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

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Abstract

I explore the role of the Just-in-Time (JIT) inventory system in the increase of cash holdings among U.S. manufacturing firms. I first demonstrate the empirical importance of JIT in shaping cash policy. I then develop a model to analyze the mechanism through which JIT affects cash and quantify its impact. In the model, both cash and inventory can serve as working capital. As firms switch from the traditional system to JIT, they shift resources from inventory to cash to facilitate transactions with suppliers. On average, this switchover accounts for over half of the observed increase in cash.

JEL Classification: E22; G31; G32; L60

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

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1 Introduction

The build-up of cash reserves among U.S. businesses has captured considerable attention from academic researchers, policy makers and financial practitioners over the past few years, and was 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) within firms. This paper aims to understand the causes behind the rise of cash holdings in the U.S. manufacturing sector.[2]

In this paper, I propose an explanation motivated by the simultaneous changes in cash and inventory in the data. As shown in Figure 1, among publicly traded U.S. manufacturing firms, the average cash-to-asset ratio increased from 8.6% in the 1970s to 26.6% in 2011, and the inventory-to-asset ratio decreased from 28.2% to 13.8%. Despite the striking changes in both, the sum of these two ratios was relatively stable over the entire 30-year period. The substantial reduction in inventory is most commonly attributed to the widespread adoption of the Just-in-Time (JIT) inventory system since the early 1980s (see Chen et al. (2005)). 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.

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 the inventory ratio is related to a 0.73 percentage point rise in the cash ratio. Second, using a sample of JIT adopters and their counterparts, I show that

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

[2] I focus on the manufacturing sector because the cash increase starting from 1980 observed at the aggregate level is possibly mainly driven by movements in manufacturing, as shown in Figure A1 in Appendix A.1. In other sectors, cash started rising at much later dates.

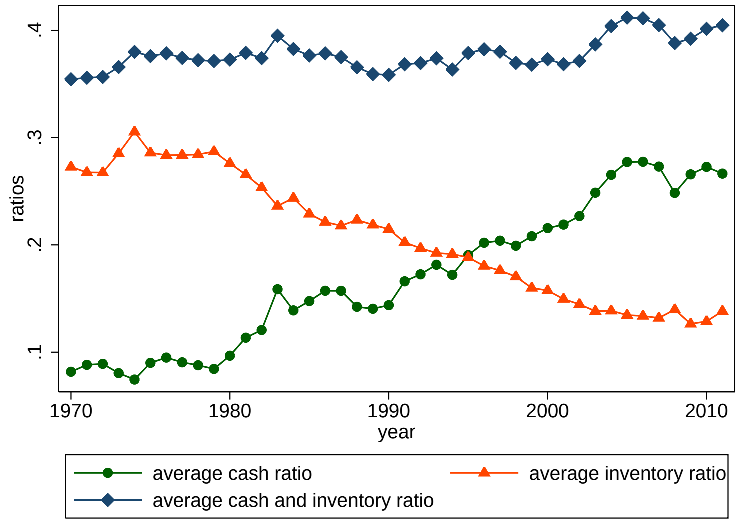

Figure 1: **Average Cash and Inventory Ratios from 1970 to 2011 in U.S. Manufacturing.** The figure plots the average cash-to-asset ratio, average inventory-to-asset ratio and sum of those two ratios over time. The sample includes all Compustat firm-year observations from 1970 to 2011 with positive total assets and sales for U.S. manufacturing firms. Both cash and inventory ratios are winsorized between zero and one.

implementing JIT leads firms to progressively accumulate cash.

After demonstrating the importance of JIT in explaining the increase in cash holdings, I develop a model to explore the channel through which JIT implementation impacts cash and inventory and quantify its effects. To keep the model tractable, I focus on input inventory only.[3] 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.[4]

More specifically, in each period, the firm makes decisions on inventory adjustment, material input use, capital investment, cash savings and dividend distributions. It faces productivity uncertainty and capital market frictions. It is also required to pay upon receipt of materials ordered. The firm chooses between two systems of inventory manage-

[3]Among the components of overall inventory, 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 (WIP) inventory (see Chen et al. (2005)). Accordingly, it is reasonable to model input inventory only.

[4]In the model, I assume that both material inventory and WIP inventory are inputs purchased from suppliers and JIT is narrowly defined as JIT-purchasing. In reality, WIP inventory is produced within firms due to production inefficiency. However, the model can be extended by treating material inventory and WIP inventory separately, and the results remain unchanged. I illustrate and prove this statement in Appendix A.4.

ment: the traditional Just-in-Case (JIC) system 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 do not arrive until current-period production completes. 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. With JIT, the firm adjusts inventory holdings with full information about the state of the economy and receives new purchases before current-period production starts. Therefore, under the JIT system, the stockout motive for holding inventory is absent.

How does JIT influence a firm's cash policy? Under JIT, the firm needs to pay for input purchases before current-period production starts (or equivalently, before current-period sales revenues are received). The firm therefore has only two channels to finance its input purchases: internal cash balance and costly external financing. 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 14.1 percentage points, while the inventory ratio will decline by 12.2 percentage points. Given that two-thirds of U.S. manufacturers adopted JIT by 2008,[6] this suggests that the average cash and inventory ratios will change by 9.5 and 8.1 percentage points respectively. That is, 64% of the observed cash increase and 75% of the inventory reduction in manufacturing are attributable to the JIT adoption. Results are quantitatively similar after controlling for self-selection bias.

[5] According to Richardson (1995), taking into account service costs, storage costs and risk costs, inventory carrying costs are 19%-43% of total inventory values.

[6] See the report *Physical Risks to the Supply Chain* provided by CFO Research Services.

