Industrial Annual files are reported in Columns (1)-(3) of Table 4. According to Column (1), after adopting JIT philosophy, firms on average reduce their inventory holdings by 4.25 percentage points, which is statistically significant at the 1% level. In Columns (2) and (3), I report the results of regression (1.2) after controlling for other variables. The sign and significance of the coefficient estimate on JIT dummy variable remain the same.

Table 1.4: Effects of JIT Adoption on Corporate Inventory and Cash (Annual)

Table 1.4 reports the estimation results of the inventory and cash regressions on JIT-adoption dummy and firms' characteristics which include firm size, risk, market-to-book, cash flow, net working capital, and other commonly-used control variables. Firm fixed effects and year fixed effects are included in the regressions, and the heteroskedasticity-consistent standard errors are reported in parenthesis. Significance levels are indicated by *, **, and *** for 10%, 5%, and 1%, respectively. Columns (1)-(3) show the results of inventory regressions, and Columns (4)-(6) show the results of cash regressions. The sample is constructed from Compustat Industrial Annual files, covering the period 1980-2006.

Variables	(1) inventory	(2) inventory	(3) inventory	(4) cash	(5) cash	(6) cash
JIT-adoption	**-0.0425*****	**-0.0335*****	**-0.0283*****	**0.0207*****	**0.0114*****	**0.0141*****
	(0.0029)	(0.0029)	(0.0031)	(0.0039)	(0.0038)	(0.0043)
Size		-0.0178***	-0.0222***		-0.0040***	0.0103***
		(0.0009)	(0.0011)		(0.0016)	(0.0020)
Market-to-book		-0.0023***	-0.0024***		0.0064***	0.0064***
		(0.0003)	(0.0003)		(0.0006)	(0.0007)
Risk		-0.0221***	-0.0303***		0.0535***	0.0810***
		(0.0046)	(0.0048)		(0.0090)	(0.0096)
Cash flow		0.0027	0.0042		0.0507***	0.0143***
		(0.0022)	(0.0032)		(0.0038)	(0.0051)
Net working capital			-0.0067**			-0.0291***
			(0.0032)			(0.0054)
Capital investment			-0.0475***			-0.3685***
			(0.0121)			(0.0201)
Leverage			0.249***			-0.2089***
			(0.0038)			(0.0073)
R&D			-0.0046			-0.1127***
			(0.0082)			(0.0152)
Dividend dummy			0.0072***			0.0024
			(0.0017)			(0.0027)
Acquisition			-0.306***			-0.2347***
			(0.0076)			(0.0137)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	78,006	50,149	32,939	78,055	50,171	32,939
Adj R-squared	0.721	0.771	0.774	0.665	0.717	0.757

I next estimate regression (1.2) with a sample constructed from Compustat Industrial Quarterly. The advantage of using quarterly data, compared with annual data, is that it gives more information about how JIT adopters manage their inventory over time and therefore helps to avoid the possible lack of variations due to the small sample size of adopters. The corresponding results are reported in Columns (1)-(3) of Table 1.5. The coefficient estimate of JIT dummy is quantitatively similar to the one reported in Table 1.4. Besides, the results are fairly robust to different specifications. On average, JIT implementation leads firms to reduce inventory by 4.25 percentage points, according to Column (3) which controls a list of other explanatory variables aside from JIT adoption.

Table 1.5: Effects of JIT on Corporate Inventory and Cash (Quarterly)

Table 1.5 reports the estimation results of the inventory and cash regressions on JIT-adoption dummy and firms' characteristics which include firm size, risk, market-to-book, cash flow, net working capital, and other commonly-used control variables. Firm fixed effects and year fixed effects are included in the regressions, and the heteroskedasticity-consistent standard errors are reported in parenthesis. Significance levels are indicated by *, **, and *** for 10%, 5%, and 1%, respectively. Columns (1)-(3) show the results of inventory regressions, and Columns (4)-(6) show the results of cash regressions. The sample is constructed from Compustat Industrial Quarterly, covering the period 1980Q1-2006Q4.

Variables	(1) inventory	(2) inventory	(3) inventory	(4) cash	(5) cash	(6) cash
JIT-adoption	-0.0461***	-0.0426***	-0.0425***	0.0250***	0.0276***	0.0285***
	(0.0012)	(0.0015)	(0.0073)	(0.0016)	(0.0021)	(0.0098)
Size		-0.0185***	-0.0232***		0.0052***	0.0223***
		(0.0004)	(0.0009)		(0.0009)	(0.0019)
Market-to-book		-0.0027***	-0.0025***		0.0049***	0.0050***
		(0.0001)	(0.0002)		(0.0003)	(0.0004)
Risk		-0.0402***	-0.0711***		0.0760***	0.1665***
		(0.0089)	(0.0143)		(0.0178)	(0.0303)
Cash flow		-0.0146***	-0.0209***		0.1338***	0.0338**
		(0.0040)	(0.0076)		(0.0073)	(0.0148)
Net working capital			-0.0004			-0.0222***
			(0.0022)			(0.0048)
Capital investment			0.0447***			-0.1236***
			(0.0102)			(0.0202)
Leverage			0.0338***			-0.2150***
			(0.0034)			(0.0068)
R&D			-0.0503***			-0.2980***
			(0.0131)			(0.0299)
Dividend dummy			0.0068***			0.0005
			(0.0013)			(0.0028)
Acquisition			-0.0481***			-0.3094***
			(0.0146)			(0.0301)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	311,735	176,382	46,756	312,459	176,524	46,756
Adj R-squared	0.730	0.786	0.797	0.679	0.750	0.780

The results shown above are from the specification which assumes that the effects of JIT on inventory are the same over time. Considering the facts that JIT implementation is a long-term process and firms possibly adjust their behaviour gradually, I also estimate the following specification to allow for heterogenous effects of JIT during the post-adoption period.[13]

$$inventory_{i,t} = \beta_0 + \beta_1\, D_{i,\,year\,1-3} + \beta_2\, D_{i,\,year\,4-6} + \beta_3\, D_{i,\,year\,7-9} + \beta_4\, D_{i,\,year\;10+} + \beta_5'\, X_{i,t} + \gamma_i + \sigma_t + \epsilon_{i,t}, \tag{1.3}$$

where $D_{i,\,year\,t_1-t_2}$ is the dummy variable, taking the value one if firm i during the post-adoption period t_1 to t_2 operates in the JIT system and zero otherwise. The coefficient of the dummy variable $D_{i,\,year\,t_1-t_2}$ measures the difference between pre-adoption inventory and inventory in the post-period t_1 to t_2, which differences out the common shock affecting both adopters and non-adopters.

Columns (1)-(3) of Table 1.6 present the estimation results of regression (1.3). As expected, firms shed their inventory holdings progressively. Column (1) suggests that in the first three years after adopting the JIT system, firms reduce inventory by 3.18 percentage points, while the reduction in inventory amounts to 5.69 percentage points after 10 years' adoption. The same declining pattern of inventory, with similar magnitude, is found in Columns (2) and (3) after controlling for other explanatory variables. The inventory ratio drops by 2.7 and 2.2 percentage points in the first 3 years to a total of 5.4 and 5.8 percentage points after 10 years, respectively.

1.2.3.2 The Effect of JIT on Cash

The results of regressions (1.2) and (1.3) shown in Tables 1.3-1.5 confirm the validity of the JIT-adopter sample. In this subsection, I use it to analyze how JIT adoption affects cash holdings.

The specification I consider is analogous to the regression equation (1.2),

$$cash_{i,t} = \alpha_0 + \alpha_1\, D_{i,t} + \alpha_2'\, X_{i,t} + \gamma_i + \sigma_t + \epsilon_{i,t}, \tag{1.4}$$

where of particular interest is the coefficient estimate on the dummy variable $D_{i,t}$. The variables in $X_{i,t}$ are the ones used in the cash regression (1.1), including firm size, market-to-book ratio, cash flow risk and so forth.

The results of regression (1.4) are reported in Columns (4)-(6) of Table 1.4 and 1.5, which are estimated using annual and quarterly data, respectively. The coefficient estimate of the dummy variable $D_{i,t}$ is positive and statistically significant in all cases, suggesting that implementing JIT leads

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[13] There are ten management practices typically associated with the JIT system, which require changes throughout the entire organization, from the way that goods are ordered to the role of people working on the shop floor. These changes are not completed in one step but need continuous improvement and trial and error approach over many years.

Table 1.6: Effects of JIT on Corporate Inventory and Cash (Quarterly)

Table 1.6 reports the estimation results of the inventory and cash regressions on JIT-adoption dummies and firms' characteristics which include firm size, risk, market-to-book, cash flow, net working capital, and other commonly-used control variables. Firm fixed effects and year fixed effects are included in the regressions, and the heteroskedasticity-consistent standard errors are reported in parenthesis. Significance levels are indicated by *, **, and *** for 10%, 5%, and 1%, respectively. Columns (1)-(3) show the results of inventory regressions, and Columns (4)-(6) show the results of cash regressions. The sample is constructed from Compustat Industrial Quarterly, covering the period 1980Q1-2006Q4.

Variables	(1) inventory	(2) inventory	(3) inventory	(4) cash	(5) cash	(6) cash
$\mathbf{JIT_{year1-3}}$	-0.0318***	-0.0270***	**-0.0218*****	0.0124***	0.0184***	**0.0122***
	(0.0014)	(0.0018)	(0.0052)	(0.0018)	(0.0024)	(0.0074)
$\mathbf{JIT_{year4-6}}$	-0.0394***	-0.0366***	**-0.0325*****	0.0110***	0.0151***	**0.0193****
	(0.0014)	(0.0017)	(0.0054)	(0.0020)	(0.0026)	(0.0084)
$\mathbf{JIT_{year7-9}}$	-0.0478***	-0.0442***	**-0.0423*****	0.0202***	0.0202***	**0.0234*****
	(0.0015)	(0.0018)	(0.0056)	(0.0021)	(0.0026)	(0.0082)
$\mathbf{JIT_{year10+}}$	-0.0569***	-0.0540***	**-0.0578*****	0.0461***	0.0430***	**0.0605*****
	(0.0013)	(0.0017)	(0.0057)	(0.0020)	(0.0026)	(0.0086)
Size		-0.0185***	-0.0233***		0.0052***	0.0223***
		(0.0004)	(0.0009)		(0.0009)	(0.0019)
Market-to-book		-0.0027***	-0.0024***		0.0049***	0.0050***
		(0.0001)	(0.0002)		(0.0003)	(0.0004)
Risk		-0.0400***	-0.0707***		0.0759***	0.1659***
		(0.0089)	(0.0143)		(0.0178)	(0.0303)
Cash flow		-0.0144***	-0.0208***		0.1335***	0.0338**
		(0.0040)	(0.0076)		(0.0073)	(0.0148)
Net working capital			-0.0002			-0.0224***
			(0.0022)			(0.0048)
Capital investment			0.0445***			-0.1229***
			(0.0101)			(0.0202)
Leverage			0.0336***			-0.2147***
			(0.0034)			(0.0068)
R&D			-0.0509***			-0.2973***
			(0.0131)			(0.0299)
Dividend dummy			0.0065***			0.0009
			(0.0013)			(0.0027)
Acquisition			-0.0463***			-0.3124***
			(0.0146)			(0.0301)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	311,735	176,382	46,756	312,459	176,524	46,756
Adj R-squared	0.730	0.786	0.797	0.679	0.750	0.780

firms to accumulate more cash and the conclusion is robust with respect to different specifications and samples. According to Column (6) of Table 1.5, on average, adopting the JIT system induces firms to raise their cash balances by 2.85 percentage points. To interpret the magnitude of this effect, a 10 percentage point decline in inventory stock corresponds to a 6.7 percentage point increase in cash. JIT adoption therefore plays a significant role in shaping corporate cash holdings.

Also examined is the following specification, a counterpart of regression (1.3) which allows for different effects of JIT on cash in the post-adoption years,

$$cash_{i,t} = \alpha_0 + \alpha_1\, D_{i,\,year\,1-3} + \alpha_2\, D_{i,\,year\,4-6} + \alpha_3\, D_{i,\,year\,7-9} \\ + \alpha_4\, D_{i,\,year\;10+} + \alpha_5\, X_{i,t} + \gamma_i + \sigma_t + \epsilon_{i,t}, \qquad (1.5)$$

The estimation results are presented in Columns (4)-(6) of Table 1.6. The coefficients on JIT dummies are all positive, statistically significant and show an increasing trend, which suggest that after implementing the JIT philosophy, firms build up their cash reserves gradually over time. According to Column (6), they increase cash by 1.22 percentage points within the first three years and this number climbs up to 6.05 percentage points after ten years, which is of economical significance.

Note that the impact of JIT on cash holdings that I measure here is the lower bound for the true impact. The firms included in the sample as non-adopters may or may not use JIT. If part of those so-called "non-adopters" do implement the new system, the estimated effect should be biased downwards, which works against finding an impact.

1.2.4 International Evidence

In this subsection, I investigate whether firms in Japan, the master and pioneer of JIT, manage their inventory and cash holdings in the same way as their U.S. counterparts. Also examined are Germany and France, Europe's two largest economies following Japan in the 1980s to adopt JIT.

Figure 1.2 plots the time series dynamics of the average cash ratio (line connected with circle), the average inventory ratio (line connected with triangle) and their sum (line connected with diamond) for manufacturing firms that are publicly traded in Japan, Germany and France. The sample of Japanese companies is constructed from PACAP for the period 1975 to 1990, while the samples for Germany and France are constructed from Compustat Global covering the period from 1988 to 2009.

In Japan, JIT had gained extensive adoption by the mid 1970s. Since then, the inventory ratio has been effectively reduced from 20% to 12%. From 1988, the inventory ratio stopped decreasing and became stable. The average cash ratio within the same period moved in the opposite direction, except for the last three years. The cash decrease starting from the end of 1980s is attributed to the weakened bank power ([75]).

In Germany and France, the cash ratio and inventory ratio also go in opposite directions over time, with inventory trending down, cash trending up and the sum of those two ratios remaining stationary. More precisely,

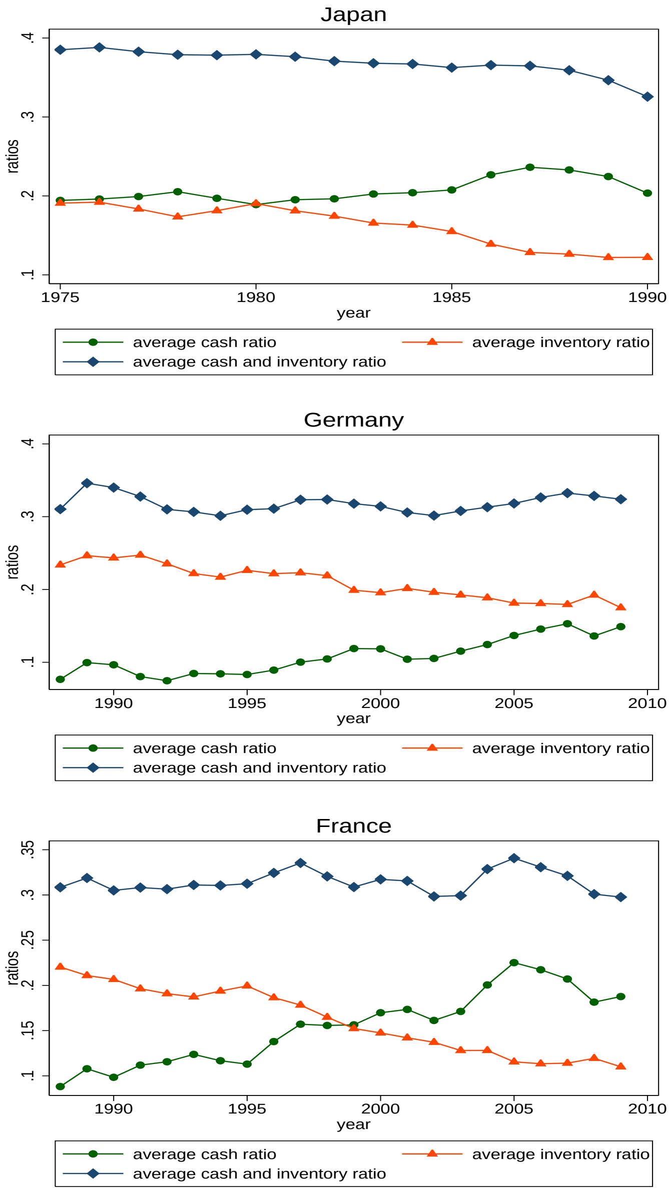

Figure 1.2: Average Cash and Inventory Ratios in Japan, Germany and France. The figure summarizes the average cash-to-asset ratio, average inventory-to-asset ratio and sum of those two ratios over time in Japan, Germany and France.

the cash ratio more than doubles over the 12-year period in both countries, rising from 7.7% and 8.8% to 14.9% and 18.8% respectively. In the meanwhile, the inventory ratio drops from 23.4% and 22% to 17.5% and 11% correspondingly and the sum of the cash and inventory ratios fluctuates roughly around 32% in both countries.

1.2.5 Discussion

In summary, I in this section demonstrate the importance of JIT adoption in understanding the substantial rise in corporate cash holdings. I first estimate the cash regression commonly used in the cash literature to show that the increase in cash holdings is mainly associated with the significant inventory reduction. A 10 percentage point decline in inventory ratio is related with a 7.3 percentage point rise in cash ratio. Then employing the Difference-in-Differences (DID) analysis with a sample of JIT adopters and non-adopters, I find that firms progressively shed inventory and accumulate cash after they implement JIT. After ten-year adoption, firms on average increase their cash reserves by over six percentage points. Lastly, I show that this cash-increase-inventory-decline phenomenon is also prevalent in Japan, Germany and France. All the empirical evidence supports the hypothesized relationship that JIT implementation is a major driver behind the observed increase in corporate cash balance.

Caution is needed due to the small sample size of JIT adopters, as well as the possible endogeneity stemming from measurement error and simultaneity in the cash regression. To cope with these potential concerns, I next turn to a structural model to understand the effect of JIT adoption on corporate cash holdings. In addition, with a structural model, I can analyze the mechanisms through which JIT implementation affects corporate cash and quantify the impacts of those channels.

1.3 Model

This section presents a partial equilibrium problem of a firm who faces uncertainty and financing frictions. I introduce inventory holdings into an otherwise standard neoclassical model of capital investment and cash accumulation by modelling raw materials as factors of production.[14] The lag in delivery of raw material purchases gives rise to the key difference between the JIC and JIT systems. In particular, the delivery lag under the

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[14] See, for instance, [79].

JIC system leads firms to purchase raw materials in anticipation of future demand and to maintain inventory as buffers to meet uncertainties. Under the JIT system, since there is no lag in delivery, firms are able to respond contemporaneously to shocks, and they place orders based on current-period demand.

I begin by specifying a firm's production technology and financing options. Then I describe the problems the firm faces when it operates as a JIC adopter and as a JIT adopter. Lastly, I characterize the firm's optimal decision rules under the JIC and JIT environments and provide the economics behind the different optimal choices on cash and inventory.

1.3.1 Technology

I consider a discrete time model of an infinitely lived firm. The firm combines physical capital k, labor l, and materials N, to produce output, and it faces a combination of demand and productivity shock, z. Maximizing labor out of the problem gives us the revenue function, $F(z, k, N)$, specified by a constant elasticity of substitution(CES) technology

$$F = z[\alpha k^{-\eta} + (1-\alpha)N^{-\eta}]^{-\frac{\theta}{\eta}}. \tag{1.6}$$

Here, curvature $\theta < 1$ captures decreasing returns to scale in production, or market power, or a combination of both; $\alpha < 1$ is the share parameter, describing the weight of physical capital and materials in revenue function; and η controls the elasticity of substitution between these two inputs.[15]

The technology is subject to a revenue shock z, following an $AR(1)$ process in logs with persistency ρ and innovation ε_z,

$$\ln z' = \rho \ln z + \varepsilon'_z. \tag{1.7}$$

A prime indicates a variable in the next period and no prime indicates a variable in the current period. The innovation ε_z has a normal distribution with mean 0 and variance σ_z^2, $\varepsilon_z \sim N(0, \sigma_z^2)$.

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[15] The revenue function can be derived from a static optimization problem. Specifically, the firm faces a demand function $y = z_1 p^{-\Theta}$ and utilizes production technology $y = z_2(l^{\beta_1}[\alpha k^{-\eta} + (1-\alpha)N^{-\eta}]^{-\frac{1-\beta_1}{\eta}})^{\Phi}$ to produce goods. Here, z_1 and z_2 are demand and productivity shocks, respectively. Given labor wage, optimization over the labor l yields a revenue function.

1.3.1.1 Capital

Every period, the firm augments its capital stock by capital investment, I, given as

$$I = k' - (1 - \delta_k)k. \tag{1.8}$$

The parameter δ_k is the capital depreciation rate, $0 < \delta_k < 1$. Adjusting capital by purchasing or selling it incurs adjustment costs, which are defined by

$$A(k, k') = \frac{\gamma_1}{2}(\frac{I}{k})^2 k. \tag{1.9}$$

This specification includes only convex adjustment costs and the parameter $\gamma_1 > 0$ captures the smoothing effect.

1.3.1.2 Inventory

The firm makes a decision on whether or not to adjust material stock based on current state. The firm has two options: either pay a fixed cost f and purchase i_s units of materials; or do not make adjustment this period. The fixed adjustment costs$f$ considered in this model consists of delivery cost, ordering and setup cost, preventive system maintenance cost and stockout cost. The speed of materials delivery depends on the manufacturing system adopted.

Each period, after uncertainty is realized, the firm makes the inventory adjustment decision, and chooses how many materials, N, to use for production. Under the JIC environment, new purchased materials arrive after production. Therefore, no matter the firm decides to adjust its inventory stock or not, the decision N is constrained by the beginning of period material stock s, $N < s$. By contrast, under the JIT environment, new material orders get delivered before production starts. If the firm decides to make the adjustment, the materials available for current-period production become $s_1 = s + i_s$. Alternatively, the firm can avoid the cost and enter production with its initial stock $s_1 = s$.

Materials fully depreciate in use and the unused ones are held as inventory and depreciate at a rate δ_s. The end of period inventory holdings are therefore given by

$$s' = (1 - \delta_s)(s_1 - N), \tag{1.10}$$

with $s_1 = s + i_s$ if the firm makes new purchases this period and $s_1 = s$ otherwise.

1.3.2 Financing

To finance investment projects, firm has three sources: current operating cash inflow from sales, internal cash holdings and external funds.

Internal cash balance, c, stored by the firm earns a risk-free rate r with the interest being taxed at a rate τ_c. The tax penalty is included to make sure the existence of an upper bound on cash holdings.

External financing takes the form of equity issuance in the model. Given the parsimonious set-up, this should not be interpreted literally. Despite in the form of equity issuance, it can be other sources of external financing, such as debt financing, line of credit from banks, and/or short-term credit from suppliers in the case of purchasing materials.[16] Issuing equity incurs costs. The functional form I assume is linear-quadratic:

$$g(e) = \phi_e(-\lambda_1 e + \frac{1}{2}\lambda_2 e^2). \tag{1.11}$$

where e denotes dividends distributed to shareholders and a negative e indicates equity issuance. The indicator function ϕ_e equals zero if dividend e is non-negative, and one otherwise. Cost parameters λ_i, $i = 1, 2$, are positive. The functional form departs from the specification used in [49], by excluding a fixed cost term. This assumption is motivated by the fact that access to lines of credit or short-term trade credit is virtually no fixed cost. The quadratic term is kept for capturing the effect of debt financing as well as simplifying numerical computation, though the estimate in [49] suggests that it is not significantly different from zero.

The sources of funds available to finance inventory adjustment differ under JIT and JIC, which stems from the lag in delivery of new purchases and the requirement to pay on receipt. Under JIC, options for funding material purchases are the same as those to finance capital investment, including operating cash flows, cash balance and external funds. For JIT, however, cash flows generated from current-period production are unavailable for purchasing materials, because now the payment is made before production begins. As such, the no lag in delivery and payment upon receipt induce an operational use of cash. That is, cash acts as a source of working capital to smooth production.

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[16] [61], based on a dataset on almost 30,000 trade credit contracts, suggest that trade credit is expensive for most buyers. The effective annual interest rate ranges from 2% to 100% , with the average rate 54%.

1.3.3 Firm's Problem

The risk-neutral firm's objective is to maximize the equity value of the firm which is discounted at the risk-free rate r, by choosing between adjusting and not adjusting inventory,

$$V(z,k,c,s) = \max\{V^n(z,k,c,s), V^a(z,k,c,s)\}. \tag{1.12}$$

$V^n(z,k,c,s)$ denotes the firm's value of inaction, and $V^a(z,k,c,s)$ is the value of adjusting inventory stocks, as a function of shock z, beginning-of-period capital stock k, cash balance c and inventory s.

1.3.3.1 Firm's Problem under JIC

Conditional on not adjusting inventory, the firm's problem is:

$$V^n(z,k,c,s) = \max_{k',c',N}\{e_1 - g(e_1) + \beta EV(z',k',c',s')\}, \tag{1.13}$$

$$e_1 = F(z,k,N) - \tau_c[F(z,k,N) - \delta_k k - N] - (c' - \hat{R}c) - [k' + A(k',k) - (1-\delta_k)k],$$

$$\beta = \frac{1}{1+r},$$

$$c' \geq 0,$$

$$s' = (1-\delta_s)(s-N) \geq 0,$$

$$\hat{R} = 1 + r(1-\tau_c).$$

After shock is realized, the firm makes its decision on how many materials to use in producing goods, but constrained by the quantity available in stock. The remaining materials are stored as inventory. They depreciate and are transferred to next period. The firm also decides how much to invest in capital to build capital stock which can be utilized in next-period production, and decides how much to save in cash with non-negative cash balance constraint. If current period after-tax cash inflow is not sufficient to fund physical capital investment and cash saving, the firm issues equity and pays the corresponding issuance costs. If current resources are enough to cover those expenses, the firm distributes dividends.

In the case of adjusting inventory, the firm solves a problem similar to the inaction scenario described above, except that now the firm decides how many new materials, i_s, to purchase as well. With everything else the same, the firm's problem is modified as follows:

$$V^a(z,k,c,s) = \max_{N,i_s,k',c'}\{e_1 - g(e_1) + \beta EV(z',k',c',s')\}, \tag{1.14}$$

where

$$e_1 = F(z,k,N) - \tau_c[F(z,k,N) - \delta_k k - N] - (c' - \hat{R}c) - [k' + A(k',k) - (1-\delta_k)k]$$
$$-(f + i_s),$$

$$c' \geq 0,$$
$$s \geq N,$$
$$s' = (1-\delta_s)(s - N + i_s).$$

The firm makes inventory adjustment decision before production. However, the delivery lag leads to the unavailability of the newly-purchased materials for current production, $N \leq s$, and the timing of the payment makes the current-period cash flows available for funding material transactions. In other words, as a result of the lags in delivery and the requirement to pay upon receipt, the adjustment decision prior to the production is equivalent to the case of post-production adjustment.

1.3.3.2 Firm's Problem under JIT

In the case of inaction, the firm's problem is the same as the one under JIC. Contingent on adjusting inventory, the problems that the firm faces under JIT and JIC are different because of the delivery lag.

Under the JIT system, the firm's problem can be viewed as two stages. In the first stage, after shock realization but before production, the firm makes a choice on material purchase. With the newly-purchased and immediately-delivered materials, the firm enters the second stage in which it solves a problem the same as inaction but with different levels of cash and inventory holdings,

$$V^a(z,k,c,s) = \max_{i_s>0}\{\phi_{e_0}[e_0 - g(e_0)] + V^n(z,k,\frac{(1-\phi_{e_0})e_0 - f}{\hat{R}}, s + i_s)\}, \tag{1.15}$$

$$e_0 = \hat{R}c - i_s,$$

$$\phi_{e_0} = \begin{cases} 1 & \text{if } e_0 \leq 0 \\ 0 & \text{otherwise,} \end{cases}$$

where $e_0 = \hat{R}c - i_s$ reflecting the first stage transaction, and i_s is the new purchase. The firm makes the payment out of internal cash balance. If internal funds are insufficient to cover the costs ($\phi_{e_0} = 1$), the firm resorts to equity finance and pays issuing costs and enters the second stage with zero cash. Otherwise, the remaining cash, $e_0 > 0$ normalized by $\hat{R}$, is carried forward into the second stage. The materials available for production after the adjustment are the sum of the initial stock and the new purchase, $s + i_s$. Then the firm, with the new resource constraint, makes choices on material usage, capital investment and cash saving. Note that the fixed inventory adjustment cost f is paid in the second stage, considering that the cost comprises not only delivery cost, but also ordering and setup cost, preventive system maintenance cost and stockout cost which are internal operating costs and not payable to suppliers.

1.3.4 Optimal Policy Rules

In this subsection, I characterize the optimal decision rules for the firm's problem under JIC and JIT and develop the intuition behind them.

1.3.4.1 Cash Holding under JIC

Solving the optimization problem (10) for the JIC system gives the optimal cash level, which satisfies

$$\begin{aligned} 1 + \phi_{e_1}(\lambda_1 - \lambda_2 e_1) = {} & \beta\hat{R} + \beta\hat{R}E[\phi'_{V^a}\phi'_{e_1^a}(\lambda_1 - \lambda_2 e_1'^{a})] \\ & + \beta\hat{R}E[(1 - \phi'_{V^a})\phi'_{e_1^n}(\lambda_1 - \lambda_2 e_1'^{n})] + \mu_1, \end{aligned} \tag{1.16}$$

where

$$\phi'_{V^a} = \begin{cases} 1 & \text{if the firm adjusts inventory next period,} \\ 0 & \text{otherwise,} \end{cases}$$

and $e^i, i = a, n$, denotes dividends or equity issuance in the case of adjusting inventory ($i = a$) or inaction ($i = n$).

The left hand side of equation (1.16) represents the marginal cost of saving an additional unit of cash, that is, forgone dividends, or the sum of equity issuance and its corresponding cost in case of issuing equity to finance cash saving in current period. The right hand side of the equation is the marginal benefit of cash saving. It equals the sum of the discounted expected return (the first term), the discounted expected reduction in the equity issuance costs in the case of adjusting inventory next period (the second term) and in the case of inaction next period (the third term). The last term of the right hand side in equation (1.16) is the Lagrange multiplier of nonnegativity constraint on cash and gives the shadow price of cash holdings.

Equation (1.16) implies that capital market imperfection leads the firm to accumulate internal funds. Without financing frictions, $\lambda_1 = 0$ and $\lambda_2 = 0$, the firm never saves cash as there is a tax penalty on cash and accordingly the return on cash is lower than risk free rate, $\beta\hat{R} < 1$. In addition, optimal saving is positively correlated with the probability of issuing equity. As the firm anticipates a higher likelihood of the insufficiency of internal funds to finance future capital and/or inventory investments, it retains more cash because more issuing costs are likely to be saved.

1.3.4.2 Cash Holding under JIT

Under the JIT system, the optimal cash policy is given by

$$\begin{aligned} 1+\phi_{e_1}(\lambda_1-\lambda_2 e_1) = \beta\hat{R}+\beta\hat{R}E\{\phi'_{V^a}[\phi'_{e_0^a}(\lambda_1-\lambda_2 e_0'^{a})+(1-\phi'_{e_0^a})\phi'_{e_1^a}(\lambda_1-\lambda_2 e_1'^{a})] \\ + \beta\hat{R}E[(1-\phi'_{V^a})\phi'_{e_1^n}(\lambda_1-\lambda_2 e_1'^{n})] + \mu_1, \qquad (1.17) \end{aligned}$$

where

$$\phi'_{e_0^a} = \begin{cases} 1 & \text{if issue equity when adjusting inventory next period, } e_0'^{a} \leq 0, \\ 0 & \text{otherwise,} \end{cases}$$

and $e_i, i = 0, 1$, stands for equity issuance in the first stage ($i = 0$) and second stage ($i = 1$) under the JIT system, respectively.

With everything else remaining the same, equation (1.17) differs from equation (1.16) through having an extra term, $\phi'_{e_0^a}(\lambda_1 - \lambda_2 e_0'^{a})$. It characterizes the scenario in which next period the firm will issue equity to augment inventory stock in the first stage when internal cash balance is not sufficient to make the transaction.

Why does a firm hold more cash under JIT than under JIC? Comparing equation (1.16) with equation (1.17) reveals that the firm tending to save more cash is because of the higher probability of issuing equity under JIT. Adjusting inventory prior to production brings in a disconnection between material purchases (use of funds) and cash flows generated this period (source of funds). As a result, cash flows, an important source of internal liquidity, are not available to pay for materials. In order to avoid tapping into expensive external funds, the firm carries cash forward to make the payment and smooth future production.

Equation(1.17) shows that under JIT, cash serves two purposes: financing investment opportunities and facilitating production. The former is the precautionary motive for cash holdings, or rather, cash is held as a hedge against risk that future cash flow shortfalls and capital market frictions result in underinvestment. The latter is the transaction motive for cash holdings, that is, cash is needed in ordinary daily operations to make payments for material purchases in the presence of financing frictions. Cash becomes a perfect substitute for inventory, acting as a source of working capital. The second motive for cash holding is absent under JIC.

1.3.4.3 New Purchase under JIC and JIT Systems

I next turn to the optimal material purchase decision conditional on adjusting. Under the JIC system, the condition is given by

$$1+\phi_{e_1}(\lambda_1-\lambda_2 e_1)=(1-\delta_s)\beta E\frac{\partial V'}{\partial s'}. \tag{1.18}$$

The marginal cost of purchasing one more unit of good, shown by the left hand side, is the foregone dividend (or the sum of issued equity and issuing costs) this period, while its marginal benefit is the expected present marginal value of an additional unit of end-of-period inventory in next period, but net of depreciation.

Equation (1.19) describes the optimal condition of material purchase under the JIT system,

$$\phi_{e_0}[1+\phi_{e_0}(\lambda_1-\lambda_2 e_0)]+(1-\phi_{e_0})[1+\phi_{e_1}(\lambda_1-\lambda_2 e_1)]=(1-\delta_s)\beta E\frac{\partial V'}{\partial s'}+\mu_2, \tag{1.19}$$

with

$$\phi_{e_0^a}=\begin{cases}1 & \text{if issue equity while adjusting inventory this period, } e_0^a\leq 0,\\ 0 & \text{otherwise,}\end{cases}$$

and μ_2 denoting the Lagrange multiplier associated with the constraint $s+i_s-N\geq 0$. The marginal cost under JIT relies on the sufficiency of funds in the first stage to purchase an additional unit of materials. If there is a shortage of internal liquidity, the marginal cost is the issued equity and its costs in the first stage; or, the marginal cost is the same as that under the JIC system. The marginal benefit for purchasing one more unit of materials is greater than that in the JIC case, captured by the extra term μ_2 which appears in the equation as a result of the availability of newly-purchased materials in current-period production. Under JIT, the firm makes new purchases not only for building up inventory to avoid stockouts next period, but also for meeting current needs.

1.3.4.4 Material Usage

The optimal material use under JIT and JIC systems is characterized by the same equation,

$$[1+\phi_{e_1}(\lambda_1-\lambda_2 e_1)][(1-\tau_c)F_N+\tau_c]=(1-\delta_s)\beta E\frac{\partial V'}{\partial s'}+\mu_2. \qquad (1.20)$$

Here, F_N denotes the marginal revenue generated by an additional unit of material inputs and μ_2 is the multiplier of the constraint that material use cannot exceed inventory available in stock.

The left-hand side of equation (1.20) represents the marginal benefit of using one additional unit of materials in production, which is the increased dividend payment generated from the marginal revenue and the deduced tax from material expenses. The right-hand side shows the corresponding marginal cost, which is the expected present marginal value of an additional unit of end-of-period inventory for next period, but net of depreciation.

