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

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December 27, 2012

*I would like to thank Viktoria Hnatkovska and Henry Siu for their encouragement and guidance. I am also grateful to Paul Beaudry, Murray Carlson, Mick Devereux, Adlai Fisher, Hiroyuki Kasahara, Vadim Marmer and Yaniv Yedid-Levi for their comments and suggestions. All remaining errors are mine.

Abstract

Cash holdings in the U.S. corporate sector have increased dramatically since the early 1980s. In this paper, I shed light on the causes of this phenomenon by exploring the role of the Just-in-Time (JIT) inventory system. I first demonstrate the importance of JIT in shaping corporate cash policy: the empirical estimates suggest that a 1 percentage point drop in inventory ratio is associated with a 0.67-0.73 percentage point rise in cash. I then develop a dynamic stochastic model to analyze the mechanisms through which JIT affects cash and inventory holdings 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 to ensure smooth transactions with suppliers. On average, this switchover accounts for 45% of the observed cash increase. The often-discussed explanation in previous studies is the rise in idiosyncratic risk. Compared to it, JIT accounts for a much larger share of the trend. I also use the model to evaluate the impact of JIT adoption on firm performance. I find that, on average, it increases firm value by 47% in the long run.

JEL Classification: E22; G31; G32; L60

Keywords: Cash holding; Inventory; Just-in-Time; Investment; Costly external financing.

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, 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 the observed cash increase.

[Figure 1 about here.]

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

[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, "The Myth of Corporate Cash Hoarding", by Alan Reynolds, The Wall Street Journal, February 23, 2011; "Apple Earnings: What Will It Say About Its Cash?", by Shira Ovide, The Wall Street Journal, April 20, 2011; "Companies Shun Investment, Hoard Cash", by Ben Casselman, The Wall Street Journal, September 17, 2011; "Corporate savings: dead money", The Economist, November 3, 2012.

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] 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

[2]When looking at the components of overall inventory, Chen, Frank, and Wu (2005) find that the significant 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 B. 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.

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 raising expensive external funds, the firm preserves financial flexibility by building up its cash stock (Baumol (1952)). 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, Bates, Kahle, and Stulz (2009)).[6] I use

[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.

[5]According to Richardson (1995), 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, Campbell, Lettau, and Malkiel (2001), Comin and Philippon (2005), and Irvine and Pontiff (2009).

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 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. Bates, Kahle, and Stulz (2009) 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

[7] Balakrishnan, Linsmeier, and Venkatachalam (1996) 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. Huson and Nanda (1995) and Kinney and Wempe (2002), on the contrary, find that firms adopting JIT outperform their matched non-adopters, in terms of earnings per share and profit margin.

[8] There is a number of papers examining the cash hoarding behaviour of U.S. firms. An incomplete list includes Bates, Kahle, and Stulz (2009), Morellec and Nikolov (2009), Seta (2011), Armenter and Hnatkovska (2011) and Boileau and Moyen (2010).

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 Lins, Servaes, and Tufano (2010)). 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 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.

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.

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.

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 Bates, Kahle, and Stulz (2009) 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 Bates, Kahle, and Stulz (2009) 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,

$$cash = \alpha_0 + \alpha_1\, firm\ size + \alpha_2\, risk + \alpha_3\, inventory + \alpha_4' X + \sum industry + \sum year + \sum cohort + \epsilon_1. \tag{1}$$

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 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

[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.

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 reports descriptive statistics for these variables, which have similar characteristics to those in prior studies.[10]

[Table 1 about here.]

Table 2 summarizes the estimation results of regression (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) with 4-digit SIC industry dummy variables, and firm fixed effects respectively.

[Table 2 about here.]

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 and economically significant. The coefficients of other independent variables are consistent with those estimated in Bates, Kahle, and Stulz (2009). 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

[10]See, for instance, Morellec and Nikolov (2009).

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 Bates, Kahle, and Stulz (2009).