Previous studies typically view the increase in firms' idiosyncratic risk as the main driver behind the cash increase (see, for example, Bates et al. (2009)).[7] I use my model to investigate whether this explanation is sufficiently strong to quantitatively account for the trend. I find that firms would raise their cash ratios by 2.5 percentage points if risk doubled. Accordingly, the precautionary motive associated with the increase in idiosyncratic risk can account for only 26% of the increase in corporate cash holdings. By contrast, the transaction motive related to JIT adoption can account for 64% of the increase in cash.

This paper fits into three broad strands of literature. First, it helps to understand the reasons behind the significant rise in corporate cash holdings over the past thirty years.[8] It explores the role of JIT and finds that it can explain over half of the trend in average cash movements in the U.S. manufacturing sector. While Bates et al. (2009) also highlight the change in inventory holdings as an important factor in understanding cash hoarding, they neither estimate its effects nor explore the mechanism underlying 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 the corporate cash literature by modelling cash as a source of working capital. There are a number of structural cash models focusing on the non-operational use of cash. In those studies, cash is modelled as a precautionary hedge against future uncertainty. In my model, cash serves two motives: non-operational use (precautionary savings) and operational use (working capital). When operating under the JIT system, firms hold cash not only to finance future capital investment, but also to purchase production inputs and facilitate operations. This is consistent with survey

[7] The rise in the average firm-level risk is well documented in the literature. See for example, Campbell et al. (2001), Comin and Philippon (2005), and Irvine and Pontiff (2009).

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

evidence that a large portion of corporate cash savings is held for operational purposes (see Lins et al. (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 links JIT with cash management, despite abundant evidence showing that JIT is an efficient approach to reduce inventory. How do firms allocate resources released from inventory after switching to JIT? My model suggests that firms choose to augment their cash stocks to maintain smooth operations.

The remainder of the paper is organized as follows. Section 2 provides empirical evidence that JIT implementation plays a role in affecting corporate cash policy. Section 3 presents 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. Section 6 concludes.

2 Empirical Evidence

In this section, I use firm-level data to present empirical evidence regarding the effect of JIT on firms' cash management. I start by estimating the negative correlation between inventory and cash holdings. This in turn helps to infer the impact of JIT on cash balance, given its role in reducing inventory. I then focus on a sample of JIT adopters to directly investigate the difference between their pre-adoption and post-adoption cash saving behavior.

2.1 Just-in-Time (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 (JIT purchasing) and the production stage (JIT manufacturing). 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 Toyota 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. According to the report *Physical Risks to the Supply Chain* provided by CFO Research Services, nearly two-thirds of U.S. firms had implemented JIT inventory practices by 2008.

Prior to the introduction of JIT, U.S. firms employed the Just-in-Case (JIC) system. They held buffer stocks at every stage in the production process in order to meet unexpected demand fluctuations.

2.2 Cash and Inventory

Motivated by the time-series patterns of the cash and inventory ratios illustrated in Figure 1, the first question I address is the relationship between cash and inventory, after controlling for other factors that affect cash holdings.

To answer this question, I use the baseline cash regression in Bates et al. (2009) and make three changes to it. First, I separate inventory from net working capital 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 variation to identify the effect of risk on cash. Lastly, I include cohort dummies which are constructed based on firms' IPO listing dates and time dummies. The cohort fixed effects are motivated by the fact that more recently listed companies hold more cash than older cohorts (Bates et al. (2009)), and the year fixed effects are used to capture the common macroeconomic shocks across firms. The cash regression is therefore specified as follows,

$$cash_{i,t} = \alpha_0 + \alpha_1\, firm\ size_{i,t} + \alpha_2\, risk_{i,t} + \alpha_3\, inventory_{i,t} + \alpha_4' X_{i,t}$$

$$+ \sum industry + \sum year + \sum cohort + \epsilon_{i,t}. \tag{1}$$

In this regression equation, cash is the ratio of cash and short-term investments to total assets; firm size is defined as the natural logarithm of total assets; risk is computed as the standard deviation of the ratio of the annual operating cash flow to total assets for the previous five periods; and inventory is measured as the ratio of inventory to total assets. Other explanatory variables, X, include market-to-book ratio, firm's operating cash flow, working capital net of cash and inventory, capital investment, and so forth. A detailed description of these covariates is provided in the Appendix A.2.

The sample is constructed from the Compustat Fundamentals Annual files, constituting an unbalanced panel of manufacturing firms (SIC 2000-3999) that covers 1980 to 2006.[9] To control for outliers in the sample, I delete firms with negative total assets or negative sales, and winsorize continuous variables. Leverage, cash, and inventory ratios are winsorized between zero and one. R&D, acquisition and capital investment ratios are winsorized at the top and bottom 1%. Cash flow ratio and net working capital are winsorized at the bottom 1%, and market-to-book ratio is winsorized at the top 1%. Table 1 reports the descriptive statistics for these variables, which have similar

[9] I use a pre-crisis sample to ensure that estimation results are not driven by the Great Recession.

characteristics to those in previous studies.[10]

Table 1: **Summary Statistics**
Table 1 presents the descriptive statistics for the variables used in the estimation. The sample is constructed from Compustat Fundamentals Annual files over the period 1980-2006. A detailed definition of variables is provided in Appendix A.2.

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 summarizes the estimation results of regression model (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 equation (1) with 4-digit SIC industry dummy variables and firm fixed effects respectively.