1.3.4.5 Capital Investment

Lastly, I discuss the optimal capital investment policy which is described by the following equation,

$$\begin{aligned}[1+\phi_{e_1}(\lambda_1-\lambda_2 e_1)][1+A_{k'}(k,k^{'})]=\beta E\{[1+\phi^{'}_{e_1}(\lambda_1-\lambda_2 e^{\prime}_1)][(1-\tau_c)F_{k'}+\tau_c\delta_k \\ +(1-\delta_k)-A_{k'}(k^{'},k^{''})]\}, \qquad (1.21)\end{aligned}$$

in which $F_{k'}$ is the marginal revenue next period generated by an additional unit of capital investment.

The Euler equation is the same as the one we generally see in neo-classical framework, other than extra terms on equity issuing costs. Investing in capital this period incurs both direct costs and adjustment costs, which cuts current dividend payments to the shareholders. But it also benefits shareholders next period: the expected discounted revenue earned from extra outputs produced by one additional unit of capital, the reduced tax payment from capital depreciation, the expected discounted value of that additional unit of capital net of depreciation, and the reduction in adjustment costs from that increment to capital stock.

1.4 Simplified Model with Analytical Solution

In the previous section, I present a dynamic stochastic model and characterize a firm's optimal decisions under JIT and JIC systems. To illustrate and stress the main intuition behind the substitution between cash and inventory holdings and to examine whether my model is able to deliver a negative correlation of a similar magnitude to that observed in the data, I in this section present a simplified model that yields closed form solutions for cash and inventory holdings.

I simplify the problem by assuming that there are no fixed costs of inventory adjustment, $f = 0$, and no uncertainty, $\rho = 0$ and $\sigma_z = 0$, and I show analytically that adopting JIT leads firm to reallocate resources from inventory to cash.

1.4.1 Steady State under JIC System

Without the fixed inventory adjustment costs, a firm adjusts its inventory stock each period, and the firm's problem is reduced to an adjusting case. I restate the firm's problem in the JIC environment as follows,

$$V(k, c, s) = \max_{i_s > 0, N, k', c'} \{e_1 - g(e_1) + \beta V(k', c', s'), \}$$

where

$$e_1 = F(0, k, N) - \tau_c[F(0, k, N) - \delta_k k - N] - (c' - \hat{R}c) - [k' + A(k', k) - (1 - \delta_k)k] - i_s,$$

$$c' \geq 0,$$

$$s \geq N,$$

$$s' = (1 - \delta_s)(s - N + i_s).$$

Rewriting the problem with multipliers, the first order conditions of cash, inventory holdings and new purchases are given by:

$$V(k, c, s) = \max_{N, i_s, k', c'} \{e_1 - g(e_1) + \beta V(k', c', (1 - \delta_s)(s - N + i_s)) + \mu_1 c' + \mu_2 (s - N)\},$$

$$c' \;:\; 1 + \phi_{e_1}(\lambda_1 - \lambda_2 e_1) = \beta \hat{R} + \beta \hat{R}[\phi'_{e_1}(\lambda_1 - \lambda_2 e'_1)] + \mu_1,$$

$$N \;:\; [1 + \phi_{e_1}(\lambda_1 - \lambda_2 e_1)][(1 - \tau_c)F_N + \tau_c] = (1 - \delta_s)\beta \tfrac{\partial V'}{\partial s'} + \mu_2,$$

$$i_s \;:\; 1 + \phi_{e_1}(\lambda_1 - \lambda_2 e_1) = (1 - \delta_s)\beta \tfrac{\partial V'}{\partial s'},$$

$$s \quad : \quad \frac{\partial V}{\partial s} = (1-\delta_s)\beta \frac{\partial V'}{\partial s'} + \mu_2.$$

I characterize the steady state below. Let a star (*) indicate the steady state value of a variable. With the Euler equations derived above, I can show that in equilibrium, a firm carries positive inventory but zero cash under JIC.

Proposition 1 *In the steady state of the JIC system,* $s^* = N^* = (1-\delta_s)i_s^* > 0$.

Proof. The proof is by contradiction. Suppose $\mu_2^* = 0$ and therefore $i_s^* > 0$, the first order condition of s,

$$\frac{\partial V}{\partial s^*} = (1-\delta_s)\beta \frac{\partial V}{\partial s^*} + \mu_2^*,$$

implies that $\frac{\partial V}{\partial s^*} = 0$. Substituting this into the Euler equation of i_s gives $1 + \phi_{e_1}^*(\lambda_1 - \lambda_2 e_1^*) > 0$. This in turn implies $i_s^* = 0$, because the marginal cost is larger than the marginal benefit of purchasing new materials. This contradicts with $i_s^* > 0$. Therefore, in the steady state, $\mu_2^* > 0$, and we can conclude that $s^* = N^* = (1-\delta_s)i_s^*$. The first equality is derived from complementary slackness $\mu_2^*(s^* - N^*) = 0$ and the second equality is obtained from the law of motion in s, $s^* = (1-\delta_s)(s^* - N^* + i_s^*)$. ■

Proposition 2 *In the steady state of the JIC system,* $c^* = 0$.

Proof. The proof is by contradiction. Suppose $c^* > 0$, complementary slackness implies that $\mu_1^* = 0$. From the Euler equation of cash holdings,

$$1 + \phi_{e_1}^*(\lambda_1 - \lambda_2 e_1^*) = \beta\hat{R} + \beta\hat{R}[\phi_{e_1}^*(\lambda_1 - \lambda_2 e_1^*)] + \mu_1^*,$$

this implies that $1 \leq \beta\hat{R}$. This contradicts with the tax penalty on cash savings, $1 > \beta\hat{R}$, therefore $c^* = 0$. ■

1.4.2 Steady State under JIT

The firm's problem under the JIT environment is rewritten as

$$V(k,c,s) = \max_{i_s>0,N,k',c'} \{\phi_{e_0}[e_0 - g(e_0)] + [e_1 - g(e_1)] + \beta V(k',c',s')\},$$

where

$$e_0 = \hat{R}c - i_s,$$

$$
\begin{gathered}
e_1 = F(0,k,N) - \tau_c[F(0,k,N) - \delta_k k - N] - (c' - \hat{R}c) - [k' + A(k',k) - (1-\delta_k)k], \\
c' \geq 0, \\
s + i_s \geq N, \\
s' = (1-\delta_s)(s - N + i_s).
\end{gathered}
$$

Again, the Bellman equation with multipliers can be reformulated as

$$
\begin{aligned}
V(k,c,s) = \max_{i_s > 0, N, k', c'} \{ & \phi_{e_0}[e_0 - g(e_0)] + [e_1 - g(e_1)] + \beta V(k', c', (1-\delta_s)(s - N + i_s)) \\
& + \mu_1 c' + \mu_2 (s + i_s - N) \},
\end{aligned}
$$

and the corresponding Euler equations are

$$
\begin{aligned}
c' \quad &: \quad 1 + \phi_{e_1}(\lambda_1 - \lambda_2 e_1) = \beta\hat{R} + \beta\hat{R}[\phi'_{e_0}(\lambda_1 - \lambda_2 e'_0), \\
&\qquad\qquad + (1 - \phi'_{e_0})\phi'_{e_1}(\lambda_1 - \lambda_2 e'_1)] + \mu_1 \\
N \quad &: \quad [1 + \phi_{e_1}(\lambda_1 - \lambda_2 e_1)][(1-\tau_c)F_N + \tau_c] = (1-\delta_s)\beta\tfrac{\partial V'}{\partial s'} + \mu_2, \\
i_s \quad &: \quad 1 + \phi_{e_0}(\lambda_1 - \lambda_2 e_0) = (1-\delta_s)\beta\tfrac{\partial V'}{\partial s'} + \mu_2, \\
s \quad &: \quad \tfrac{\partial V}{\partial s} = (1-\delta_s)\beta\tfrac{\partial V'}{\partial s'} + \mu_2.
\end{aligned}
$$

Different from the JIC case, under JIT, the firm chooses to hold cash to facilitate operations. The next two propositions exhibit that the steady state values of cash and inventory are positive and zero, respectively.

Proposition 3 *In the steady state of the JIT system,* $s^* = 0$.

Proof. The proof is similar to the one in Proposition 2. It is straightforward to show that $\mu_2^* > 0$ by contradiction. From the constraint $s^* + i_s^* - N^* = 0$ and the law of motion of inventory holdings $s^* = (1-\delta_s)(s^* - N^* + i_s^*)$, we can derive that in the steady state $s^* = 0$ and $i_s^* = N^* > 0$. ■

Proposition 4 *In the steady state of the JIT system,* $c^* \to \frac{i_s^*}{\hat{R}} = \frac{N^*}{\hat{R}} > 0$ *if external financing is expensive relative to internal funds* ($\lambda_1 \geq r$).

Proof. The proof is by assuming the contrary. First, in steady state the firm does not issue equity at the second stage, otherwise firm value would turn out to be negative. That is, $\phi_{e_1}^* = 0$. Next, suppose $c^* = 0$, which implies that the firm does not have internal funds to finance new purchases at the first stage and therefore the firm has to issue equity, $\phi^*_{e_0} > 0$. Substituting both $\phi^*_{e_0} > 0$ and $\phi^*_{e_1} = 0$ into Euler equation of cash holdings, we have

$$1 < \beta\hat{R}(1 + \lambda_1 - \lambda_2 e^*_0) + \mu^*_1.$$

Because $\lambda_1 \geq r > \frac{1-\mu^*_1}{\beta\hat{R}} - 1 + \lambda_2 e^*_0$, the marginal benefit of holding an additional unit of cash is greater than its marginal cost, which indicates that the firm would have an incentive to increase cash holdings. This contradicts with the assumption $c^* = 0$ in steady state, and therefore $c^* > 0$.

To determine the optimal cash holdings, I next suppose $c^* > 0$ but $\phi^*_{e_0} = 0$. That is, the firm holds some cash, which however is insufficient to pay for the entire newly-purchased materials. The Euler equation becomes

$$1 < \beta\hat{R}(1 + \lambda_1 - \lambda_2 e^*_0).$$

Because external funds are costly, $\lambda_1 > r$, the marginal benefit of holding an additional unit of cash remains larger than the marginal cost, the firm therefore continues to save cash. Would the firm hold enough cash so that it does not need to resort to external sources? I assume $\phi^*_{e_0} = 0$. Then the Euler equation is reduced to

$$1 > \beta\hat{R}.$$

In this case, the marginal cost of holding an additional unit of cash is greater than its marginal benefit, so that the firm tends to save less and the optimal cash holdings is given by $c^* \to \frac{i^*_s}{\hat{R}}$. ■

1.4.3 Discussion

The results established in Propositions (1)-(4) allow us to understand the different incentives for carrying cash and inventory under JIT relative to JIC.

In the steady state, the firm operating in the JIC situation holds zero cash, because cash in this environment serves for a precautionary purpose only. In the absence of uncertainty, the firm has full information on future liquidity needs and plans manufacturing to generate enough cash flows to finance investments, both capital and inventory. Therefore, the firm has no incentive to save cash. Contrary to cash, inventory under this system works as working capital, and is not adjustable next period before production. Anticipating the level of material uses, the firm holds inventory forward to smooth future manufacturing.

By contrast, under JIT, cash is saved in spite of the absence of uncertainty, whereas inventory holdings are zero. This is because that implementing JIT allows the firm to flexibly adjust its inventory stock before organizing production each period. The firm, hence, no longer has motives to store inventory which is very costly. Instead, the firm chooses to transfer exact amount of cash forward to purchase materials required to produce goods. Relative to the JIC system, cash in this environment takes the place of inventory, acting as working capital to facilitate operation.

The simplified model gives intuition on how implementing JIT drives the substitution between cash and inventory. More importantly, it generates a very similar magnitude of substitutability to that presented in the empirical section. Unconditionally, as shown in Figure 1, the substitution ratio between cash and inventory is approximately 1. After controlling for other variables, the ratio drops slightly to 0.73. Comparing the steady state values of cash and inventory under the two different systems, we can see that cash goes up to $\frac{N^*}{\hat{R}}$ from 0, while inventory decreases from N^* to 0. The implied substitution ratio lies in the range [0.73,1] obtained from data.

To summarize, the model provides an explanation for the substitutability between cash and inventory and reproduces a reasonable substitution ratio close to the data.

1.5 Quantitative Analysis

This section reports numerical results of the dynamic stochastic model built in Section 3. I begin by considering three main features of the JIT system and evaluating their impacts on firms' cash policy and inventory management. I then conduct a comparison between the explanation often-discussed in the literature and mine on the performance of explaining cash increase. Lastly, I use my model as a laboratory to study whether the adoption of JIT increases firm value.

To examine the model's quantitative predictions, I first calibrate parameters based on the JIC environment with a sample of manufacturing firms from Compustat. Then I parameterize the JIT environment with the same set of values to assess the impact of a change in the delivery lag, one of the major differences between JIC and JIT philosophy, on cash holdings by isolating other possible factors. I also re-calibrate some parameters to reflect other main features of JIT and analyze how those changes influence a firm's cash saving as well as other decisions.

1.5.1 Calibration

The time period t in my model corresponds to one year.[17] The parameter values are therefore calibrated to match firm-level and aggregate-level moments at annual frequency in the early 1980s, or chosen based on parameter values that are standard in the literature whenever possible. The calibration strategy is discussed below.

Firm's Revenue Function. The curvature of the revenue function θ captures both return to scale in production and a firm's market power. [48], [49], [32] and [41] estimate the parameter to be 0.551, 0.627, 0.59 and 0.64, respectively. I set it to be 0.55, the lower bound of the interval. The parameter η is set equal to 2, reflecting the elasticity of substitution between capital and materials is roughly 0.33. [28] estimates this parameter with post war U.S. aggregate data and suggests a low elasticity of substitution between capital and inventory with the two-standard-error interval approximately [0,0.63]. [15] calibrate this parameter with Compustat data and find $\eta = 0.5$, that is, the elasticity of substitution is 0.67. My choice of the elasticity of substitution lies in the range established in these two studies. The last parameter in the revenue function needed to be determined is the share parameter α. I will return to this discussion below.

Stochastic Process. To parameterize the stochastic process by choosing the persistence parameter ρ and the standard deviation σ, I draw on a large literature that estimates the process with Compustat data. At annual frequency, [39] and [4] estimate a serial correlation around 0.24-0.45 with the corresponding standard deviation around 0.15-0.45, while [40], [48], [49] and [55] have a serial correlation and the standard deviation in the ranges 0.62-0.74 and 0.12-0.15, respectively. Considering model similarities as well as shock specifications, I choose persistency $\rho = 0.7$ which falls in the upper end of the estimates, and its corresponding standard deviation $\sigma = 0.15$.

Capital Adjustment. Using simulated method of moment (SMM) estimation and Compustat data, Nikolov and Whited (2010) estimate γ_1, the quadratic capital adjustment cost, to be in the range of 0.41-0.71 with four slightly different models. Following their study, I set γ_1 to be 0.7. The capital depreciation rate δ_k is set equal to the average of depreciation to the gross capital stock, 0.12, a value derived from Compustat manufacturing industries in the early 1980s.

Inventory Adjustment. The parameters governing the inventory dynamics are the fixed adjustment costs f and the inventory depreciation rate

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[17] Solving the model at annual frequency instead of quarterly frequency reduces computational time substantially, but hardly changes the results.

δ_s. I calibrate them together with the capital-share parameter α by matching the average cash to asset ratio, average inventory to asset ratio and average capital to sales ratio in manufacturing in 1980 in Compustat.[18] The first target, the average cash to asset ratio, is informative about the fixed costs f. The simplified model presented in Section 4 shows that without fixed adjustment costs, a firm adjusts its inventory stocks each period and has no need to hold cash. The presence of the fixed cost along with uncertainty makes the firm cautious. It chooses to adjust inventory less frequently and accumulate cash to pay for the non-convex cost. The second target, the average inventory to asset ratio, is informative about the inventory carrying costs which is captured by the depreciation rate δ_s.[19] Intuitively, the firm is reluctant to hold inventory if it faces high carrying costs. The last moment, the average capital to sales ratio, provides information on the share parameter α, given the elasticity of substitution between capital and materials in production and the curvature of the revenue function.

Financing, Corporate Income Tax and Interest Rate. [49] use structural estimation to infer the magnitude of external financing costs. They estimate the linear cost of equity issuance to be 0.091, when allowing for non-convex equity issuance costs. When excluding the non-convex term, [73] estimate the linear cost to be approximately within the range [0.13,0.18]. Considering that external financing in my model does not incur non-convex cost and can be other cheaper sources other than equity issuance, I set the parameter to be 0.10, which is lower than the estimates in [73] but slightly higher than the one in [49]. The quadratic equity issuance cost λ_2 is selected equal to 0.0004, following the estimate in [49].[20] The real risk-free rate r is set at 4%, a difference between the average annual Treasury-bill rate in the early 1980s and the average annual inflation rate in the same period. This corresponds with the discount factor β=0.96. The corporate income tax τ_c is set at 46%, according to the corporation income tax brackets and rates reported by Internal Revenue Service (IRS).[21]

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[18] The average firm-level capital-to-sales ratio fluctuates over time. As an attempt to control the business cycles in the early 1980s recessions, I compute the average capital-to-sales ratio for the period 1980-1983.

[19] Given the theoretical setup in which I focus on input inventory only, I calibrate the model to match average input inventory to asset ratio. All conclusions/results presented in the previous *Empirical Evidence* section also hold for input inventory. Results available upon request.

[20] A firm's cash holding decision appears to be insensitive to the parameter λ_2. See also [79].

[21] Between 1980 to 1986, a tax rate of 46% is applied on corporate income bracket over $100,000.

Table 1.7: Model Parameterizations

Table 1.7 summarizes the parameters used to solve the model. Panel A reports the parameters specifying revenue function and governing revenue shocks, the parameters characterizing the evolvement of physical capital and inventory stock, and the parameters describing a firm's external financing conditions as well as corporate income tax rate and interest rate. Panel B presents calibration results. The data moments are computed based on the sample period of the early 1980s. Panel C reports the model predictions on the mean and variance of capital investment ratio under the JIC system.

Panel A: Assigned Parameters		
Technology and Shock Process		
curvature (θ)		0.55
elasticity of substitution between capital and material ($\frac{1}{1+\eta}$)		0.33
standard deviation of shock (σ_z)		0.15
persistency of shock (ρ)		0.7
Capital and Inventory		
quadratic capital adjustment cost (γ_1)		0.7
capital depreciation rate (δ_k)		0.12
Financing		
linear equity cost (λ_1)		0.10
quadratic equity cost (λ_2)		0.0004
risk-free rate (r)		0.04
corporate income tax (τ_c)		0.46
Panel B: Calibration		
Calibrated Parameters		
capital share (α)		0.90
fixed adjustment cost (f)		0.055
inventory holding cost (δ_s)		0.32
Moments Used for Calibration	Data	JIC
average capital to revenue ($k/F(z,k,N)$)	0.838	0.835
average cash ratio ($c/(k+c+s)$)	0.098	0.099
average inventory ratio ($s/(k+c+s)$)	0.193	0.200
Panel C: Predictions under JIC		
Capital Investment ($I/(k+c+s)$)	Data	JIC
average investment	0.076	0.082
variance of investment	0.001	0.003

Table 1.7 presents the parameter values used for solving the JIC model. Panel A summarizes the parameters borrowed from other studies. The first set of parameters describes a firm's revenue function and the exogenous stochastic process that the firm faces. The second set of parameters specifies the dynamics of physical capital stock. And the last set characterizes the firm's external financing conditions, corporate income tax rate and interest rate.

Panel B of Table 1.7 reports the data moments I select to target, their model counterparts and the calibration results. The estimated capital share α is 0.90, a value between those suggested in [28] and [15]. The inventory carrying costs amount to 32% of a firm's inventory holdings, which falls within the range estimated by [78]. The fixed adjustment costs f is required to be 0.055 in order for a firm to have strong incentives to hold the level of cash we observe in the data. The value is approximately equivalent to 14% of average revenue. The fixed adjustment costs considered in this model consist of delivery costs, ordering and setup costs (such as costs for unloading and internal handling), preventive system maintenance costs and stockout costs.

1.5.2 Quantifying Key Features of JIT

With the calibrated parameters, I now examine the quantitative implications of my JIT model to see if it has the potential to provide a powerful explanation for the cash hoarding phenomenon. I quantify the impacts of JIT on cash holdings by decomposing it into three main changes — no lag in delivery, increased inventory adjustment costs, and long-term contracts with reliable suppliers — and then examining the impact of each.

1.5.2.1 No Lag in Delivery

The most important change introduced by JIT philosophy is the speedy delivery and therefore operation flexibility. It allows firms to free resources tied up in materials and products sitting in warehouses, and to save utilities and space costs incurred in keeping inventory from perishing. To estimate the effect of this change, I set all parameters in the JIT environment to their values in the JIC environment. The results are reported in the column titled *No Lag in Delivery* of Table 1.8.

In this environment, firms on average have cash-asset ratio of 24.7%, which implies that the production flexibility alone leads firms to increase cash ratio by 15 percentage points or hold cash balance roughly 2.5 times as large as that in the JIC environment. Moreover, firms on average hold zero inventory. The reason for the zero inventory but skyrocketing cash balance is that operation flexibility makes materials much cheaper. Firms therefore decide to employ more materials in production compared with the JIC environment. Because of the complementarity of materials and physical capital in producing products, firms also augment their capital stock, which along with materials boosts sales/revenue. Relative to revenue, fixed inventory adjustment costs now are negligible, and firms choose to purchase materials each period. As a result, firms hoard cash instead of carrying inventory forward. This in turn makes cash and inventory ratios nearly invariable, indicated by their zero variances.

Table 1.8: Implications under the JIT System

Table 1.8 presents the parameter values used in simulating models under JIC and JIT and their corresponding simulated moments. Panel A summarizes the parameter values used in the JIC model and the models with different frictions under JIT. In Panel B, Column (2) reports the data moments computed based on a sample of manufacturing firms in 1980 from Compustat. Column (3) reports the simulated moments generated in the benchmark JIC model. Column (4) reports the data moments computed based on a sample of manufacturing firms in post-2000 period from Compustat. Columns (5)-(7) report the simulated moments under JIT environments with different frictions.

	Data 1980	JIC	Data 2000s	No Lag in Delivery	Increased Fixed Adjustment Costs	Long-term Contracts
Panel A: **Parameters**						
fixed adjustment cost (f)		0.055		0.055	0.101	0.101
linear equity cost (λ_1)		0.10		0.10	0.10	0.04
Panel B: **Moments**						
Cash						
Average cash	0.098	0.099	0.251	0.247	0.231	0.203
Variance of cash			0.010	0.000	0.022	0.027
Inventory						
Average inventory	0.193	0.200	0.082	0.000	0.077	0.084
Variance of inventory			0.001	0.000	0.006	0.007
Investment						
Average investment	0.076	0.082	0.044	0.089	0.082	0.086
Variance of investment			0.001	0.001	0.001	0.001

1.5.2.2 Increased Inventory Adjustment Costs

As shown in the previous subsection, the immediate delivery of parts enables firms to gain efficiency through operation flexibility and inventory carrying cost reduction. It leads firms to devote more resources to production, using more material inputs and investing more in physical capital. Therefore, the material order quantity conditional on adjusting inventory stocks also endogenously grows. Intuitively, larger order sizes incur higher inventory adjustment costs, by requiring more labor to unload and handle purchased materials and higher shipping charges. To take into account this change, I increase the fixed inventory adjustment cost.

I compare the average material order size i_s under JIC and JIT environments, and raise the fixed inventory adjustment cost f by the same proportion as the changes in the average order size. I therefore set $f = 0.101$ under JIT. All other parameters take the same values as the ones used in assessing the effect of speedy material delivery.

The corresponding results are reported in the column titled *Increased Fixed Adjustment Costs* of Table 1.8. Although the stockout motive for inventory holdings is absent, to economize on the fixed adjustment costs, firms choose to carry some level of inventory forward instead of replenishing the stock before production at the beginning of each period. This drives the average inventory level up by 7.7 percentage points and leads to more volatile inventory ratio. The presence of inventory stock also makes cash holdings less important in facilitating operation and production. Firms on average lower cash balance by 1.6 percentage points, with the ratio dropping from 24.7% to 23.1%.

1.5.2.3 Long-term Commitment Contracts with Suppliers

[87] finds that companies implementing JIT usually try to develop a nurturing and reliable long-term relationship with their suppliers. More friendly terms and conditions of trade credit may be obtained by entering this kind of long-term commitment. I capture this feature by lowering borrowing costs. Due to the lack of information on trade credit contracts between JIT adopters and their suppliers, I set the linear equity issuance cost to 0.04 which is as low as the risk-free rate. Note that the number obtained will give the lower bound of the effect of JIT on corporate cash, considering that the borrowing cost should be at least equal to the risk-free rate. All other parameter values remain the same as those in the economy with increased inventory adjustment costs.

The results are summarized in the column *Long-term Contracts* of Table 1.8. Relaxed financial frictions lower the value of financial flexibility provided by internal cash, and encourage firms to resort to external financing. The reduced borrowing cost, from 10% to 4%, leads to a drop in average cash ratio by 2.8 percentage points, from 23.1% to 20.3%. Besides, cheaper external financing leads firms to invest more in inventory and capital. Compared to the economy with increased inventory adjustment costs, both the inventory and capital investment ratios rise.

1.5.2.4 Discussion

I quantify the impacts of the JIT system on corporate cash holdings by considering three main changes and adding each to the benchmark model sequentially.

The results reported in Table 8 suggest that if all firms in the economy switch their operating system from JIC to JIT, (i) operation flexibility contributes to a 14.8 percentage-point increase in cash ratio, (ii) increased inventory adjustment costs, along with speedy delivery, lead to a 13.2 percentage-point increase in total, and (iii) conditional on both speedy delivery and increased inventory adjustment costs, the long-term commitment contract between producers and their suppliers causes the average cash ratio to drop by at most 2.8 percentage points. Overall, the implementation of JIT results in at least 10.5 percentage-point increase in cash holdings.

My model also does a good job in explaining the decline in inventory holdings. It predicts that firms on average have inventory ratios of 8.4% in the post-adoption period, which is a 11.6-percentage-point reduction relative to the JIC system. However, the simulated capital investment ratio overshoots its data counterpart, 8.6% vs. 4.4%. I conjecture that this discrepancy arises because in the real world manufacturers gradually opted to outsource more and more of their production to suppliers abroad for cost reduction purposes, which in turn reduces their capital investment commitments. Also, the model fails to generate reasonable variances of cash and inventory ratios. The simulated variances are nearly three and seven times the data. One possible reason for the inaccurate predictions is that it is hard to observe lumpiness in inventory investment with firm-level data.

1.5.3 JIT and the Rise in Corporate Cash

The subsequent exercise is to quantify the fraction of the observed cash increase attributed to the JIT implementation. To perform this analysis, we need to know the percentage of firms using JIT in the economy and make appropriate adjustments to the results derived above. According to the report *Physical Risks to the Supply Chain* provided by CFO Research Services in collaboration with FM Global, nearly two-thirds of manufacturing firms have implemented Just-in-Time inventory practices by 2008.[22]

1.5.3.1 A Weighted-average Approach

I suppose that shifting from JIC to JIT requires a one-time fixed cost and the switchover is irreversible. The one-period fixed cost is heterogenous among firms and stochastic. Each period, firms operating under the JIC system draw their fixed costs from a distribution. The prospective adopters will choose JIT if and only if they receive a better draw such that the benefit of adopting outweighs the cost. Since the cost is stochastic, the decision to

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[22] CFO research Services conducted a survey among senior finance executives in North America in the fall of 2008.

Table 1.9: The Role of JIT in Explaining the Rise in Corporate Cash

Table 9 presents the adjusted results that take into account the adoption rate of JIT and control for self-selection bias. Panel A summarizes the data moments for the sample periods, 1980 and post-2000, as well as the changes of cash and inventory ratios between those two periods. In Panel B, the first two columns report the simulated moments generated under the JIC and JIT environments. Column (3) considers an economy in which two-thirds of the firms implement JIT, and adjusts the results with a weighted-average approach. Column (4) computes the difference between Column (3) and Column (1). Panel C repeats the exercises in Panel B, except that it controls for self-selection bias when making the adjustment.

Panel A: Data Moments				
	Data (1980)		Data (post-2000)	Change
Average cash	0.098		0.251	0.153
Average inventory	0.193		0.082	-0.111
Panel B: Weighted-Average	(1)	(2)	(3)	(4)
	JIC	JIT	Adjusted Results	Change
Average cash	0.099	0.203	0.168	**0.069**
Average inventory	0.200	0.084	0.123	**-0.077**
Panel C: Self-Selection	(1)	(2)	(3)	(4)
	JIC	JIT	Adjusted Results	Change
Average cash	0.097	0.205	0.171	**0.074**
Average inventory	0.200	0.085	0.127	**-0.073**

implement JIT is random and uncorrelated with cash holdings. A weighted average is therefore a reasonable approach to make the adjustments. Given that two-thirds of firms have switched from JIC to JIT, the adjusted cash and inventory ratios for the economy are 16.8% ($\frac{1}{3} \times 0.099 + \frac{2}{3} \times 0.203$) and 12.3% ($\frac{1}{3} \times 0.200 + \frac{2}{3} \times 0.084$), respectively.

Table 1.9 summarizes the results, with Panel A reporting data moments and Panel B reporting the model counterparts. In the data, the average cash ratio has increased by 15.3 percentage points since 1980, from 9.8% to 25.1%. During the same period, the average inventory ratio has decreased by 11.1 percentage points, from 19.3% to 8.2%. Panel B suggests that the implementation of JIT can explain a large share of the observed cash and inventory changes, 45.1% of the cash increase and 69.4% of the input inventory reduction.

1.5.3.2 Controlling for Self-selection

In the subsection above, I suppose that the adoption cost is random and use a weighted-average to evaluate the contribution of JIT adoption on cash hoarding. In this subsection, I perform a robustness check by assuming that the one-period fixed cost, C, is identical to all firms and modelling the adoption decision to control for the induced self-selection bias.

Each period, after the realization of revenue shocks, firms operating under JIC weigh the expected benefits of the switch-over against the cost and make decisions. If the adoption benefits are greater relative to the cost C, firms decide to implement JIT. Switching back from JIT to JIC is an unavailable option.[23]

Assessing the contribution of JIT requires information on the one-period adoption cost C. I calibrate C to match the adoption rate in the data. More specifically, I simulate a sample of 1000 firms for 100 periods, by starting from the same initial state $\{z_1, k_1, c_1, s_1\}$ and drawing 1000 sequences of revenue shocks ε_z from the same distribution $N(0, \sigma_z^2)$. For the first 50 periods, all firms are restricted to operating under JIC. From the period 51, firms are allowed to select between JIC and JIT. Once switchover, firms operate under JIT permanently. Prospective adopters make adoption decisions each period. I choose $C = 0.55$ such that two-thirds (approximately 67%) of firms are JIT adopters after 28 periods since the JIT system becomes an option.[24] Among those adopters, a large portion are large firms who have more resources to afford adoption costs. This model implication is consistent with the empirical findings suggested in [88]. According to a survey conducted among small and large U.S. manufacturers, they find that large firms are more likely to implement JIT systems than small ones.

Results are summarized in the column *Adjusted* in the Panel C of Table 1.9. Those moments are computed based on the simulated data in the post-adoption periods (period 71 to period 78). Quantitatively, they are very similar to the ones obtained with the weighted-average method. After controlling for self-selection, JIT contributes 48.4% and 65.8% to the observed

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[23] The irreversibility assumption can be justified by the fact that implementing JIT involves physical plant changes as well as changes throughout the whole organization.

[24] The lump sum cost $C = 0.55$ is equivalent to 125% of the average total asset (measured by the sum of capital stock, cash and inventory holdings) under JIC. This number measures both the direct costs of system adoption and the indirect costs of adapting to the new system, for example, including high initial investment (purchasing more sophisticated equipment, information system and softwares, and changing the layout of facilities) and extensive training for employees on different machines and in different functions.

rise in cash and reduction in inventory.[25]

1.5.4 Comparison with the Risk-based Explanation

Previously, I investigate whether JIT is related to changes in cash holdings and quantify its contribution. I next rely on the model to evaluate the role of increased idiosyncratic risk in explaining the observed cash growth, which is highlighted in previous cash hoarding studies ([11]). I then conduct a comparison between the risk-based explanation (precautionary motive for cash holdings) and the one I propose in this paper (transaction motive for cash holdings).

Table 1.10: JIT-based Explanation vs. Risk-based Explanation

Table 1.10 summarizes the comparison results between the JIT-based explanation and the risk-based explanation. Panel A presents the parameter values used in each model, while Panel B reports their corresponding simulated moments as well as data moments.

	Data 1980	JIC	Data 2000s	JIT-based (JIT)	Risk-based (JIC)
Panel A: **Parameters**					
fixed adjustment cost (f)		0.055		0.101	0.055
linear equity cost (λ_1)		0.10		0.04	0.10
standard deviation (σ)		0.15		0.15	0.35
Panel B: **Moments**					
Cash					
Average cash	0.098	0.099	0.251	**0.203**	**0.107**
Variance of cash			0.010	0.027	0.029
Inventory					
Average inventory	0.193	0.200	0.082	**0.084**	**0.166**
Variance of inventory			0.001	0.007	0.007
Investment					
Average investment	0.076	0.082	0.044	0.086	0.080
Variance of investment			0.001	0.001	0.012

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[25] The simulated mean and within-firm variance of cash and inventory ratios under JIC and JIT are reported in the columns *JIC* and *JIT*. These moments are derived by setting cost $C = 0$ in the simulations and dropping the first 20 periods under each system to exclude the possible bias introduced by the initial states and transitional periods. That is, the moments in the columns *JIC* and *JIT* are computed with simulated data for pre-adoption periods (period 21 to period 50) and post-adoption periods (period 71 to period 100).

To this end, I recalibrate the standard deviation σ under the JIC system and compute the corresponding average cash ratio as well as other simulated moments. [31] measure the median of firm-level risk by 10-year centered rolling standard deviation of sales growth. Their measure of risk has grown from 0.15 to 0.21 in the past three decades. Following their approach, the average firm-level risk measured with my sample increases from 0.26 in the 1980s to 0.32 in the post-2000 period, and the risk measure used in my empirical section goes from 0.08 to 0.18 within the same period. All these three risk measures climb up over time, with the largest increase by a factor of approximately 2. I therefore set the standard deviation σ to 0.35, and keep all other parameters the same as their values in JIC. The results are reported in the last column of Table 1.10.

In the economy with a more-than-doubled risk, firms have an average cash ratio 10.7%, raising the ratio by 0.8 percentage points from the benchmark case. Relative to JIT-implementation which explains 8.1 percentage-point increase, the rise in firm level uncertainty accounts for a small share of the cash growth observed in the data. The difficulty in generating precautionary cash saving has been discussed in the literature. In the JIC setup, a firm's cash flow (source of funds) is perfectly positively correlated with the firm's investment opportunities and expenses (use of funds). The firm therefore has a low incentive to save cash. The risk-based model also underpredicts the declining in the average inventory ratio, missing by a factor of 2. On the other dimensions, since risk doubles and investment opportunity is perfectly correlated with productivity, it is not surprising to see that the risk-based model performs poorly in volatility-related moments as well. The variances of cash, inventory and investment ratios overshoot their data counterparts by a factor of 3, 7 and 12, respectively.[26]

My findings on cash are in line with the results found in [19]. They focus on a risk-based explanation. They consider two possible channels through which risk affects cash holdings, by introducing two sources of uncertainty — revenue shocks and expense shocks. They find that the rise in cash is mostly attributable to current-period liquidity needs (liquidity/transaction motive) rather than future prospects (precautionary motive). My work derives the same conclusion as [19], but distinguishes itself by specifying what the "liquidity needs" are. More importantly, my work models cash as work-

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[26] As a robustness check, I set the standard deviation to 0.45 by tripling the value in the benchmark setup and compute the corresponding average cash and inventory ratios. The former goes up to 14.3% and the latter drops to 14.8%, both of which still undershoot the changes observed in the data. Besides, the trippled risk dramatically drives up the volatility of cash, inventory and investment ratios.

ing capital and implies that even if in the absence of uncertainty, firms would hold cash to facilitate transactions.