2.3 Cash and JIT

I showed above that the inventory and cash ratios are negative 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 Kinney and Wempe (2002).[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 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.

[11] Please refer to Kinney and Wempe (2002) for the detailed sample selection and screening procedures.
[12] The description of the JIT adopter sample is provided in Appendix A.3.

[Table 3 about here.]

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,

$$inventory_{i,t} = \beta_0 + \beta_1\, D_{i,t} + \beta_2'\, X_{i,t} + \gamma_i + \sigma_t + \epsilon_{i,t}, \tag{2}$$

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 (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 (2) after controlling for other variables. The sign and significance of the coefficient estimate on JIT dummy variable remain the same.

[Table 4 about here.]

I next estimate regression (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 5. The coefficient estimate of JIT dummy is quantitatively similar to the one reported in Table 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 5 about here.]

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:

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

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.

[Table 6 about here.]

Columns (1)-(3) of Table 6 present the estimation results of regression (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.

2.3.2 The Effect of JIT on Cash

The results of regressions (2) and (3) shown in Tables 3-5 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 (2),

$$cash_{i,t} = \alpha_0 + \alpha_1 \, D_{i,t} + \alpha_2' \, X_{i,t} + \gamma_i + \sigma_t + \epsilon_{i,t}, \tag{4}$$

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), including firm size, market-to-book ratio, cash flow risk and so forth.

The results of regression (4) are reported in Columns (4)-(6) of Table 4 and 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 firms to accumulate more cash and the conclusion is robust with respect to different specifications and samples. According to Column (6) of Table 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 (3) which allows for different effects of JIT on cash in the post-adoption years,

$$cash_{i,t} = \alpha_0 + \alpha_1 \, D_{i,\, year\, 1-3} + \alpha_2 \, D_{i,\, year\, 4-6} + \alpha_3 \, D_{i,\, year\, 7-9} + \alpha_4 \, D_{i,\, year\ 10+} + \alpha_5 \, X_{i,t} + \gamma_i + \sigma_t + \epsilon_{i,t}. \tag{5}$$

The estimation results are presented in Columns (4)-(6) of Table 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.

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 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.

[Figure 2 about here.]

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 (Pinkowitz and Williamson, 2001).

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, 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.

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.

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.[13] 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 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.

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

$$F = z[\alpha k^{-\eta} + (1-\alpha)N^{-\eta}]^{-\frac{\theta}{\eta}}. \tag{6}$$

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.[14]

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

[13] See, for instance, Riddick and Whited (2009).

[14] 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.

persistency ρ and innovation ε_z,

$$\ln z' = \rho \ln z + \varepsilon'_z.$$

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, $\varepsilon_z \sim N(0, \sigma_z^2)$.

3.1.1 Capital

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

$$I = k' - (1 - \delta_k)k. \tag{7}$$

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

$$A(k, k') = \frac{\gamma_1}{2}(\frac{I}{k})^2 k. \tag{8}$$

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

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

$$s' = (1 - \delta_s)(s_1 - N), \tag{9}$$

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

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.[15] Issuing equity incurs costs. The functional form I assume is linear-quadratic:

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

where e denotes dividends distributed to shareholders and a negative e indicates equity issuance.

[15] Klapper, Laeven, and Rajan (2010), 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%.

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 Hennessy and Whited (2007), 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 Hennessy and Whited (2007) 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.

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,

$$V(z, k, c, s) = \max\{V^n(z, k, c, s), V^a(z, k, c, s)\}. \tag{10}$$

$V^n(z, k, c, s)$ 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.

3.3.1 Firm's Problem under JIC

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

$$V^n(z,k,c,s) = \max_{k',c',N}\{e_1 - g(e_1) + \beta \mathbb{E} V(z',k',c',s')\}, \tag{11}$$

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

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

$$c' \geq 0,$$

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

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

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:

$$V^a(z,k,c,s) = \max_{N,i_s,k',c'}\{e_1 - g(e_1) + \beta \mathbb{E} V(z',k',c',s')\}, \tag{12}$$

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.