The variable of particular interest here is the inventory ratio. According to Column (1), a 1 percentage point decrease in inventory is correlated with a 0.69 percentage point increase in a firm's cash holdings, which is statistically and economically significant. The coefficients of other independent variables are consistent with those estimated in Bates et al. (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

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

Table 2: **The Regression Results on Corporate Cash Holdings**
Table 2 reports the estimation results of the cash regression (1) on firms' characteristics. Industry, cohort and year fixed effects are included in the regressions. The heteroskedasticity-consistent standard errors reported in parentheses 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) Fixed Effect	(4) Fixed Effect
Inventory	**-0.6928*****	**-0.6894*****	**-0.7417*****	**-0.7299*****
	(0.0210)	(0.0201)	(0.0137)	(0.0134)
Size	-0.0101***	-0.0107***		-0.0059***
	(0.0008)	(0.0012)		(0.0018)
Market-to-book	0.0067***	0.0067***		0.0047***
	(0.0008)	(0.0008)		(0.0006)
Risk	0.0627**	0.0604***		0.0589***
	(0.0114)	(0.0111)		(0.0089)
Cash flow	0.0361***	0.0333***		0.0174***
	(0.0058)	(0.0056)		(0.0047)
Net working capital	-0.0096	-0.0077		-0.0340***
	(0.0067)	(0.0067)		(0.0052)
Capital investment	-0.7484***	-0.7330***		-0.4033***
	(0.0305)	(0.0307)		(0.0183)
Leverage	-0.2497***	-0.2409***		-0.1908***
	(0.0105)	(0.0105)		(0.0068)
R&D	0.1397***	0.1160***		-0.1160***
	(0.0185)	(0.0182)		(0.0139)
Dividend	-0.0291***	-0.0253***		0.0077***
	(0.0047)	(0.0045)		(0.0025)
Acquisition	-0.3894***	-0.3767***		-0.2571***
	(0.0190)	(0.0189)		(0.0124)
Industry FE (3-digit)	Yes			
Industry FE (4-digit)		Yes		
Firm FE			Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Cohort dummy	Yes	Yes		
Observations	32,939	32,939	32,939	32,939
R-squared	0.572	0.585	0.770	0.799

and regression methodologies. In particular, the coefficient of the inventory ratio varies within a fairly narrow interval [-0.69,-0.74].[11]

[11] In addition to changes in inventory, Bates et al. (2009) also link the rise in cash with increasing R&D spending. I estimate the conditional correlation between cash and inventory for both high and low R&D firms. Interestingly, the negative correlation is stronger for high R&D group relative to the low one, -0.83 vs. -0.6.

2.3 Cash and JIT

I showed above that the inventory and cash ratios are highly negatively correlated. Given the role of JIT 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 cash holdings by employing a difference-in-differences (DID) approach.

The JIT adopter sample is based on Kinney and Wempe (2002).[12] Of the 201 adopters, 14 firms are no longer available in Compustat; of the remaining 187 firms, I drop 18 non-manufacturing firms. My final sample therefore includes 169 JIT adopters.[13] I then pool these adopters with other manufacturing firms (non-adopters) from Compustat Fundamentals Annual and extract financial data for each firm.

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,

$$inventory_{i,t} = \beta_0 + \beta_1\, JIT_{i,t} + \beta_2'\, X_{i,t} + \gamma_i + \sigma_{t\in T, i\in I} + \epsilon_{i,t}. \tag{2}$$

Here, inventory is the ratio of inventory to total assets. Dummy variable $JIT_{i,t}$ takes the value one if firm i at time t implements JIT and zero otherwise. The control variables, $X_{i,t}$, are similar to those included in the cash regression, and γ_i and $\sigma_{t\in T,i\in I}$ are firm fixed effects and industry-specific year fixed effects respectively. I identify β_1, the average effect of JIT on inventory holdings, by assuming that (i) all the unobserved heterogeneity that leads to the correlation between JIT adoption and the error term is captured by firm fixed effects, and that (ii) variation of the dependent variable due to

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

changes in the macroeconomic environment are captured by industry-specific year fixed effects, which are common to firms in both the treated and the control groups within the same industry.

I estimate regression model (2) with a sample constructed from Compustat Fundamentals 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.[14] The corresponding results are reported in Columns (1)-(2) of Panel A in Table 3.[15] On average, JIT implementation leads firms to reduce inventory by 3.65 percentage points, according to Column (2) which controls a list of other explanatory variables, $X_{i,t}$, aside from JIT adoption.

Model (2) assumes that the effects of JIT on inventory are the same over time. Considering the fact that JIT implementation is a long-term process, I also estimate the following specification to allow for heterogeneous effects of JIT during the post-adoption period.[16]

$$inventory_{i,t} = \beta_0 + \beta_1\, JIT_{i,\,year\,1\,to\,3} + \beta_2\, JIT_{i,\,year\,4\,to\,6} + \beta_3\, JIT_{i,\,year\,7\,to\,9}$$

$$+\beta_4\, JIT_{i,\,year\;10+} + \beta_5'\, X_{i,t} + \gamma_i + \sigma_{t\in T, i\in I} + \epsilon_{i,t}, \tag{3}$$

where $JIT_{i,\,year\,t_1\,to\,t_2}$ is a dummy variable, taking the value one if firm i operates in the JIT system during the post-adoption period t_1 to t_2 and zero otherwise. The coefficient of the dummy variable $JIT_{i,\,year\,t_1\,to\,t_2}$ 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. The estimation results are presented

[14]Estimating regression model (2) with Compustat Fundamentals Annual gives similar results, which are available upon request.

[15]Full estimation results for Tables 3 are available upon request.

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

Table 3: **Effects of JIT on Inventory and Cash Holdings (Quarterly)**

Table 3 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, capital investment, leverage, R&D, dividend payment and acquisition. Firm fixed effects and year fixed effects are included in the regressions, and the heteroskedasticity-consistent standard errors are reported in parentheses. Significance levels are indicated by *, **, and *** for 10%, 5%, and 1%, respectively. The sample is constructed from Compustat Fundamentals Quarterly, covering the period 1980Q1-2006Q4.