1.5.5 Impacts of JIT on Firm Values

Can implementing JIT enhance firm performance? This question is of particular interest to managers and practitioners. Empirical studies that examine this relationship have reported mixed results, but with more and more recent research providing evidence of the success of JIT in improving firm's financial performance ([54]; [10]; [21]; [60]; [38]; and [68]). I in this section reinvestigate this question by using the model to assess the firm value changes due to the JIT implementation.

One of the main values of this exercise added to the existing JIT literature is its ability to isolate all other elements possibly affecting a firm's performance aside from JIT, and to deliver quantitative evaluations. Moreover, previous empirical studies use a three-year or five-year window to analyze the impact of JIT adoption. Given the long-run nature of the implementation process, it takes a longer period of time for JIT to prove its advantages. This may provide a partial explanation of limited empirical support of positive effects of JIT on firm performance in early stages. Here, I focus on the long-run impact of JIT implementation and gauge it by comparing the stationary distributions in JIC and JIT systems. Lastly, this exercise also helps to answer the question how firm characteristics generate heterogeneity in the benefits from JIT implementation, especially for different firm sizes.

To quantify the extent to which JIT implementation affects firm performance, I compare the stationary equity values under JIC and JIT.[27] Specifically, I simulate a sample of 1000 firms for 50 periods under JIC and JIT systems respectively and compute the percentage change in the stationary equity values under each system for each firm. The ratio represents the value change as a result of JIT. The results are summarized in Table 1.11.

1.6 Conclusion

In the past three decades, the U.S. corporate sector has gradually shifted resources from inventory to cash. In this paper, I propose an explanation—the implementation of Just-in-Time (JIT) inventory system — to understand the observed high substitution rate between cash and inventory, and

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[27] For JIC, I consider the benchmark model, while for JIT, I consider the model taking into account all three changes.

Table 1.11: JIT Adoption and Changes in Firm Value

Table 1.11 reports the percentage changes in firm value as a result of JIT adoption and the correlation between the change and firm size. It summarizes the minimum, mean and maximum value change in three environments: *No Lag in Delivery*, *Increased Inventory Adjustment Costs* and *Long-term Contracts*.

	mean change	minimum change	maximum change	$corr(\Delta V, k)$
No Lag in Delivery	110%	71.5%	154%	−0.75
Increased Adjustment Costs	46.9%	13.3%	81.7%	−0.66
Long-term Contracts	47.4%	14.1%	81.9%	−0.67

in turn to shed light on corporate cash hoarding behavior which has attracted extensive attention recently.

I begin by providing strong evidence for the importance of Just-in-Time (JIT) system adoption in understanding inventory reduction and cash accumulation. I then develop a structural model to explore how JIT influences inventory and cash policies and quantify its effects. In the model, I emphasize the transaction motive for cash savings. Adopting JIT helps firms to eliminate non-value-added inventory; it also leads firms to allocate released resources to cash, in order to purchase production materials and facilitate operations without tapping into expensive external borrowing. I show that the model reproduces a high negative correlation between cash and inventory, and find that JIT adoption can account for at least 45% of the cash increase and 69% of the inventory reduction observed in the data. There is a lively debate on the causes of corporate cash hoarding, raising concerns about possible resource misallocation from physical capital to cash. My results suggest that at least 45% of the accumulated cash can be rationalized as a normal and positive investment.

I also use my model to examine whether JIT improves firm performance. I find that all firms benefit from implementing JIT in the long run, regardless of firm characteristics. The average beneficial effect is a 47% increase in firm value. In addition, the magnitude of the effects decreases in firm size. Smaller firms profit more from the introduced production flexibility. These findings suggest that there will be potentially significant efficiency gains available for the corporate sector from implementing JIT.

This paper provides an explanation for the corporate cash hoarding behavior within a partial equilibrium model. In subsequent research, I would like to extend the work to a general equilibrium framework and study the effects of corporate cash holdings on the real economy.

Chapter 2

Competition and Risk: When the Choice between Cash and Inventory Matters

2.1 Introduction

Cash and inventory are two important components of a firm's assets. They account for 33% of total assets for U.S. non-financial, non-utility publicly traded firms in 2009.[28] Cash facilitates the daily operation of firms and hedges against adverse shocks. Inventory provides protection from uncertainty in product demand and is a reversible store of liquidity as it can be converted into cash when necessary. This paper analyzes cash and inventory within a unified framework to shed new light on corporate liquidity management.

Although empirical studies in corporate finance treat inventory as a substitute to cash by including working capital net of cash as an explanatory variable in cash regressions (see for example, [74], and [11]), almost nothing is known regarding the resource allocation choices between these two margins. This paper contributes to the literature by providing theoretical foundation and empirical support for the cash-inventory tradeoff.

This is particularly important to understand in light of the substantial changes in firms' portfolio choices in the past thirty years. Figure 2.1 depicts how cash-to-asset and inventory-to-asset ratios vary over time for U.S. non-financial, non-utility publicly traded firms. The average cash ratio soars from 9.6% in the mid-1970s to 23.5% in 2009, simultaneously there is a significant decline in the average inventory ratio from 24.4% to 9.5%, while the sum of these two ratios is approximately constant over time. The former, cash hoarding behavior, has recently attracted considerable attention from financial economists. By contrast, macroeconomists have focused on the

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[28] This ratio stays roughly constant over the last three decades, as shown in Figure 1 below.

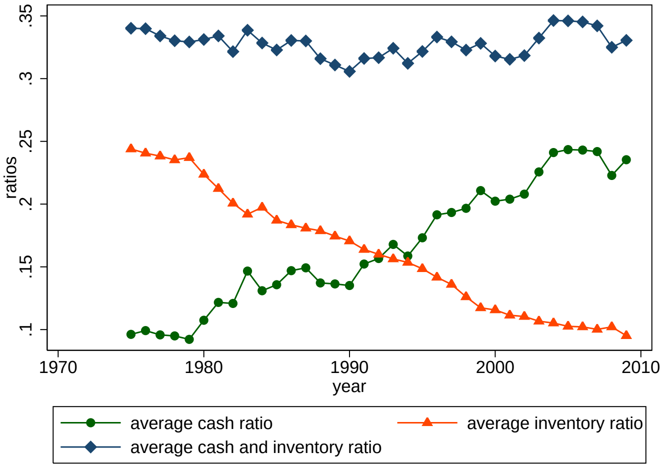

Figure 2.1: Average Cash and Inventory Ratio from 1975 to 2009 in the U.S.. The figure summarizes the average cash-to-asset ratio, average inventory-to-asset ratio and the sum of those two ratios over time. The sample includes all Compustat firm-year observations from 1975 to 2009 with positive values for the book value of total assets and sales revenue for non-financial and non-utility firms incorporated in the United States. The cash ratio is measured as the ratio of cash, cash equivalents and short term investments to the book value of total assets. The inventory ratio is measured as the ratio of inventory to the book value of total assets.

latter, the significant reduction in inventory, and emphasized it as central to an understanding of the Great Moderation.[29] Each of these two parallel but separate streams of studies offers an incomplete picture of the systematic portfolio restructuring in corporate sector.[30] Analyzing cash and inventory jointly helps to generate important insight neglected in previous studies.

In this paper I investigate how firms manage internal liquidity by allocating resources between cash and inventory to avoid raising costly external financing. Using a three-period model, I show that competition in the product market and risk are two key determinants of the tradeoff between saving cash and carrying inventory forward. More specifically, I set up a model in which a risk-neutral firm operates in a product market with some degree of market power (captured by the price elasticity of demand) and faces stochas-

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[29] The Great Moderation in economics refers to a decline in the U.S. macroeconomic volatility since the mid-1980s.

[30] One exception is [11]. They highlight the importance of inventory in understanding the cash dynamics in the past thirty years.

tic productivity shocks. The firm has an investment opportunity which can be financed through three channels: cash flows generated from selling inventory and newly-produced products, cash holdings, and external equity. The capital market is assumed to be imperfect and modelled by equity issuance costs. To avoid raising expensive external funds, the firm attempts to meet liquidity needs by saving cash and/or holding inventory. Cash earns a lower rate of interest than the risk-free rate, while inventory earns a rate contingent on the future state of the world and depreciates when carried forward to next period.

How do firms choose between cash and inventory when they face the tradeoff described above? My model implies that the choice between these two margins depends largely on a firm's market power and the risk the firm faces. Firms with greater market power place more weight on inventory relative to cash, and firms operating in a riskier environment rely more on cash. The intuition for these results is as follows. When firms face relatively inelastic demand, that is, have greater market power, firms are able to charge a higher product price without losing customers, which in turn yields a higher expected return from holding inventory. Therefore firms facing less elastic demand allocate more resources in inventory than those with more elastic demand. When firms operate in a more uncertain environment, firms are more likely to experience extreme states of the world, including both low-productivity states and high-productivity states. As a result of the risk aversion induced by costly external borrowing, firms are more concerned about a liquidity shortage (i.e., low-productivity states of the world). To avoid resorting to expensive external equity, riskier firms save more liquid assets, mainly in the form of cash. This is because inventory is particularly valuable in fairly low-productivity states, while cash delivers the same return in all states in which there is a liquidity need. Consequently, relative to less risky firms, riskier firms have higher cash ratios and lower inventory ratios.

The model also provides new insight into inventory holdings. Firms not only hold inventory to avoid stockouts, or to expect capital gains from a price increase, but also treat inventory as an important part of their liquidity instruments. Hence, holding all other relevant factors constant, financially-constrained firms choose to hold more inventory, so that they have more internal resources to draw down whenever necessary.

I test model implications using a sample of manufacturing firms constructed from Compustat Industrial Annual files over the period 1980-2009. When examining how market power and uncertainty affect the choice between cash and inventory, I use the cash-to-inventory ratio as the dependent variable to capture the relative use of cash versus inventory in liquidity management, as suggested in [83]. In order to exclude the possibility that the results found are solely driven by one of these two margins, I also regress cash-to-asset ratio and inventory-to-asset ratio on controls separately. Subsequently, I analyze whether financially-constrained firms behave differently when managing inventory. This tests the liquidity motive for inventory holdings.

The results are strongly supportive of the model predictions. Specifically, firms with higher ability to set price over cost rely more heavily on inventory relative to cash when managing liquidity needs, while firms exposed to more risks act in the opposite way. Financially-constrained firms on average store more inventory than financially-unconstrained firms with the same pricing power, implying that inventory is indeed treated as a source of funds. The first two findings shed light on the substantial portfolio restructuring shown in Figure 1. They suggest that the rise in market competition (see, for instance, [31] and [56]) and the rise in risk (see, for instance, [22] and [30]) can partially explain the observed resource reallocation from inventory to cash.

This paper contributes in several ways to the literature. First, it adds to the previous studies on liquidity management by taking into account an additional form of internal liquidity besides cash, inventory holdings, and explores the interaction between them. There is a rich literature focusing on the precautionary motive for corporate cash. It suggests that in the face of financing frictions and uncertainty, firms accumulate cash to fund future investments and/or to cover current expenses (see, for example, [1], [79], [19] and [53]).[31] My paper extends these analyses by incorporating another source of internal funds — inventory, and examines how firms make choices between inventory and cash in the presence of costly external finance. To the best of my knowledge, this is the first paper to analyze the tradeoffs between cash and inventory.

Second, this paper helps to understand corporate cash hoarding behavior.[32] [71] and [82] examine the effects of product market competition on

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[31] Besides the precautionary motive, other main motives for cash saving identified in the literature include facilitating transaction ([12]), agency issues ([73]), smoothing R&D ([20]), avoiding double taxation of foreign income ([37]), and managing competition from product market (e.g. [46], [71]). In this paper, I only consider the precautionary motive of cash holding.

[32] [11] first formally document this phenomenon and emphasize inventory, accounts receivable, idiosyncratic risk and R&D investment as four major drivers behind it. Other related papers include [19] and [5]. [19] analyze revenue uncertainty and expense uncertainty, and quantify their effects on corporate cash balance. They find that the rise in cash holdings is mainly because of current-period liquidity needs rather than future prospects.

cash and link cash hoarding to increased market competition. My paper derives the same conclusion, but distinguishes itself from those two studies by presenting an additional mechanism through which market competition shapes cash policy. The above papers suggest that market competition increases the option value of remaining active in the market and therefore firms hold cash to avoid inefficient closure. My model provides a more concrete story. Increased market competition limits firms' pricing ability and in turn reduces firms' profitability. This affects cash through two channels: first, it lowers cash flows and increases needs for internal resources (cash and inventory) to preserve liquidity; second, it lowers the return on inventory and makes inventory a less desirable source of funds relative to cash. Therefore, as the product market becomes more competitive, firms prefer to raise cash for liquidity management. I test this hypothesized mechanism and find that inventory is indeed positively related to market power. This is consistent with the model prediction.

Lastly, this paper contributes to the inventory literature in two dimensions. First, it proposes new explanations for the inventory declining observed in the data. The substantial reduction in inventory holdings is most commonly attributed to Just-in-Time (JIT) philosophy implementation. My analysis suggests that changes in the business environment (market competitiveness and uncertainty) also contribute to the pattern. Second, this paper models and tests a new motive for holding inventory. In macroeconomics, a range of motives have been identified, including production-smoothing motive ([52], [17] and [64]), stockout-avoidance motive ([57] and [58]), and cost shock-hedge motive ([66], [18] and [80]). This paper models inventory as a source of funds and explores the liquidity motive for inventory holdings. [36], in their empirical analysis, find that financially-constrained firms sell inventory to smooth capital investment. In this paper, I present new evidence on the liquidity motive for inventory holdings by showing that financially-constrained firms on average keep more inventory.

The remainder of the paper is structured as follows. In Section 2, I develop a three-period model, characterize optimal financial policies and derive implications. Section 3 contains empirical tests and Section 4 concludes.

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[5] study firms' financing choices among debt, equity and financial assets and highlight the dividend tax cut as an important factor contributing to the corporate saving increase.

2.2 Model

In this section, I present a model in which a risk-neutral firm builds its liquidity reserves to avoid raising costly external financing. Firm's liquid assets can be composed of cash and inventory. Cash earns a rate $\hat{R}$ which is lower than the gross risk-free rate, while inventory depreciates at a rate δ when transferred to next period and earns a rate contingent on the price change between the current and next period. This tradeoff determines the composition of the firm's optimal liquidity buffers.

2.2.1 Structure

The model has three periods, denoted by $t = 1$, 2 and 3. At period 1, the firm is endowed with w_1, $w_1 = 1$, units of good, as well as a risky asset (capital) which produces random $f(z_1)$ units of good in period 2 only. The good is divisible. At period 2, after the realization of a productivity shock z_1, the firm faces an investment opportunity which costs I, $I = 1$. This investment opportunity allows the firm to invest in a risk-free asset which produces deterministic units of good, w_3, at period 3.

The firm pays I out of either internal or external funds or a combination of both. The firm has two tools to transfer resources internally from period 1 to period 2. One is to save cash out of cash flows. This option earns a rate of return $\hat{R} > 1$, which is lower than the risk-free rate. The alternative is to carry inventory forward. Inventory depreciates at the end of period 1 at a rate δ, $0 < \delta < 1$, and can be sold to generate cash flows in period 2. If the firm has insufficient internal resources to finance the investment in period 2, it can issue equity which incurs unit costs λ.

The risky asset produces output in period 2, which is given by

$$f(z_1) = e^{z_1},$$

where the productivity shock z_1 has a normal distribution with mean μ and variance σ^2, $z_1 \sim N(\mu, \sigma^2)$.

The firm operates in a monopolistically competitive market and faces demand with the following specification:

$$Q = P^{-\theta}.$$

Here P denotes the price charged by the firm, while Q is the quantity demanded. Product demand exhibits a constant price elasticity θ, $\theta > 1$.[33] To

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[33] For an equilibrium to exist, the price elasticity of demand must be greater than one.

simplify the model, the firm is only allowed to set prices in period 1, given the endowment level w_1. The unsold products are stored as inventory and carried forward to period 2. In period 2, I assume that all products must be sold. Therefore, price is no longer a choice variable, but a function of the beginning-of-period inventory holdings and the products produced by the risky asset in place. In period 3, product price is exogenous and equal to 1.

2.2.2 Firm's Problem

In period 1, the firm allocates endowed resources into three choices, cash saving c_2, inventory holding s_2 and dividend payment d_1. Given the endowment w_1, the firm makes its decision on how many units of good to sell to generate cash flows, under a constraint on the quantity of products currently available for sale, w_1. The unsold products are stored as inventory, s_2. They depreciate and are transferred to period 2. The firm also decides how much to save as cash, c_2, out of the cash flows. The parameter $\hat{R}$ denotes the effective rate of return on cash saving.

$$d_1 = p_1 q_1 - \frac{c_2}{\hat{R}},$$

where

$$\begin{gathered} q_1 = \min\{w_1, p_1^{-\theta}\}, \\ p_1 = q_1^{-\frac{1}{\theta}}, \\ c_2 \geq 0, \\ s_2 = (1-\delta)(w_1 - q_1) \geq 0. \end{gathered}$$

In period 2, the firm has an opportunity to invest in a risk-free asset which costs I. If the firm does not have sufficient internal resources to cover the cost, that is, cash saving c_2 plus the realized cash flows $p_2 q_2$ is less than I, the firm issues costly equity. If the firm can afford the cost with the available internal resources, the remaining funds are distributed as dividend.

$$d_2 = (1 + \lambda\phi)[p_2 q_2 + c_2 - I],$$

where

$$\begin{gathered} q_2 = f(z_1) + s_2, \\ p_2 = q_2^{-\frac{1}{\theta}}, \\ \phi = \begin{cases} 1 & \text{if } d_2 \leq 0, \\ 0 & \text{otherwise.} \end{cases} \end{gathered}$$

The first two constraints correspond to the assumption that all products are sold in period 2. The quantity q_2 and the price p_2 therefore are determined by the shock realization z_1 and the beginning-of-period inventory holdings s_2. The indicator function ϕ equals to 1 if the firm needs to access to the capital market and issue equity, and 0 otherwise. Note that here I assume that w_3 is so large that the firm chooses to invest in period 2 with probability 1.

In the last period, the dividend distributed is the cash flows generated by the investment, w_3 units of products valued at a price of 1:

$$d_3 = w_3.$$

The risk neutral firm's objective is to maximize the expected discounted value of future stream of dividends, by choosing optimal inventory holdings s_2 and cash saving c_2. The firm's problem can be written as follows:

$$\max_{s_2 \geq 0, c_2 \geq 0} d_1 + \beta E_1 d_2 + \beta^2 E_1 d_3, \tag{2.1}$$

where the discount factor β equals to $\frac{1}{1+r}$, r is the risk-free rate, and dividends d_1, d_2 and d_3 are specified as above.

2.2.3 Optimal Policy Rules

In this subsection, I characterize optimal decision rules for the firm's problem and develop the intuition behind them.

2.2.3.1 Cash

Solving the optimization problem (2.1) gives the optimal cash saving, which satisfies

$$1 = \hat{R}\beta + \lambda \hat{R}\beta E\phi + \mu_1, \tag{2.2}$$

where

$$\phi = \begin{cases} 1 & \text{if } d_2 \leq 0, \\ 0 & \text{otherwise.} \end{cases}$$

The left-hand side of equation (2.2) represents the marginal cost of saving an extra unit of cash, that is, forgone dividend in period 1. The right-hand side of the equation is the marginal benefit of cash saving, the sum of discounted expected return (the first term) and discounted expected reduction in the cost of equity issuance (the second term). The last term of the right-hand side in equation (2.2) is the Lagrange multiplier of the nonnegativity constraint on cash and gives the shadow price of cash holdings.

Equation (2.2) shows that the optimal cash saving is positively correlated with the cost of issuing equity and the probability of issuing equity to finance investment opportunities. Without costly equity issuance, that is, $\lambda = 0$, the firm never saves cash as the return on cash is lower than risk-free rate. As the equity issuance cost and the probability of issuing equity rise, the firm retains more cash because more money can be saved if it needs to issue equity next period.

2.2.3.2 Inventory

Next, I turn to the optimal inventory policy, or equivalently, the firm's pricing rule or optimal quantity choice. The optimality condition is given by

$$\frac{\theta-1}{\theta}q_1^{-\frac{1}{\theta}} = (1-\delta)\beta E\frac{\partial d_2}{\partial s_2} + \mu_2, \tag{2.3}$$

where parameter θ is price elasticity of demand. The left-hand side of equation (2.3) gives the marginal cost of carrying one additional unit of good forward to period 2, which is $\frac{\theta-1}{\theta}q_1^{-\frac{1}{\theta}}$ dollars of forgone revenue and in turn foregone dividends in period 1. The right-hand side shows the marginal benefit, which is the expected present marginal value of an additional unit of end-of-period inventory for period 2 after depreciation. The parameter μ_2 is the Lagrange multiplier of the nonnegativity constraint on inventory.

Substituting the demand function into equation (2.3), I can rewrite the optimal condition in a more familiar form. In the case of an interior solution, equation (2.3) becomes

$$p_1 = \frac{\theta}{(\theta-1)}[(1-\delta)\beta E\frac{\partial d_2}{\partial s_2}]. \tag{2.4}$$

The above equation describes the optimal pricing rule of a monopolistically competitive firm. That is, the firm charges a constant markup over marginal cost. Here, the constant markup is $\frac{\theta}{\theta-1}$. The marginal cost is the firm's marginal value of an additional unit of inventory, $(1-\delta)\beta E\frac{\partial d_2}{\partial s_2}$.

Under the assumption that all products must be sold in period 2, equation (2.4) can be written as follows, which relates the charged price in period 1 with the expected price in period 2,

$$\frac{\theta-1}{\theta}p_1 = (1-\delta)\beta E\{\frac{\theta-1}{\theta}p_2\} + \lambda(1-\delta)\beta E\{\phi\frac{\theta-1}{\theta}p_2\}. \tag{2.5}$$

According to equation (2.5), the model presents two reasons for holding inventory. The first is a stockout-avoidance motive, captured by the first term on the right-hand side of the equation. The firm makes the carrying decision based on the prospects for benefiting from a price increase between the current and next period. This might happen when the firm expects a large negative productivity shock which will drive up next period's product price and create an expectation of a gain from holding inventory. The second motivation of holding inventory is to reduce equity issuance costs, as indicated by the second term on the right-hand side of equation (2.5). Inventory is ready for sale to generate cash flows. As a source of funds, it can save expected costs of issuing equity, playing the same role as cash.

2.2.4 Choice between Cash and Inventory

2.2.4.1 Deterministic Environment

As shown in the model, both cash and inventory are sources of funds used to finance capital investment and/or cover operation costs. To illustrate and understand how the firm allocates resources between cash and inventory when managing its liquidity needs, I in this subsection simplify the model by assuming that the risky asset produces $e^{x_1} < 1$ units of good, which is insufficient to finance the investment opportunity in period 2 with probability 1. This assumption guarantees that the firm will transfer resources over period, with the resources composed of cash and/or inventory, and makes it easy to characterize and analyze the cash-inventory tradeoff.

The optimality of the firm's financial policy requires the firm to be indifferent between cash and inventory. Accordingly, the firm chooses to carry more inventory when the price change net of depreciation is greater or equal to the effective rate of return on cash holdings:

$$\frac{q_2^{-\frac{1}{\theta}}(1-\delta)}{q_1^{-\frac{1}{\theta}}} \geq \hat{R}.$$

Combined with model assumptions, it can be written as

$$(e^{x_1} + s_2)^{-\frac{1}{\theta}}(1-\delta) \geq \hat{R}[(1 - \frac{s_2}{1-\delta})^{-\frac{1}{\theta}}].$$

This inequality implies that the optimal inventory holding is given by

$$s^* = max\{0, \frac{a - e^{x_1}}{1 + \frac{a}{1-\delta}}\}, \tag{2.6}$$

where $a = (\frac{1-\delta}{\hat{R}})^{\theta}$. Since the return on cash is lower than the gross risk-free rate, the firm never chooses to hold cash more than the unfilled liquidity shortage. The optimal cash holding then is as follows,

$$c^* = max\{0, 1 - (e^{x_1} + s^*)^{1-\frac{1}{\theta}}\}. \tag{2.7}$$

I next analyze the properties of the equilibrium and explore how different parameter values affect the firm's optimal financial policy. Proposition 5 summarizes the results, which I prove in Appendix B.1.

Proposition 5 *Define the cutoff value of* θ, $\bar{\theta} = \frac{x_1}{\ln(1-\delta) - \ln \hat{R}}$. *A firm's optimal financial policy depends on the extent of its market power, holding costs and future prospects:*
1. If $\theta \geq \bar{\theta}$, $s^* = 0$. *Firms use cash for liquidity management.*
2. If $1 < \theta < \bar{\theta}$, *the optimal inventory holdings* s^* *and optimal cash holdings* c^* *are characterized by equations (2.6) and (2.7), respectively.*
3. The optimal inventory holdings s^* *decrease in the price elasticity of demand* θ, *inventory holding costs* δ *and, the effective return on cash holdings* $\hat{R}$, *while the optimal cash holdings* c^* *increase in* θ, δ *and* $\hat{R}$.
4. The cutoff value $\bar{\theta}$ *decreases in inventory holding costs* δ, *the effective return on cash holdings* $\hat{R}$, *and the productivity realization* x_1 *in period 2.*

Proposition 5 states that a firm will cover its liquidity needs fully with cash when the firm's market power is lower than a threshold. If the firm's market power is greater than the critical value, the firm will carry some level of inventory forward, and the rest of the liquidity shortage will be financed by cash. Furthermore, the optimal level of inventory holdings increases in the firm's market power, while cash moves in the opposite direction. Lastly, inventory carrying costs δ, and the cash holding return $\hat{R}$ make inventory undesirable and expensive to hold relative to cash. One point that deserves attention here is that these properties remain unchanged if adding a demand shock to the model.[34] The intuition is that the decision on inventory holdings

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[34] In the presence of a demand shock, the demand function can be written as

$$Q = e^{z_2} P^{-\theta}.$$

Assuming that the realization of the demand shock is x_2 in period 2, the corresponding optimal inventory holding is given by

$$s^* = max\{0, \frac{a - e^{x_1}}{1 + \frac{a}{1-\delta}}\},$$

with $a = e^{x_2}(\frac{1-\delta}{\hat{R}})^{\theta}$. The cutoff value $\bar{\theta}$ becomes $\frac{x_1 - x_2}{\ln(1-\delta) - \ln \hat{R}}$. Following the proof in Appendix B.1, we can show that equilibrium properties stated in Proposition 1 still hold.

relies on the price change between two periods, which is determined by the net effect of shifts in demand and supply. Therefore, in the absence of a demand shock, the productivity shock in the model can be interpreted as the relative supply. Also worth noting is that implied by the fourth statement in Proposition 5, in the case of extremely small productivity realization x_1 in period 2, or equivalently, extremely large demand realization in period 2, a perfectly competitive firm ($\bar{\theta} \to \infty$) may transfer inventory across periods.

The discussion above highlights the idea that one of the key determinants of a firm's choice between cash and inventory to meet future liquidity needs is the firm's market power, or the elasticity faced by the firm. The intuition is that, the degree of market power largely affects firms' profitability as well as the return on inventory. When the elasticity of demand is relatively low, firms are able to set a high price over cost. Therefore they have high gross margins and acquire a high return on holding inventory. As demand becomes more responsive to prices, both the profit and the prospect of gaining from holding inventory drop. To preserve financial flexibility, firms start switching to cash.

2.2.4.2 Stochastic Environment

In the following, I remove the assumption made in the previous subsection and analyze the role of risk in determining a firm's decisions on carrying inventory and holding cash. I also reexamine the statements presented in Proposition 1 by plotting the comparative statics of the equilibrium with respect to key parameters in the model.

To understand how uncertainty affects a firm's cash decision, I rewrite the Euler equation for cash by incorporating the assumed uncertainty structure:

$$1 = \hat{R}\beta + \lambda \hat{R}\beta \Phi(\frac{\ln b - \mu}{\sigma}) + \mu_1, \tag{2.8}$$

where $\Phi(\cdot)$ is cumulative distribution function (CDF) of standard normal distribution, and the parameter b equals to $(1 - c^*)^{\frac{\theta}{\theta - 1}} - s^*$. Parameters μ and σ are the mean and standard deviation of the productivity shock z_1.

Equation (2.8) suggests that the standard deviation σ shapes the optimal cash holdings by changing the probability of tapping into external funds next period $\Phi(\frac{\ln b - \mu}{\sigma})$. As a result of the external financing costs, the firm's problem becomes strictly concave, which in turn makes the firm behave like a risk-averse agent. In response to an increase in uncertainty which drives up the probability of issuing equity in the future, the firm chooses to cut the current-period dividend payment and accumulate more precautionary savings. Proposition presents the result, which is proved in Appendix B.2.

Proposition 6 *The optimal cash holding increases in a firm's risk σ.*

To analyze the impact of risk on the optimal inventory policy, I express equation (2.5) as

$$\frac{\theta-1}{\theta}p_1=(1-\delta)\beta\frac{\theta-1}{\theta}E\{p_2\}+\lambda(1-\delta)\beta\frac{\theta-1}{\theta}\{E\phi Ep_2+Cov(\phi,p_2)\}. \quad (2.9)$$

A rise in risk generates a strong incentive for the firm to carry more inventory forward. It raises the probability of equity issuance in the future $E\phi$, creats a higher expectation on future price $Ep_2=e^{-\frac{\mu}{\theta}+\frac{\sigma^2}{2\theta^2}}$, and also increases the covariance of the indicator function of equity issuance and product price next period $Cov(\phi,p_2)$ (i.e., the firm is more likely to face financial difficulties when the productivity is low and thus the product price is high). This result is formalized in Proposition 7 and proved in Appendix B.3.

Proposition 7 *The optimal inventory holding increases in a firm's risk σ.*

Figure 2.2 illustrates how the firm responds to changes in the risk σ by allocating resources between cash and inventory differently. It shows that the effects of uncertainty on the optimal *level* of cash and inventory are monotone. An increase in risk σ results in simultaneous rises in the cash and inventory holdings. Furthermore, the magnitude of the rise in cash dominates that of inventory increase (i.e., an increases in risk raises the *share* of cash), because a rise in uncertainty drives up the marginal benefit of inventory holdings chiefly through the probability of equity issuance in the future $E\phi$, rather than its relative return compared to cash, $Ep_2+\frac{Cov(\phi,p_2)}{E\phi}-\hat{R}$.

Intuitively, as the productivity shock becomes more volatile, a liquidity shortage is more likely to occur in the future. To avoid raising costly outside funds, the firm chooses to accumulate more inside resources as a combination of cash and inventory. Inventory is more valuable than cash in extremely low states, that is, when future productivity is lower than some threshold value. Since the probability of future productivity dropping below the cutoff increases as risk rises, the firm holds more inventory. For the rest states of the world, in which the probability of issuing equity remains positive, the firm chooses to raise cash balance, by selling inventory today and saving

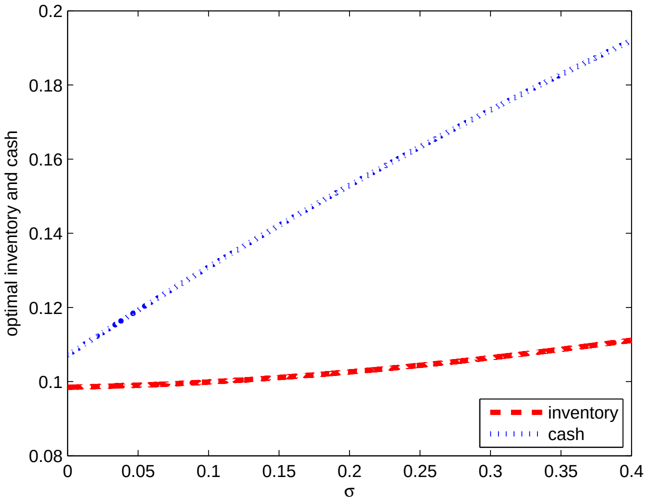

Figure 2.2: The Effects of Changes in Risk on the Optimal Cash and Inventory Holdings. This figure depicts the optimal cash and inventory holdings as a function of uncertainty σ.

the proceeds of the sale. In this manner, the firm transfers resources from future states with relatively high cash flows to the present and then channels resources back into all future states. An increase in risk therefore induces the firm to hoard liquid assets mainly through accumulating cash.

One point worth noting is that Proposition 7 is an artifact of my choice of the specification of demand function. If a linear demand is assumed, an increase in risk will lower the expected future price by driving up the expect future supply $e^{\mu+\frac{1}{2}\sigma^2}$. Then the overall effect of a risk increase on the optimal *level* of inventory holdings is ambiguous. It depends on which effect dominates — the decline in the expected future price, or the increase in the covariance between the equity issuance probability and the expected price. However, the impact of risk on inventory *level* plotted in Figure 2.2 is the upper bound, so the conclusion about the changes in the *share* of cash and inventory in internal liquidity due to a risk increase, which will be tested in the empirical section, is still true.

In the presence of uncertainty, all properties of the equilibrium described in Proposition 5 still hold. Figure 2.3 provides a graphical description of the impacts of the price elasticity of demand (θ), inventory carrying costs (δ), the effective return on cash holdings ($\hat{R}$), and the mean of productivity

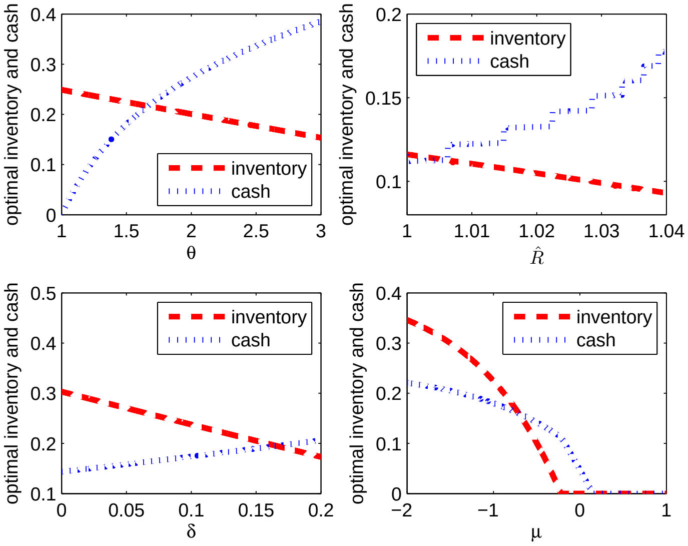

Figure 2.3: Comparative Statics in a Stochastic Environment. This figure illustrates the impacts of product market environment θ (the top left panel), the effective return on cash $\hat{R}$ (the top right panel), inventory carrying costs δ (the bottom left panel) and the expected future productivity μ (the bottom right panel) on the optimal cash and inventory holdings.

innovation (μ) on the tradeoff between cash and inventory under a stochastic environment.

Illustrated in the upper left panel of Figure 2.3, an increase in θ leads the firm to reallocate resources from inventory to cash. As θ increases, the demand function becomes flatter, and the degree of responsiveness in demand quantity with respect to price rises. The firm therefore has lower pricing power and is more likely to experience a cash flow shortfall. To avoid raising expensive external funds, the firm needs to hold more liquid assets. Considering the firm has a lower degree of control over price, holding inventory becomes less desirable, so the firm holds more cash and less inventory.

A rise in the effective rate of return on cash, $\hat{R}$, drives up the value of cash saving in each state of the world. The firm therefore shifts resources from inventory to cash, as shown in the upper right panel. Similarly, a higher inventory carrying cost δ makes it more expensive to hold inventory. As a result, the firm chooses to transfer less inventory and more cash over periods to meet future liquidity needs.

The lower right panel of Figure 2.3 illustrates the effect of the expected future supply (captured by the mean productivity shock μ) on the cash and inventory decisions. The larger the mean value of productivity shocks, the higher a cash flow is expected to arrive in the future, and also less likely the firm will need to issue equity next period. Accordingly, the firm has a weaker incentive to accumulate liquid assets and reduces both inventory and retaining earnings. In addition, an increase in the mean value of future relative supply drives down the expected price increase and in turn the value of inventory. The firm thus reduces inventory holdings even further.