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,

$$V^a(z,k,c,s) = \max_{i_s > 0} \{\phi_{e_0}[e_0 - g(e_0)] + V^n(z,k,\frac{(1-\phi_{e_0})e_0 - f}{\hat{R}}, s + i_s)\}, \tag{13}$$

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

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

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.

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.

3.4.1 Cash Holding under JIC

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

$$1 + \phi_{e_1}(\lambda_1 - \lambda_2 e_1) = \beta\hat{R} + \beta\hat{R}\mathbb{E}[\phi'_{V^a}\phi'_{e_1^a}(\lambda_1 - \lambda_2 e_1'^a)] + \beta\hat{R}\mathbb{E}[(1 - \phi'_{V^a})\phi'_{e_1^n}(\lambda_1 - \lambda_2 e_1'^n)] + \mu_1, \quad (14)$$

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 (14) 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 (14) is the Lagrange multiplier of nonnegativity constraint on cash and gives the shadow price of cash holdings.

Equation (14) 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.

3.4.2 Cash Holding under JIT

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

$$\begin{aligned} 1 + \phi_{e_1}(\lambda_1 - \lambda_2 e_1) = \beta\hat{R} + \beta\hat{R}\mathbb{E}\{\phi'_{V^a}[\phi'_{e_0^a}(\lambda_1 - \lambda_2 e_0'^a) + (1 - \phi'_{e_0^a})\phi'_{e_1^a}(\lambda_1 - \lambda_2 e_1'^a)]\} \\ + \beta\hat{R}\mathbb{E}[(1 - \phi'_{V^a})\phi'_{e_1^n}(\lambda_1 - \lambda_2 e_1'^n)] + \mu_1, \end{aligned} \tag{15}$$

where

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

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 (15) differs from equation (14) 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 (14) with equation (15) 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(15) 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.

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

$$1 + \phi_{e_1}(\lambda_1 - \lambda_2 e_1) = (1 - \delta_s)\beta\mathbb{E}\frac{\partial V'}{\partial s'}. \tag{16}$$

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

$$\phi_{e_0}[1 + \phi_{e_0}(\lambda_1 - \lambda_2 e_0)] + (1 - \phi_{e_0})[1 + \phi_{e_1}(\lambda_1 - \lambda_2 e_1)] = (1 - \delta_s)\beta\mathbb{E}\frac{\partial V'}{\partial s'} + \mu_2, \tag{17}$$

with

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

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.

3.4.4 Material Usage

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

$$[1 + \phi_{e_1}(\lambda_1 - \lambda_2 e_1)][(1 - \tau_c)F_N + \tau_c] = (1 - \delta_s)\beta\mathbb{E}\frac{\partial V'}{\partial s'} + \mu_2. \tag{18}$$

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 (18) 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.

3.4.5 Capital Investment

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

$$[1 + \phi_{e_1}(\lambda_1 - \lambda_2 e_1)][1 + A_{k'}(k, k^{'})] = \beta\mathbb{E}\{[1 + \phi^{'}_{e_1}(\lambda_1 - \lambda_2 e_1')][(1 - \tau_c)F_{k'} + \tau_c\delta_k + (1 - \delta_k) - A_{k'}(k^{'}, k^{''})]\}, \tag{19}$$

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.

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 economics 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.

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:

$$V(k,c,s) = \max_{N,i_s,k',c'} \{e_1 - g(e_1) + \beta V(k',c',(1-\delta_s)(s-N+i_s)) + \mu_1 c' + \mu_2(s-N)\}, \tag{20}$$

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

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

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

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

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 $c^* = 0$. ■

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

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

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

$$c' \geq 0,$$

$$s + i_s \geq N,$$

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

Again, the Bellman equation with multipliers can be reformulated as

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

and the corresponding Euler equations are

$$c' \;:\; 1 + \phi_{e_1}(\lambda_1 - \lambda_2 e_1) = \beta\hat{R} + \beta\hat{R}[\phi^{'}_{e_0}(\lambda_1 - \lambda_2 e^{'}_0) + (1-\phi^{'}_{e_0})\phi^{'}_{e_1}(\lambda_1 - \lambda_2 e^{'}_1)] + \mu_1,$$

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

$$i_s \;:\; 1 + \phi_{e_0}(\lambda_1 - \lambda_2 e_0) = (1-\delta_s)\beta\tfrac{\partial V'}{\partial s'} + \mu_2,$$

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

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 $c^* \to \frac{i_s^*}{\hat{R}}$. ■

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.