	(1)	(2)	(3)	(4)
	Panel A: Constant Post-adoption Effect			
	inventory	inventory	cash	cash
JIT-adoption	**-0.0448*****	**-0.0365*****	**0.0201*****	**0.0298*****
	(0.0012)	(0.0074)	(0.0016)	(0.0102)
X		Yes		Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE × Industry FE (2-digit)	Yes	Yes	Yes	Yes
Observations	311,735	46,756	311,735	46,756
Adj R-squared	0.730	0.800	0.698	0.782
	Panel B: Heterogeneous Post-Adoption Effects			
	inventory	inventory	cash	cash
$\mathbf{JIT_{year1\ to\ 3}}$	-0.0327***	**-0.0208*****	0.0108***	**0.0172****
	(0.0015)	(0.0052)	(0.0019)	(0.0073)
$\mathbf{JIT_{year4\ to\ 6}}$	-0.0398***	**-0.0291*****	0.0082***	**0.0223*****
	(0.0014)	(0.0055)	(0.0020)	(0.0083)
$\mathbf{JIT_{year7\ to\ 9}}$	-0.0458***	**-0.0362*****	0.0153***	**0.0251*****
	(0.0015)	(0.0057)	(0.0021)	(0.0081)
$\mathbf{JIT_{year10+}}$	-0.0529***	**-0.0470*****	0.0373***	**0.0607*****
	(0.0014)	(0.0058)	(0.0021)	(0.0086)
X		Yes		Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE × Industry FE (2-digit)	Yes	Yes	Yes	Yes
Observations	311,735	46,756	311,735	46,756
Adj R-squared	0.733	0.800	0.682	0.782
	Panel C: First-difference Approach			
	Δ inventory$_{t-(t-12)}$	Δ inventory$_{t-(t-24)}$	Δ cash$_{t-(t-12)}$	Δ cash$_{t-(t-24)}$
ΔJIT	**-0.0286*****	**-0.0483*****	**0.0294****	**0.0435*****
	(0.0080)	(0.0106)	(0.0132)	(0.0155)
ΔX	Yes	Yes	Yes	Yes
Year FE × Industry FE (2-digit)	Yes	Yes	Yes	Yes
Observations	20,575	12,072	20,575	12,072
R-squared	0.078	0.099	0.109	0.129

in Columns (1)-(2) of Panel B in Table 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 3.27 percentage points, while the reduction in inventory amounts to 5.29 percentage points after ten years' adoption. The same declining pattern of inventory, with similar magnitude, is found in Column (2) after controlling for other variables.

Regression models (2) and (3) estimate the effect of JIT with firm fixed effects. As a robustness check, I next use the first-difference specification to estimate it,

$$\Delta inventory_{i,\,t-t_1} = \beta_0 + \beta_1\, \Delta JIT_{i,\,t-t_1} + \beta_2'\, \Delta X_{i,\,t-t_1} + \sigma_{t\in T, i\in I} + \Delta\epsilon_{i,\,t-t_1}. \quad (4)$$

The variable $\Delta JIT_{i,\,t-t_1}$ is the change in the dummy variable JIT (whether implement JIT or not) for firm i between period t and period t_1. I consider both twelve-quarter (i.e. three-year) and twenty-four-quarter (i.e. six-year) time lags and report results in Panel C of Table 3.

The estimation results confirm the findings in Panel A and Panel B. They suggest that firms gradually reduce their inventory holdings after switching to JIT, from 2.86 percentage points after three-year implementation to 4.83 percentage points after six-year implementation.

2.3.2 The Effect of JIT on Cash

The regressions of models (2)-(4) validate the JIT-adopter sample. In this subsection, I use the sample to analyze how JIT adoption affects cash holdings.

The first specification I consider is analogous to the regression equation (2),

$$cash_{i,t} = \alpha_0 + \alpha_1\, JIT_{i,t} + \alpha_2'\, X_{i,t} + \gamma_i + \sigma_{t\in T, i\in I} + \epsilon_{i,t}, \quad (5)$$

where the coefficient estimate on the dummy variable $JIT_{i,t}$ is of particular interest. 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, etc.

Columns (3)-(4) of Panel A in Table 3 report the results. The coefficient estimate of the dummy variable $JIT_{i,t}$ is positive and statistically significant in both cases, suggesting that implementing JIT leads firms to accumulate more cash. According to Column (4), on average, adopting the JIT system induces firms to raise their cash ratio by 2.98 percentage points. To interpret the magnitude of this effect, a 10 percentage point decline in inventory corresponds to a 8.2 percentage point increase in cash. JIT adoption therefore plays a significant role in affecting corporate cash holdings.

Next, I consider the following specification which is a counterpart of regression equation (3) and allows for different effects of JIT on cash holdings in the post-adoption periods,

$$cash_{i,t} = \alpha_0 + \alpha_1\ JIT_{i,\,year\,1-3} + \alpha_2\ JIT_{i,\,year\,4-6} + \alpha_3\ JIT_{i,\,year\,7-9}$$

$$+\alpha_4\ JIT_{i,\,year\ 10+} + \alpha_5'\ X_{i,t} + \gamma_i + \sigma_{t\in T, i\in I} + \epsilon_{i,t}. \tag{6}$$

The estimation results are presented in Columns (3)-(4) of Panel B in Table 3. The coefficients on JIT dummies are all positive, statistically significant and show an increasing trend, which suggest that after implementing JIT, firms build up their cash reserves gradually over time. According to Column (4), they increase cash by 1.72 percentage points within the first three years and this number climbs up to 6.07 percentage points after ten years, which is of economic significance.

Also examined is the first-difference specification,

$$\Delta cash_{i,\,t\,-\,t_1} = \alpha_0 + \alpha_1\ \Delta JIT_{i,\,t\,-\,t_1} + \alpha_2'\ \Delta X_{i,\,t\,-\,t_1} + \sigma_{t\in T, i\ni I} + \Delta\epsilon_{i,\,t\,-\,t_1}. \tag{7}$$

The regression results reported in Panel C of Table 3 again support the hypothesis that JIT implementation leads to a gradual accumulation of cash holdings within firms.