2.2.5 Testable Hypothesis

The model produces three testable hypotheses on corporate cash and inventory holdings, which I formally test in the next section.

Hypothesis 1 *A firm's choice between cash and inventory for liquidity management is largely driven by its market power. Firms with greater market power rely more heavily on inventory than on cash.*

Hypothesis 2 *Risk is another key determinant of the tradeoff between cash and inventory. As risk rises, firms respond by storing more resources mainly in the form of cash. Therefore, the share of cash in firms' total asset increases, while the share of inventory declines.*

Aside from these two hypotheses, equation (2.5) suggests that firms carry inventory forward not only for avoiding stockout or expecting a capital gain, but also for reducing expected external financing costs. The former is identified as one of main motives for holding inventory in the macroeconomics literature. I test and highlight the latter— the liquidity motive for inventory. This implication is depicted in Figure 2.4.

Hypothesis 3 *Given the same degree of market power, financially constrained firms hold more inventory than non-financially-constrained firms.*

2.3 Estimation and Results

In Subsection 2.2.4, I prove and illustrate through simulations how a firm's cash holding and inventory carrying decisions depend on the price elasticity of demand and uncertainty. In this section, I perform formal empirical tests on those two predictions. Also tested is the model's implication on the liquidity motive for inventory holdings.

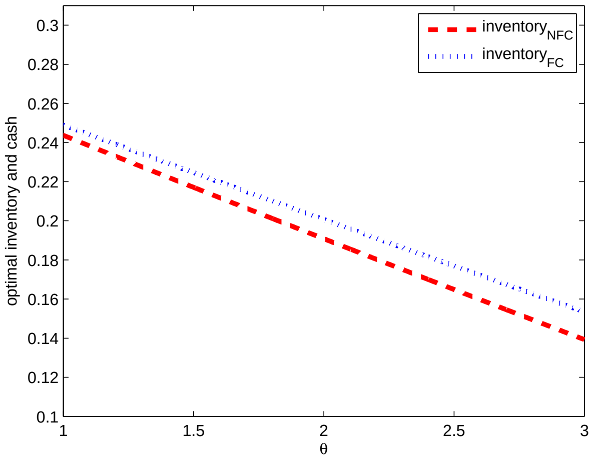

Figure 2.4: Financial Constraints and Inventory Holdings. This figure shows the optimal inventory holdings for financially-constrained firms ($\lambda > 0$) and non-financially-constrained firms ($\lambda = 0$), as a function of market power.

2.3.1 Methodology

2.3.1.1 The Choice between Cash and Inventory

I now turn to testing the central insight provided by this model that the choice between cash and inventory can be driven by firms' market power and the risk they face. More specifically, firms with higher market power (lower price elasticity of demand θ in the model) tend to hold more inventory and less cash relative to firms with lower market power; and firms facing higher uncertainty keep more cash and less inventory.

To implement a test of these implications, I build on the baseline empirical model in [11] and specify the regression as

$$\frac{cash}{inventory} = \alpha_0 + \alpha_1 market\ power + \alpha_2 risk + \alpha_3 firm\ size + \alpha_4 market\ to\ book$$
$$+ \alpha_5 cash\ flow + \alpha_6' X + \sum_j industry_j + \sum_t year_t + \sum_l cohort_l + \epsilon_1. \qquad (2.10)$$

In this regression, following [83], I use cash-to-inventory ratio as the dependent variable to capture the relative use of cash versus inventory in liquidity management. The ratio is calculated as the natural logarithm of the ratio of cash and short-term investments to inventory. To proxy a firm's market power, I use two measures. One is pseudo markup, reflecting a firm's ability to make profits. It is measured by sales over the sum of cost of goods sold (COGS) and selling, general and administrative expense (XSGA). The other proxy is a firm's market share.[35] I construct this variable by computing a firm's sales as a share of total sales in the 4-digit Standard Industrial Classification (SIC) industry where the firm operates. I take a natural logarithm of the two proxies of market power. Using a log form for both cash-to-inventory and market power, rather than a level form, is to simplify the interpretation of results. The coefficient α_1 can be interpreted as the elasticity, that is, a 1% change in market power results in α_1% change in cash.[36] To measure firm risk, I compute the standard deviation of the annual operating cash flow ratio over the previous five years, and I also use a log form of it in the regression.

Firm size is the natural logarithm of total assets. Market-to-book ratio is measured as the ratio of the sum of market equity and book debt over the book value of total asset. Cash flow is the ratio of operating cash flows over total asset. X are variables commonly used in the cash regression, including capital investment, net working capital, leverage, R&D expenditures, a dividend dummy, and acquisition expenses. A detailed description of these covariates is provided in Appendix B.4. I control for industry fixed effects to use intra-industry variations to identify the effects of different characteristics on cash holdings. I also include year fixed effects which are used to capture the common macroeconomic shocks across firms, and cohort dummies which are constructed based on firms' IPO listing dates. The inclusion of cohort fixed effects are motivated by the fact documented in [11] that most recent listed companies on average hold more cash than older cohorts.

I use lagged values for variables in X, testing the hypothesis that the beginning-of-period information (that is, the state of one period) has impacts on a firm's cash-inventory management. However, it is possible that the error terms are serially correlated, which results in an endogeneity problem and makes coefficient estimates inconsistent. The reason is as follows.

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[35] The constructed market share is immune to the criticism that focusing on publicly-traded firms in Compustat instead of all public and private firms in the industry may provide misleading results on the effect of market competition. The reason is that changes in denominator have no impacts on the intra-industry relative market shares, which are the variations employed to identify the effect of market power on corporate cash and inventory policies.

[36] As a robustness check, I also run regressions with both variables expressed in levels. There is no qualitative change in the coefficient of market power that we are interested in here. Results are available upon request.

In light of the simultaneity between cash, inventory and other investment decisions, although controls are beginning-of-period information, serial correlation in the disturbances $corr(\epsilon_{t-1}, \epsilon_t) \neq 0$ leads to a correlation between the error term and covariates, $corr(X, \epsilon_t) \neq 0$, and in turn causes OLS coefficient estimates to be biased. Therefore, serially uncorrelated disturbances are required to ensure the coefficient estimates consistent. I assume $corr(\epsilon_{t-1}, \epsilon_t) = 0$ for now. In the last subsection, I perform robustness checks by coping with the possible serial correlation in the error terms and by implementing dynamic models.

As an attempt to alleviate the concern that the results of regression (2.10) are driven solely by one side, that is, market power and risk affect cash or inventory only, I next examine them separately. I estimate the following two equations:

$$\begin{aligned} cash = \alpha_0 + \alpha_1 market\,power + \alpha_2 risk + \alpha_3 firm\ size + \alpha_4 market\ to\ book \\ + \alpha_5 cash\ flow + \alpha_6' X + \sum_j industry_j + \sum_t year_t + \sum_l cohort_l + \epsilon_2, \end{aligned} \tag{2.11}$$

and

$$\begin{aligned} inventory = \beta_0 + \beta_1 market\,power + \beta_2 risk + \beta_3 firm\ size + \beta_4 market\ to\ book \\ + \beta_5 cash\ flow + \beta_6' X + \sum_j industry_j + \sum_t year_t + \sum_l cohort_l + \epsilon_3. \end{aligned} \tag{2.12}$$

The standard errors are corrected by allowing for heteroscedastic and cross-equation correlated residuals, in addition to the possible correlation within a firm cluster.

The dependent variables, cash and inventory, are measured as the natural logarithm of the cash-to-asset ratio and inventory-to-asset ratio. Also modified is the corresponding net working capital included in X. It is now defined as the ratio of working capital net of cash and net of inventory over total asset, respectively. All other covariates are the same as those included in the regression equation (2.10).

2.3.1.2 Liquidity Motive for Inventory Holdings

Not only does my model provide insight into the relationship between market power, risk and working capital management (cash and inventory), but it also predicts that, in addition to avoiding future stockout and profiting from a price increase, firms carry inventory over time to preserve financial flexibility and keep themselves from resorting to costly external funds.

This leads to our third testable implication: financially-constrained firms hold more inventory than financially-unconstrained firms with the same degree of market power. The test specification is as follows:

$$inventory = \gamma_0 + \gamma_1 market\, power + \gamma_2 D + \gamma_3 risk + \gamma_4 size + \gamma_5 market\ to\ book$$
$$+ \gamma_6 cash\ flow + \gamma_7' X + \sum_j industry_j + \sum_t year_t + \sum_l cohort_l + \epsilon_4. \tag{2.13}$$

Holding other explanatory variables to be the same as those in the baseline regression of inventory (equation [2.12]), I add a dummy variable D to capture the intensity of financial constraints. The dummy variable is equal to one if the firm is classified as financially constrained, and zero otherwise. This dummy variable is a variable of particular interest here. Based on the model prediction that financial constraints lead firms to hold more inventory, we should expect that the coefficient γ_2 is positive. To reflect the stockout-avoidance motive of corporate inventory holdings, which is commonly emphasized in macroeconomics literature, an alternative specification controlling for sales growth is examined as well.

To test this model implication, measures of intensity of financial frictions are required. Following [44], I use two measures: firm size defined as the natural logarithm of total asset and Size-Age (SA) index which is computed as:

$$SA = -0.737 * size + 0.043 * size^2 - 0.04 * age.$$

To construct the financially constrained firm indicator, for each year, I rank firms based on their firm size and SA index and identify financially constrained (unconstrained) firms as being in the bottom (top) 25% of the size distribution and the top (bottom) 25% of the Size-Age (SA) index distribution, respectively.[37]

2.3.2 Data and Summary Statistics

I construct the sample from Compustat Fundamentals Annual files for the period 1980 to 2009. I focus on manufacturing industry (SIC 2000-3999) and process data following [11].

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[37] Also, [49] suggest that firm size is best suited as a proxy for high costs of external funds which is the definition of financial frictions in my model, while Cleary, White-Wu and Kaplan-Zingales indices seem best suited as proxies for a high need for external funds.

Table 2.1 reports summary statistics for regression variables. The mean and median cash-to-asset ratio are 20% and 9% respectively, implying a significantly positive skew. In contrast to cash ratio, inventory-to-asset ratio is much more symmetric, with the mean 19% slightly greater than median 16%. The explanatory variables of particular interest, markup and market share, exhibit different distributions. The former is relatively symmetrically distributed, with the mean equal to 1.03 and the median equal to 1.10. The latter, regardless of levels of industry fineness, is positively skewed.

Table 2.1: Summary Statistics

Table 2.1 presents descriptive statistics for the variables used in the estimation. The sample is constructed from Compustat Annual Industrial files over the period 1980-2009. Table 1 reports the mean, median, standard deviation, 25th and 75th percentile, and number of observations of each variable for manufacturing. A detailed definition of variables is provided in Appendix B.4.

Variables	Mean	Median	Std. Dev.	25%	75%	Obs.
Cash	0.20	0.09	0.24	0.02	0.28	86054
Inventory	0.19	0.16	0.14	0.08	0.27	85991
Markup	1.03	1.10	0.33	1.00	1.17	79348
Market share (4-digit)	0.07	0.008	0.17	0.001	0.05	86187
Market share (3-digit)	0.04	0.002	0.12	0.0001	0.02	86188
Size	4.31	4.20	2.58	2.57	6.00	86054
Risk	0.12	0.04	0.23	0.02	0.10	59936
Market-to-Book	2.31	1.20	3.71	0.78	2.18	74919
Cash flow	-0.13	0.06	0.66	-0.08	0.12	86054
Net working capital (cash)	0.03	0.12	0.62	-0.01	0.26	85278
Net working capital (inventory)	0.04	0.08	0.65	-0.05	0.28	85232
Capital investment	0.06	0.04	0.06	0.02	0.07	85148
Leverage	0.26	0.20	0.25	0.04	0.38	85893
R&D	0.13	0.05	0.22	0.02	0.14	60615
Dividend dummy	0.30	0	0.46	0	1	86189
Acquisition	0.02	0	0.05	0	0	82553
Sale growth	0.10	0.08	0.47	-0.05	0.22	77112

2.3.3 Results

2.3.3.1 The Choice between Cash and Inventory

Columns (1)-(3) in Table 2.2 present pooled-OLS estimates of regression (2.10) and its alternative specifications, which are identified with intra-industry variations. Column (1) reports the regression results for a simplified model, controlling for basic explanatory variables as well as 4-digit SIC industry fixed effects, year fixed effects and cohort fixed effects. Column (2) extends the basic cash model by adding a list of other control variables, whereas Column (3) controls for 3-digit instead of 4-digit SIC industry fixed effects, allowing for a sufficient number of firms in each industry so as to avoid a possible lack of variations in estimation. To address the concern over the possibility of spurious regression due to trending variables, Column (4) reports estimation results with Fama-MacBeth approach. Columns (5)-(8) repeat the exercises in Columns (1)-(4), using market share as a proxy for market power.[38] All heteroskedasticity-consistent standard errors are clustered by firm.

Table 2.2: The Choice between Cash and Inventory Holdings

Table 2.2 reports the results of regressions of cash-to-inventory ratio on a firm's market power, risk and other commonly-included control variables. Industry, year and cohort fixed effects are included in the regressions and the heteroskedasticity-consistent standard errors reported in parenthesis account for possible correlation within a firm cluster. Significance levels are indicated by *, **, and *** for 10%, 5%, and 1%, respectively.

	Dependent variable: Cash-to-Inventory							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Variables	Pooled OLS	Pooled OLS	Pooled OLS	Fama MacBeth	Pooled OLS	Pooled OLS	Pooled OLS	Fama MacBeth
Markup	-0.74***	-0.57***	-0.57***	-0.30**				
	(0.08)	(0.07)	(0.07)	(0.12)				
Market share					-0.69***	-0.62***	-0.76***	-0.96***
					(0.03)	(0.02)	(0.03)	(0.02)
Risk	0.13***	0.18***	0.19***	0.15***	0.15***	0.18***	0.18***	0.15***
	(0.02)	(0.02)	(0.02)	(0.01)	(0.02)	(0.02)	(0.02)	(0.01)
Size	0.14***	0.18***	0.19***	0.16***	0.75***	0.72***	0.87***	1.05***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.03)	(0.02)	(0.03)	(0.02)
Market-to-Book	0.13***	0.12***	0.12***	0.16***	0.11***	0.10***	0.10***	0.12***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Cash flow	0.84***	0.57***	0.58***	0.64***	0.57***	0.46***	0.50***	0.84***
	(0.06)	(0.06)	(0.06)	(0.08)	(0.04)	(0.04)	(0.04)	(0.10)
Net working capital		-0.03	-0.02	-0.01		-0.10*	-0.11*	-0.12*
		(0.06)	(0.06)	(0.07)		(0.06)	(0.06)	(0.06)
Capital investment		-1.50***	-1.44***	-1.48***		-1.37***	-1.36***	-1.47***
		(0.34)	(0.36)	(0.32)		(0.31)	(0.32)	(0.31)
Leverage		-2.55***	-2.63***	-2.54***		-2.34***	-2.40***	-2.33***
		(0.11)	(0.11)	(0.11)		(0.10)	(0.10)	(0.11)
R&D		1.08***	1.43***	0.58***		1.35***	1.52***	1.04***
		(0.20)	(0.19)	(0.25)		(0.16)	(0.17)	(0.19)
Dividend		-0.12***	-0.16***	-0.11***		-0.07	-0.08*	-0.02
		(0.05)	(0.05)	(0.02)		(0.05)	(0.05)	(0.02)
Acquisition		-1.12***	-1.11***	-0.80***		-1.46***	-1.43***	-1.03***
		(0.18)	(0.19)	(0.26)		(0.18)	(0.18)	(0.24)
Industry FE (3-digit)			Yes				Yes	
Industry FE (4-digit)	Yes	Yes		Yes	Yes	Yes		Yes
Year FE	Yes	Yes	Yes		Yes	Yes	Yes	
Cohort	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	32,803	32,803	32,803	33,300	34,289	34,289	34,289	34,800
R-squared	0.30	0.37	0.35	0.40	0.38	0.44	0.43	0.48

In accordance with model predictions, the results in Column (1) suggest that cash-to-inventory ratio declines with firms' ability to set price over cost, and increases with uncertainty that firms face. A 1% decrease in a firm's markup leads to an approximate 0.74% increase in a firm's cash-to-inventory ratio, while a 1% increase in a firm's risk pushes the ratio up by 0.13%. The results are statistically and economically significant.

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[38] 4-digit and 3-digit market shares are constructed separately.

Besides, the estimation results are robust with respect to different specifications, sources of variations and estimation methods. The estimated coefficient on risk vary little across columns, moving between the lowest 0.13 and the highest 0.19. The estimates of the coefficient on market power are also quantitatively similar. In Column (2), after controlling for a host of other explanatory variables, the value slightly changes to -0.57. With 3-digit SIC industry fixed effects, the coefficient of markup is unchanged compared to the one estimated in Column (2). In Columns (5)-(7), the economic magnitude of the coefficient on market share is larger relative to Columns (1)-(3), from -0.62 to -0.76. Estimating the regression equation (2.10) with Fama-MacBeth method confirms the robustness of the results.

As a further test of model implications, I regress cash and inventory separately on control variables included in the regression (2.10) and then conduct a joint test of whether market power and risk affect cash and inventory holdings in a way consistent with the theory. This helps to exclude the possibility that the results obtained in Table 2.2 are mostly affected by one margin rather than both. The standard errors are heteroskedasticity and autocorrelation consistent (HAC) and taken into account contemporaneous cross-equation correlations of the error terms. The results are reported in Tables 2.3-2.4.

Table 2.3 uses markup to measure market power. Estimation results support model predictions: a firm's cash holdings decrease with its market power but increase with risk, while inventory behaves in an opposite manner. The coefficients on markup and risk in the cash regression have the correct signs and are statistically significant at the one percentage level in all specifications. The results suggest that the elasticity of cash holdings to market power lies in the range of 0.19% to 0.34% and the elasticity of cash holdings to risk ranges from 0.05% to 0.10%. This implies that cash policy is at least three times more sensitive to product market environment than to risk. The estimated coefficients on other covariates conform with those in previous studies, except for firm size. The difference can arise due to the information on market power contained in the variable firm size.

Column (2) reports the results for inventory. The coefficient on markup indicates that a 1% decrease in a firm's markup results in a 0.42% drop in a firm's inventory stock. The inclusion of other covariates (Column [4]) and the change of across-group variations (Column [6]) overall hardly affect the estimation results. The elasticity drops only slightly to 0.36% and 0.35%, respectively. The response of inventory to risk is also consistent with the model prediction. On average, a 1% rise in risk leads to a 0.08% drop in inventory holdings.

Table 2.3: OLS Regression of Cash and Inventory: by Mark-up

Table 2.3 reports the results of regressions of cash and inventory holdings separately on a firm's market power proxies by markup, risk and other commonly-included control variables. Industry, year and cohort fixed effects are included in the regressions and the heteroskedasticity-consistent standard errors reported in parenthesis account for possible correlation within a firm cluster. Significance levels are indicated by *, **, and *** for 10%, 5%, and 1%, respectively.

Variables	(1) cash	(2) inventory	(3) cash	(4) inventory	(5) cash	(6) inventory
Markup	-0.34***	0.42***	-0.19***	0.36***	-0.20***	0.35***
	(0.04)	(0.05)	(0.04)	(0.04)	(0.04)	(0.04)
Risk	0.05***	-0.07***	0.09**	-0.08***	0.10***	-0.08***
	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Size	0.02**	-0.12***	0.06***	-0.11***	0.06***	-0.12***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Market-to-Book	0.09***	-0.04***	0.07***	-0.04***	0.07***	-0.04***
	(0.01)	(0.00)	(0.01)	(0.00)	(0.01)	(0.00)
Cash flow	0.53***	-0.26***	0.40***	-0.12***	0.41***	-0.12***
	(0.04)	(0.03)	(0.04)	(0.03)	(0.04)	(0.03)
Net working capital			-0.48***	-0.41***	-0.50***	-0.44***
			(0.05)	(0.04)	(0.05)	(0.04)
Capital investment			-2.48***	-1.12***	-2.53***	-1.23***
			(0.24)	(0.17)	(0.25)	(0.17)
Leverage			-2.45***	-0.05	-2.54***	-0.07
			(0.08)	(0.05)	(0.08)	(0.05)
R&D			0.64***	-0.23**	0.84***	-0.34***
			(0.12)	(0.12)	(0.12)	(0.11)
Dividend			-0.08**	0.04*	-0.11***	0.05**
			(0.04)	(0.02)	(0.04)	(0.02)
Acquisition			-1.70***	-0.59***	-1.72***	-0.61***
			(0.15)	(0.08)	(0.15)	(0.08)
Industry FE (3-digit)					Yes	Yes
Industry FE (4-digit)	Yes	Yes	Yes	Yes		
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Cohort	Yes	Yes	Yes	Yes	Yes	Yes
Observations	33,590	33,590	33,590	33,590	33,590	33,590
R-squared	0.25	0.33	0.35	0.36	0.33	0.34
Joint test: α_1=0, β_1=0	p-value=0.00		p-value=0.00		p-value=0.00	
Joint test: α_2=0, β_2=0	p-value=0.00		p-value=0.00		p-value=0.00	

Table 2.4 replicates the analysis in Table 2.3 with market share as the proxy for market power. The results suggest that the relationship between market power, risk and working capital management still holds. The estimated coefficients of market share and risk have the expected signs and are stable across various regressions. Compared to the estimates reported in Table 2.3, the results are quantitatively similar.

As robustness checks, I next turn to firm fixed effect and Fama-MacBeth approaches. In Table 2.5, I replace industry dummy variables in regression equations (2.11) and (2.12) with firm-specific dummy variables. The corresponding results are identified from within-firm over-time variations. Table 6 presents results with Fama-MacBeth method which uses cross-sectional variations to estimate coefficients. Columns (1) and (2) in each table report the results for the cash model with market power proxied by markup and

Table 2.4: Pooled OLS Regression of Cash and Inventory: by Market Share

Table 2.4 reports the results of regressions of cash and inventory holdings separately on a firm's market power proxies by market share, risk and other commonly-included control variables. Industry, year and cohort fixed effects are included in the regressions and the heteroskedasticity-consistent standard errors reported in parenthesis account for possible correlation within a firm cluster. Significance levels are indicated by *, **, and *** for 10%, 5%, and 1%, respectively.

Variables	(1) cash	(2) inventory	(3) cash	(4) inventory	(5) cash	(6) inventory
Market share	-0.30***	0.37***	-0.24***	0.33***	-0.27***	0.42***
	(0.01)	(0.02)	(0.01)	(0.01)	(0.01)	(0.02)
Risk	0.06***	-0.09***	0.08***	-0.09***	0.09***	-0.08***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Size	0.29***	-0.44***	0.26***	-0.40***	0.30***	-0.49***
	(0.02)	(0.01)	(0.01)	(0.01)	(0.02)	(0.02)
Market-to-Book	0.07***	-0.03***	0.06***	-0.03***	0.06***	-0.03***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Cash flow	0.37***	-0.11***	0.32***	-0.05***	0.34***	-0.07***
	(0.03)	(0.02)	(0.03)	(0.02)	(0.03)	(0.02)
Net working capital			-0.38***	-0.32***	-0.40***	-0.30***
			(0.04)	(0.03)	(0.04)	(0.03)
Capital investment			-2.29***	-1.01***	-2.37***	-1.08***
			(0.22)	(0.15)	(0.23)	(0.15)
Leverage			-2.19***	-0.07	-2.27***	-0.07
			(0.08)	(0.05)	(0.08)	(0.05)
R&D			0.68***	-0.46***	0.77***	-0.49***
			(0.08)	(0.10)	(0.08)	(0.09)
Dividend			-0.05	0.02	-0.07**	0.02
			(0.04)	(0.02)	(0.04)	(0.02)
Acquisition			-1.88***	-0.38***	-1.89***	-0.40***
			(0.15)	(0.08)	(0.15)	(0.08)
Industry FE (3-digit)					Yes	Yes
Industry FE (4-digit)	Yes	Yes	Yes	Yes		
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Cohort	Yes	Yes	Yes	Yes	Yes	Yes
Observations	36,383	36,383	36,383	36,383	36,383	36,383
R-squared	0.32	0.42	0.41	0.44	0.39	0.44
Joint test: α_1=0, β_1=0	p-value=0.00		p-value=0.00		p-value=0.00	
Joint test: α_2=0, β_2=0	p-value=0.00		p-value=0.00		p-value=0.00	

market share respectively. Columns (3) and (4) show results for inventory regressions.

In Table 2.5, the estimated effects of market power and risk are qualitatively the same as those in Tables 2.3 and 2.4, although smaller in magnitude. The coefficients on some other explanatory factors yield slightly different results in sign and significance, including R&D expenditure, dividend distribution dummy and acquisition expenses. Table 2.6 delivers the same pattern with only one exception. Besides, the identified impacts of product market environment and uncertainty on cash and inventory are even stronger, relative to those shown in Table 2.3-2.5.

In summary, Tables 2.2-2.6 provide strong evidence in support of model predictions on the relations between market power, risk, and the cash-inventory management. I next turn to the last hypothesis about the motive

Table 2.5: Firm Fixed Effect Regression of Cash and Inventory

Table 2.5 presents the results of regressing cash and inventory ratios on a firm's market power and risk with firm fixed effect specifications. Standard errors reported in parenthesis account for clustering by firm. Significance levels are indicated by *, **, and *** for 10%, 5%, and 1%, respectively.

	A: Cash		B: Inventory	
Variables	(1)	(2)	(3)	(4)
Markup	-0.10***		0.28***	
	(0.04)		(0.05)	
Market share		-0.16***		0.21***
		(0.01)		(0.01)
Risk	0.06***	0.06***	-0.05***	-0.05***
	(0.01)	(0.01)	(0.01)	(0.01)
Size	0.04*	0.13***	-0.18***	-0.32***
	(0.02)	(0.02)	(0.01)	(0.02)
Market-to-Book	0.05***	0.04***	-0.01***	-0.01**
	(0.00)	(0.00)	(0.00)	(0.00)
Cash flow	0.25***	0.24***	-0.12***	-0.07***
	(0.04)	(0.03)	(0.03)	(0.02)
Net working capital	-0.31***	-0.22***	-0.13***	-0.09***
	(0.04)	(0.04)	(0.03)	(0.03)
Capital investment	-2.00***	-1.90***	-0.13	-0.13
	(0.20)	(0.19)	(0.12)	(0.11)
Leverage	-1.48***	-1.28***	-0.09**	-0.11***
	(0.08)	(0.07)	(0.04)	(0.04)
R&D	-0.08	0.02	-0.08	-0.09
	(0.12)	(0.07)	(0.11)	(0.09)
Dividend	0.00	0.00	0.05***	0.06***
	(0.04)	(0.04)	(0.02)	(0.02)
Acquisition	-1.22***	-1.22***	0.01	0.02
	(0.13)	(0.12)	(0.05)	(0.05)
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	33,388	36,176	33,005	34,496
R-squared	0.09	0.09	0.15	0.18

for holding inventory.

2.3.3.2 Inventory and Financing Frictions

In the model, the presence of financial frictions generates a distinct reason for holding inventory from those identified and stressed in the previous literature (e.g., the production-smoothing, the stockout-avoidance and the transaction motives), namely, the liquidity motive. To test this implication, I run regression (2.13) and report the results in Tables 2.7-2.8. I pay particular attention to the coefficient on financially constrained firm dummy. In the regression, financing frictions are measured by firm size and SA index as suggested in [44]. The dummy variable is equal to one if a firm is classified as financially constrained, and is equal to zero otherwise.

According to the first two rows of Column (1) in Table 2.7, on average,

Table 2.6: Fama-MacBeth Regression of Cash and Inventory

Table 2.6 presents the results of regressing cash and inventory ratios on a firm's market power and risk with Fama-MacBeth approach. Significance levels are indicated by *, **, and *** for 10%, 5%, and 1%, respectively..

	A: Cash		B: Inventory	
Variables	(1)	(2)	(3)	(4)
Markup	0.05		0.29***	
	(0.09)		(0.05)	
Market share		-0.33***		0.48***
		(0.02)		(0.02)
Risk	0.05***	0.06***	-0.08***	-0.07***
	(0.01)	(0.01)	(0.01)	(0.01)
Size	0.03***	0.35***	-0.11***	-0.55***
	(0.01)	(0.02)	(0.01)	(0.02)
Market-to-Book	0.09***	0.07***	-0.04***	-0.03**
	(0.01)	(0.01)	(0.01)	(0.00)
Cash flow	0.51***	0.66***	-0.10***	-0.11***
	(0.06)	(0.09)	(0.04)	(0.03)
Net working capital	-0.95***	-0.82***	-0.62***	-0.44***
	(0.13)	(0.12)	(0.06)	(0.05)
Capital investment	-2.82***	-2.63***	-1.32***	-1.13***
	(0.20)	(0.20)	(0.16)	(0.16)
Leverage	-2.54***	-2.31***	-0.15***	-0.11***
	(0.11)	(0.11)	(0.04)	(0.03)
R&D	-0.67***	0.71***	0.02	-0.25**
	(0.14)	(0.10)	(0.14)	(0.11)
Dividend	-0.08***	-0.04***	0.03***	-0.01
	(0.02)	(0.02)	(0.01)	(0.01)
Acquisition	-1.46***	-1.56***	-0.62***	-0.45***
	(0.20)	(0.21)	(0.09)	(0.08)
Industry FE (4-digit)	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Cohort	Yes	Yes	Yes	Yes
Observations	33,886	36,691	33,508	35,014
R-squared	0.43	0.46	0.42	0.51

firms have a regular tendency to raise their inventory by 0.27% in response to a 1% increase in market power; furthermore, holding market power constant, financial frictions contribute to 1.08 percentage points increase in inventory ratio. These results are again robust when using 4-digit SIC industry fixed effects in Column (2), controlling for stockout-avoidance motive in Column (3), estimating with Fama-MacBeth approach in Column (4), and using another proxy for market power in Columns (5)-(8). The coefficients on the financially-constrained firm dummy variable are all positive and statistically significant. I re-estimate model (2.13) with an alternative measure of financial friction intensity in Table 2.8. The results are quantitatively similar.

The results shown in Tables 2.7 and 2.8 support the model prediction that inventory is an important component of a firm's financial policy. [36] derive a similar conclusion by showing the significant negative impacts of inventory investment on capital investment. They argue that in the presence

Table 2.7: Inventory For Constrained and Unconstrained Firms: by Firm Size

Table 2.7 presents the results of regressing inventory on a financially-constrained firm dummy. Financing frictions are measured by firm size. Robust standard errors reported in parenthesis are clustered at firm level. Significance levels are indicated by *, **, and *** for 10%, 5%, and 1% respectively.

Variables	(1) Pooled OLS	(2) Pooled OLS	(3) Pooled OLS	(4) Fama MacBeth	(5) Pooled OLS	(6) Pooled OLS	(7) Pooled OLS	(8) Fama McBeth
Markup	0.27***	0.29***	0.29***	0.29***				
	(0.05)	(0.05)	(0.05)	(0.06)				
Market share					0.35***	0.28***	0.28***	0.11***
					(0.02)	(0.02)	(0.02)	(0.01)
FC dummy	0.08***	0.09**	0.10**	0.06***	0.07***	0.19***	0.19***	0.09***
	(0.03)	(0.04)	(0.04)	(0.01)	(0.02)	(0.04)	(0.04)	(0.02)
Risk	-0.09***	-0.10***	-0.10***	-0.09**	-0.08***	-0.09***	-0.10***	-0.08***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Sales growth			0.04				0.03	
			(0.03)				(0.03)	
Size	-0.11***	-0.11***	-0.11***	-0.10***	-0.43***	-0.34***	-0.34***	-0.18***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)	(0.02)	(0.02)	(0.01)
Market-to-Book	-0.04***	-0.04***	-0.04***	-0.04***	-0.02***	-0.02***	-0.02***	-0.03***
	(0.01)	(0.01)	(0.01)	(0.00)	(0.01)	(0.01)	(0.01)	(0.00)
Cash flow	-0.12***	-0.12***	-0.13***	0.08*	-0.06***	-0.06**	-0.06**	0.05
	(0.04)	(0.03)	(0.04)	(0.05)	(0.03)	(0.03)	(0.03)	(0.03)
Net working capital	-0.28***	-0.27***	-0.27***	-0.56***	-0.18***	-0.20***	-0.20***	-0.50***
	(0.04)	(0.04)	(0.04)	(0.07)	(0.03)	(0.03)	(0.03)	(0.07)
Capital investment	-0.71***	-0.78***	-0.78***	-0.95***	-0.69***	-0.71***	-0.72***	-0.73***
	(0.23)	(0.21)	(0.21)	(0.20)	(0.20)	(0.19)	(0.19)	(0.21)
Leverage	-0.02	0.02	0.02	-0.12***	-0.01	0.02	0.02	-0.11***
	(0.06)	(0.06)	(0.06)	(0.04)	(0.06)	(0.06)	(0.06)	(0.04)
R&D	-0.30**	-0.19	-0.20	-0.00	-0.37***	-0.37***	-0.38***	-0.26*
	(0.14)	(0.14)	(0.14)	(0.16)	(0.12)	(0.12)	(0.12)	(0.15)
Dividend	0.10***	0.10***	0.10***	0.08***	0.07***	0.07***	0.08***	0.08***
	(0.03)	(0.03)	(0.03)	(0.01)	(0.03)	(0.03)	(0.03)	(0.01)
Acquisition	-0.62***	-0.54***	-0.56***	-0.55***	-0.44***	-0.39***	-0.41***	-0.48***
	(0.11)	(0.10)	(0.10)	(0.10)	(0.10)	(0.09)	(0.10)	(0.10)
Industry FE (3-digit)	Yes			Yes	Yes			Yes
Industry FE (4-digit)		Yes	Yes			Yes	Yes	
Year FE	Yes	Yes	Yes		Yes	Yes	Yes	
Cohort	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	17,627	18,310	18,310	17,889	18,407	19,112	19,112	18,678
R-squared	0.36	0.39	0.39	0.44	0.42	0.43	0.43	0.44

of finance constraints, firms decumulate inventory to smooth capital investment for a limited source of funds. My work complements [36] by providing a piece of new evidence on the financing role of inventory. That is, caeteris paribus, firms facing finance constraints store more inventory so that they have more internal resources to draw down whenever necessary.

2.3.4 Robustness Checks

As mentioned in Subsection 2.3.1, if the error terms in equation (2.10) are serially correlated, the OLS coefficient estimates obtained are biased. In this subsection, I undertake robustness checks by allowing for serially correlated error terms. I also estimate a dynamic model for the cash-to-inventory

Table 2.8: Inventory For Constrained and Unconstrained Firms: by SA Index

Table 2.8 presents the results of regressing inventory on a financially-constrained firm dummy. Financing frictions are measured by Size-Age (SA) index. Robust standard errors reported in parenthesis are clustered at firm level. Significance levels are indicated by *, **, and *** for 10%, 5%, and 1% respectively.