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.

5.1 Calibration

The time period t in my model corresponds to one year.[16] 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.

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

[Table 7 about here.]

Firm's Revenue Function. The curvature of the revenue function θ captures both return to scale in production and a firm's market power. Hennessy and Whited (2005), Hennessy and Whited (2007), Cooper and Haltiwanger (2006) and Gourio (2008) 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. Christiano (1988) 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]. Belo and Lin (2012) 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, Gilchrist and Sim (2010) and Arellano, Bai, and Kehoe (2011) estimate a serial correlation around 0.24-0.45 with the corresponding standard deviation around 0.15-0.45, while Gomes (2001), Hennessy and Whited (2005), Hennessy and Whited (2007) and Imrohoroglu and Tuzel (2011) 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 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.[17] 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.[18] 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. Hennessy and Whited (2007) 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, Nikolov and Whited (2010) 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 Nikolov and Whited (2010) but slightly higher than the one in Hennessy and Whited (2007). The quadratic equity issuance cost λ_2 is selected equal to 0.0004, following the estimate in Hennessy and Whited (2007).[19] The real risk-free rate r is set at 4%, a difference between the average annual Treasury-bill rate in the

[17] 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.

[18] 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.

[19] A firm's cash holding decision appears to be insensitive to the parameter λ_2. See also Riddick and Whited (2009).

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).[20]

Table 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 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 Christiano (1988) and Belo and Lin (2012). The inventory carrying costs amount to 32% of a firm's inventory holdings, which falls within the range estimated by Richardson (1995). 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.

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.

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

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 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 8 about here.]

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 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%.

5.2.3 Long-term Commitment Contracts with Suppliers

Walleigh (1986) 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 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.

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.

5.3 JIT Implementation 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.[21]

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 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 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.

[Table 9 about here.]

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

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.[22]

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.[23] 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 White, Pearson, and Wilson (1999). 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 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.

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

[23] 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.

After controlling for self-selection, JIT contributes 48.4% and 65.8% to the observed rise in cash and reduction in inventory.[24]

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 (Bates, Kahle, and Stulz (2009)). 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 10 about here.]

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. Comin and Philippon (2005) 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 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

[24]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).

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.[25]

My findings on cash are in line with the results found in Boileau and Moyen (2010). 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 Boileau and Moyen (2010), but distinguishes itself by specifying what the "liquidity needs" are. More importantly, my work models cash as working capital and implies that even if in the absence of uncertainty, firms would hold cash to facilitate transactions.

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 (Huson and Nanda (1995); Balakrishnan, Linsmeier, and

[25]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.

Venkatachalam (1996); Callen, Fader, and Krinsky (2000); Kinney and Wempe (2002); Fullerton, McWatters, and Fawson (2003); and Maiga and Jacobs (2009)). 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.[26] 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 11.

[Table 11 about here.]

Implementing JIT creates values to equity holders. The beneficial effect on average is a 47.4% increase in equity values. The gain mainly comes from speedy delivery which alone increases firm value by 122%. The additional inventory adjustment costs that JIT system brings about, by contrast, destroy firm value by 75.1%. Long-term contracts relax the financing frictions on firms, but barely changes the real investment decisions and therefore only improves firm performance slightly.