The above regression equations (5)-(7) focus on the major source of the endogeneity of JIT-adoption and tackle the issue by controlling for the time-invariant unobserved firm heterogeneity. To account for possible self-selection which would induce contemporaneous correlation between the adoption decision and the error term, I next employ the Heckman selection model and estimate the impact of JIT using the maximum likelihood method:

$$\Delta cash_{i,\,t-t_1} = \alpha_0 + \alpha_1\,\Delta JIT_{i,\,t-t_1} + \alpha_2'\,\Delta X_{i,\,t-t_1} + \sigma_{t\in T, i\in I} + \Delta\epsilon_{i,\,t-t_1},$$

$$\Delta JIT^*_{i,\,t-t_1} = \omega' Z_{i,t_1-1} + \upsilon_{i,t},$$

$$\Delta JIT = 1, \text{ if } \Delta JIT^* > 0; \;\; \Delta JIT = 0, \text{ if otherwise.} \tag{8}$$

The outcome equation is the same as the first-difference specification (7) and I consider six-year time lags. In the selection equation, the variable ΔJIT^* indicates the propensity of a firm implementing JIT, and Z is a vector of independent variables used to predict the adoption decision.

The variables Z included in the selection equation are the average firm size seven years ago, the firm risk seven years ago, the average number of days' sales in inventory (defined as the inventory-to-sales ratio multiplied by 365) seven years ago, and their first differences. The reasons for the choice of these variables as the factors driving the adoption decision are as follows. Larger firms have greater resources to rely on and therefore are more likely to be able to afford JIT. Firms with relatively stable sales and in turn low risks can ensure efficient capital utilization rates. They benefit more from JIT and thereby have higher incentives to adopt the new system. Firms who actively manage their inventory are also inclined to adopt JIT to further improve efficiency.

As these multi-period lagged variables, Z_{t_1-1}, are persistent, they may have direct effects on the dependent variable $\Delta cash_{i,t-t_1}$ in the outcome equation. However, the inclusion of those variables in successive periods, $\Delta X_{i,t-t_1}$, in the outcome equation helps to resolve the concern. For example, $size_{t_1}$ in the outcome equation contains the information of $size_{t_1-1}$ and therefore absorbs the direct effect of $size_{t_1-1}$ on $\Delta cash_{i,t-t_1}$. That is, conditional on $\Delta X_{i,t-t_1}$, Z_{t_1-1} only affects cash holdings through JIT implementation. The identification of the treatment effect relies on both the exclusion restriction and the non-linearity of the propensity of adopting JIT.

Table 4: **Effects of JIT (Quarterly): The Treatment Regression**

Table 4 reports the estimation results of the cash regression using the Heckman selection model. Column (1) reports the first-stage probit regression with the JIT-adoption dummy as the dependent variable. Column (2) reports the outcome regression of cash holdings on the first differences in firms' characteristics which include firm size, risk, market-to-book, cash flow, net working capital, and other commonly-used control variables. Year fixed effects are included in the regressions, and the heteroskedasticity-consistent standard errors are reported in parentheses. Significance levels are indicated by *, **, and *** for 10%, 5%, and 1%, respectively. The sample is constructed from Compustat Fundamentals Quarterly, covering the period 1980Q1-2006Q4.

Variables	(1) Δ JIT$_{t-(t-24)}$		(2) Δ cash$_{t-(t-24)}$
Size$_{\overline{(t-25)\ to\ (t-28)}}$	0.1023***	**ΔJIT**$_{t-(t-24)}$	**0.3580***
	(0.0222)		(0.0250)
Risk$_{t-25}$	-24.89***	Δ Size$_{t-(t-24)}$	0.0095***
	(9.90)		(0.0030)
Days sales in inventory$_{\overline{(t-25)\ to\ (t-28)}}$	-0.0002**	Δ Market-to-book$_{t-(t-24)}$	0.0082***
	(0.0001)		(0.0009)
Δ Size$_{(t-25)-(t-26)}$	-0.8134***	Δ Risk$_{t-(t-24)}$	0.2705***
	(0.2867)		(0.0869)
Δ Risk$_{(t-25)-(t-26)}$	24.20***	Δ Cash flow$_{t-(t-24)}$	-0.0534
	(8.52)		(0.0347)
Δ Days sales in inventory$_{(t-25)-(t-26)}$	0.00003	Δ Net working capital$_{t-(t-24)}$	-0.0239***
	(0.0003)		(0.0078)
Constant	-2.737***	Δ Capital investment$_{t-(t-24)}$	-0.0871**
	(0.1271)		(0.0416)
		Δ Leverage$_{t-(t-24)}$	-0.2225***
			(0.0111)
		Δ R&D$_{t-(t-24)}$	-0.5827***
			(0.0697)
		Δ Dividend dummy$_{t-(t-24)}$	0.0172***
			(0.0048)
		Δ Acquisition$_{t-(t-24)}$	-0.2835***
			(0.0575)
		Year FE $\times$ Industry FE (2-digit)	Yes
Correlation ρ			$\rho=-0.6618$***
Observations			10,769

Table 4 exhibits the estimation results of regression model (8), with Column (1) showing the results of the selection equation and Column (2) reporting the results of the outcome equation. The variables chosen to predict the selection process have the expected effects on the adoption decision. The coefficients of those variables are statistically significant, except for the first-differenced days' sales in inventory. After taking into account the time-varying unobserved heterogeneity across firms, the coefficient on JIT adoption is again positive and significant at the 1% level.[17]

[17]The effect of JIT estimated here is much larger than that reported in Table 3, 35.8% vs. 4.35%. This is possibly because the effect estimated in regression euqation (8) is the local average treatment effect, reflecting the effect on the firm whose adoption decision is affected by the variables included in the selection equation.

Note that the impact of JIT on cash holdings that I find in this section is the lower bound of the true impact. The firms included in the sample as non-adopters may or may not use JIT in reality. If some 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 Discussion

In summary, in this section I demonstrate the importance of JIT adoption in understanding the substantial rise in corporate cash holdings. I first estimate a cash regression to show that the increase in cash holdings is highly associated with inventory reduction. Then employing a Difference-in-Differences (DID) analysis with a sample of JIT adopters and non-adopters, I find that firms gradually adjust inventory downwards and cash upwards after they implement JIT. Results are robust when using a first-difference specification and allowing for time-varying unobserved firm heterogeneity.