Variables	(1) Pooled OLS	(2) Pooled OLS	(3) Pooled OLS	(4) Fama MacBeth	(5) Pooled OLS	(6) Pooled OLS	(7) Pooled OLS	(8) Fama McBeth
Markup	0.31***	0.33***	0.32***	0.30***				
	(0.06)	(0.05)	(0.05)	(0.04)				
Market share					0.36***	0.29***	0.29***	0.10***
					(0.02)	(0.02)	(0.02)	(0.01)
FC dummy	0.09**	0.08**	0.08**	0.06	0.11***	0.12***	0.13***	0.11***
	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)
Risk	-0.09***	-0.09***	-0.09***	-0.08***	-0.08***	-0.09***	-0.09***	-0.07***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Size	-0.11***	-0.11***	-0.11***	-0.10***	-0.42***	-0.36***	-0.36***	-0.16***
	(0.01)	(0.01)	(0.01)	(0.00)	(0.02)	(0.02)	(0.02)	(0.01)
Sales growth			0.05*				0.04	
			(0.03)				(0.03)	
Market-to-Book	-0.04***	-0.03***	-0.04***	-0.04***	-0.02***	-0.02***	-0.02***	-0.03***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)
Cash flow	-0.13***	-0.12***	-0.12***	-0.09*	-0.07***	-0.05*	-0.05*	-0.05
	(0.04)	(0.04)	(0.04)	(0.04)	(0.03)	(0.03)	(0.03)	(0.04)
Net working capital	-0.30***	-0.29***	-0.29***	-0.56***	-0.19***	-0.21***	-0.21***	-0.50***
	(0.04)	(0.04)	(0.04)	(0.07)	(0.03)	(0.03)	(0.03)	(0.07)
Capital investment	-0.86***	-0.81***	-0.81***	-1.08***	-0.82***	-0.73***	-0.73***	-0.84***
	(0.23)	(0.21)	(0.21)	(0.24)	(0.20)	(0.19)	(0.19)	(0.23)
Leverage	-0.03	0.01	0.02	-0.12***	-0.02	0.02	0.02	-0.10***
	(0.06)	(0.06)	(0.06)	(0.04)	(0.06)	(0.06)	(0.06)	(0.04)
R&D	-0.33**	-0.22	-0.24	0.02	-0.42***	-0.38***	-0.40***	-0.25
	(0.15)	(0.15)	(0.14)	(0.18)	(0.13)	(0.13)	(0.13)	(0.16)
Dividend	0.08***	0.08***	0.08***	0.07***	0.05**	0.06**	0.06**	0.06***
	(0.03)	(0.03)	(0.03)	(0.01)	(0.03)	(0.03)	(0.03)	(0.01)
Acquisition	-0.50***	-0.49***	-0.52***	-0.57***	-0.34***	-0.32***	-0.35***	-0.47***
	(0.10)	(0.10)	(0.10)	(0.13)	(0.10)	(0.10)	(0.10)	(0.13)
Industry FE (3-digit)	Yes			Yes	Yes			Yes
Industry FE (4-digit)		Yes	Yes			Yes	Yes	
Year FE	Yes	Yes	Yes		Yes	Yes	Yes	
Cohort	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	18,139	18,770	18,770	18,427	18,893	19,544	19,544	19,158
R-squared	0.35	0.39	0.39	0.44	0.42	0.44	0.44	0.44

regression, considering the possibility that the model presented in previous sections are misspecified.[39]

With the assumption that the disturbances in equation (2.10) follow an AR(1) process, the cash-to-inventory model can be written as

$$\frac{cash}{inventory} = \alpha_0 + \alpha_1 market\ power + \alpha_2 risk + \alpha_3 firm\ size + \alpha_4 market\ to$$

$$book + \alpha_5 cash\ flow + \alpha_6' X_{-1} + \sum_j industry_j + \sum_t year_t$$

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[39] For instance, [34] estimate a target adjustment model to analyze the evolution of corporate cash holdings.

$$+\sum_l cohort_l + \epsilon_4, \tag{2.14}$$

where $\epsilon_{4,t} = \rho\epsilon_{4,t-1} + \nu_t$ and ν_t is independent and identically distributed.

Also estimated is the dynamic model specified as follows:

$$\frac{cash}{inventory} = \alpha_0 + \alpha_1 market\ power + \alpha_2 risk + \alpha_3 \frac{cash}{inventory}_{-1} + \alpha_4 firm\ size$$

$$+\alpha_5 market\ to\ book + \alpha_6 cash\ flow + \alpha_7' X + \alpha_8' X_{-1}$$

$$+\sum_j industry_j + \sum_t year_t + \sum_l cohort_l + \epsilon_5, \tag{2.15}$$

Regression equation (2.15) is the extension of equation (2.10), with the inclusion of lagged dependent variable, $\frac{cash}{inventory}_{-1}$, and lagged explanatory variables X, X_{-1}, on the right-hand side to account for the dynamics of financial policy and time adjustment process. The coefficient α_1 indicates the short-term impact of market power on corporate cash and inventory decisions, while the long-run effect is given by $\frac{\alpha_1}{1-\alpha_3}$.

Table 2.9 summarizes the results. In Column (1), I model AR(1)-in-errors and follow the Cochrane-Orcutt procedure to estimate the persistence parameter ρ. Column (2) presents the results of the dynamic regression (equation [2.15]) with 4-digit SIC industry fixed effects and time fixed effects. In Column (3), I consider an alternative specification by adding more lagged dependent and independent variables as explanatory factors to regression (2.15). Columns (4)-(6) re-estimate the regressions in Columns (1)-(3) with market share.

As shown in Column (1) of Table 2.9, allowing for serial correlation in the error terms gives qualitatively similar results to those reported in Tables 2.2. The coefficient on markup is still negative and significant at the 1% level. In Column (2), the coefficient on markup captures the short-term effect of market power. The result suggests that a 1% decline in markup raises cash-inventory ratio by 0.12% in the short run, while in the long run, the overall impact is a 0.46% increase. Changing the lag structure by including more lagged dependent and independent variables barely changes short-run and long-run impacts of markup on cash-inventory ratio. According to the estimates in Column (3), the short-term effect of markup drops slightly to -0.11%; overall, a 1% decrease in markup drives up 0.50% of cash-inventory ratio. The estimated effect remains unchanged when market share is used as the alternative measure of market power.

Table 2.9: Robustness Checks: The Choice between Cash and Inventory Holdings

Table 2.9 reports the results of dynamic cash-inventory models. The heteroskedasticity-consistent standard errors reported in parenthesis account for possible correlation within a firm cluster. Significance levels are indicated by *, **, and *** for 10%, 5%, and 1% respectively.

Variables	(1) Cochrane-Orcutt	(2) Dynamic	(3) Dynamic	(4) Cochrane-Orcutt	(5) Dynamic	(6) Dynamic
Markup	-0.40***	-0.12***	-0.11***			
	(0.05)	(0.04)	(0.03)			
Market share				-0.47***	-0.19***	-0.18***
				(0.02)	(0.01)	(0.01)
Risk	0.09***	0.05***	0.04***	0.09***	0.05***	0.04***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Lagged cash (first order)		0.74***	0.62***		0.73***	0.61***
		(0.01)	(0.01)		(0.01)	(0.01)
Lagged cash (second order)			0.16***			0.15***
			(0.01)			(0.01)
Size	0.16***	0.05***	0.04***	0.56***	0.22***	0.21***
	(0.01)	(0.00)	(0.00)	(0.02)	(0.01)	(0.01)
Market-to-Book	0.04***	0.05***	0.04***	0.04***	0.04***	0.04***
	(0.01)	(0.00)	(0.00)	(0.01)	(0.00)	(0.00)
Cash flow	0.37***	0.39***	0.40***	0.28***	0.42***	0.42***
	(0.05)	(0.04)	(0.04)	(0.04)	(0.03)	(0.03)
Net working capital	-0.02	-0.14***	-0.12**	-0.06	-0.19***	-0.17***
	(0.05)	(0.06)	(0.06)	(0.05)	(0.05)	(0.05)
Capital investment	-0.65***	-0.88***	-1.20***	-0.70***	-0.82***	-1.12***
	(0.19)	(0.19)	(0.20)	(0.18)	(0.19)	(0.19)
Leverage	-0.81***	-0.11	-0.20***	-0.70***	-0.12	-0.19***
	(0.07)	(0.08)	(0.08)	(0.07)	(0.07)	(0.07)
R&D	0.96***	0.69***	0.36**	0.83***	0.77***	0.51***
	(0.15)	(0.17)	(0.16)	(0.12)	(0.14)	(0.13)
Dividend	-0.05	0.03	-0.02	-0.03	-0.02	0.01
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Acquisition	-0.16	-0.64***	-1.06***	-0.07	-0.69***	-1.10***
	(0.10)	(0.12)	(0.12)	(0.10)	(0.12)	(0.12)
Lagged X (first order)		Yes	Yes		Yes	Yes
Lagged X (second order)			Yes			Yes
Industry FE (4-digit)	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Cohort	Yes	Yes	Yes	Yes	Yes	Yes
Observations	32,803	30,568	28,481	34,289	31,863	29,627
R-squared	0.15	0.72	0.73	0.19	0.74	0.75

The effect of risk is also similar to that found in Table 2.2. The estimates of the coefficient on risk are statistically significant and positive in all cases. The estimate in Column (2) indicates that a 1% increase in risk contributes to a 0.05% rise in the cash-inventory ratio in the short run and around a 0.19% increase in the long run, which is of economic significance.

2.3.5 Trends in Cash and Inventory Holdings

Figure 2.1 shows that in the past three decades, corporate sector has been hoarding cash and at the same time decumulating its inventory stock. This paper presents insight into the joint dynamics of cash and inventory ratios.

The model suggests that riskier and increasingly competitive product market environments lead firms to reallocate resources from inventory stock to cash reserve. A decline in market power limits firms' ability to raise product prices over marginal costs without losing customers, and in turn reduces firm profitability and the value of inventory. Firms therefore shift resources from inventory to cash in order to maintain financial flexibility. In addition, an increase in risk raises the probability of occurrence of extreme events. Costly external finance leads firms to concern more about low-productivity states (negative outcomes) and firms respond to a riskier environment by saving more out of current resources. Inventory is highly valued in fairly low productivity states of the world, while cash, delivering the same rate of return in all states, is valued whenever the probability of failing to meet liquidity needs is positive. Consequently, firms transfer resources from future high productivity states (by drawing down inventory) to present, store the proceeds and use them to fund all states in the future if necessary. Overall, an increase in risk leads firms to put more weight on cash than on inventory when managing liquidity.

It is empirically well documented that product market competition and firm-level risk have increased over time. [31] use turnover of leaders within industry to proxy market competition and identify industry leaders based on a firm's operating income and market value. They find that there is a steady increase in turnover among leaders over time. Similarly, [56] analyze the time trend of product market competitiveness. They employ three variables, industry turnover, return on assets, and the market share of foreign competitors, to measure market competition. They also find that product market becomes increasingly competitive and domestic producers lose market shares to their foreign rivals. The increase in firm-level volatility for publicly traded firms is first comprehensively documented in [22]. They use stock return data in CRSP to measure firm-level volatility and find that there is a significant positive time trend in idiosyncratic risk. [30] use the volatility of the growth rate of sales to measure firm-level risk and find the same upward trend after controlling for sample composition effects.

Therefore, my model provides possible explanations for the patterns shown in Figure 2.1: increases in risk and market competitiveness can contribute to the simultaneous changes in corporate cash and inventory holdings. Similar conclusions on cash holdings are derived in [71] and [82]. They use a real option model to show that both market competition and risk drive up the option value of exit by affecting the closure threshold and firms hold cash to prevent inefficient exit. This paper distinguishes itself from those two studies by proposing an additional mechanism relating product market environment, risk and cash holdings: the reason for which firms prefer raising cash rather than other alternative sources of internal finance for liquidity management, when the total internal liquidity demand is higher due to a tougher business environment.

2.4 Conclusion

While previous studies have focused on cash holdings, I in this paper consider an additional source of internal liquidity which is often neglected: inventory. I analyze the tradeoff firms face when choosing between holding cash and inventory to manage liquidity needs. Using a model that assumes uncertain productivity shocks and imperfect capital markets, I show that a firm's market power and exposure to risk affect the choice between cash and inventory. Firms facing relatively inelastic demand and thus having greater pricing power find themselves more likely to benefit from carrying inventory than saving cash. Firms operating in a riskier environment have a greater chance of experiencing a cash flow shortfall and thus a liquidity shortage. They respond by raising internal liquidity, mainly in the form of cash.

I verify the model implications by showing that firms with higher market power accumulate more inventory but less cash and riskier firms act in the opposite way, after controlling for other determinants. These implications in turn suggest that the dramatic change in the composition of firms' current assets observed in the data can be explained by increased market competition and increased firm-level risk. This paper also adds to the existing inventory literature by modeling inventory as a source of funds and presents evidence on it. The empirical results show that financially-constrained firms hold more inventory than their counterparts, which supports the liquidity motive for inventory holdings.

An interesting extension to the work in subsequent research is to consider an infinite-horizon model. The current framework limits the role of market power in affecting cash and inventory. In the three-period setup, to simplify the model I assume that firms have to sell all products in the second period, which implies that firms are not allowed to manage cash flows by (dis)investing in inventory. In other words, an infinite-horizon model allowing for price setting and therefore inventory investment in each period can endogenize cash flows (one of the most important internal liquidity) and, to some degree, absorb the adverse effects of uncertainty. Besides, an infinite-horizon model can be used to quantitatively evaluate the impacts of market power and uncertainty on cash and inventory.

Chapter 3

Limited Participation in International Business Cycle Models: A Formal Evaluation

3.1 Introduction

A number of existing studies have shown that access to international borrowing and lending is important for international business cycles. We verify this result formally by means of a novel statistical procedure applied to several versions of a standard two-country two-good model. We show that a model with no cross-border asset trades (financial autarky) is the specification that outperforms other models in matching the data and that the differences in performance are statistically significant. We then propose a competing model that allows for within country household heterogeneity in participation in asset markets. Using our test we show that this amended model does significantly better in matching the data than a representative agent benchmark. Furthermore, when limited participation is introduced, complete markets specification performs as well as financial autarky in fitting the data.

How does access to different financial assets affect the functioning of the economy? In a seminal work, [7, 8], BKK hereafter, document the key business cycle regularities in industrial countries related to volatilities of consumption, output, investment and their cross-country co-movements, and develop an international business cycles model with complete asset markets in an attempt to rationalize the data facts. They show that only some of the regularities can be explained by the model. The BKK model fails in three key dimensions. First, while cross-country consumption correlations tend to be similar to cross-country output correlations in the data, the model predicts consumption correlations far exceeding those for outputs. This is the so-called “quantity” puzzle [7]. Second, investment and employment are positively correlated across countries while the model predicts a negative correlation. This data-model disconnect is usually referred to as the “international comovement” puzzle [13]. Third, the model generates significantly less volatility in the terms of trade and the real exchange rate relative to the data. The model also predicts a positive correlation between real exchange rate and the ratio of domestic to foreign consumption, again contrary to the data.[40]

To account for the disconnect between the model and data, [14], [62], [6], [33] study economies in which the only asset traded internationally is a non-contingent bond. They show that these economies admit different allocations from those arising under complete asset markets only if productivity shocks are very persistent and do not spill over across countries. [47] develop this argument further by considering an economy in which no international assets are traded. They call it financial autarky. They find that the equilibrium dynamics under financial autarky are similar to those in the data. Their conclusion, however, is based primarily on an “eyeball” comparison of various moments predicted by the model with those of competing models and with the data. In fact, such informal moment comparison is standard practice in the literature.

There are several important shortcomings of the “eyeball” approach. First, it does not inform whether differences in the model performance are statistically significant. Namely, an “eyeball” approach cannot credibly distinguish between the systematic differences in model performance (in the sense that the model uncovers important relationships between the variables at the population level) and, therefore, is likely to be found in other data sets; and differences arising due to random variations in the data. Second, often model comparison is hindered by the fact that one model performs better in matching some moments, but competing models perform better in matching other moments. Without a metric that aggregates across various moments of interest, informal model comparison remains inconclusive.

In this paper we propose a testing procedure that allows the researcher to assess the statistical significance of results when comparing DSGE models to the data. The procedure builds upon [50] and is a version of Vuong-type tests for misspecified models [86] adopted for the DSGE framework. Suppose that the researcher is interested in evaluating whether a newly proposed economic structure is important for explaining some chosen data

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[40] A detailed recent discussion of various puzzles in the international business cycles models can be found in [69].

patterns. For that purpose, a Vuong-type procedure compares the empirical fit of the new model with that of a leading benchmark model, and tests the null hypothesis that they are equal. If the null hypothesis is accepted, then the researcher must conclude that there is no sufficient empirical evidence in favor of the new model. On the other hand, if the null hypothesis is rejected in favor of the new model, the researcher can credibly argue that the new economic structure provides a superior explanation to the data patterns over that of the benchmark model. The procedure does not require that either of the competing models be correctly specified, and therefore the conclusions are robust to misspecification.[41]

The procedure consists of several steps. In the first step we determine the values of the deep structural parameters in each of the competing models. This can be done either informally by setting the parameters to their values typically used in the literature or through formal estimation where the values for the parameters are chosen to match certain characteristics of the data. In the second step, we compute the weighted Euclidean distance between the vectors of model-predicted characteristics and their estimates from the data. We then obtain the test statistic as the difference between the estimated measures of fit of the two competing models as well as its standard error. The standard error has to take into account how the values for the structural parameters were obtained in the first step. Lastly, we reject the null hypothesis of equal fits if the studentized difference in fits exceeds a standard normal critical value.

We apply the methodology to a popular class of models in the international business cycles literature in order to determine which of the asset market structures used extensively in that literature has the strongest explanatory power for observed empirical regularities. More precisely, we compare three key models: financial autarky, single risk-free bond economy, and an economy with complete asset markets. Our comparison is based on a set of standard data characteristics: variances of key macroeconomic aggregates, such as consumption, investment, labor input, etc.; correlations of these aggregates with output, and their cross-country co-movements. Our procedure recognizes that different data characteristics have different scales (i.e. variances can take any non-negative values, while correlations are restricted by $[-1, 1]$ interval). This makes model comparison based on the equally-weighted aggregation of characteristics problematic. Instead, we

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[41] We define a structural model to be misspecified if it cannot predict the population values of the chosen data characteristics for any combination of the deep structural parameters. See [50] for details.

propose a data-dependent weighting scheme which allows us to normalize various characteristics by their data counterparts and aggregate them easily. We show that based on both sets of moments (variances and correlations) our test indeed picks financial autarky as the winning specification – consistent with the informal conclusion in [47].

We then propose a competing model that allows for agent heterogeneity. We focus on a simple dimension of heterogeneity – asset market participation. In our competing model there are two groups of agents in each country: those with access to international and domestic financial markets (participants) and non-participants. We characterize the business cycle properties of the model with limited asset market participation (LAMP) and then apply our test to evaluate the ability of this amended model relative to models with a representative agent in matching the properties of the data. As before, we consider three specifications for international asset markets: financial autarky, single risk-free bond economy, and an economy with complete asset markets, except that in the economy with LAMP these financial regimes apply to participants only. We show that in the setup with LAMP, financial autarky remains a preferred model if the comparison is based on volatilities of key macroeconomic aggregates. However, if the comparison is performed based on co-movements with output and cross-country correlations, then a complete markets economy is chosen as the winner. This is mainly due to the fact that LAMP improves the performance of the model for cross-country correlations: it significantly raises the cross-country correlation in hours of work and investment. Thus, it improves on the "international comovement" puzzle. Adding LAMP also raises the cross-country correlation of output, and lowers the corresponding correlation for consumption, thus bringing the two closer together. Therefore, our models with LAMP also improve on the "quantity" puzzle. Lastly, based on the overall performance (variances and correlations), we find that a complete markets model with LAMP performs no worse than financial autarky and outperforms all other models. In a majority of cases the improvements are statistically significant.

Adding LAMP alters the behavior of a representative agent benchmark in three key ways. First, non-participants are hand-to-mouth consumers whose consumption closely tracks their income. Therefore, LAMP raises the sensitivity of aggregate consumption to income shocks, in line with the data. Second, non-participants' only income is from their labor earnings, making their hours inelastic. Therefore, LAMP reduces the sensitivity of aggregate labor supply to productivity shocks. Third, with consumption responding more and labor supply responding less to shocks, investment becomes less sensitive to productivity shocks. These modifications improve the model's performance in some dimensions (i.e. cross-country correlations, volatility of consumption and its comovement with output), but worsen its performance in other dimensions (i.e. volatilities of output, investment, hours, etc.). Thus, ex-ante, the overall contribution of LAMP is ambiguous. This result highlights the need for a procedure that allows to compare models formally.

We contrast the overall performance of LAMP against the model with a representative agent by aggregating the fits across all three financial regimes. We find that LAMP class of models significantly outperforms the original BKK model class. We verify the robustness of our results to the presence of investment specific technology shocks and with respect to the elasticity of substitution between labor inputs of participants and non-participants. Overall, our results indicate that adding LAMP to a standard international business cycles model significantly improves its ability to match business cycle facts and can overturn the existing result that financial autarky provides a better fit to the data. To the best of our knowledge, ours is the first paper to perform a statistical model evaluation and comparison based on the agents' heterogeneity over a large set of international business cycle statistics.

We believe that our model with LAMP provides a simple, but empirically important extension of the standard business cycle framework. The fact that only a small fraction of households participate in the stock market has been documented by [70], who showed that only 24% of US households owned equities in 1984; in 2007 this fraction was 51.1% based on the Survey of Consumer Finance.[42] Limited asset market participation has received attention in the theoretical asset pricing literature (see 76; 85 and others). [27] provide its quantitative evaluation and show that a model with LAMP (and incomplete markets) can account for high volatility of equity risk premium in the data. [26] investigate the implications of LAMP and heterogeneous trading technologies for asset prices and wealth distribution and show that such a model matches well the high volatility of returns and the low volatility of the risk-free rate. Implications of LAMP for monetary policy have been studied by [43], [24], [2], [16]. They show that LAMP improves model performance for nominal aggregates. [84] studies the importance of LAMP and borrowing constraints for cross-country consumption correlations and welfare.

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[42] The share of US households who own equities, while increasing dramatically since 1984, has remained relatively stable at around 50% in the past 15 years, based on the Survey of Consumer Finances. Thus, based on the Survey, the share was 31.6% in 1989, in 1992 – 36.7%, in 1995 – 40.4%, in 1998 – 48.9%, in 2001 – 52.2%, in 2004 – 50.2%, and in 2007 – 51.1%.

Relative to the above papers, the key contribution of our work is to statistically examine the consequences of LAMP for a large set of business cycle moments as well as formally evaluate its performance relative to alternative models popular in the literature. Our results build the case for LAMP further by showing its importance for international business cycles.

The paper also makes methodological contributions by extending [50] in two respects. First, we extend the procedure to account for simulation uncertainty. The complexity of DSGE models often makes exact calculations of model predicted moments very cumbersome. In such cases, it is convenient to resort to simulations as we do in this paper. We show how the standard error of the model comparison test statistic can be adjusted to account for simulation uncertainty, which can be used to ensure that no power is lost due to simulations. Second, we propose a class-based test that allows one to compare the overall performances of classes of model with several models in each class. Such an extension is useful when, as in our case, each model has several structurally different versions.

Our paper is related to the growing literature on the comparison of structural models by means of statistical methods. To name a few, comparison of misspecified DSGE models has been studied from the Bayesian perspective by [81]. The method we employ in this paper can be viewed as a frequentist counterpart of the [81] procedure.[43] More recently, [59] proposed a Vuong-type test for comparison of misspecified asset pricing models in terms of the Hansen-Jagannathan distance.

The remainder of the paper is organized as follows. Section 3.2 presents our model economies. We discuss calibration and model solution in Section 3.3. Section 3.4 describes our testing methodology. Section 3.5 presents our results, and Section 3.6 concludes.

3.2 Model Economies

To study the role of asset market structure in capturing the properties of international business cycles, we consider a sequence of three economies: an economy in which there are no markets for international asset trades (we refer to it as financial autarky, FA); an economy in which a single non-contingent bond is traded – bond economy, BE; and an economy with complete markets, CM. The structure of these economies follows closely that

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[43] While in [81] a structural model that achieves the lowest average posterior loss is selected, we follow the approach of [86] and test the null hypothesis that two competing models have equal losses.

proposed by [7, 8] and studied in [47]. For completeness, we present it here as well. To study the role of investors heterogeneity we extend the three versions of the model to incorporate limited asset market participation. Aside from asset market structure and investors' heterogeneity, all our economies have common structure. We describe it next.

We consider the world consisting of two symmetric countries, H and F, each specializing in the production of its intermediate good. Each country is populated by a continuum of firms and households.

3.2.1 Firms

Firms are perfectly competitive and reside in two sectors: intermediate-goods sector and final-goods sector. Firms in the intermediate goods sector (i-firms) hire domestically-located capital, k^j, and labor, n^j, $j = \{\text{H,F}\}$, to produce intermediate goods. The i-firms in country H specialize in the production of good a, while i-firms in country F specialize in the production of good b. Period t production by a representative i-firm in country j is

$$F(z_t^j, k_t^j, n_t^j) = e^{z_t^j} \left(k_t^j\right)^{\theta} \left(n_t^j\right)^{1-\theta}, \tag{3.1}$$

with $\theta > 0$, and z_t^j being the exogenous state of productivity in country j. Let w_t^j and r_t^j denote the real wage and rental rate on capital in country j in period t, measured in terms of the domestic intermediate good. The problem facing i-firms in country j then becomes

$$\max \ F(z_t^j, k_t^j, n_t^j) - w_t^j n_t^j - r_t^j k_t^j,$$

subject to $n_t^j > 0$, $k_t^j > 0$, and equation (3.1). The intermediate goods produced by H and F i-firms can be freely traded in the international goods markets and can be costlessly transported between countries. Under these conditions, the law of one price must prevail to eliminate arbitrage opportunities. Households, who are the owners of the i-firms, sell their holdings of intermediate goods to domestic final goods producing firms (f-firms), and use the proceeds for consumption, c_t^j and investment, x_t^j. Investment adds to the stock of physical capital available for production next period according to

$$k_{t+1}^j = (1-\delta)k_t^j + x_t^j,$$

where δ is the depreciation rate.

The f-firms are also perfectly competitive and produce final goods from the H and F intermediate goods using constant returns to scale (CRS) technology:

$$G(a_t^j, b_t^j) = \left[\omega^j \left(a_t^j\right)^{\frac{\sigma-1}{\sigma}} + \left(1-\omega^j\right)\left(b_t^j\right)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}, \tag{3.2}$$

where ω^j is the weight that f-firms from country j assigns to the intermediate goods produced in country H. When $\omega^j > 0.5$ there is home bias in the production of final goods in country j. The elasticity of substitution between H and F-produced intermediate goods is $\sigma > 0$. Let $q_{a,t}^j$ and $q_{b,t}^j$ denote the prices of intermediate goods a and b in country j in units of the final good produced in country j. Then, the problem facing f-firms in country j is

$$\max \ G(a_t^j, b_t^j) - q_{a,t}^j a_t^j - q_{b,t}^j b_t^j,$$

subject to $n_t^j > 0$, $k_t^j > 0$, and equation (3.2).

Productivity in intermediate good sectors is governed by an exogenous process. In particular, we assume that the vector $z_t \equiv [z_t^{\text{H}}, z_t^{\text{F}}]'$ follows an AR(1) process:

$$z_t = \alpha z_{t-1} + e_t, \tag{3.3}$$

where e_t is a (2×1) vector of independently normally distributed, mean zero shocks with covariance Ω_e.

3.2.2 Households

Each country is also populated by a continuum of households, whose preferences are defined over consumption and leisure. In particular, the preferences of households in country j are represented by

$$E_0 \sum_{t=0}^{\infty} \beta^t U(c_t^j, 1-n_t^j), \tag{3.4}$$

where $0 < \beta < 1$ is the discount factor, and $U(.)$ is a concave sub-utility function. Period utility function of the household in country j is given by $U(c_t^j, 1-n_t^j) = \frac{1}{\gamma}\left[\left(c_t^j\right)^{\mu}\left(1-n_t^j\right)^{1-\mu}\right]^{\gamma}$. Households choose consumption, c_t^j, and hours of work, $n_t^j \in [0,1]$, to maximize their lifetime expected utility subject to a sequence of budget constraints, which depend on the financial structure of the model economy. We consider three such structures. Under financial autarky (FA), households can not trade any international financial assets. Under bond economy (BE), households can hold a single non-state contingent internationally traded bond. The third case we consider is that of complete markets (CM). Here households have access to a complete set of Arrow securities. We now describe the budget constraints facing households under each of these different financial structures.

3.2.2.1 Financial Autarky, FA

In the financial autarky, households do not have access to international financial assets. As a result, households consume and invest out of their factor income. The period$-t$ budget constraint of households in country j is

$$c_t^j + x_t^j = q_{a,t}^j \left(w_t^j n_t^j + r_t^j k_t^j \right).$$

Notice that FA rules out the possibility of international borrowing or lending, so neither country can have positive or negative trade balance.

3.2.2.2 Bond Economy, BE

In the bond economy households only trade a single non-state-contingent international bond. We assume that bonds are denominated in the units of intermediate good a. Let B_t^j denote bond holdings of country j households and Q_t be the price of the bonds. Then the period$-t$ budget constraint of households in country j is

$$c_t^j + x_t^j + q_{a,t}^j Q_t B_t^j = q_{a,t}^j \left(w_t^j n_t^j + r_t^j k_t^j \right) + q_{a,t}^j B_{t-1}^j.$$

3.2.2.3 Complete Markets, CM

Following [47] we assume that households complete the markets by trading in a complete set of Arrow securities denominated in units of intermediate good a. Thus the households' budget constraint can be written as

$$c_t^j + x_t^j + q_{a,t}^j \sum_{s_{t+1}} Q_t(s^t, s_{t+1}) B_t^j(s^t, s_{t+1}) = q_{a,t}^j \left(w_t^j n_t^j + r_t^j k_t^j \right) + q_{a,t}^j B_{t-1}^j(s^{t-1}, s_t),$$

where $s^t = (s_0, s_1, s_2, ..., s_t)$ denotes the entire state history of the economy till date t.

3.2.2.4 Equilibrium

An equilibrium in this economy consists of a set of goods' prices $\{q^j_{a,t}, q^j_{b,t}\}$, and asset prices (i.e. $\{Q_t\}$ under BE or $\{Q_t(s^t, s_{t+1})\}$ under CM) such that all markets clear when households optimally make their consumption, investment, and asset allocation decisions, taking goods and asset prices as given.

Market clearing in the intermediate goods markets requires

$$\begin{aligned} a^{\mathrm{H}}_t + a^{\mathrm{F}}_t &= F(z^{\mathrm{H}}_t, k^{\mathrm{H}}_t, n^{\mathrm{H}}_t), \\ b^{\mathrm{H}}_t + b^{\mathrm{F}}_t &= F(z^{\mathrm{F}}_t, k^{\mathrm{F}}_t, n^{\mathrm{F}}_t). \end{aligned}$$

Market clearing in the final goods markets requires

$$c^j_t + x^j_t = G(a^j_t, b^j_t), \qquad j = \{\mathrm{H}, \mathrm{F}\}.$$

The market clearing conditions in financial markets vary according to the financial structure of the economy. Under BE, the bond market clearing condition requires

$$0 = B^{\mathrm{H}}_t + B^{\mathrm{F}}_t.$$

Under CM, a similar condition applies for every s_{t+1}:

$$0 = B^{\mathrm{H}}_t(s^t, s_{t+1}) + B^{\mathrm{F}}_t(s^t, s_{t+1}).$$

3.2.3 Limited Asset Market Participation

Next, we introduce LAMP in our model economy. This feature is used to capture the empirical observation that a large fraction of population does not hold any financial assets. Thus, we assume that each country is populated by two types of households: non-participants and participants. Non-participants do not own any capital, do not have access to international markets, and only choose how much time to work and how much to consume. Participants hold all of the capital stock in the economy and can borrow and lend at the international markets (if the model specification allows it). They also supply labor services to the intermediate goods producing firms and make all investment decisions. We assume that there is a fraction λ of such households in each country.

The problem facing non-participants (N) is

$$\max E_0 \sum_{t=0}^{\infty} \beta^t U(c^j_{\mathrm{N},t}, 1 - n^j_{\mathrm{N},t}),$$

subject to

$$c^j_{\mathrm{N},t} = q^j_{a,t} w^j_t n^j_{\mathrm{N},t},$$

where subscript N is used to denote the variables pertinent to non-participants. Note that the non-participants' problem remains the same independent of the assumed asset market structure.

The problem facing participants (P) is the same as in the economy with a representative agent:

$$\max E_0 \sum_{t=0}^{\infty} \beta^t U(c^j_{\mathrm{P},t}, 1 - n^j_{\mathrm{P},t}),$$

subject to a budget constraint. Here subscript P is used to denote the variables specific to asset market participants. For participants the exact form of the budget constraint varies with the financial structure of the economy. For instance, the budget constraint of participants in the financial autarky is

$$c^j_{\mathrm{P},t} + x^j_t = q^j_{a,t} \left(w^j_t n^j_{\mathrm{P},t} + r^j_t k^j_t \right)$$

In the bond economy the budget constraint becomes

$$c^j_{\mathrm{P},t} + x^j_t + q^j_{a,t} Q_t B^j_t = q^j_{a,t} \left(w^j_t n^j_{\mathrm{P},t} + r^j_t k^j_t \right) + q^j_{a,t} B^j_{t-1},$$

while under complete markets, it is

$$c^j_{\mathrm{P},t} + x^j_t + q^j_{a,t} \sum_{s_{t+1}} Q_t(s^t, s_{t+1}) B^j_t(s^t, s_{t+1}) = q^j_{a,t} \left(w^j_t n^j_{\mathrm{P},t} + r^j_t k^j_t \right) + q^j_{a,t} B^j_{t-1}(s^{t-1}, s_t).$$

Note that in this case, the asset markets are complete internationally for participants only. The optimization problems solved by i-firms and f-firms remain unchanged.

Aggregate labor input in the economy consists of labor inputs of participants and non-participants and is defined as:

$$n^j_t = \left[\lambda \left(n^j_{\mathrm{P},t} \right)^{\frac{\upsilon-1}{\upsilon}} + (1-\lambda) \left(n^j_{\mathrm{N},t} \right)^{\frac{\upsilon-1}{\upsilon}} \right]^{\frac{\upsilon}{\upsilon-1}},$$

where υ is the elasticity of substitution between the two types of labor.

The market clearing conditions in the goods markets remain the same, while the market clearing conditions in the asset markets apply to participants only.

3.2.4 Investment-specific Technology (IST) Shocks

Several recent papers have emphasized the role played by investment-specific technology (IST) shocks in the international business cycles (IBC). In a framework similar to ours, [77] shows that IST shocks can help account for a number of puzzles in the business cycles literature. He emphasizes the Backus-Smith puzzle – the fact that consumption and real exchange rate tend to be negatively correlated in the data, while a standard IBC framework predicts the opposite; and the "price" puzzle – the fact that models generate far lower volatility of international relative prices relative to the data. At the same time, [69] show that an IBC model with IST shocks estimated from the data fails to reproduce the moments emphasized in [77]. Our interest in IST shocks is motivated by their potentially important interactions with LAMP. When only a segment of population has access to capital and asset markets IST shocks will have differential effects on the participants and non-participants, leading to important distributional effects between them. We investigate the role of IST shocks by incorporating them in our models as in [42] and [77], but using the properties of these shocks as estimated in [69]. In what follows we highlight the new model features introduced by IST shocks.

The problem facing non-participants does not change when IST shocks are introduced. Objective functions of participants and their budget constraints also remain unchanged. In the presence of IST shocks, capital accumulation equation becomes

$$k_{t+1}^{j} = (1-\delta)k_{t}^{j} + e^{v_{t}^{j}} x_{t}^{j},$$

where e^{v^j} is the IST shock in country j. As shown in [42], in a competitive equilibrium, e^{-v^j} is interpreted as the relative price of capital goods in terms of consumption goods. We assume that IST shocks, $v_t \equiv [v_t^{\text{H}}, v_t^{\text{F}}]'$ follow an AR(1) process:

$$v_t = \alpha_v v_{t-1} + \zeta_t, \tag{3.5}$$

where ζ_t is a (2×1) vector of independently normally distributed, mean zero shocks with covariance Ω_ζ. All other model equations remain unchanged.

3.2.5 Definitions

There are several variables of interest that we define here. Gross domestic product in country j expressed in terms of final consumption goods is given by $y_t^j = q_{a,t}^j F(z_t^j, k_t^j, n_t^j)$. Net exports are $nx_t^{\text{H}} = q_{a,t}^{\text{H}} a_t^{\text{F}} - q_{b,t}^{\text{H}} b_t^{\text{H}}$. Imports ratio for home country is defined following [47], as the ratio of imports to domestically consumed intermediate goods, both measured at the steady state prices which are symmetric under the benchmark calibration, giving $ir_t^{\mathrm{H}} = b_t^{\mathrm{H}}/a_t^{\mathrm{H}}$. Terms of trade in H country are defined as the price of imports divided by the price of exports, $p_t^{\mathrm{H}} = q_{b,t}^{\mathrm{H}}/q_{a,t}^{\mathrm{H}}$, while the real exchange rate is defined as the relative price of foreign consumption goods to domestic consumption goods, giving $rer_t^{\mathrm{H}} = q_{a,t}^{\mathrm{H}}/q_{a,t}^{\mathrm{F}}$.