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

There exists large heterogeneity in the benefits from JIT adoption, with the minimum being 14.1% value increase and the maximum being 81.9% value increase. The heterogeneity of beneficial effects is related to differences with respect to firm size: Smaller firms gain more from the adoption. The model-implied correlation between firm value change and firm size equals to -0.67. Intuitively, this result is linked with the complementary of materials and capital in production and decreasing returns to scale. Implementing JIT provides firms with cheaper materials by reducing carrying costs of inventory holdings dramatically. Firms therefore scale up their operations, by using more materials and capital to produce goods. On the other hand, although gaining from production flexibility as well, decreasing returns to scale discourage large firms from further expansion.

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 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.

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Appendix

A.1 Variable Definitions

Following Bates, Kahle, and Stulz (2009), 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 (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.

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), and present results below in Tables 12 and 13.

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 12 about here.]

As shown in Table 13, 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.

[Table 13 about here.]

In addition, I show the dynamics of average cash and inventory ratios by industries in Figure 3. The constant average cash and inventory ratio prevails in most industries, except for agriculture and wholesale.

[Figure 3 about here.]

A.3 Description of the JIT-adopter Sample

Table 14 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 14 about here.]

Table 15 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 15 about here.]

B 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. 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.

B.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

$$s_1 \geq N_1,$$

$$s_2 \geq N_2,$$

$$s_1' = (1 - \delta_s)(s_1 - N_1 + i_s),$$

$$s_2' = (1 - \delta_s)(s_2 - N_2 + N_1).$$

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:

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

$$N_1 \quad : \quad \beta(1 - \delta_s)\beta\frac{\partial V'}{\partial s_2'} + \mu_2 = \beta(1 - \delta_s)\frac{\partial V'}{\partial s_1'} + \mu_1,$$

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

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

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

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

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

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

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

B.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

$$s_1' \geq N_1,$$

$$s_2' + N_1 \geq N_2,$$

$$s_1' = (1-\delta_s)(s_1 - N_1 + i_s),$$

$$s_2' = (1-\delta_s)(s_2 - N_2 + N_1).$$

The Bellman equation with multipliers can be formulated as

$$V(s_1, s_2) = \max_{i_s>0, N_1, N_2} \{N_2^\alpha - i_s + \beta V((1-\delta_s)(s_1 - N_1 + i_s), (1-\delta_s)(s_2 - N_2 + N_1)) + \mu_1(s_1 - N_1) + \mu_2(s_2 + N_1 - N_2)\}, \tag{B.2}$$

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

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

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

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

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

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 $s_2^* = 0$.

B.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 5. I then parameterize the model to quantitatively measure the magnitude of the rise in material inventory as firms implement JIT-manufacturing.

Proposition 5 *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 4 about here.]

Figure 4 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.