The empirical evidence supports the hypothesis that JIT implementation is an important driver behind the cash increase found in the data. It also suggests that we observe a steady rise in the average cash ratio over time, rather than a one-time shift, because (i) there is a gradual increase in the adoption rate as shown in Table A2 (Appendix A.3), and (ii) firms gradually accumulate their cash holdings after switching over to JIT.

Caution is needed due to the small sample size of JIT adopters. To cope with this potential concern, I next turn to a structural model to estimate the effect of JIT on cash holdings. In addition, with a structural model, I can analyse the mechanisms through which JIT affects corporate cash holdings.

3 Model

This section presents a partial equilibrium problem of a firm that faces uncertainty and financing frictions. I introduce inventory into an otherwise standard neoclassical model of capital investment and cash accumulation by modelling raw materials as factors of production.[18] The lag in delivery of 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 materials in anticipation of future demand and to maintain inventory as buffers to meet uncertainty. 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.

3.1 Technology

Consider a discrete time model of an infinitely-lived firm. The firm combines 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 the revenue function, $F(z, k, N)$, specified by a constant elasticity of substitution(CES) function

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

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 weights of capital and material in revenue function; and η reflects the elasticity of substitution

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

between these two inputs.[19,20]

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

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

$$I = k' - (1 - \delta_k)k.$$

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

$$A(k, k') = \gamma_0 k \mathbf{1}_{I \neq 0} + \frac{\gamma_1}{2}(\frac{I}{k})^2 k.$$

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

[19]See also Christiano (1988) and Belo and Lin (2012).

[20]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.

3.1.2 Inventory

In every period, the firm must decide whether or not to adjust its material stock s based on the current state. Adjusting the material stock incurs an adjustment cost, which consists of a fixed part f_0 and a linear part f_1. The firm has two options: either pay the adjustment cost and purchase i_s units of materials; or do not make an adjustment this period. The fixed adjustment cost f_0 considered in this model consists of part of the delivery and ordering costs which the firm incurs irrespective of the size of material purchases. The linear adjustment cost f_1 includes delivery cost and the labor costs associated with unloading and internal handling, which are in proportion to purchase size. The speed of material delivery depends on the inventory system adopted.

In each period, after uncertainty is realized, the firm makes the inventory adjustment decision, and chooses how much material, N, to use for producing goods. Under JIC, new purchased materials arrive after production. Therefore, whether the firm decides to adjust its inventory stock or not, the decision on N is constrained by the material stock s at the beginning of period, $N < s$.

By contrast, under JIT, new material orders get delivered before production starts. If the firm decides to make the adjustment, the material available for current-period production becomes $s_1 = s + i_s$. Alternatively, the firm can avoid the cost and enter production with its initial stock $s_1 = s$.

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

$$s' = (1 - \delta_s)(s_1 - N),$$

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

3.2 Financing

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

The 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 ensure the existence of an upper bound on cash holdings (see Riddick and Whited (2009)).

External financing can take the form of equity issuance, debt financing, line of credit from banks, and/or short-term credit from suppliers in the case of purchasing materials.[21] Financing externally incurs costs. I assume a linear-quadratic functional form for the cost:

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

where e denotes dividends distributed to shareholders and a negative e indicates external borrowing. The indicator function ϕ_e equals zero if 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 has no fixed cost. The quadratic term is kept for capturing the effect of debt financing and 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. The difference 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 for financing capital investment, including operating cash flows, cash balance and

[21] Klapper et al. (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 being 54%.

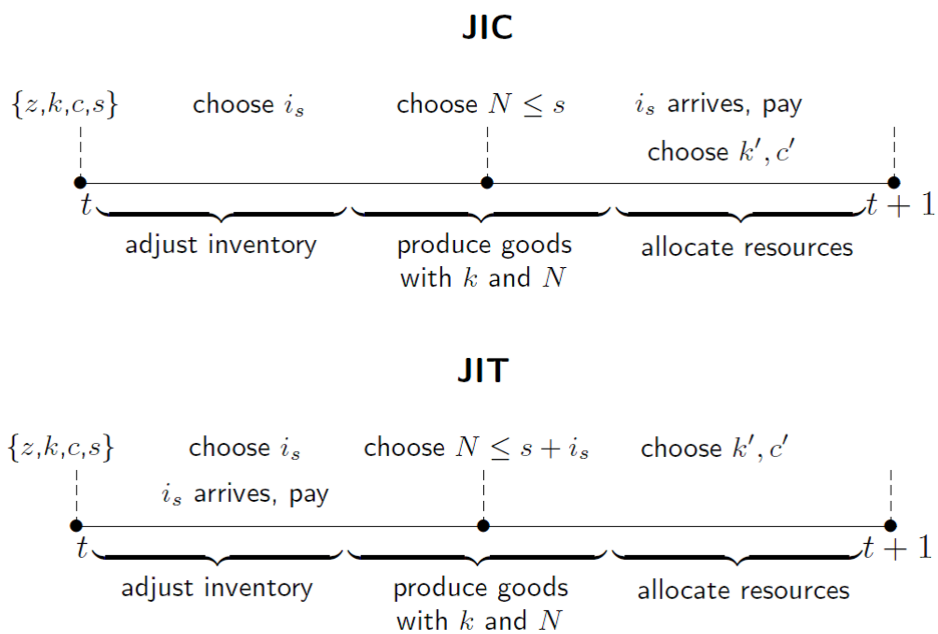

Figure 2: **Timeline for the Model**

external funds. For JIT, however, cash flows generated from current-period production are unavailable for purchasing materials, because the payment has to be made before production begins.