3.3 Calibration and Model Solution

In calibrating the model we assign some parameters their values commonly used in the literature, while we estimate other parameters from the data. Such an approach has become standard in the literature. In our application it also allows us to illustrate our testing procedure in the most general case when some parameters are fixed while other parameters are estimated.[44]

In the calibration we consider the world economy as consisting of two countries: country 1 matching the properties of the US economy in quarterly data, and country 2 as the rest of the world. Most of the parameter values are borrowed from [47]. We summarize them in Table 3.1. We set discount factor to 0.99, which implies annual real interest rate of 4 percent. Risk aversion coefficient is set at 2. As in [47], we fix consumption share parameter at $\mu = 0.34$. We assume that capital income share, θ is 0.34; and depreciation rate δ of 2.5 percent. Parameter ω, which controls the consumption home bias in household's preferences is set to match the observed import share in the U.S. equal to 15 percent of GDP. We set the elasticity of substitution between domestic and imported intermediate goods at 0.9, which is the value estimated in [47]. This is above the value of this parameter used in [77] and [69], but more along the lines of the values used in the IBC literature.[45]

In the model with LAMP a new parameter, λ, is introduced. It captures the share of nonparticipants, which we calibrate to match the share of US households who did not hold any equity as reported in the 2007 Survey of Consumer Finance equal to 51.1%. Therefore, we set $\lambda = 0.5$. The only remaining parameter is υ which equals the elasticity of substitution between labor input of participants and non-participants in the model. For simplicity and given the lack of estimates of this parameter in the literature, we assume

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[44] As we discuss in Section 3.4.1, when some model parameters are estimated, we must take into account the uncertainty due to this estimation when computing standard errors of our test statistics.

[45] For instance, [7, 8] use a value of 1.5. [63] uses traded elasticity values as low as 0.6; [23] and [35] use 1.5.

that the two types of labor are perfectly substitutable. In what follows we check the robustness of our results with respect to this parameter.

Table 3.1: Benchmark Parameter Values without Estimation Step

Panel A: Preferences		
discount factor	β	0.99
risk-aversion	$1-\gamma$	2
consumption share	μ	0.34
Panel B: Technology		
capital income share	θ	0.36
depreciation rate	δ	0.025
import share	is (ω)	0.15
elasticity of subst, b/n goods a and b	σ	0.9
share of P households	λ	0.5
Panel C: IST shocks		
transition matrix	$\alpha^I = \begin{bmatrix} \rho_{11} & \rho_{12} \\ \rho_{21} & \rho_{22} \end{bmatrix}$	$\begin{bmatrix} 0.975 & 0.024 \\ 0.024 & 0.975 \end{bmatrix}$
std. dev. of innovations	$\sigma^I_{e_1} = \sigma^I_{e_2}$	0.0066
corr. of innovations	$\sigma^I_{e_1 e_2}$	0.1955

TFP shocks are assumed to be persistent, but temporary. We estimate the process for TFP shocks as in [47]. Namely, we compute productivity sequences for the US and the rest of the world during 1973:1-2007:4 period, where the rest of the world is identified with the aggregate of 21 major trade partners for the U.S..[46] In our estimation, we impose the symmetry restrictions $\rho_{11} = \rho_{22}$ and $\rho_{12} = \rho_{21}$.

Our estimation results for productivity process are presented in Table 3.2 and they are very similar to the estimates in [47]. Namely, our estimates of productivity persistence ρ_{11} and spill-over ρ_{12} are almost the same, while the standard deviation of productivity innovations σ_{e_1} and the correlation between domestic and foreign productivity innovations $\sigma_{e_1 e_2}$ are somewhat smaller than their values.[47]

In calibrating IST shocks, we follow the findings of [69] who show that IST processes for the U.S. and the rest of the world are very persistent and exhibit no spill-overs across countries. Importantly, [69] show that the variance of these shocks is of the same magnitude as the variance of TFP shocks. Motivated by these results, and to facilitate the comparison of the models with and without IST shocks, we assume that IST shocks are fully symmetric to TFP shocks, with no spillovers across the two types of shocks.

Each model is solved by linearizing the sequence of equilibrium conditions and solving the resulting system of linear difference equations. We

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[46] Details on sample construction and data sources are provided in the Appendix C.1.

[47] When simulating the models we use $\sigma_{e_1} = \sigma_{e_2} = 0.0066$.

Table 3.2: Estimated Productivity Process

Table 3.2 reports coefficient estimates and their standard errors of the estimated productivity process. Following [47], we estimate productivity shock process using: $\begin{bmatrix} z_{1,t} \\ z_{2,t} \end{bmatrix} = \begin{bmatrix} \rho_{11} & \rho_{21} \\ \rho_{12} & \rho_{22} \end{bmatrix} \begin{bmatrix} z_{1,t-1} \\ z_{2,t-1} \end{bmatrix} + \begin{bmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \end{bmatrix}$ with the symmetry restriction imposed, $\rho_{11} = \rho_{22}$ and $\rho_{12} = \rho_{21}$.

productivity transition matrix	$\alpha = \begin{bmatrix} \rho_{11} & \rho_{12} \\ \rho_{21} & \rho_{22} \end{bmatrix}$	$\begin{bmatrix} 0.975 & 0.024 \\ (0.009) & (0.009) \\ 0.024 & 0.975 \\ (0.009) & (0.009) \end{bmatrix}$
std. dev. of productivity innovations	σ_{e_1}	0.0066
	σ_{e_2}	0.0039
corr. of productivity innovations	$\sigma_{e_1 e_2}$	0.1955

derive the second moments of model's variables by simulating the model over 100 periods. The statistics based on which the model comparison is conducted are derived from 10000 simulations. All series, except net exports, are logged and Hodrick-Prescott (HP) filtered with a smoothing parameter of 1600.

3.4 Econometric Methodology

For a formal statistical comparison of the considered models, we rely on a Vuong-type [86] test for potentially misspecified calibrated models proposed in [50, 51]. Relative to this work we develop two key extensions. First, we adjust the procedure to account for simulation uncertainty. This becomes important when the model moments can not be computed exactly and instead simulations must be used.[48] Second, we introduce a class-based test that allows us to compare classes of models with several models in each class. This becomes important when one is interested in evaluating the model's performance with different features, for different parameter values, or with different shocks. In this case, one needs a way to aggregate model fits across the different scenarios, which is what our proposed class-based test does.

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[48] Using simulations to obtain model implied moments is a common practice in the business cycles literature.

3.4.1 Pairwise Comparison

We begin by assuming that data can be summarized using two mutually exclusive vectors of characteristics denoted by h_1 and h_2, where the first vector is used for estimation of unknown structural parameters, while the second vector is used to compare structural models. This reflects a standard practice in applied macroeconomics, when parameters are calibrated to one group of data characteristics, while models are evaluated on another. We assume that h_1 and h_2 can be estimated from data without employing a structural model. For example, in our case, h_1 consists of the estimated productivity shocks, while h_2 consists of volatilities and correlations between the variables of interest as described in Tables 3.3-3.5 below.

Suppose that there are two structural models denoted $f(\theta)$ and $g(\beta)$, where θ and β are the corresponding structural parameters describing consumer's preferences, technology, etc. Here, $f(\theta)$ and $g(\beta)$ denote the value of h_2 predicted by models f and g, respectively. Naturally, vectors h_2, $f(\theta)$ and $g(\beta)$ must be of the same dimension; we assume that they are m-vectors. We allow for the competing models to be misspecified, i.e. it is possible that for all permitted values of θ and β, $h_2 \neq f(\theta)$ and $h_2 \neq g(\beta)$.

The models are allowed to share some of the parameters. Note, however, that θ and β contain only the parameters that must be estimated from data. We allow that some of the parameters may be assigned fixed values, for example, values that are commonly used in the literature. Such parameters are excluded from θ and β and absorbed into f and g.[49]

We are interested in testing a hypothesis that models f and g have equivalent fit to the data as described by h_2. For an $m \times m$ symmetric and positive definite weight matrix W_{h_2}, the null hypothesis of the models' equivalence is

$$H_0 : (h_2 - g(\beta))' W_{h_2} (h_2 - g(\beta)) - (h_2 - f(\theta))' W_{h_2} (h_2 - f(\theta)) = 0.$$

The notation indicates that the weight matrix W_{h_2} can depend on h_2. A simple choice for a weight matrix is to use the identity matrix. In that case, the weight matrix is independent of h_2, and the models are compared in terms of their squared prediction errors. Another example for W_{h_2} is a diagonal matrix with the reciprocals of the elements of h_2 on the main diagonal. With such a choice of the weight matrix, the models are compared in terms of the squares of their percentage prediction errors. In our application, we use a combination of the two. That is to evaluate the models, for some

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[49] In our application θ and β are the same and describe the productivity process.

parameters, such as correlations, we use prediction errors, while for others, such as volatilities, we use percentage prediction errors.

The alternative hypotheses are

$$\begin{aligned} H_f &: (h_2 - g(\beta))' W_{h_2} (h_2 - g(\beta)) - (h_2 - f(\theta))' W_{h_2} (h_2 - f(\theta)) > 0, \\ H_g &: (h_2 - g(\beta))' W_{h_2} (h_2 - g(\beta)) - (h_2 - f(\theta))' W_{h_2} (h_2 - f(\theta)) < 0, \end{aligned}$$

where f has a better fit according to H_f, and g has a better fit according to H_g.

Let $\hat{h}_1$ and $\hat{h}_2$ denote the estimators of h_1 and h_2, respectively. We assume that $\hat{h}_1$ and $\hat{h}_2$ do not require the knowledge of the true structural model, are consistent and asymptotically normal as described in the following assumption:

$$\sqrt{n} \begin{pmatrix} \hat{h}_1 - h_1 \\ \hat{h}_2 - h_2 \end{pmatrix} \to_d N\left(0, \begin{pmatrix} \Lambda_{11} & \Lambda_{12} \\ \Lambda_{12}' & \Lambda_{22} \end{pmatrix}\right), \tag{3.6}$$

where n denotes the sample size used in estimation of h_1 and h_2, Λ_{11} and Λ_{22} denote the asymptotic variance-covariance matrices of $\hat{h}_1$ and $\hat{h}_2$ respectively, and Λ_{12} denotes the asymptotic covariance between $\hat{h}_1$ and $\hat{h}_2$. Let $\hat{\Lambda}_{11}$, $\hat{\Lambda}_{22}$ and $\hat{\Lambda}_{12}$ denote consistent estimators of the corresponding elements in the above asymptotic variance-covariance matrix. In a typical time-series application, Λ_{11}, Λ_{22} and Λ_{12} are long-run variances and covariances and, therefore, require HAC-type estimators, see [72] and [3].

Let $\hat{\theta}$ and $\hat{\beta}$ denote the estimators of θ and β respectively. We assume that the estimators are asymptotically linear in h_1:

$$\sqrt{n}\big(\hat{\theta} - \theta\big) = A\sqrt{n}\big(\hat{h}_1 - h_1\big) + o_p(1), \tag{3.7}$$

$$\sqrt{n}\big(\hat{\beta} - \beta\big) = B\sqrt{n}\big(\hat{h}_1 - h_1\big) + o_p(1), \tag{3.8}$$

where matrices A and B may depend on the elements of h_1. This specification is satisfied by most estimators used in practice. Appendix C.2 contains the derivations of equation (3.7) for our estimators.[50] We assume that A and B can be consistently estimated, and use $\hat{A}$ and $\hat{B}$ to denote their estimators.

When functions $f(\theta)$ and $g(\beta)$ are too complicated for analytical or even exact numerical calculations, we assume that they can be estimated by simulations. For example, as in our case, one can draw random shocks and solve the models as described in Section 3.2 using $\hat{\theta}$ for model f and $\hat{\beta}$ for

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[50] In our application, because β and θ are the same, we do not use equation (3.8).

model g, and obtain a set of random equilibrium values for the variables of interest. By repeating this process R times, one obtains a sample of R observations for the variables of interest, which can be used to estimate f and g by averaging across the simulations. Let $\hat{f}(\hat{\theta})$ and $\hat{g}(\hat{\beta})$ denote such estimators.

We assume that, at the true values θ and β, estimators $\hat{f}(\theta)$ and $\hat{g}(\beta)$ are independent of $\hat{h}_1$ and $\hat{h}_2$, and satisfy the following assumption:

$$\sqrt{R}\begin{pmatrix} \hat{f}(\theta) - f(\theta) \\ \hat{g}(\beta) - g(\beta) \end{pmatrix} \to_d N\left(0, \begin{pmatrix} \Lambda_{ff} & \Lambda_{fg} \\ \Lambda'_{fg} & \Lambda_{gg} \end{pmatrix}\right). \tag{3.9}$$

We use $\hat{\Lambda}_{ff}$, $\hat{\Lambda}_{gg}$ and $\hat{\Lambda}_{fg}$ to denote consistent estimators of the asymptotic variances and covariance in (3.9).

Our test is based on the difference between the estimated fits of the two models:

$$S = \big(\hat{h}_2 - \hat{g}(\hat{\beta})\big)' W_{\hat{h}_2} \big(\hat{h}_2 - \hat{g}(\hat{\beta})\big) - \big(\hat{h}_2 - \hat{f}(\hat{\theta})\big)' W_{\hat{h}_2} \big(\hat{h}_2 - \hat{f}(\hat{\theta})\big).$$

Under the assumptions in (3.6)-(3.9), S is asymptotically normal, and its standard error can be computed as $\hat{\sigma}/\sqrt{n}$, where[51]

$$\hat{\sigma}^2 = 4\hat{\sigma}_1^2 + 4\hat{\sigma}_2^2, \tag{3.10}$$

$$\begin{aligned} \hat{\sigma}_1^2 = {} & \begin{pmatrix} \hat{A}' \frac{\partial \hat{f}\left(\hat{\theta}\right)'}{\partial \theta} W_{\hat{h}_2}\left(\hat{h}_2 - \hat{f}\left(\hat{\theta}\right)\right) - \hat{B}' \frac{\partial \hat{g}\left(\hat{\beta}\right)'}{\partial \beta} W_{\hat{h}_2}\left(\hat{h}_2 - \hat{g}\left(\hat{\beta}\right)\right) \\ W_{\hat{h}_2}\left(\hat{f}\left(\hat{\theta}\right) - \hat{g}\left(\hat{\beta}\right)\right) + 0.5 \frac{\partial w\left(\hat{h}_2\right)'}{\partial h_2} J' K\left(\hat{h}, \hat{f}\left(\hat{\theta}\right), \hat{g}\left(\hat{\beta}\right)\right) \end{pmatrix}' \begin{pmatrix} \hat{\Lambda}_{11} & \hat{\Lambda}_{12} \\ \hat{\Lambda}'_{12} & \hat{\Lambda}_{22} \end{pmatrix} \\ & \times \begin{pmatrix} \hat{A}' \frac{\partial \hat{f}\left(\hat{\theta}\right)'}{\partial \theta} W_{\hat{h}_2}\left(\hat{h}_2 - \hat{f}\left(\hat{\theta}\right)\right) - \hat{B}' \frac{\partial \hat{g}\left(\hat{\beta}\right)'}{\partial \beta} W_{\hat{h}_2}\left(\hat{h}_2 - \hat{g}\left(\hat{\beta}\right)\right) \\ W_{\hat{h}_2}\left(\hat{f}\left(\hat{\theta}\right) - \hat{g}\left(\hat{\beta}\right)\right) + 0.5 \frac{\partial w\left(\hat{h}_2\right)'}{\partial h_2} J' K\left(\hat{h}, \hat{f}\left(\hat{\theta}\right), \hat{g}\left(\hat{\beta}\right)\right) \end{pmatrix}, \end{aligned} \tag{3.11}$$

$$\hat{\sigma}_2^2 = \frac{n}{R} \begin{pmatrix} W_{\hat{h}_2}\left(\hat{h}_2 - \hat{f}\left(\hat{\theta}\right)\right) \\ -W_{\hat{h}_2}\left(\hat{h}_2 - \hat{g}\left(\hat{\beta}\right)\right) \end{pmatrix}' \begin{pmatrix} \hat{\Lambda}_{ff} & \hat{\Lambda}_{fg} \\ \hat{\Lambda}'_{fg} & \hat{\Lambda}_{gg} \end{pmatrix} \begin{pmatrix} W_{\hat{h}_2}\left(\hat{h}_2 - \hat{f}\left(\hat{\theta}\right)\right) \\ -W_{\hat{h}_2}\left(\hat{h}_2 - \hat{g}\left(\hat{\beta}\right)\right) \end{pmatrix}. \tag{3.12}$$

In the expression for $\hat{\sigma}_1^2$,

$$K(h, f, g) = ((h - g) \otimes (h - g)) - ((h - f) \otimes (h - f)), \tag{3.13}$$

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[51] The asymptotic variance formula is explained in Appendix C.3

vector $w(h_2)$ collects the element of W_{h_2} without duplicates, and J denotes a known $m^2 \times m$ selection matrix of zeros and ones such that

$$\mathrm{vec}(W_{h_2}) = Jw(h_2). \tag{3.14}$$

For example, when W_{h_2} is a diagonal matrix with the reciprocals of the elements of h_2 on the main diagonal, we have that $w_i(h) = 1/h_i$, $i = 1, \ldots, m$, and

$$J = \begin{pmatrix} J_1 \\ \vdots \\ J_m \end{pmatrix},$$

where, for $i = 1, \ldots, m$, J_i is an $m \times m$ matrix with 1 in position (i, i) and zeros everywhere else.

In (3.10), the first term, $\hat{\sigma}_1^2$, reflects the uncertainty due to estimation of θ, β, and h_2. For example, when comparing the models at some known fixed parameter values $\bar{\theta}$ and $\bar{\beta}$, matrices $\hat{A}$ and $\hat{B}$ should be replaced by zeros. Similarly, when comparing the models using a known fixed weight matrix (independent of h_2), the terms $0.5(\partial w(\hat{h})'/\partial h)J'K(\hat{h}, \hat{f}, \hat{g})$ in (3.11) should be replaced with zeros.

The second term in (3.10), $\hat{\sigma}_2^2$, is due to the simulations uncertainty in computation of $\hat{f}(\hat{\theta})$ and $\hat{g}(\hat{\beta})$. This term is zero when f and g can be evaluated numerically (without resorting to simulations). Uncertainty due to simulations can be ignored if one can select a large number of simulations R so that the ratio n/R is sufficiently small.

Our asymptotic test with significance level α is:

$$\text{Reject } H_0 \text{ in favor of } H_f \text{ when } \sqrt{n}S/\hat{\sigma} > z_{1-\alpha/2},$$
$$\text{Reject } H_0 \text{ in favor of } H_g \text{ when } \sqrt{n}S/\hat{\sigma} < -z_{1-\alpha/2},$$

where $z_{1-\alpha/2}$ denotes a standard normal critical value.

3.4.2 Comparison of Model Classes

When there are general classes of models with each class containing several sub-models, the researcher may be interested in overall comparison of classes instead of pairwise comparison of each sub-model. We discuss such a procedure in this section.

Suppose that we have two classes of models with k models in each class: $\mathcal{F} = \{f_1(\theta), \ldots, f_k(\theta)\}$ and $\mathcal{G} = \{g_1(\beta), \ldots, g_k(\beta)\}$. We are interested in comparing the overall performances of $\mathcal{F}$ and $\mathcal{G}$. More specifically, we are testing whether $\mathcal{F}$ and $\mathcal{G}$ have the same distance from the moments vector h_2. Here we adopt the von Mises-type (or average) distance between a set $\mathcal{F}$ and a point h_2:

$$D_M(\mathcal{F}, h_2) = \sum_{j=1}^{k} d(f_j(\theta), h_2; W_{h_2}),$$

where $d(f_j(\theta), h_2; W_{h_2})$ denotes the previously used weighted Euclidean distance between vectors $f_j(\theta)$ and h_2:

$$d(f_j(\theta), h_2; W_{h_2}) = (h_2 - f_j(\theta))' W_{h_2} (h_2 - f_j(\theta)).$$

Note that, alternatively, one could use a Kolmogorov-type distance between $\mathcal{F}$ and h_2: $D_{min}(\mathcal{F}, h_2) = \min_{j=1,\ldots,k} d(f_j(\theta), h_2; W_{h_2})$ or $D_{max}(\mathcal{F}, h_2) = \max_{j=1,\ldots,k} d(f_j(\theta), h_2; W_{h_2})$. While with a Kolmogorov-type distance each class is represented by its best (or worst) performer, the von Mises-type distance measures the average performance of a class of models, and we find it more appropriate when the object of interest is the overall performance of a class.

Thus, our null hypothesis of interest can now be stated as

$$H_0 : D_M(\mathcal{F}, h_2) = D_M(\mathcal{G}, h_2), \tag{3.15}$$

and a test can be based on the difference of sample analogues of $D_M(\mathcal{F}, h_2)$ and $D_M(\mathcal{G}, h_2)$:[52]

$$S^M = \sum_{j=1}^{k} \left(d(\hat{g}_j(\hat{\beta}), \hat{h}_2; W_{\hat{h}_2}) - d(\hat{f}_j(\hat{\theta}), \hat{h}_2; W_{\hat{h}_2}) \right).$$

Let $\hat{\sigma}_M$ denote the standard error of S^M. As before, the null hypothesis in (3.15) should be rejected when the studentized statistic $\sqrt{n} S^M / \hat{\sigma}_M$ exceeds standard normal critical values. The standard error can be computed as follows.[53] Define

$$Q_j = \begin{pmatrix} A' \frac{\partial f_j(\theta)'}{\partial \theta} W_{h_2}(h_2 - f_j(\theta)) - B' \frac{\partial g_j(\beta)'}{\partial \beta} W_{h_2}(h_2 - g_j(\beta)) \\ W_{h_2}(f_j(\theta) - g_j(\beta)) + 0.5 \frac{\partial w(h_2)'}{\partial h} J' K(h_2, f_j(\theta), g_j(\beta)) \end{pmatrix},$$

---

[52] We assume here, as in our case, that the same estimator of structural parameters is used inside each class of models. A generalization allowing for model-specific estimators inside each class is straightforward.

[53] The details of the derivation are provided in Appendix C.4.

and let $\hat{Q}_j$ denote a consistent estimator of Q_j. Ignoring the simulation uncertainty, the standard error of S^M is given by the square-root of

$$\hat{\sigma}_M^2 = 4\left(\sum_{j=1}^{k}\hat{Q}_j\right)'\begin{pmatrix}\hat{\Lambda}_{11} & \hat{\Lambda}_{12}\\ \hat{\Lambda}_{12}' & \hat{\Lambda}_{22}\end{pmatrix}\left(\sum_{j=1}^{k}\hat{Q}_j\right). \tag{3.16}$$

The expression in (3.16) can be easily adjusted to account for simulation uncertainty. Note that the formula will depend on whether each model is simulated independently or if the same simulated structural shocks used in all models. In our case, the number of simulations is sufficiently large for the simulation uncertainty to be ignored.

3.5 Empirical Results

In this section we present the findings from the numerical solutions of our models and model comparisons. We conduct model comparisons based on two sets of moments: volatilities of endogenous variables and correlations, which include co-movements of key macroeconomic aggregates with output and cross-country correlations. To perform the comparison, we estimate the corresponding moments in the U.S. quarterly data over the period of 1973:1-2007:4. Details on data sources and calculations are provided in the Appendix C.1.

We begin by presenting the results for the BKK and LAMP economies under the benchmark calibration. Then we conduct several extensions. In particular, (i) we consider model scenario in which labor input of participants and non-participants are imperfect substitutes by varying the elasticity of substitution between them, υ; (ii) we allow for investment-specific technology shocks.

3.5.1 Benchmark Case

In this section we present the results from our simulations of BKK and LAMP models under the benchmark parameterization. Table 3.3 presents the volatilities of various macroeconomic aggregates in the data and in different versions of our models. Thus, panel (a) reports the statistics from the original BKK model specification. Panel (b) reports the corresponding statistics in the model with LAMP under perfect substitutability in labor inputs of participants and non-participants.

As in [47], financial autarky model generates significantly higher volatilities of exports, imports and especially relative prices, in comparison with

Table 3.3: Volatilities: Benchmark Calibration

Table 3.3presents actual and simulated percent standard deviations for the U.S. economy. The data statistics are for the period of 1973:1-2007:4. Details on the data are available in the Appendix C.1. Model-based statistics are obtained from 10000 simulations, 100 periods long, each. All series, except net exports (nx), are logged and HP-filtered. The following models are considered: (a) original BKK; (b) BKK with LAMP. FA, BE and CM refer, respectively, to financial autarky, bond economy and complete markets economy.

	% std dev	$\frac{\text{\% std dev}}{\text{\% std dev of y}}$			% std dev					
	y	c	x	n	ex	im	nx	ir	p	rx
U.S. Data	1.49	0.62	2.92	0.68	3.93	4.98	0.50	3.84	2.64	3.55
(a) BKK										
FA	0.98	0.54	1.86	0.25	1.07	1.07	0.00	1.37	1.53	1.00
BE	1.01	0.54	2.71	0.29	0.81	0.81	0.20	0.75	0.83	0.54
CM	1.01	0.55	2.73	0.29	0.82	0.82	0.21	0.70	0.78	0.51
(b) LAMP										
FA	0.95	0.59	1.67	0.20	1.03	1.03	0.00	1.31	1.46	0.95
BE	0.97	0.62	2.47	0.23	0.79	0.79	0.19	0.67	0.75	0.49
CM	0.97	0.63	2.49	0.22	0.80	0.80	0.20	0.62	0.69	0.45

the complete markets and bond economies; but implies lower volatilities of output, consumption, investment and employment relative to bond economy and complete markets economy. These results are driven by the inability of agents in the environment of financial autarky to run trade imbalances. In such a framework, following productivity shocks, it is impossible to shift final goods production to the country that has comparative advantage in doing so. As a result, a larger adjustment in relative prices, such as terms of trade, is needed to clear the markets. Such larger movements in the terms of trade under financial autarky partially offset the productivity changes (as in 29), thus reducing the incentives to work and invest. Consequently, employment, investment, output and consumption all become less volatile when no access to financial assets is available.

When agents become heterogeneous in terms of their access to financial instruments, there are two key changes in the volatility characteristics of our economies. First, volatility of consumption increases across all financial regimes; second, the volatility of all other variables declines across all financial regimes. In our setup, introducing LAMP implies that asset markets become incomplete within a country. Namely, the non-participants can not trade any assets (neither financial, nor real, like capital) and only consume their labor income. Their consumption, as a result becomes more volatile, thus raising the volatility of aggregate consumption in the country. On the other hand, employment is the only source of income for non-participants, as a result, their labor supply is inelastic. This implies that aggregate employment, output and investment, all become less volatile relative to the economy with no LAMP.

Next, we evaluate the performance of our model in terms of co-movements with output. The results are summarized in Table 3.4**.** As before, the top row of the table reports the co-movements in the data, while panels (a) and (b) report them, respectively, in the original BKK model and in the economy with LAMP.

Table 3.4: Correlations with Output: Benchmark Calibration

Table 3.4 presents actual and simulated correlations of macroeconomics aggregates with output for the U.S. economy. The data statistics are for the period of 1973:1-2007:4. Details on the data are available in the Appendix C.1. Model-based statistics are obtained from 10000 simulations, 100 periods long, each. All series, except net exports (nx), are logged and HP-filtered. The following models are considered: (a) original BKK; (b) BKK with LAMP. FA, BE and CM refer, respectively, to financial autarky, bond economy and complete markets economy.

	correlation between								
	c, y	x, y	n, y	ex, y	im, y	nx, y	p, y	rx, y	$rx, c_1 - c_2$
U.S. Data	0.82	0.94	0.85	0.42	0.82	-0.37	-0.16	0.16	-0.17
(a) BKK									
FA	0.89	0.99	0.98	1.00	0.07	0.01	0.64	0.64	0.96
BE	0.93	0.95	0.96	0.55	0.80	-0.65	0.64	0.64	0.99
CM	0.94	0.95	0.96	0.50	0.84	-0.65	0.64	0.64	0.99
(b) LAMP									
FA	0.93	0.99	0.99	1.00	0.08	0.01	0.64	0.64	0.99
BE	0.97	0.95	0.97	0.54	0.83	-0.64	0.63	0.63	0.97
CM	0.97	0.95	0.97	0.48	0.87	-0.64	0.62	0.62	0.97

As was the case for volatilities, the financial autarky economy is the most distinct among our three financial regimes. The fact that all trades in this economy must be *quid pro quo* implies that net exports are acyclical. Financial autarky also generates more procyclical exports and less procyclical imports relative to the bond and complete markets economies. In terms of these co-movements financial autarky economy departs from the data relative to the other two financial regimes. When LAMP is introduced, the comovement properties of the model do not change much. The only exception is the comovement of consumption with output, which increases when LAMP is introduced. The main reason is again the behavior of non-participants, whose work hours are inelastic, which in turn makes their wage income and thus consumption more sensitive to productivity changes. Consumption of non-participants, therefore, is more strongly procyclical than consumption of participants. This makes aggregate consumption move more closely with output relative to the original BKK framework. Both BKK and LAMP economies fail to replicate the negative correlation between real exchange rate and relative consumption of domestic to foreign economies that is observed in the data. This mismatch of theory and data is a well-known Backus-Smith puzzle due to [9] and [62]. Adding LAMP reduces this correlation, but only marginally.

Lastly, we summarize the model performance based on cross-country co-movements of various macroeconomic aggregates. Table 3.5 reports our results. The top row reports the estimates in the data, the second panel summarizes them in the BKK economies, and the bottom panel - in the economies with LAMP. There are several puzzles associated with the cross-country correlations, and they can be seen clearly from Table 3.5. First, is the fact that consumption is less correlated than output across countries in the data, while models predict the opposite ("quantity" puzzle). Second, in the data the correlations of investment and employment across countries are positive, while complete markets and bond economy models predict negative correlations ("international comovement" puzzle). Financial autarky, on the other hand, generates investment and employment across countries that are positively correlated, consistent with the data. So, as was the case with volatilities, financial autarky model seems to provide a better match to the data even when it comes to the cross-country co-movements.

Table 3.5: Cross-country Correlations: Benchmark Calibration

Table 3.5presents actual and simulated cross-country correlations for the U.S. economy and the rest of the world. The data statistics are for the period of 1973-2007. Details on the data are available in the Appendix C.1. Model-based statistics are obtained from 10000 simulations, 100 periods long, each. All series are logged and HP-filtered. The following models are considered: (a) original BKK; (b) BKK with LAMP. FA, BE and CM refer, respectively, to financial autarky, bond economy and complete markets economy.

	correlation between			
	y_1, y_2	c_1, c_2	x_1, x_2	n_1, n_2
U.S. Data	0.58	0.43	0.41	0.45
(a) BKK				
FA	0.16	0.86	0.29	0.01
BE	0.08	0.68	-0.42	-0.32
CM	0.09	0.64	-0.43	-0.29
(b) LAMP				
FA	0.17	0.79	0.37	0.10
BE	0.12	0.57	-0.39	-0.22
CM	0.13	0.53	-0.40	-0.18

Adding agents' heterogeneity in asset market access works towards resolving these puzzles. In particular, LAMP reduces the cross-country correlation of consumption, while simultaneously increasing it for output; and does so for all three financial regimes considered. It also significantly increases the cross-country correlation in investment and employment.

To understand these results, consider what happens to employment, investment, consumption and output in the economy with a representative households following a positive productivity shock. The country experiencing a productivity improvement (say, home country) sees its real wages rise, leading to an increase in labor supply, output and investment. At the same time, following the shock, the terms of trade depreciate in the home country, thus making foreign households relatively wealthier.[54] As a result,

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[54] There are several channels through which wealth effect in the foreign country arises following productivity improvement in the home country. First is the fact that productivity shocks spill over across countries. Second, is the terms of trade effect mentioned in the text. Third effect works through the world interest rate (whenever any assets are traded across countries). In particular, interest rate in the country experiencing a productivity improvement rises, creating an additional positive wealth effect for foreign households,

they reduce their labor supply, lowering real output. For consumption in the foreign country to go up, investment must fall. When markets are complete or a single non-contingent bond is available these adjustments imply a negative correlation of employment and investment between home and foreign economies. In the financial autarky, where shifting production across countries is not an option, terms of trade must adjust to eliminate the incentives to do so. These terms of trade movements are larger than in the bond or complete market economies as was argued before. By offsetting some of the productivity improvement in the home country, terms of trade adjustment implies that output, consumption, investment and employment in this country increase by less under financial autarky than under bond or complete market regimes. Correspondingly, in the foreign country, these macroeconomic aggregates increase by more as foreign households take advantage of larger favorable terms of trade movements. These adjustments imply positive cross-country correlations under financial autarky.

Adding LAMP changes these dynamics. With LAMP non-participants allocate all their time endowment to work. Thus, only households participating in the asset and capital markets adjust their labor supply following the shock. Consequently, aggregate labor supply in both countries responds to shocks less relative to the economy with a representative agent. This results in larger cross-country correlation of hours and output in the LAMP economy.[55] In the bond and complete market economies this reduces the incentives to shift production across countries following the shocks and increases the cross-country correlation in investment. With investment responding less, so does consumption, thus lowering consumption correlation across countries. This result highlights how the absence of risk-sharing within a country spills into lower international risk-sharing.

The results above show that different versions of our model perform better in matching different data characteristics. Financial autarky economy does best in matching volatilities of macroeconomic aggregates, but can not account for the cyclical properties of trade variables. Complete markets and bond economies do better in accounting for the cyclical properties of the data, but under-perform in terms of volatilities and cross-country correlations. Adding LAMP has three key effects in the model: (i) it raises the

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who want to lend following the shock.

[55] While adding LAMP moderates the dynamics of hours, it is quantitatively distinct from lowering labor supply elasticity in the representative agent BKK economy. In fact, our experiments show that reducing labor supply elasticity in the BKK economy leads to a larger negative correlation of labor inputs and investment across countries; as well as larger positive cross-country correlation of consumption. This deepens the puzzles.

sensitivity of aggregate consumption to income shocks; (ii) it reduces the sensitivity of aggregate labor supply to productivity shocks; (iii) it makes investment less responsive to productivity shocks. These effects improve models performance primarily in matching cross-country correlations of consumption, output, investment and employment, but worsen their performance in matching volatilities. Given these results, a formal statistical test is necessary to aggregate various characteristics and pick a winner among our model variants. We turn to this next.

3.5.2 Comparison Results

To determine which version of the model described above provides the best fit to the data, we apply our test described in Section 3.4.1 to all possible pair-wise model comparisons. Our null hypothesis is that any two models considered provide an equivalent fit to the data. We evaluate each model's performance based on three criteria: (i) its ability to match volatilities; (ii) its ability to match co-movements with output and cross-country correlations; and (iii) on its overall performance which aggregates all of the aforementioned characteristics. Aggregation of model characteristics is equivalent to choosing the weight matrix W_{h_2} defined above and deserves a special note. The simplest approach would be to assign equal weights to all model characteristics, that is to use an identity weighting matrix. Such an approach, however, may not be very informative if different data characteristics have significantly different scales. For instance, in our case, variances can take any non-negative values, while correlations are restricted by $[-1, 1]$ interval. Thus, if we use an identity weighting matrix to aggregate across such variances and correlations, the overall model performance will be heavily influenced by its performance for the moments that are larger - variances in our case.