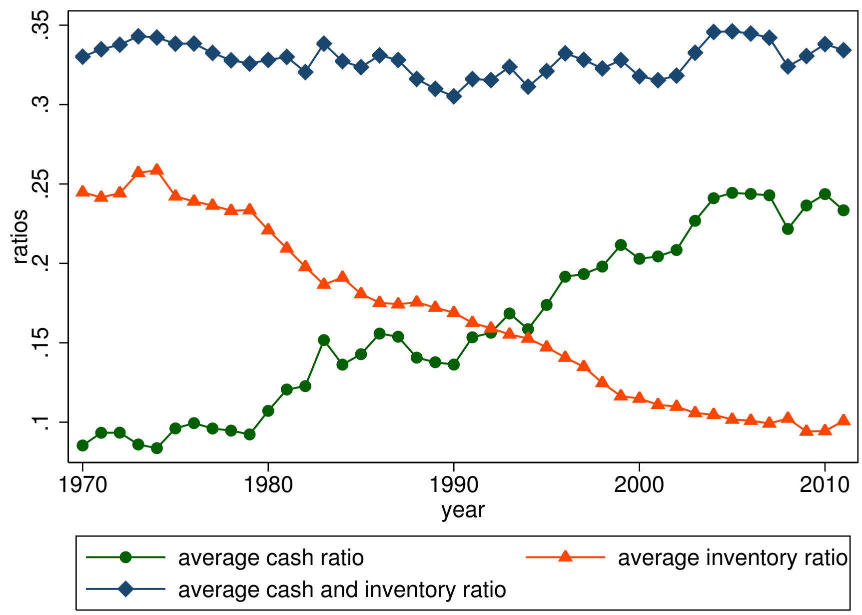

Figure 1: Average Cash and Inventory Ratio from 1970 to 2011 in the U.S.. The figure plots the average cash-to-asset ratio, average inventory-to-asset ratio and sum of those two ratios over time. The sample includes all Compustat firm-year observations from 1970 to 2011 with positive values for the book 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.

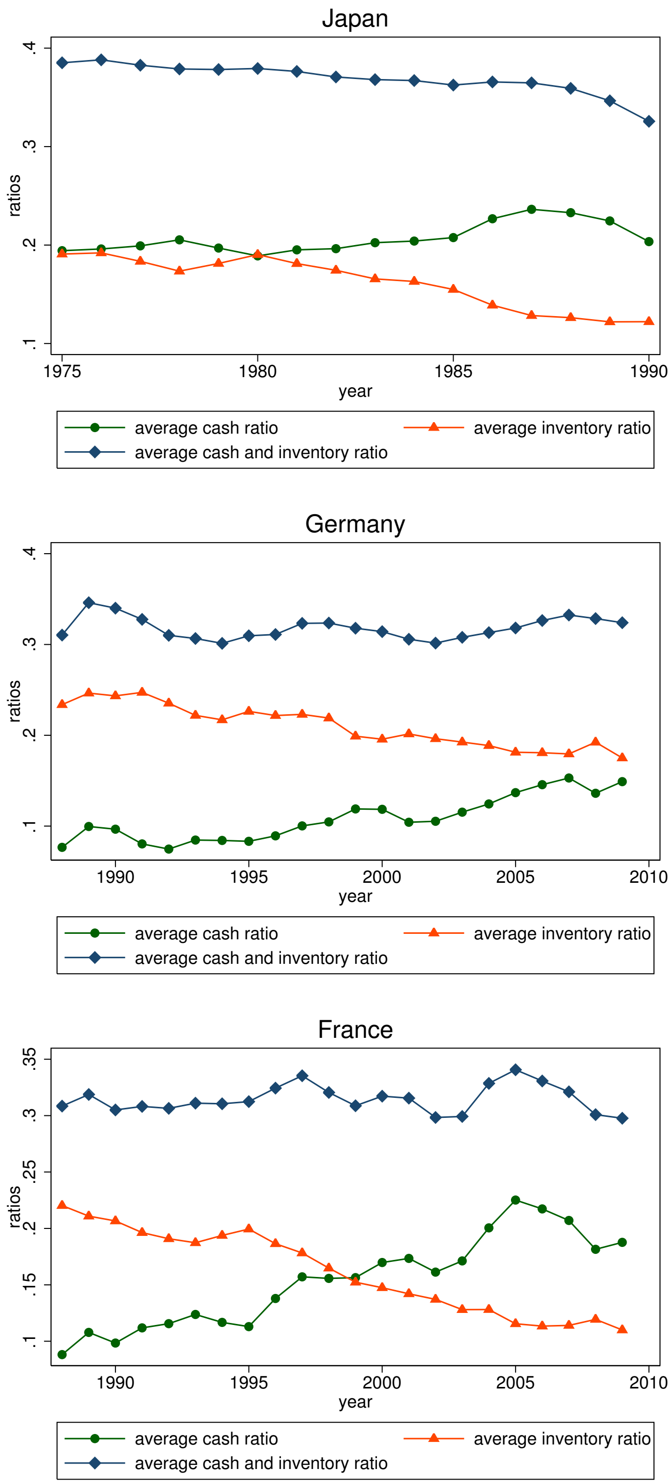

Figure 2: Average Cash and Inventory Ratios in Japan, Germany and France. The figure summarizes the average cash-to-asset ratio, average inventory-to-asset ratio and sum of those two ratios over time in Japan, Germany and France.