3.3 Firm's Problem

The timeline for the model — under both JIC and JIT environments— is illustrated in Figure 2. At the beginning of period t, after observing the shock realization z, the firm decides whether or not to adjust its inventory s by ordering more materials i_s. The firm then produces goods using capital and materials on hand. The firm also decides how to spend the current-period cash flow from sales. The key difference between JIC and JIT lies in the timing of the delivery and payment of material orders conditional on adjusting inventory. I assume payment upon receipt and model JIT as immediate delivery of material orders. As such, under JIT, there is no shipping lag and the firm is required to pay for its ordered materials before production.

3.3.1 Firm's Problem under JIC

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

$$V(z,k,c,s) = \max\{V^n(z,k,c,s), V^a(z,k,c,s)\}. \tag{9}$$

$V^n(z,k,c,s)$ denotes the firm's value with no action, and $V^a(z,k,c,s)$ is the value with inventory adjustment, as a function of shock z, beginning-of-period capital stock k, cash balance c and inventory s.

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

$$V^n(z,k,c,s) = \max_{N \le s, k', c' \ge 0} \{e_1 - g(e_1) + \beta \mathbb{E} V(z',k',c',s')\},$$

$$e_1 = \underbrace{F(z,k,N) - \tau_c[F(z,k,N) - \delta_k k - N]}_{\text{after-tax profit}} - \underbrace{(c' - \hat{R}c)}_{\text{cash saving}} - \underbrace{[k' + A(k',k) - (1-\delta_k)k]}_{\text{capital investment}},$$

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

where $\beta = \frac{1}{1+r}$ and $\hat{R} = 1 + r(1-\tau_c)$. After the shock is realized, the firm makes its decision on how much material to use in producing goods, but constrained by the quantity available in stock. The remaining material is stored as inventory. It depreciates and is transferred to the next period. The firm also decides how much to invest in capital and how much to save in cash, with a non-negative cash balance constraint. If current period after-tax cash inflow is insufficient to fund capital investment and cash saving, the firm borrows externally and pays costs; otherwise, 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 much new material, i_s, to purchase as well. With everything else the same, the firm's problem is modified as follows:

$$V^a(z,k,c,s) = \max_{i_s, N \leq s, k', c' \geq 0} \{e_1 - g(e_1) + \beta \mathbb{E} V(z',k',c',s')\},$$

where

$$e_1 = F(z,k,N) - \tau_c[F(z,k,N) - \delta_k k - N] - (c' - \hat{R}c) - [k' + A(k',k) - (1-\delta_k)k] - \underbrace{[f_0 + (1+f_1)i_s]}_{\text{material purchase}},$$

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

The firm makes the inventory adjustment decision before production. However, the delivery lag leads to the unavailability of the newly-purchased material for current production, $N \leq s$, and the timing of the payment makes the current-period cash flow available for funding material transactions. Therefore, the adjustment decision prior to the production is equivalent to the case of post-production adjustment.

3.3.2 Firm's Problem under JIT

As above, the firm must choose between adjusting and not adjusting inventory. In the case of inaction, the firm's problem is the same as the analogous problem under JIC. However, contingent on adjusting inventory, the problems that the firm faces under JIT and JIC are different as a result of different shipping speeds.

Under the JIT system, the firm's problem can be viewed in two stages. In the first stage, after shock realization but before production, the firm makes a choice on material purchase i_s. With the newly-purchased and immediately-delivered materials, the firm enters the second stage in which it decides material usage and chooses the best way to allocate resources among capital, cash and dividends. The second stage problem is the same as the non-adjustment case, but with different levels of cash and inventory holdings. The firm's problem is:

$$V^a(z,k,c,s) = \max_{i_s>0}\{\underbrace{\phi_{e_0}[e_0 - g(e_0)]}_{\text{first stage}} + \underbrace{V^n(z,k,\frac{(1-\phi_{e_0})e_0}{\hat{R}}, s+i_s)}_{\text{second stage}}\},$$

$$e_0 = \hat{R}c - f_0 - (1+f_1)i_s,$$

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

Here $e_0 = \hat{R}c - f_0 - (1+f_1)i_s$ reflects the first stage transaction. The firm pays for materials out of its internal cash balance. If internal cash is insufficient to cover the expenses ($\phi_{e_0} = 1$), the firm resorts to external borrowing, pays borrowing costs and enters the second stage with zero cash. Otherwise, the remaining cash in the first stage is carried forward into the second stage. The material available for the second stage is the sum of the initial stock and the new purchase, $s + i_s$. With the new cash and inventory stocks, the firm solves a problem similar to the inaction problem in the second stage.

4 Simplified Model with Analytical Solution

To illustrate the main idea behind the substitution between cash and inventory, in this section I present a simplified model that yields closed form solutions for optimal cash and inventory holdings.

I simplify the problem presented in Section 3 by assuming that there are no inventory adjustment costs (i.e. $f_0 = 0$ and $f_1 = 0$) and no uncertainty (i.e. $\rho = 0$ and $\sigma_z = 0$). I show analytically that adopting JIT leads firms to reallocate resources from inventory to cash.

4.1 Steady State under JIC

Without inventory adjustment costs, the firm will adjust its inventory stock in each period, and the firm's problem is reduced to the adjustment case only. I restate the firm's problem under JIC as follows,

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

where

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

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

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

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

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

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

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

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

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 environment,* $s^* = N^* = (1-\delta_s)i_s^* > 0$.

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 $i_s^* > 0$. 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 environment,* $c^* = 0$.

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 the tax penalty on cash savings, $1 > \beta\hat{R}$, therefore $c^* = 0$. ■

4.2 Steady State under JIT

The firm's problem under JIT is rewritten as

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

where

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

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

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

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

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

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

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

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

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 inventory and cash are zero and positive, respectively.