To account for the differences in scale we utilize a data-dependent weighting scheme in which various characteristics of interest are brought to a common base, thus facilitating their aggregation. According to our weighting scheme, prediction errors are assigned weights that are inversely related to the values of corresponding moments in the data. This way, instead of measuring absolute distance between the model and data to construct the test statistic as with the identity weighting matrix, we measure the percentage error made by the model relative to the data. In other words, we compute the ratio of the distance between model and data over the data moment, $(h - f)/h$ where f is the model moment and h is its data counterpart, and use it to construct a scale-free measure of the test statistic.[56] We use such percentage errors in the case of volatilities. Since correlations are unit-free, we aggregate them using simple prediction errors.[57]

The comparison results for BKK and LAMP models with various financial structures are presented in Table 3.6. Three panels in the table identify the set of characteristics based on which we conduct the comparisons: variances (panel (a)), co-movements with output and cross-country correlations (panel (b)), and overall performance (panel (c)). The test statistic is computed as the difference between the loss function of the model in the row (model g) and the loss function of the model in the column (model f). Therefore, a positive sign of the test statistic implies that the model in the row does worse in matching data moments as compared with the model in the column. In addition, the larger the test statistic, the worse the model in the row performs. We report p-values in parenthesis below the test statistics.

First, consider the original BKK models. Among the three financial regimes our test picks financial autarky as the winning specification based on volatilities, correlations and the overall performance. This result is in accord with the informal findings in the literature. Extending comparisons to include LAMP economies, our test results show that financial autarky with no LAMP outperforms all other models based on volatilities. Its superior performance for volatilities is statistically significant in all five pair-wise comparisons. Based on co-movements with output and cross-country correlations, our test picks complete market economy with LAMP as the model that matches data best. This result is also statistically significant in three pair-wise comparisons out of five possible. Finally, based on the overall performance, complete markets economy with LAMP outperforms all other models, with most comparisons being highly statistically significant. The only exception is autarky economies, but the difference in their overall performance is not statistically significant.

The pair-wise model comparisons discussed above are informative in iso-

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[56] To bring the variances to a (0,1) base that is more comparable with the correlations we apply a logistic re-scaling to them.

[57] Another possibility is to use a weight matrix that is inversely related to the asymptotic variance-covariance matrix of data moments. Such an approach gives a scale-free measure of fit which is reminiscent of the GMM approach, i.e. moments that are more precisely estimated are assigned greater weights. Note, however, that in the time-series context where the asymptotic variance-covariance matrix is estimated by HAC methods, the uncertainty in the estimation of the weight matrix will dominate the uncertainty in estimation of parameters and moments. This is because HAC estimators converge at a slower than square root-n rate (see, for example, [45] for details. As a result, such a test may have poor power in finite samples.

Table 3.6: Test Results from Benchmark Models Comparisons

Table 3.6 reports the test statistics for comparison of the model in the row (model g) against the model in the column (model f). Positive numbers for the test statistic indicate that, compared with the model in the column, the model in the row provides a worse fit to the data moments. P-values are in the parentheses. * p-value$\leq$0.10, ** p-value$\leq$0.05, *** p-value$\leq$0.01.

	Model f					
Model g		BKK			LAMP	
(a) Volatilities	FA	BE	CM	FA	BE	CM
BKK, FA	0					
BKK, BE	0.19***	0				
	(0.00)					
BKK, CM	0.20***	0.02***	0			
	(0.00)	(0.00)				
LAMP, FA	0.03***	-0.16***	-0.17***	0		
	(0.00)	(0.00)	(0.00)			
LAMP, BE	0.23***	0.04***	0.03***	0.20***	0	
	(0.00)	(0.00)	(0.00)	(0.00)		
LAMP, CM	0.25***	0.06***	0.05***	0.22***	0.02***	0
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	
(b) Correlations (with output and cross-country)						
BKK, FA	0					
BKK, BE	0.13	0				
	(0.77)					
BKK, CM	0.05	-0.08***	0			
	(0.91)	(0.00)				
LAMP, FA	-0.12	-0.25	-0.17	0		
	(0.40)	(0.65)	(0.76)			
LAMP, BE	-0.22	-0.35***	-0.27**	-0.10	0	
	(0.57)	(0.00)	(0.03)	(0.84)		
LAMP, CM	-0.31	-0.45***	-0.36***	-0.19	-0.09***	0
	(0.42)	(0.00)	(0.01)	(0.68)	(0.00)	
(c) Overall	FA	BE	CM	FA	BE	CM
BKK, FA	0					
BKK, BE	0.32	0				
	(0.47)					
BKK, CM	0.25	-0.07***	0			
	(0.57)	(0.00)				
LAMP, FA	-0.09	-0.41	-0.34	0		
	(0.52)	(0.46)	(0.54)			
LAMP, BE	0.01	-0.31***	-0.24**	0.10	0	
	(0.97)	(0.01)	(0.05)	(0.83)		
LAMP, CM	-0.06	-0.38***	-0.31**	0.03	-0.08***	0
	(0.87)	(0.01)	(0.02)	(0.95)	(0.00)	
LAMP - BKK			**-0.71***			
class comparison			**(0.07)**			

lating the combinations of model features that produce the closest fit to the data (e.g. LAMP and complete markets, as above). But does the asset participation margin improve model performance independent of the assumed international financial regime? To provide such an evaluation we apply our class-based test from Section 3.4.2. The test evaluates the overall performance of LAMP class of models relative to a representative agent BKK class of models by aggregating the fits across the three financial regimes within each class. We test whether these two model classes have the same distance from the data moments. We find that LAMP specification provides a better fit to the data relative to a representative agent benchmark, and the difference is statistically significant. More precisely, the resulting test statistic, reported at the bottom of Table 3.6, is -0.71 in favor of LAMP with the standard error of 0.39 and the resulting p-value of 0.07.

3.5.3 Extensions

Next we consider the robustness of our results with respect to parameter υ and to the presence of IST shocks. The results under alternative calibrations are presented in Table 3.7 for volatilities, Table 3.8 for correlations with output, and Table 3.9 for cross-country correlations.

Panel (a) in each table presents the results for the case of imperfect substitutability in labor inputs of participants and non-participants, where we set the elasticity parameter υ to 0.5. Panels (b) and (c) report, respectively, second moments from the specifications of BKK and LAMP models with IST shocks. In each exercise we keep all remaining parameters unchanged.

Table 3.7: Volatilities: Robustness

Table 3.7 presents actual and simulated volatilities for the U.S. economy. All data statistics are for the period of 1973:1-2007:4. Details on the data are available in the Appendix C.1. Model-based statistics are obtained from 10000 simulations, 100 periods long, each. All series, except net exports (*nx*), are logged and HP-filtered. The following models are considered: (a) LAMP with imperfectly substitutable labor input of participants and non-participants; (b) BKK with IST shocks; (c) LAMP with IST shocks. FA, BE and CM refer, respectively, to financial autarky, bond economy and complete markets economy.

	% std dev	$\frac{\%\ \text{std dev}}{\%\ \text{std dev of y}}$			% std dev					
	y	c	x	n	ex	im	nx	ir	p	rx
U.S. Data	1.49	0.62	2.92	0.68	3.93	4.98	0.50	3.84	2.64	3.55
(a) LAMP, $\upsilon = 0.5$										
FA	0.90	0.65	1.49	0.13	0.98	0.98	0.00	1.24	1.38	0.90
BE	0.92	0.69	2.25	0.15	0.76	0.76	0.18	0.60	0.67	0.44
CM	0.91	0.70	2.27	0.15	0.78	0.78	0.19	0.55	0.61	0.40
(b) BKK with IST										
FA	1.00	0.61	2.27	0.38	1.09	1.09	0.00	1.41	1.57	1.02
BE	1.04	0.57	3.86	0.45	1.42	1.43	0.33	1.03	1.15	0.75
CM	1.04	0.57	3.90	0.45	1.48	1.49	0.35	0.89	1.15	0.75
(c) LAMP with IST										
FA	0.96	0.63	1.97	0.30	1.04	1.04	0.00	1.34	1.48	0.97
BE	0.99	0.62	3.48	0.36	1.44	1.44	0.33	1.04	1.16	0.76
CM	0.98	0.63	3.52	0.35	1.50	1.50	0.34	0.68	1.17	0.77

Consider first the scenario where labor inputs of participants and non-participants are imperfectly substitutable with elasticity $\upsilon = 0.5$. In this case, the distinction between the original BKK and LAMP models becomes quantitatively sharper. In particular, relative to the case of perfect substitutability between two labor types reported in panel (b) of Tables 3.3, 3.4, and 3.5, volatility of consumption rises further, while volatilities of all other aggregates fall. Reducing elasticity of substitution in labor has the largest effect on cross-country correlations. In particular, it significantly lowers cross-correlation of consumption, and raises the cross-correlation of employment and investment. These changes are reflected in the formal model comparison. We find that while qualitatively, our test results remain unchanged, quantitatively they become stronger and more significant.[58]

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[58] Given that test results do not change qualitatively in this case, we do not report them in the paper. These results are available from the authors upon request.

Table 3.8: Correlations with Output: Robustness

Table 3.8 presents actual and simulated correlations of macroeconomics aggregates with output for the U.S. economy. The data statistics are for the period of 1973:1-2007:4. Details on the data are available in the Appendix C.1. Model-based statistics are obtained from 10000 simulations, 100 periods long, each. All series, except net exports (nx), are logged and HP-filtered. The following models are considered: (a) LAMP with imperfectly substitutable labor input of participants and non-participants; (b) BKK with IST shocks; (c) LAMP with IST shocks. FA, BE and CM refer, respectively, to financial autarky, bond economy and complete markets economy.

	correlation between								
	c, y	x, y	n, y	ex, y	im, y	nx, y	p, y	rx, y	$rx, c_1 - c_2$
U.S. Data	0.82	0.94	0.85	0.42	0.82	-0.37	-0.16	0.16	-0.17
(a) LAMP, $\upsilon = 0.5$									
FA	0.95	0.99	0.99	1.00	0.10	0.01	0.63	0.63	1.00
BE	0.98	0.95	0.97	0.52	0.86	-0.63	0.61	0.61	0.95
CM	0.99	0.95	0.98	0.46	0.89	-0.63	0.61	0.61	0.95
(b) BKK with IST									
FA	0.69	0.89	0.75	1.00	0.06	0.02	0.65	0.65	0.26
BE	0.78	0.78	0.74	0.17	0.59	-0.52	0.35	0.35	0.98
CM	0.81	0.78	0.74	0.13	0.60	-0.52	0.30	0.30	0.95
(c) LAMP with IST									
FA	0.80	0.90	0.74	1.00	0.08	0.02	0.64	0.64	0.55
BE	0.90	0.77	0.72	0.18	0.56	-0.48	0.31	0.31	0.78
CM	0.92	0.76	0.72	0.15	0.57	-0.48	0.26	0.26	0.67

Next, we turn to IST shocks. The simulated moments for the original BKK models with IST shocks are shown in panel (b) of Tables 3.7, 3.8, 3.9; while those for the LAMP model with IST shocks are in panel (c) of the same three tables. Not surprisingly, when IST shocks are introduced, all volatilities go up, especially for investment, international trade variables and relative prices. This increase is particularly pronounced in the bond economy and complete markets economy. Correlations with output, on the other hand, decline. Cross-country correlations of output and consumption also fall, while those of investment and employment turn more negative. These changes are characteristic of both BKK and LAMP economies.

Table 3.9: Cross-country Correlations: Robustness

Table 3.9 presents actual and simulated cross-country correlations for the U.S. economy and the rest of the world. The data statistics are for the period of 1973:1-2007:4. Details on the data are available in the Appendix C.1. Model-based statistics are obtained from 10000 simulations, 100 periods long, each. All series are logged and HP-filtered. The following models are considered: (a) LAMP with imperfectly substitutable labor input of participants and non-participants; (b) BKK with IST shocks; (c) LAMP with IST shocks. FA, BE and CM refer, respectively, to financial autarky, bond economy and complete markets economy.

	correlation between			
	y_1, y_2	c_1, c_2	x_1, x_2	n_1, n_2
U.S. Data	0.58	0.43	0.41	0.45
(a) LAMP, $\upsilon = 0.5$				
FA	0.18	0.73	0.44	0.18
BE	0.15	0.48	-0.38	-0.12
CM	0.15	0.44	-0.38	-0.06
(b) BKK with IST				
FA	0.14	0.54	0.11	-0.17
BE	0.05	0.59	-0.64	-0.48
CM	0.06	0.57	-0.64	-0.45
(c) LAMP with IST				
FA	0.17	0.63	0.21	-0.08
BE	0.09	0.56	-0.62	-0.39
CM	0.10	0.53	-0.62	-0.36

What is behind these results? As in [77] and [69], IST shocks in our setup act as demand shocks. For instance, consider a positive IST shock in the domestic economy. Following this shock, domestic investment demand goes up, appreciating home terms of trade, on impact. To accommodate higher investment demand, domestic households must reduce their consumption. In bond and complete market economies, imports from abroad also rise to finance domestic investment boom, leading to trade deficit. Domestic households also increase their labor supply in response to the shock. As home output goes up and investment demand subsides (with temporary IST shocks), domestic terms of trade begin to depreciate. So does the real exchange rate. The impact appreciation of the terms of trade and real exchange rate, followed by depreciation some quarters later helps understand the higher volatility of these variables in the economy with IST shocks.

Foreign economy, on the other hand, being relatively less productive, cuts down its investment and employment. Released resources are used for temporarily higher consumption by foreign households. These dynamics imply low (for consumption) or negative (for output, employment and investment) cross-country correlations after IST shocks.

Overall, adding temporary IST shocks to our benchmark economies helps improve their performance on some dimensions, such as volatilities and some correlations. However, the models fit also worsens in some other dimensions, such as cross-country co-movements of investment and employment. As a result, a formal statistical method of model comparison is again warranted. Our results from comparison of models with IST shocks are presented in Table 3.10, where as before, to measure overall performance we aggregate variances and covariances using data-dependent weighting matrix.

In the presence of IST shocks our test picks BKK bond economy as the preferred model specification among all pair-wise comparisons when the objective is to match volatilities. The results are statistically significant in all but one pair. If the objective is to match correlations, out test implies that BKK autarky with IST shocks comes out at the top. When the overall performance (variances and correlations) is considered, BKK autarky economy with IST shocks is chosen as the winner, although this superior performance is statistically significant in only two out of five possible pairs.

Turning to the comparison between BKK and LAMP models classes, we find that LAMP with IST shocks outperforms the original BKK representative agent model with IST shocks and that this superior performance is highly statistically significant. More precisely, the test statistic for the overall test between LAMP and BKK model classes is -1.34 in favor of LAMP, with the standard error of 0.29 and implied p-value of 0.00 (see the bottom of Table 3.10). These results imply that also in the presence of IST shocks,

Table 3.10: Comparison Results of Models with IST Shocks

Table 3.10 reports the test statistics for comparison of the model in the row (model g) against the model in the column (model f). Positive numbers for the test statistic indicate that, compared with the model in the column, the model in the row provides a worse fit to the data moments. P-values are in the parentheses. * p-value$\leq$0.10, ** p-value$\leq$0.05, *** p-value$\leq$0.01.

	Model *f*					
Model *g*		BKK			LAMP	
(a) Volatilities	FA	BE	CM	FA	BE	CM
BKK, FA	0					
BKK, BE	-0.01	0				
	(0.65)					
BKK, CM	-0.00	0.01**	0			
	(0.89)	(0.03)				
LAMP, FA	0.03***	0.05*	0.04	0		
	(0.00)	(0.09)	(0.14)			
LAMP, BE	-0.01	0.01*	-0.00	-0.04	0	
	(0.83)	(0.10)	(0.66)	(0.18)		
LAMP, CM	0.03	0.04***	0.03***	-0.01	0.03***	0
	(0.29)	(0.00)	(0.00)	(0.86)	(0.00)	
(b) Correlations (with output and cross-country)						
BKK, FA	0					
BKK, BE	1.19***	0				
	(0.00)					
BKK, CM	1.02**	-0.17***	0			
	(0.02)	(0.00)				
LAMP, FA	0.12	-1.08**	-0.90*	0		
	(0.54)	(0.03)	(0.07)			
LAMP, BE	0.48	-0.71***	-0.54***	0.37	0	
	(0.20)	(0.00)	(0.00)	(0.42)		
LAMP, CM	0.21	-0.99***	-0.81***	0.09	-0.28***	0
	(0.60)	(0.00)	(0.00)	(0.85)	(0.00)	
(c) Overall						
BKK, FA	0					
BKK, BE	1.18***	0				
	(0.00)					
BKK, CM	1.02***	-0.17***	0			
	(0.01)	(0.00)				
LAMP, FA	0.15	-1.03**	-0.87*	0		
	(0.43)	(0.03)	(0.08)			
LAMP, BE	0.48	-0.70***	-0.54***	0.33	0	
	(0.20)	(0.00)	(0.00)	(0.47)		
LAMP, CM	0.23	-0.95***	-0.78***	0.08	-0.24***	0
	(0.54)	(0.00)	(0.00)	(0.86)	(0.00)	
LAMP - BKK			**-1.34*** **			
class comparison			**(0.00)**			

LAMP delivers a better match to the data.

3.6 Conclusion

In this paper we propose a novel statistical test to conduct evaluation and formal comparison of DSGE models. Our procedure explicitly accounts for the possibility that a DSGE model might be misspecified. It also accounts for simulation uncertainty, the fact that some model parameters are estimated rather than calibrated, and allows for both pair-wise comparison of models and comparison of model classes. We apply our test to a standard international business cycles model with three specifications for asset markets structure: financial autarky, single risk-free bond economy, and an economy with complete asset markets. We find that financial autarky economy indeed fits the data best, in line with the informal findings in the literature. We then allow for domestic asset market incompleteness by introducing hand-to-mouth consumers that do not participate in the domestic or foreign financial markets. With limited asset market participation (LAMP), the models' performance is improved in matching cross-country correlations, but worsened in matching volatilities. Formal statistical comparison finds that the improvements brought out by LAMP are statistically significant, allowing economies with LAMP to outperform the representative agent benchmark economies. The superior performance of LAMP is robust to lower substitutability in labor inputs of participants and non-participants, and to the presence of the investment-specific productivity shocks.

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Appendix A

A.1 Variable Definitions

Following [11], I construct the sample from Compustat and define variables used in the cash and inventory regressions as follows:
Cash is defined as the ratio of cash and short-term investments over total asset;
Inventory is the ratio of total inventories over total asset;
Firm size is the natural logarithm of total asset;
Risk is computed as the standard deviation of annual operating cash flow in the past five years, with operating cash flow defined as earnings after interest, dividends and tax but before depreciation divided by total asset;
Market-to-book ratio is the sum of market value and debt over total asset;
Net working capital is equal to working capital net of cash and inventory over total asset;
Capital investment is the ratio of capital expenditure over total asset;
Leverage is the sum of long-term debt and debt in current liabilities normalized by total asset;
R&D investment is research and development expenses to total asset ratio;
Dividend is a dummy variable taking value of one if dividend payout (common) is non-zero;
Acquisition is the ratio of acquisition over total asset.

A.2 Corporate Cash Holdings in Wholesale, Retail and Services

As a robustness check, I also examine the correlation between cash and inventory in wholesale, retail and service industries. I re-estimate regression equation (1.1), and present results below in Tables A.1 and A.2.

A negative, statistically significant correlation between cash and inventory is also found in wholesale and retail trade, although the magnitude becomes smaller compared to manufacturing. With cross-sectional variations, the estimated magnitude of the correlation lies within the range

[0.329, 0.372]. Using within-firm over-time variations, the magnitude goes up to 0.524.

Table A.1: Cash Holdings in Wholesale and Retail

Table A.1 reports the estimation results of Regression (1.1) with a sample of firms operating in wholesale and retail industries from Compustat during 1980-2006. The heteroskedasticity-consistent standard errors reported in parenthesis account for possible correlation within a firm cluster. Significance levels are indicated by *, **, and *** for 10%, 5%, and 1%, respectively.

Variables	(1) Pooled OLS	(2) Pooled OLS	(3) Pooled OLS	(4) Fixed Effect
Inventory	**-0.3289*****	**-0.3666*****	**-0.3718*****	**-0.5241*****
	(0.0258)	(0.0293)	(0.0316)	(0.0254)
Size	-0.0098***	-0.0107***	-0.0111***	-0.0145***
	(0.0022)	(0.0021)	(0.0026)	(0.0036)
Market-to-book	0.0113***	0.0113***	0.0116***	0.0089***
	(0.0027)	(0.0026)	(0.0026)	(0.0022)
Risk	0.0050	0.0149	0.0164	-0.0134
	(0.0253)	(0.0227)	(0.0235)	(0.0201)
Cash flow	0.0819***	0.0775***	0.0765***	0.0394***
	(0.0152)	(0.0152)	(0.0160)	(0.0138)
Net working capital	-0.0857***	-0.0784***	-0.0737***	-0.0521***
	(0.0141)	(0.0138)	(0.0143)	(0.0124)
Capital investment	-0.3825***	-0.3961***	-0.3946***	-0.2818***
	(0.0481)	(0.0485)	(0.0483)	(0.0262)
Leverage	-0.2086***	-0.1976***	-0.1939***	-0.1484***
	(0.0183)	(0.0180)	(0.0184)	(0.0114)
R&D	0.1350	0.0987	0.0992	-0.1273*
	(0.1115)	(0.1028)	(0.1032)	(0.0727)
Dividend	-0.0062	0.0015	0.0011	0.0077***
	(0.0072)	(0.0073)	(0.0074)	(0.0025)
Acquisition	-0.1977***	-0.1799***	-0.1784***	-0.2571***
	(0.0309)	(0.0312)	(0.0314)	(0.0124)
Industry FE (2-digit)	Yes			
Industry FE (3-digit)		Yes		
Industry FE (4-digit)			Yes	
Firm FE				Yes
Year FE	Yes	Yes	Yes	Yes
Cohort dummy	Yes	Yes	Yes	
Observations	6,858	6,858	6,858	6,858
R-squared	0.359	0.388	0.397	0.722

As shown in Table A.2, similar results are found for service industries. There is a significant negative correlation between cash and inventory. According to column (4), a 10 percentage-point decrease in inventory will be correlated with a 5.8 percentage-point increase in cash holdings.

In addition, I show the dynamics of average cash and inventory ratios by industries in Figure A.1. The constant average cash and inventory ratio prevails in most industries, except for agriculture and wholesale.

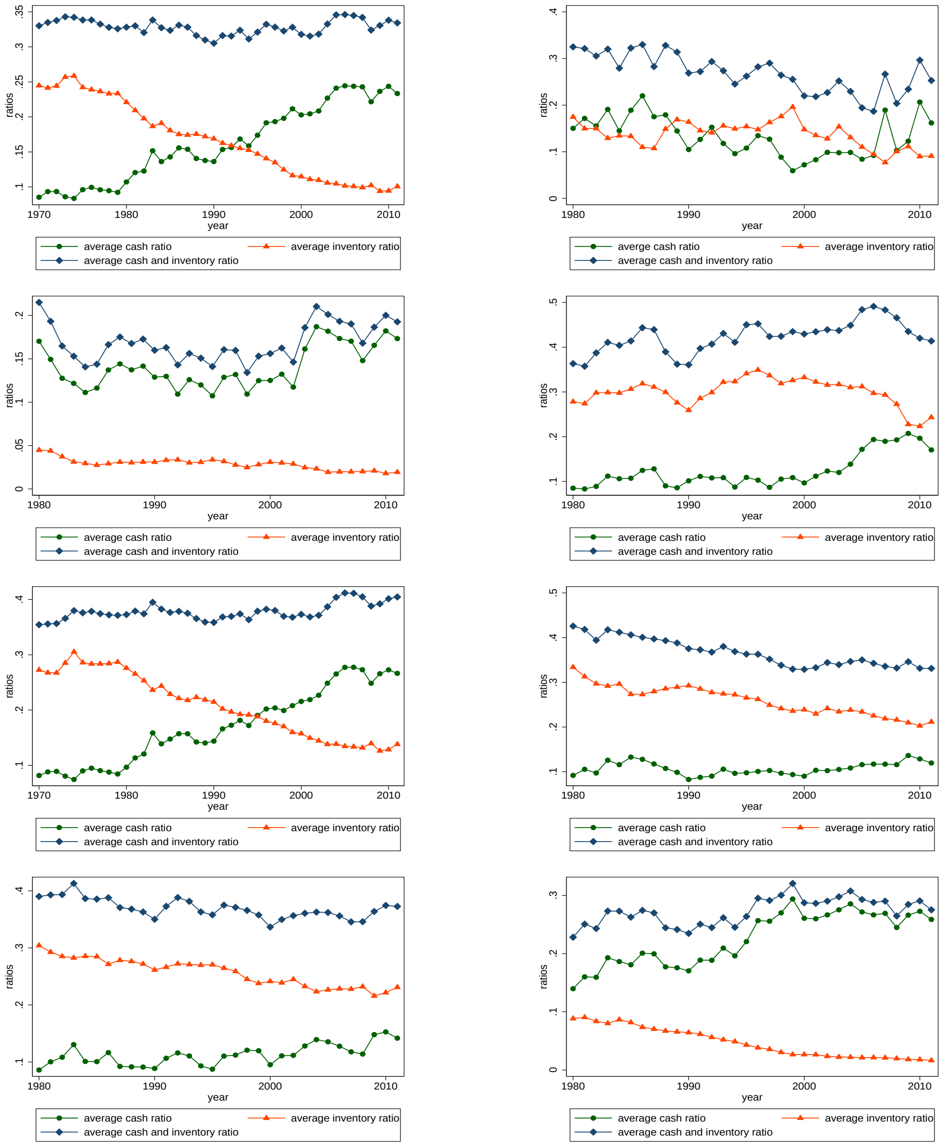

Figure A.1: Average Cash and Inventory Ratios by Industries. The figure summarizes the average cash-to-asset ratio, average inventory-to-asset ratio and sum of those two ratios over time in (1) All industries; (2) Agriculture; (3) Mining; (4) Construction; (5) Manufacturing; (6) Wholesale; (7) Retail; (8) Services.

Table A.2: Cash Holdings in Services

Table A.2 reports the estimation results of Regression (1.1) with a sample of firms operating in services from Compustat during 1980-2006. The heteroskedasticity-consistent standard errors reported in parenthesis account for possible correlation within a firm cluster. Significance levels are indicated by *, **, and *** for 10%, 5%, and 1%, respectively.

Variables	(1) Pooled OLS	(2) Pooled OLS	(3) Pooled OLS	(4) Fixed Effect
Inventory	**-0.3953*****	**-0.3928*****	**-0.3820*****	**-0.5806*****
	(0.0336)	(0.0343)	(0.0359)	(0.0436)
Size	0.0032	0.0040*	0.0026	-0.0087**
	(0.0024)	(0.0025)	(0.0025)	(0.0043)
Market-to-book	0.0104***	0.0100***	0.0096***	0.0066***
	(0.0015)	(0.0014)	(0.0014)	(0.0010)
Risk	0.0421***	0.0405***	0.0389***	0.0156
	(0.0140)	(0.0138)	(0.0140)	(0.0144)
Cash flow	0.0238***	0.0234***	0.0227***	0.0104
	(0.0086)	(0.0085)	(0.0086)	(0.0081)
Net working capital	-0.0204**	-0.0181**	-0.0157*	-0.0165*
	(0.0089)	(0.0090)	(0.0089)	(0.0093)
Capital investment	-0.4162***	-0.3832***	-0.3339***	-0.3576***
	(0.0524)	(0.0533)	(0.0530)	(0.0390)
Leverage	-0.3200***	-0.3045***	-0.2948***	-0.1861***
	(0.0193)	(0.0193)	(0.0197)	(0.0154)
R&D	0.1111***	0.0936***	0.0730**	-0.0471*
	(0.0286)	(0.0292)	(0.0298)	(0.0283)
Dividend	-0.0264**	-0.0317***	-0.0219*	0.0047
	(0.0129)	(0.0129)	(0.0123)	(0.0088)
Acquisition	-0.4507***	-0.4545***	-0.4536***	-0.3770***
	(0.0343)	(0.0339)	(0.0336)	(0.0299)
Industry FE (2-digit)	Yes			
Industry FE (3-digit)		Yes		
Industry FE (4-digit)			Yes	
Firm FE				Yes
Year FE	Yes	Yes	Yes	Yes
Cohort dummy	Yes	Yes	Yes	
Observations	7,713	7,713	7,713	7,713
R-squared	0.356	0.371	0.380	0.702

A.3 Description of the JIT-adopter Sample

Table A.3 provides the distribution of the JIT adoption year for the sample of 169 JIT adopters. About 11% of the firms in the sample adopted JIT in the first half of 1980s (1980-1984), with the earliest in 1982. Over 50% of the sample firms implemented JIT in the second half of 1980s. The number of adopters in the sample reached the peak in 1990, and declined since then.

Table A.4 reports the distribution of adopters by two-digit SIC industry. A large portion (approximately 70%) of adopters operate in four industries. In order by number, these industries are: electronic equipment (SIC 36, 23.7%), industrial equipment (SIC 35, 21.9%), instrumentation (SIC 38, 13%), and motor vehicles (SIC 37, 10.7%). The rest of adopters in the sample are relatively evenly distributed in other industries.

Table A.3: Descriptive Statistics for 169 JIT Adopters

Distribution of JIT Adoption Years

Year	Number of Firms	Distribution
1982	3	1.77%
1983	5	2.96%
1984	11	6.51%
1985	13	7.69%
1986	14	8.28%
1987	17	10.1%
1988	21	12.4%
1989	22	13.0%
1990	23	13.6%
1991	18	10.7%
1992	12	7.10%
1993	10	5.92%
Total	169	100%

A.4 Work-in-process Inventory and JIT manufacturing

In the main body of the paper, I assume that firms purchase both material and work-in-process inventory from suppliers and defining JIT as JIT-purchasing. In the background, I have in mind that firms also use JIT-manufacturing. This section shows that as firms adopt JIT-manufacturing to improve production efficiency, firms shift resources from work-in-process inventory to material inventory. As such, once firms adopt JIT (both purchasing and manufacturing), all input inventory — material inventory and work-in-process inventory — will be converted into cash.

JIT-manufacturing is defined as efficient production. Prior to its implementation, production takes time. Work-in-process inventory is generated in the process of transforming materials into finished goods due to waiting.

Table A.4: Descriptive Statistics for 169 JIT Adopters (*continued*)

Distribution of Two-Digit Industry Classifications

2-Digit SIC Code	Industry	Number of Firms	Distribution
20	Food	1	0.59%
22	Textile mill product	2	1.18%
23	Apparel	1	0.59%
24	Lumber	1	0.59%
25	Furniture	7	4.14%
26	Paper	4	2.37%
27	Printing, publishing	4	2.37%
28	Chemicals	4	2.37%
30	Rubber and plastics	4	2.37%
31	Leather	2	1.18%
33	Primary metals	9	5.32%
34	Fabricated metals	8	4.73%
35	Industrial equipment	37	21.9%
36	Electronic equipment	40	23.7%
37	Motor vehicles	18	10.7%
38	Instrumentation	22	13.0%
39	Other manufacturing	5	2.96%
Total		169	100%

That is, with JIC-manufacturing, firms transform materials into work-in-process goods which however are not ready for being processed into final products in current period. As firms adopt JIT, they operate in such an efficient way that they can produce products with raw materials in time to satisfy customers' needs.

I model JIC-manufacturing and JIT-manufacturing as follows. Firms use linear technology, $G_1(N) = N$, to transform materials into work-in-process products which are then used to produce final goods with technology $G_2(N) = N^\alpha$ with $0 < \alpha < 1$. Production process is inefficient in JIC environment. Newly-generated work-in-process products from materials cannot be converted into final goods. To smooth operation, firms hold both material inventory s_1 and work-in-process inventory s_2 as working capital. Both depreciate at the same rate δ_s. JIT-manufacturing shortens production time and makes newly-generated work-in-process inventory available for current-period final-good production.

Similar to the model presented in Section 4, here I assume away uncertainty and fixed inventory adjustment costs. To further simplify the model, I assume that there are no financial frictions, capital or cash, and that firms use JIC-purchasing in both manufacturing environments. Without inventory adjustment costs, a firm adjusts its material inventory holdings each period.

The firm's problem is to maximize the expected value of the discounted future dividend stream by choosing how many materials to purchase i_s, and how many materials N_1 and work-in-process products N_2 to use in production, given the beginning of period material and work-in-process inventory stocks, s_1 and s_2.

A.4.1 Steady State under JIC-manufacturing

In the JIC-manufacturing environment, production inefficiency causes the unavailability of the newly-generated half-finished goods for producing current period finished goods. I write the firm's problem in the JIC environment as follows,

$$V(s_1, s_2) = \max_{i_s > 0, N_1, N_2} \{N_2^{\alpha} - i_s + \beta V(s_1', s_2')\},$$

where

$$\begin{aligned} s_1 &\geq N_1, \\ s_2 &\geq N_2, \\ s_1' &= (1-\delta_s)(s_1 - N_1 + i_s), \\ s_2' &= (1-\delta_s)(s_2 - N_2 + N_1). \end{aligned}$$

Rewriting the problem with multipliers, the first order conditions of material use, work-in-process goods use, new purchases, material inventory holdings and work-in-process inventory holdings are given by:

$$\begin{aligned} V(s_1, s_2) = \max_{i_s > 0, N_1, N_2} \{ & N_2^{\alpha} - i_s + \beta V((1-\delta_s)(s_1 - N_1 + i_s), (1-\delta_s)(s_2 - N_2 + N_1)) \\ & + \mu_1(s_1 - N_1) + \mu_2(s_2 - N_2)\}, \end{aligned}$$

$$\begin{aligned} N_1 &: \beta(1-\delta_s)\beta \tfrac{\partial V'}{\partial s_2'} + \mu_2 = \beta(1-\delta_s)\tfrac{\partial V'}{\partial s_1'} + \mu_1, \\ N_2 &: \alpha N_2^{\alpha-1} = \beta(1-\delta_s)\tfrac{\partial V'}{\partial s_2'} + \mu_2, \\ i_s &: 1 = \beta(1-\delta_s)\tfrac{\partial V'}{\partial s_1'}, \\ s_1 &: \tfrac{\partial V}{\partial s_1} = \beta(1-\delta_s)\tfrac{\partial V'}{\partial s_1'} + \mu_1, \end{aligned}$$

$$s_2 \quad : \quad \frac{\partial V}{\partial s_2} = \beta(1-\delta_s)\frac{\partial V'}{\partial s_2'} + \mu_2.$$

Solving the system of equations above at the steady state gives the steady state material inventory level and work-in-process inventory level:

$$s_1^* = \frac{[\beta^2(1-\delta_s)^2\alpha]^{\frac{1}{1-\alpha}}}{1-\delta_s},$$

$$s_2^* = [\beta^2(1-\delta_s)^2\alpha]^{\frac{1}{1-\alpha}}.$$

A.4.2 Steady State under JIT-manufacturing

In the JIT-manufacturing environment, efficient internal operations make direct conversion from materials into finished goods feasible. The firm's problem in the JIT environment is therefore written as

$$V(s_1, s_2) = \max_{i_s>0, N_1, N_2} \{N_2^\alpha - i_s + \beta V(s_1', s_2')\},$$

where

$$\begin{aligned} s_1' &\geq N_1, \\ s_2' + N_1 &\geq N_2, \\ s_1' &= (1-\delta_s)(s_1 - N_1 + i_s), \\ s_2' &= (1-\delta_s)(s_2 - N_2 + N_1). \end{aligned}$$

The Bellman equation with multipliers can be formulated as

$$V(s_1, s_2) = \max_{i_s>0, N_1, N_2} \{N_2^\alpha - i_s + \beta V((1-\delta_s)(s_1 - N_1 + i_s), (1-\delta_s)(s_2 - N_2 + N_1))$$
$$+ \mu_1(s_1 - N_1) + \mu_2(s_2 + N_1 - N_2)\},$$

$$N_1 \quad : \quad \beta(1-\delta_s)\beta\frac{\partial V'}{\partial s_2'} = \beta(1-\delta_s)\frac{\partial V'}{\partial s_1'} + \mu_1,$$

$$N_2 \quad : \quad \alpha N_2^{\alpha-1} = \beta(1-\delta_s)\frac{\partial V'}{\partial s_2'} + \mu_2,$$

$$i_s \quad : \quad 1 = \beta(1-\delta_s)\frac{\partial V'}{\partial s_1'},$$

$$s_1 \quad : \quad \frac{\partial V}{\partial s_1} = \beta(1-\delta_s)\frac{\partial V'}{\partial s_1'} + \mu_1,$$

$$s_2 \quad : \quad \frac{\partial V}{\partial s_2} = \beta(1-\delta_s)\frac{\partial V'}{\partial s_2'} + \mu_2.$$

Again, I can derive the equilibrium material inventory and work-in-process inventory: $s_1^* = [\beta(1-\delta_s)\alpha]^{\frac{1}{1-\alpha}}$ and $s_2^* = 0$.