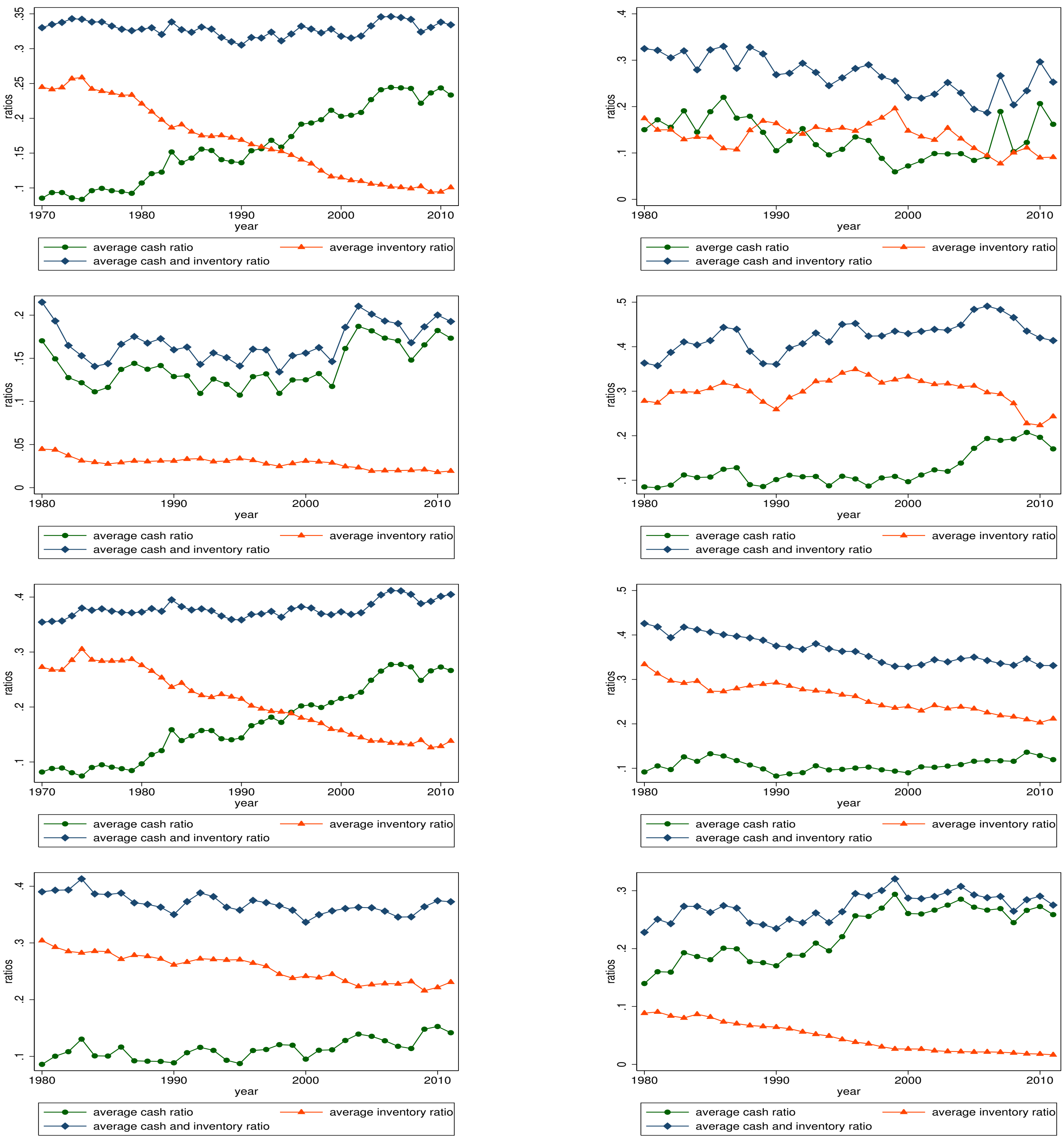

Figure 3: Average Cash and Inventory Ratios by Industries. The figure summarizes the average cash-to-asset ratio, average inventory-to-asset ratio and sum of those two ratios over time in (1) All industries; (2) Agriculture; (3) Mining; (4) Construction; (5) Manufacturing; (6) Wholesale; (7) Retail;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