A.4.3 Discussion

I first show analytically that the optimal level of material inventory holdings under JIT is greater than the optimal level under JIC, illustrated in Proposition 8. I then parameterize the model to quantitatively measure the magnitude of the rise in material inventory as firms implement JIT-manufacturing.

Proposition 8 *As firms switch from JIC-manufacturing to JIT manufacturing, they increase their material inventory holdings,* $s_{1,JIT}^* > s_{1,JIC}^*$.

Proof.

$$\begin{aligned} s_{1,JIT}^* - s_{1,JIC}^* &= [\beta(1-\delta_s)\alpha]^{\frac{1}{1-\alpha}} - \beta^{\frac{2}{1-\alpha}}(1-\delta_s)^{\frac{2}{1-\alpha}-1}\alpha^{\frac{1}{1-\alpha}} \\ &= [\beta(1-\delta_s)\alpha]^{\frac{1}{1-\alpha}}[1-\beta^{\frac{1}{1-\alpha}}(1-\delta_s)^{\frac{\alpha}{1-\alpha}}] \\ &> [\beta(1-\delta_s)\alpha]^{\frac{1}{1-\alpha}}[1-\max\{\beta^{\frac{1+\alpha}{1-\alpha}}, (1-\delta_s)^{\frac{1+\alpha}{1-\alpha}}\}] \\ &> 0, \end{aligned}$$

The last equality follows from the non-negativity of returns to scale $\alpha > 0$ and therefore $\max\{\beta, 1-\delta_s\}^{\frac{1+\alpha}{1-\alpha}} < 1$. ■

Intuitively, this result arises from production efficiency. JIT manufacturing reduces production costs by eliminating work-in-process inventory. The improved productivity leads firm to invest more resources in production by using more materials. In the absence of JIT-purchasing, firms hoard materials to smooth production.

Figure A.2 plots the ratio of optimal material inventory holdings under JIT over the sum of optimal material and work-in-process inventory holdings under JIC as a function of inventory depreciation rate δ_s, given the parameter values used in the main body of the paper $\beta = 0.96$ and $\alpha = 0.55$. As the inventory depreciation rate rises from 20% to 40%, the ratio increases from 80% to 127%. When δ_s is 0.32, the value calibrated in the paper, the ratio equals to 1.04. That is, as firms switch from JIC-manufacturing to JIT-manufacturing, firms allocate approximately the same amount of resources from work-in-process inventory to material inventory.

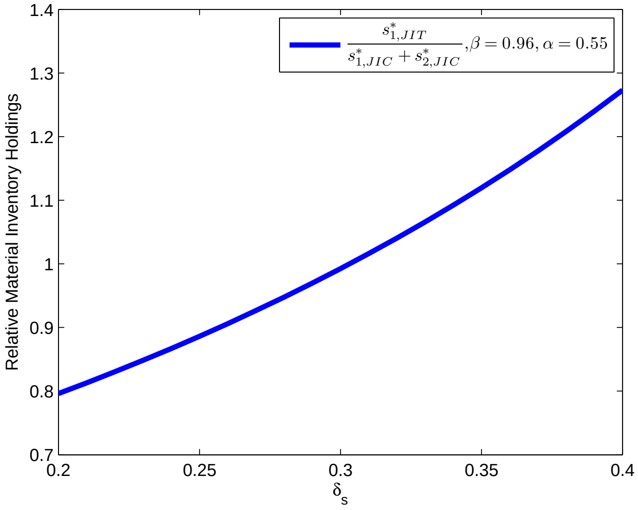

Figure A.2: Relative Material Inventory Holdings after the Adoption of JIT manufacturing. This figure plots the model-implied ratio of the steady-state material inventory holdings under JIT-manufacturing to the total input inventory holdings (both material and work-in-progress) under JIC-manufacturing. It illustrates that firms shift resources from work-in-progress inventory to material inventory when switching to JIT. With reasonable parameter values on inventory holding costs δ_s, the steady-state material inventory holdings under JIT range from 80% to 127% of the steady-state pre-adoption input inventory holdings.

Appendix B

B.1 Proof of Proposition 5

Proof. (1) and (2): Under the condition $x_1 < \ln(1-\delta) - \ln\hat{R} < 0$, $\bar{\theta} > 1$ exists and equals to $\frac{x_1}{\ln(1-\delta)-\ln\hat{R}}$. It follows that if $\theta \geq \bar{\theta}$, s^* drops below zero, which contradicts with the non-negativity condition of inventory holdings. Thus if $\theta \geq \bar{\theta}$, $s^* = 0$. If $\theta < \bar{\theta}$, $s^* > 0$ exists.

(3): Under the condition $\theta < \bar{\theta}$ when an interior solution exists, from equation (8) we can evaluate the derivative of optimal inventory holdings s^* with respective to θ:

$$\frac{\partial s^*}{\partial \theta} = [(\frac{1}{a} + \frac{1}{1-\delta})^{-2} a^{-2} + (1 + \frac{a}{1-\delta})^{-2} \frac{e^{x_1}}{1-\delta}](\frac{1-\delta}{\hat{R}})^{\theta} \ln\frac{1-\delta}{\hat{R}} < 0.$$

This is negative, because all terms on the right side except for the last one are positive.

Taking derivatives with respect to inventory holding costs δ and the return on cash $\hat{R}$, we have

$$\begin{aligned}\frac{\partial s^*}{\partial \delta} &= -(\frac{1}{a} + \frac{1}{1-\delta})^{-2}[a^{-2}\theta(\frac{1-\delta}{\hat{R}})^{\theta-1} + (1-\delta)^{-2}] \\ &- e^{x_1}(1 + \frac{a}{1-\delta})^{-2}\frac{1}{\hat{R}^{\theta}}(1-\delta)^{\theta-2}(\theta-1) < 0,\end{aligned}$$

and

$$\frac{\partial s^*}{\partial \hat{R}} = -(\frac{1}{a} + \frac{1}{1-\delta})^{-2} a^{-2}\theta\frac{(1-\delta)^{\theta}}{\hat{R}^{\theta-1}} - e^{x_1}\theta(1 + \frac{a}{1-\delta})^{-2}(\frac{1-\delta}{\hat{R}})^{\theta-1} < 0.$$

Under the condition $e^{x_1} + s^* < 1$ when an interior solution c^* exists, we can prove that optimal cash holdings increase in θ, δ and $\hat{R}$. From equation (2.7),

$$\frac{\partial \ln(1-c^*)}{\partial c^*}\frac{\partial c^*}{\partial \theta} = \theta^{-2}\ln(e^{x_1} + s^*) + (1 - \frac{1}{\theta})\frac{1}{e^{x_1} + s^*}\frac{\partial s^*}{\partial \theta} < 0,$$

which follows $\ln(e^{x_1} + s^*) < 0$ and $\frac{\partial s^*}{\partial \theta} < 0$. Because the firm will never save cash more than the amount it needs in the future,

$$\frac{\partial \ln(1-c^*)}{\partial c^*} = -\frac{1}{1-c^*} < 0,$$

which in turn implies that

$$\frac{\partial c^*}{\partial \theta} > 0.$$

Similarly, we can derive

$$\frac{\partial \ln(1-c^*)}{\partial c^*}\frac{\partial c^*}{\partial \delta} = (1-\frac{1}{\theta})\frac{1}{e^{x_1}+s^*}\frac{\partial s^*}{\partial \delta} < 0,$$

and

$$\frac{\partial \ln(1-c^*)}{\partial c^*}\frac{\partial c^*}{\partial \hat{R}} = (1-\frac{1}{\theta})\frac{1}{e^{x_1}+s^*}\frac{\partial s^*}{\partial \hat{R}} < 0,$$

which imply that

$$\frac{\partial c^*}{\partial \delta} > 0, \frac{\partial c^*}{\partial \hat{R}} > 0.$$

(4): Also, given the expression of $\bar{\theta}$ and the condition $x_1 < \ln(1-\delta) - \ln \hat{R} < 0$, we have

$$\frac{\partial \bar{\theta}}{\partial \delta} = \frac{x_1}{1-\delta}[\ln(1-\delta) - \ln \hat{R}]^{-2} < 0,$$

$$\frac{\partial \bar{\theta}}{\partial \hat{R}} = \frac{x_1}{\hat{R}}[\ln(1-\delta) - \ln \hat{R}]^{-2} < 0$$

and

$$\frac{\partial \bar{\theta}}{\partial x_1} = [\ln(1-\delta) - \ln \hat{R}]^{-1} < 0.$$

■

B.2 Proof of Proposition 6

Proof. To assess the impact of risk on optimal cash holdings, I take the total differential of equation (2.8) with respect to c^* and σ and derive the following equation

$$0 = \frac{\beta \hat{R} \lambda}{\sigma b}\Phi'(\frac{\ln b - \mu}{\sigma})\frac{\partial b}{\partial c^*}dc^* - \frac{\beta \hat{R} \lambda}{\sigma^2}\Phi'(\frac{\ln b - \mu}{\sigma})(\ln b - \mu)d\sigma,$$

where

$$b = (1-c^*)^{\frac{\theta}{\theta-1}} - s^*,$$

$$\frac{\partial b}{\partial c^*} = -\frac{\theta \hat{R}}{\theta - 1}(1-c^*\hat{R})^{\frac{1}{\theta-1}} < 0.$$

It follows that

$$\frac{dc^*}{d\sigma} = \frac{(\ln b - \mu)b}{\sigma \frac{\partial b}{\partial c^*}}.$$

The strict concavity of the firm's problem, due to the costly external borrowing, ensures that the firm is risk averse and its certainty equivalent is smaller than the expected value, $\ln b < \mu$. Therefore,

$$\frac{dc^*}{d\sigma} > 0.$$

■

B.3 Proof of Proposition 7

Proof. Assuming the existence of an interior solution, I rewrite equation (2.3) as

$$(1 - \frac{s^*}{1-\delta})^{-\frac{1}{\theta}} = \beta(1-\delta)(G_1 + G_2), \tag{B.1}$$

where

$$G_1 = \int_{-\infty}^{+\infty} (e^x + s^*)^{-\frac{1}{\theta}} f(x)dx,$$

$$G_2 = \int_{-\infty}^{\ln b} \lambda(e^x + s^*)^{-\frac{1}{\theta}} f(x)dx,$$

$$b = (1-c^*)^{\frac{\theta}{\theta-1}} - s^*,$$

and $f(x)$ is the probability density function of the random variable x which has a normal distribution, $x \sim N(\mu, \sigma^2)$.

I then take the total differential of the equation (B.1) with respect to s^* and σ,

$$[\frac{1}{\theta(1-\delta)}(1-\frac{s^*}{1-\delta})^{-\frac{1}{\theta}-1} - \beta(1-\delta)(\frac{\partial G_1}{\partial s^*} + \frac{\partial G_2}{\partial s^*})]ds^* = [\beta(1-\delta)(\frac{\partial G_1}{\partial \sigma} + \frac{\partial G_2}{\partial \sigma})]d\sigma.$$

The expressions for the derivatives of G_1 and G_2 with respect to s^* and σ are

$$\frac{\partial G_1}{\partial s^*} = \int_{-\infty}^{+\infty} -\frac{1}{\theta}(e^x + s^*)^{-\frac{1}{\theta}-1} f(x)dx,$$

$$\frac{\partial G_2}{\partial s^*} = \lambda[\frac{\partial \ln b}{\partial s^*}(e^{\ln b} + s^*)^{-\frac{1}{\theta}} f(\ln b) - \int_{-\infty}^{\ln b} \frac{1}{\theta}(e^x + s^*)^{-\frac{1}{\theta}-1} f(x)dx],$$

$$\frac{\partial G_1}{\partial \sigma} = -\frac{1}{\sigma}\{\int_{-\infty}^{+\infty} [(e^x + s^*)^{-\frac{1}{\theta}} - (e^x + s^*)^{-\frac{1}{\theta}} \frac{(x-\mu)^2}{\sigma^2}] f(x)dx\},$$

$$\frac{\partial G_2}{\partial \sigma} = -\frac{\lambda}{\sigma}\{\int_{-\infty}^{\ln b} [(e^x + s^*)^{-\frac{1}{\theta}} - (e^x + s^*)^{-\frac{1}{\theta}} \frac{(x-\mu)^2}{\sigma^2}] f(x)dx\}.$$

The derivative $\frac{\partial G_1}{\partial s^*}$ is negative, because it is an integral over a negative function. The negativity of the derivative $\frac{\partial G_2}{\partial s^*}$ follows $\frac{\partial \ln b}{\partial s^*} = -[(1-c^*)^{\frac{\theta}{\theta-1}} - s^*]^{-1} < 0$. I next show that the derivatives $\frac{\partial G_1}{\partial \sigma}$ and $\frac{\partial G_1}{\partial \sigma}$ are both positive.

Using the series representation of $(u+v)^w$,

$$(u+v)^w = \sum_{n=0}^{\infty} \frac{v^n C_n^w}{u^{\frac{1+wn}{n}}},$$

I approximate $(e^x + s^*)^{-\frac{1}{\theta}}$ by

$$(e^x + s^*)^{-\frac{1}{\theta}} \approx (e^x)^{-\frac{1}{\theta}} + g(s^*).$$

Here, C_n^w is the binomial coefficient and $g(s^*) > 0$ is a function of s^*.

Define $y = \frac{x-\mu}{\sigma}$, the expression of $\frac{\partial G_1}{\partial \sigma}$ can be written as

$$\begin{aligned}
\frac{\partial G_1}{\partial \sigma} &= -\frac{1}{\sigma}\{\int_{-\infty}^{+\infty} [(e^{\sigma y+\mu})^{-\frac{1}{\theta}} + g(s^*)]\frac{1}{\sqrt{2\pi}}e^{-\frac{1}{2}y^2}dy \\
&\quad - \int_{-\infty}^{+\infty} [(e^{\sigma y+\mu})^{-\frac{1}{\theta}} + g(s^*)]y^2\frac{1}{\sqrt{2\pi}}e^{-\frac{1}{2}y^2}dy\} \\
&= -\frac{1}{\sigma}[\int_{-\infty}^{+\infty} e^{-\frac{\sigma}{\theta}y-\frac{\mu}{\theta}}(1-y^2)\frac{1}{\sqrt{2\pi}}e^{-\frac{1}{2}y^2}dy \\
&\quad + g(s^*)\int_{-\infty}^{+\infty}(1-y^2)\frac{1}{\sqrt{2\pi}}e^{-\frac{1}{2}y^2}dy] \\
&= -\frac{1}{\sigma}[\int_{-\infty}^{+\infty} e^{-\frac{\sigma}{\theta}y-\frac{\mu}{\theta}}(1-y^2)\frac{1}{\sqrt{2\pi}}e^{-\frac{1}{2}y^2}dy] \\
&= -\frac{1}{\sigma}e^{-\frac{\mu}{\theta}}\frac{1}{\sqrt{2\pi}}[-\sqrt{2\pi}\frac{\sigma^2}{\theta^2}e^{\frac{\sigma^2}{2\theta^2}}] \\
&= \frac{\sigma}{\theta^2}e^{\frac{\sigma^2}{2\theta^2}-\frac{\mu}{\theta}},
\end{aligned}$$

which is positive, $\frac{\partial G_1}{\partial \sigma} > 0$.

Similarly, the derivative $\frac{\partial G_2}{\partial \sigma}$ can be expressed as

$$\begin{aligned}
\frac{\partial G_2}{\partial \sigma} &= -\frac{\lambda}{\sigma}\{\int_{-\infty}^{\frac{\ln b-\mu}{\sigma}}[(e^{\sigma y+\mu})^{-\frac{1}{\theta}}+g(s^*)]\frac{1}{\sqrt{2\pi}}e^{-\frac{1}{2}y^2}dy-\int_{-\infty}^{\frac{\ln b-\mu}{\sigma}}[(e^{\sigma y+\mu})^{-\frac{1}{\theta}} \\
&\quad +g(s^*)]y^2\frac{1}{\sqrt{2\pi}}e^{-\frac{1}{2}y^2}dy\} \\
&= -\frac{\lambda}{\sigma}[\int_{-\infty}^{\frac{\ln b-\mu}{\sigma}}e^{-\frac{\sigma}{\theta}y-\frac{\mu}{\theta}}(1-y^2)\frac{1}{\sqrt{2\pi}}e^{-\frac{1}{2}y^2}dy \\
&\quad +g(s^*)\int_{-\infty}^{\frac{\ln b-\mu}{\sigma}}(1-y^2)\frac{1}{\sqrt{2\pi}}e^{-\frac{1}{2}y^2}dy] \\
&= -\frac{\lambda}{\sigma}[\int_{-\infty}^{\frac{\ln b-\mu}{\sigma}}e^{-\frac{\sigma}{\theta}y-\frac{\mu}{\theta}}(1-y^2)\frac{1}{\sqrt{2\pi}}e^{-\frac{1}{2}y^2}dy+g(s^*)\frac{\ln b-\mu}{\sigma}e^{-\frac{(\ln b-\mu)^2}{2\sigma^2}}] \\
&> -\frac{\lambda}{\sigma}[\int_{-\infty}^{\frac{\ln b-\mu}{\sigma}}e^{-\frac{\sigma}{\theta}y-\frac{\mu}{\theta}}(1-y^2)\frac{1}{\sqrt{2\pi}}e^{-\frac{1}{2}y^2}dy], \text{ use } g(s^*)>0,\ln b-\mu<0 \\
&= -\frac{\lambda}{\sigma}e^{-\frac{\mu}{\theta}}\frac{1}{\sqrt{2\pi}}[-\sqrt{2\pi}\frac{\sigma^2}{\theta^2}e^{\frac{\sigma^2}{2\theta^2}}erf(\frac{-\frac{\sigma}{\theta}+y}{\sqrt{2}})|_{-\infty}^{\frac{\ln b-\mu}{\sigma}}-e^{-\frac{\sigma y}{\theta}-\frac{y^2}{2}}(-\frac{\sigma}{\theta}-y)|_{-\infty}^{\frac{\ln b-\mu}{\sigma}}], \\
&= -\frac{\lambda}{\sigma}e^{-\frac{\mu}{\theta}}\frac{1}{\sqrt{2\pi}}\{-\sqrt{2\pi}\frac{\sigma^2}{\theta^2}e^{\frac{\sigma^2}{2\theta^2}}[erf(\frac{-\frac{\sigma}{\theta}+y}{\sqrt{2}})|_{y=\frac{\ln b-\mu}{\sigma}}-erf(-\infty)] \\
&\quad -e^{-\frac{\sigma y}{\theta}-\frac{y^2}{2}}(-\frac{\sigma}{\theta}-y)|_{y=\frac{\ln b-\mu}{\sigma}}\},
\end{aligned}$$

where erf is the Gauss error function. This derivative $\frac{\partial G_2}{\partial \sigma}$ is positive, following that $y=\frac{\ln b-\mu}{\sigma}<0$ and $erf(\frac{-\frac{\sigma}{\theta}+y}{\sqrt{2}})|_{y=\frac{\ln b-\mu}{\sigma}}-erf(-\infty)>0$.

Given that $\frac{\partial G_1}{\partial s^*}<0,\frac{\partial G_2}{\partial s^*}<0,\frac{\partial G_1}{\partial \sigma}>0$ and $\frac{\partial G_2}{\partial \sigma}>0$,

$$\frac{ds^*}{d\sigma}=\frac{\beta(1-\delta)(\frac{\partial G_1}{\partial \sigma}+\frac{\partial G_2}{\partial \sigma})}{\frac{1}{\theta(1-\delta)}(1-\frac{s^*}{1-\delta})^{-\frac{1}{\theta}-1}-\beta(1-\delta)(\frac{\partial G_1}{\partial s^*}+\frac{\partial G_2}{\partial s^*})}>0.$$

■

B.4 Variable Definitions

Following [11], I construct the sample from Compustat and define variables used in the cash and inventory regressions as follows:
Cash is defined as the ratio of cash and short-term investments over total asset;

Inventory is the ratio of total inventory over total asset;
Markup is measured as sales over the sum of cost of goods sold and selling, general and administrative expenses;
Market share (4-digit) is annual sales of the firm divided by totals sales in the 4-digit SIC code industry;
Market share (3-digit) is annual sales of the firm divided by totals sales in the 3-digit SIC code industry;
Sales growth is sales changes divided by average sales of this period and the previous period;
Firm size is the natural logarithm of total asset;
Risk is computed as the standard deviation of annual operating cash flow in the past five years, with operating cash flow defined as earnings after interest, dividends and tax but before depreciation divided by total asset;
Market-to-book ratio is the sum of market value and debt over total asset;
Net working capital (cash) is equal to working capital net of cash over total asset;
Net working capital (inventory) is working capital net of inventory over total asset;
Capital investment is the ratio of capital expenditure over total asset;
Leverage is the sum of long-term debt and debt in current liabilities normalized by total asset;
R&D investment is research and development expenses to total asset ratio;
Dividend is a dummy variable taking value of one if dividend payout (common) is non-zero;
Acquisition is the ratio of acquisition over total asset.

Appendix C

C.1 Data Sources and Calculations

Following [47], we collect data from OECD Main Economic Indicator (MEI) and OECD Quarterly National Accounts (QNA) for the period 1973-2007 and construct variables using the definitions summarized in Table C.1.

Table C.1: Data Sources and Calculations

Variable	Definition	Source
The U.S.		
Output (y_1)	Gross Domestic Product (at constant price 2000)	OECD MEI
Consumption (c_1)	Private plus Government Final Consumption Expenditure (at constant price 2000)	OECD MEI
Investment (x_1)	Gross Fixed Capital Formation (at constant price 2000)	OECD MEI
Employment (n_1)	Civilian Employment Index	OECD MEI
Real exchange rate (rx)	Price-adjusted Broad Dollar Index	Board of Governors
Import price	imports at current prices/imports at constant prices	OECD QNA
Export price	exports at current prices/exports at constant prices	OECD QNA
Terms of trade (p)	import price/export price	
Net exports ratio (nx)	(import-p*export)/y_1 (all at current prices)	
Real imports ratio (ir)	import/(GDP-export)	
Rest of the World		
Output (y_2)	Aggregate of Canada, Japan and 19 European Counties (aggregate with PPP exchange rates in 2000)	OECD MEI
Consumption (c_2)	Aggregate of Canada, Japan and 19 European Counties (aggregate with PPP exchange rates in 2000)	OECD MEI
Investment (x_2)	Aggregate of Canada, Japan and 19 European Counties (aggregate with PPP exchange rates in 2000)	OECD MEI
Employment (n_2)	Aggregate of Canada, Japan and 8 European Counties (weighted with populations in 2000)	OECD MEI

However, since OECD no longer reports aggregate data series on GDP, consumption and investment for European 15 which [47] used to compute variables for the rest of the world and since consistent series for each of those 15 European counties are not available either, instead, we used 19 European countries, including Austria, Belgium,Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden and United Kingdom, Iceland, Luxembourg, Switzerland and Turkey. The employment series for the rest of the world, because of data unavailability, is computed as the weighted aggregate of Canada, Japan and 8 European countries (Austria, Finland, Germany, Italy, Norway, Spain, Sweden and UK). These differences in the sample may be contribute to the differences between the estimates of productivity shock process in [47] and in this paper.

C.2 Estimation Details

In this section, we describe our estimation procedure, and show how it corresponds with the asymptotic linearization in (3.7) and (3.8).

First, note that in our case, $\theta = \beta = (\rho_{11}, \rho_{12}, \sigma_{e_1}, \sigma_{e_1 e_2})'$. The parameters are estimated using the following estimating equations:

$$\begin{pmatrix} z_{1,t} \\ z_{2,t} \end{pmatrix} = \begin{pmatrix} \mu_1 \\ \mu_2 \end{pmatrix} + \begin{pmatrix} \rho_{11} & \rho_{12} \\ \rho_{12} & \rho_{11} \end{pmatrix} \begin{pmatrix} z_{1,t-1} \\ z_{2,t-1} \end{pmatrix} + \begin{pmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \end{pmatrix}, \tag{C.1}$$

$$\sigma_{e_1} = \sqrt{E\varepsilon_{1,t}^2}, \tag{C.2}$$

$$\sigma_{e_1 e_2} = \frac{E\varepsilon_{1,t}\varepsilon_{2,t}}{\sqrt{E\varepsilon_{1,t}^2 E\varepsilon_{2,t}^2}}. \tag{C.3}$$

Define $y_{1,t} = z_{1,t}$ and $y_{2,t} = z_{2,t}$ for $t = 2, \ldots, n$, and let Y_1 and Y_2 denote the corresponding $(n-1)$-vectors of observations. Let $X_t = (1, z_{1,t-1}, z_{2,t-1})'$ for $t = 2, \ldots, n$, and let X denote the corresponding $(n-1) \times 3$ matrix of observations. Let ε_1 and ε_2 denote the $(n-1)$-vectors of observations on the error terms. We have the following SUR system:

$$Y_* = (I_2 \otimes X)\, \gamma_* + \varepsilon_*,$$

where $Y_* = (Y_1', Y_2')'$, $\varepsilon_* = (\varepsilon_1', \varepsilon_2')'$, and $\gamma_* = (\mu_1, \rho_{11}, \rho_{12}, \mu_2, \rho_{12}, \rho_{11})'$, and note that γ_* is restricted by $R\gamma_* = 0_{2\times 1}$, where

$$R = \begin{pmatrix} 0 & 1 & 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 & -1 & 0 \end{pmatrix}.$$

Define Σ as the variance-covariance matrix of $(\varepsilon_1, \varepsilon_2)'$:

$$\Sigma = \begin{pmatrix} \sigma_{e_1} & \sigma_{e_1 e_2}\sigma_{e_1}\sigma_{e_2} \\ \sigma_{e_1 e_2}\sigma_{e_1}\sigma_{e_2} & \sigma_{e_2} \end{pmatrix},$$

and let $\hat{\Sigma}$ denote its consistent estimator. For example, $\hat{\Sigma}$ can be constructed using the residuals obtained from OLS equation-by-equation estimation of (C.1). The restricted (FGLS) efficient SUR estimator of γ_* is given by:

$$\hat{\gamma}_* = \tilde{\gamma}_* - \left(\hat{\Sigma}^{-1} \otimes (X'^{-1}\right) R' \left(R \left(\hat{\Sigma}^{-1} \otimes (X'^{-1}\right) R'\right)^{-1} R\tilde{\gamma}_*,$$

where $\tilde{\gamma}_*$ denotes the unrestricted OLS equation-by-equation estimator of γ_*.[59]

Let $\hat{\sigma}_{e_1}$ and $\hat{\sigma}_{e_1e_2}$ denote the estimators of σ_{e_1} and $\sigma_{e_1e_2}$ respectively constructed by replacing the expectations in (C.2) and (C.3) with sample averages and ε's with fitted residuals from the SUR system above. We need additional notation to describe the linearization of the estimator of β in (3.8). Define:

$$H = I_6 - \left(\Sigma^{-1} \otimes \left(\text{plim}_{n\to\infty} \frac{X'X}{n}\right)^{-1}\right) R' \left(R \left(\Sigma^{-1} \otimes \left(\text{plim}_{n\to\infty} \frac{X'X}{n}\right)^{-1}\right) R'\right)^{-1} R,$$

and let $H_{2;3}$ denote the second and third rows of H. In this case, $\sqrt{n}(\hat{\beta}-\beta)$, B, and $\sqrt{n}(\hat{h}_1 - h_1)$ in (3.8) are given by the corresponding terms in the following expression:

$$\sqrt{n} \begin{pmatrix} \begin{pmatrix} \hat{\rho}_{11} - \rho_{11} \\ \hat{\rho}_{12} - \rho_{12} \end{pmatrix} \\ \hat{\sigma}_{e_1} - \sigma_{e_1} \\ \hat{\sigma}_{e_1e_2} - \sigma_{e_1e_2} \end{pmatrix} = \begin{pmatrix} H_{2;3} & 0_{2\times1} & 0_{2\times1} & 0_{2\times1} \\ 0_{1\times6} & \frac{1}{2\sigma_{e1}} & 0 & 0 \\ 0_{1\times6} & -\frac{\sigma_{e_1e_2}}{2\sigma_{e_1}^2} & -\frac{\sigma_{e_1e_2}}{2\sigma_{e_2}^2} & \frac{1}{\sigma_{e_1}\sigma_{e_2}} \end{pmatrix} \frac{1}{\sqrt{n}} \sum_{t=2}^{n}$$

$$\begin{pmatrix} \begin{pmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \end{pmatrix} \otimes X_t \\ \varepsilon_{1,t}^2 - \sigma_{e_1}^2 \\ \varepsilon_{2,t}^2 - \sigma_{e_2}^2 \\ \varepsilon_{1,t}\varepsilon_{2,t} - \sigma_{e_1e_2}\sigma_{e_1}\sigma_{e_2} \end{pmatrix} + o_p(1),$$

where $\hat{\rho}_{11}$ and $\hat{\rho}_{12}$ denote the second and third elements of the efficient SUR estimator $\hat{\gamma}_*$.

To estimate Λ_{11} and B, one should replace the population parameters in the above expression with their sample counterparts and ε's with fitted residuals from SUR estimation. To estimate Λ_{22} and Λ_{12}, one can use a linearization (similar to that of $\hat{\sigma}_{e_1}$ and $\hat{\sigma}_{e_1e_2}$ above) for $\hat{h}_2$.

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[59] Since the two equations have the same set of regressors, the unrestricted efficient SUR estimator is the equation-by-equation OLS estimator.

C.3 Derivation of the Asymptotic Variances Formulas in (3.10)-(3.12)

When H_0 is true, S can be written as

$$\begin{aligned} S = &\left[\left(\hat{h}_2 - \hat{g}(\hat{\beta})\right)' W_{\hat{h}_2} \left(\hat{h}_2 - \hat{g}(\hat{\beta})\right) - (h_2 - g(\beta))' W_{h_2} (h_2 - g(\beta))\right] \\ &- \left[\left(\hat{h}_2 - \hat{f}(\hat{\theta})\right)' W_{\hat{h}_2} \left(\hat{h}_2 - \hat{f}(\hat{\theta})\right) - (h_2 - f(\theta))' W_{h_2} (h_2 - f(\theta))\right]. \end{aligned} \tag{C.4}$$

Next,

$$\begin{aligned} &\left(\hat{h}_2 - \hat{g}(\beta)\right)' W_{\hat{h}_2} \left(\hat{h}_2 - \hat{g}(\beta)\right) - (h_2 - g(\beta))' W_{h_2} (h_2 - g(\beta)) \qquad \text{(C.5)} \\ &= \left(\hat{h}_2 - \hat{g}(\beta)\right)' \left(W_{\hat{h}_2} - W_{h_2}\right) \left(\hat{h}_2 - \hat{g}(\beta)\right) \\ &\quad + \left(\hat{h}_2 - \hat{g}(\beta) + h_2 - g(\beta)\right)' W_{h_2} \left(\hat{h}_2 - h_2\right) \\ &\quad - \left(\hat{h}_2 - \hat{g}(\beta) + h_2 - g(\beta)\right)' W_{h_2} \left(\hat{g}(\beta) - g(\beta)\right) \\ &= \left((h_2 - g(\beta)) \otimes (h_2 - g(\beta))\right)' J \left(w(\hat{h}_2) - w(h_2)\right) \\ &\quad + 2\,(h_2 - g(\beta))' W_{h_2} \left(\hat{h}_2 - h_2\right) \\ &\quad - 2\,(h_2 - g(\beta))' W_{h_2} \left(\hat{g}(\beta) - g(\beta)\right) + o_p(1/\sqrt{n}), \end{aligned}$$

where the last equality holds by $\operatorname{vec}(ABC) = (C' \otimes A)\operatorname{vec}(B)$ (see [67], equation (5) on page 30), (3.9), and (3.14). With a similar expression for the second term in (C.4) and a first-order Taylor expansion for $w(\hat{h}_2)$, we obtain that (C.5) multiplied by $\sqrt{n}$ is equal to

$$\begin{pmatrix} 2W_{h_2}(f(\theta) - g(\beta)) + \frac{\partial w(h_2)'}{\partial h} J' K(h_2, f(\theta), g(\beta)) \\ 2W_{h_2}(h_2 - f(\theta)) \\ -2W_{h_2}(h_2 - g(\beta)) \end{pmatrix}' \begin{pmatrix} \sqrt{n}\big(\hat{h}_2 - h_2\big) \\ \sqrt{\frac{n}{R}}\sqrt{R}\big(\hat{f}(\theta) - f(\theta)\big) \\ \sqrt{\frac{n}{R}}\sqrt{R}\big(\hat{g}(\beta) - f(\beta)\big) \end{pmatrix} \tag{C.6}$$

$+o_p(1)$.

Next, by a first-order Taylor expansion,

$$\begin{aligned} \left(\hat{h}_2 - \hat{g}(\hat{\beta})\right)' W_{\hat{h}_2} \left(\hat{h}_2 - \hat{g}(\hat{\beta})\right) = &\left(\hat{h}_2 - \hat{g}(\beta)\right)' W_{\hat{h}_2} \left(\hat{h}_2 - \hat{g}(\beta)\right) \\ &- 2\left(\hat{h}_2 - \hat{g}(\beta)\right)' W_{\hat{h}_2} \frac{\partial g(\beta)}{\partial \beta'} \left(\hat{\beta} - \beta\right) \\ &+ o_p(1/\sqrt{n}). \end{aligned}$$

By combining this result (and a similar expansion for model f) with the results in (C.6) and (C.4), and using (3.7)-(3.8), we obtain:

$$\sqrt{n}S = 2 \begin{pmatrix} A'\frac{\partial f(\theta)'}{\partial \theta} W_{h_2}(h_2 - f(\theta)) - B'\frac{\partial g(\beta)'}{\partial \beta} W_{h_2}(h_2 - g(\beta)) \\ W_{h_2}(f(\theta) - g(\beta)) + 0.5\frac{\partial w(h_2)'}{\partial h} J'K(h_2, f(\theta), g(\beta)) \\ W_{h_2}(h_2 - f(\theta)) \\ -W_{h_2}(h_2 - g(\beta)) \end{pmatrix}' \times \begin{pmatrix} \sqrt{n}\big(\hat{h}_1 - h_1\big) \\ \sqrt{n}\big(\hat{h}_2 - h_2\big) \\ \sqrt{\frac{n}{R}}\sqrt{R}\big(\hat{f}(\theta) - f(\theta)\big) \\ \sqrt{\frac{n}{R}}\sqrt{R}\big(\hat{g}(\beta) - f(\beta)\big) \end{pmatrix} + o_p(1). \tag{C.7}$$

The results in (3.10)-(3.12) now follow by (3.6) and (3.9).

C.4 Derivation of the Standard Error Formula in (3.16)

When H_0 is true, one can write

$$S^M = \sum_{j=1}^{k} \Big(d(\hat{g}_j(\hat{\beta}), \hat{h}_2; W_{\hat{h}_2}) - d(\hat{f}_j(\hat{\theta}), \hat{h}_2; W_{\hat{h}_2}) - d(g_j(\beta), h_2; W_{h_2}) + d(f_j(\theta), h_2; W_{h_2}\Big).$$

Assuming that the contribution of simulation uncertainty is negligible, it follows from (C.7) that

$$\sqrt{n}S^M = 2\sum_{j=1}^{k} Q_j \sqrt{n} \begin{pmatrix} \hat{h}_1 - h_1 \\ \hat{h}_2 - h_2 \end{pmatrix} + o_p(1),$$

where note that Q_j is the same as the first two row-blocks of the multiplication matrix appearing in (C.7). The result in (3.16) follows.