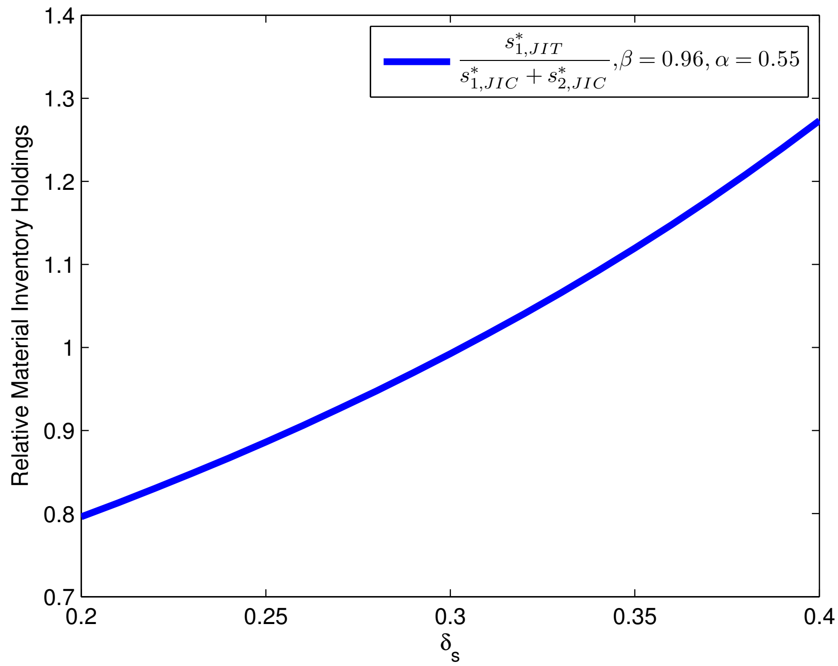

Figure 4: Relative Material Inventory Holdings after the Adoption of JIT-manufacturing. This figure plots the model-implied ratio of the steady-state material inventory holdings under JIT-manufacturing to the total input inventory holdings (both material and work-in-progress) under JIC-manufacturing. 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.

Table 1: Summary Statistics

Table 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 2: The Regression Results on Corporate Cash Holdings

Table 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			

Table 3: Summary Statistics for 169 JIT Adopters

Table 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

Table 4: The Effect of JIT Adoption on Corporate Inventory and Cash (Annual)

Table 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

Table 5: The Effect of JIT Adoption on Corporate Inventory and Cash (Quarterly)

Table 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

Table 6: The Effect of JIT Adoption on Corporate Inventory and Cash (Quarterly)

Table 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

Table 7: Model Parameterizations

Table 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 ($i_k/(k+c+s)$)	Data	JIC
average investment	0.076	0.082
variance of investment	0.001	0.003

Table 8: Implications under the JIT System

Table 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

Table 9: The Role of JIT Adoption 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**

Table 10: JIT-based Explanation vs. Risk-based Explanation for Corporate Cash Hoarding

Table 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 Explanation (JIT)	Risk-based Explanation (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

Table 11: JIT Adoption and Changes in Firm Value

Table 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 Inventory Adjustment Costs	46.9%	13.3%	81.7%	-0.66
Long-term Contracts	47.4%	14.1%	81.9%	-0.67

Table 12: The Regression Results on Corporate Cash Holdings in Wholesale and Retail

Table 12 reports the estimation results of Regression (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

Table 13: The Regression Results on Corporate Cash Holdings in Services

Table 13 reports the estimation results of Regression (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

Table 14: 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%

Table 15: 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%