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

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 environment,* $c^* \rightarrow \frac{i_s^*}{\hat{R}} = \frac{N^*}{\hat{R}} > 0$ *if external financing is expensive relative to internal funds* ($\lambda_1 \geq r$)*.*

Proof. The proof is by assuming the contrary. First, in the steady state the firm does not borrow externally in 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 in the first stage and therefore the firm has to use external finance, $\phi_{e_0}^* > 0$. Substituting both $\phi_{e_0}^* > 0$ and $\phi_{e_1}^* = 0$ into the 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 the assumption $c^* = 0$ in the steady state, and therefore $c^* > 0$.

To determine the optimal cash holding, I next suppose that $c^* > 0$ 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 holding 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 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 flow to finance investments. Therefore, the firm has no incentive to save cash. On the other hand, inventory under this system functions as working capital, and is not adjustable before next period production. Anticipating the level of material use, 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 is zero. This is because JIT allows the firm to flexibly adjust its inventory stock before organizing production in each period. Hence, the firm no longer has a motive to store inventory which is very costly. Instead, the firm chooses to transfer the 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 provides intuition on how implementing JIT drives the substitution between cash and inventory.

5 Quantitative Analysis

This section reports numerical results of the dynamic stochastic model built in Section 3. I begin by calibrating the JIC environment with a sample of manufacturing firms from the Compustat Fundamentals Annual files in 1980. The year for calibration is picked to ensure that the JIT system was unavailable in the U.S. and therefore all firms implemented the JIC system during that year. I then parameterize the JIT environment with the same set of values and assess the impact of adopting JIT (a change in the delivery lag) on firms' cash policy and inventory management. I also use my model as a laboratory to study how important financing frictions are for understanding cash holdings by performing counterfactual experiments. Lastly, I use the model to compare the performance of this JIT-based explanation with the risk-based explanation highlighted in previous cash hoarding studies.

5.1 Calibration

The time period t in my model corresponds to one quarter. I aggregate the quarterly quantity variables to the annual frequency. I calibrate the parameter values in the JIC environment to match firm-level and aggregate-level annual moments in 1980, or choose the values that are standard in the literature whenever possible. The calibration strategy is discussed below.

Firm's Revenue Function. The curvature of the revenue function θ captures both returns to scale in production and a firm's market power. Cooper and Haltiwanger (2006), Hennessy and Whited (2007), Gourio (2008), and Nikolov and Whited (2010) estimate the parameter to be 0.59, 0.63, 0.64, and 0.90, respectively. I set it to be 0.75, the mid-value 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

Table 5: **Model Parameterizations**

Table 5 summarizes the parameters used to solve the model at the quarterly frequency. Panel A reports the parameters specifying revenue function and governing revenue shocks, the parameters characterizing the evolvement of physical capital and inventory stock, the parameters describing a firm's external financing conditions, corporate income tax rate and interest rate. Panel B presents calibration results by matching three JIC-model moments to data moments in 1980.

Panel A: **Assigned Parameters**	
Technology and Shock Process	
curvature (θ)	0.75
elasticity of substitution between capital and material ($\frac{1}{1+\eta}$)	0.33
standard deviation of shock (σ_z)	0.10
persistency of shock (ρ)	0.89
Capital and Inventory	
linear capital adjustment cost (γ_0)	0.039
quadratic capital adjustment cost (γ_1)	0.7
capital depreciation rate (δ_k)	0.03
linear inventory adjustment cost (f_1)	0.039
Financing	
linear costs of external finance (λ_1)	0.025
quadratic costs of external finance (λ_2)	0.0004
risk-free rate (r)	0.01
corporate income tax (τ_c)	0.46
Panel B: **Calibrated Parameters**	
capital share (α)	0.93
fixed inventory adjustment cost (f_0)	0.117
inventory depreciation rate (δ_s)	0.05

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. In subsection 5.7, I check the robustness of my main results with respect to these two parameters. 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, 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 and shock specifications, I choose the quarterly persistency of the shock at $\rho = 0.89$ and its standard deviation $\sigma = 0.10$, corresponding to the annual persistency at 0.7 and standard deviation 0.15.

Capital Adjustment. I follow Cooper and Haltiwanger (2006) to set the linear capital adjustment cost $\gamma_0 = 0.039$. 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 3% per quarter.

Inventory Adjustment. The parameters governing the inventory dynamics are the fixed adjustment cost f_0, the linear adjustment cost f_1 and the inventory depreciation rate δ_s. I assume that the linear inventory adjustment cost is fully symmetric to the linear capital adjustment cost and set $f_1 = 0.039$. I calibrate the other two parameters f_0 and δ_s together with the capital-share parameter α by matching the average cash to asset ratio, average inventory to asset ratio and average beginning-of-period capital to sales ratio in 1980 with Compustat manufacturing firms.[22,23] The first target, the average cash to asset ratio, is informative about the fixed costs f_0. 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 inventory carrying cost which is captured by depreciation rate δ_s. The last moment, the average beginning-of-period capital to sales ratio, provides information on the share parameter α, given the elasticity of substitution between capital and material and the curvature of revenue function.

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

[23]Given the theoretical setup in which I only focus on input inventory, I calibrate the model to match average input inventory to asset ratio.

Financing, Corporate Income Tax and Interest Rate. Nikolov and Whited (2010) estimate the linear cost of external borrowing to be approximately within the range [0.13,0.18]. I set the parameter λ_1 to be 0.025, which corresponds to an annual rate lower than the estimates in Nikolov and Whited (2010). The quadratic cost of external financing λ_2 is selected equal to 0.0004, following the estimate in Hennessy and Whited (2007).[24] The real risk-free rate r at quarterly frequency is set at 1%, a difference between the average Treasury-bill rate in the early 1980s and the average inflation rate in the same period. This corresponds with the discount factor $\beta = 0.99$. The corporate income tax τ_c is set at 46%, the top statutory rate in 1980 according to the corporation income tax brackets and rates reported by Internal Revenue Service (IRS).[25]

Table 5 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 inventory holdings. The last set characterizes the firm's external financing conditions, corporate income tax rate and interest rate.

Panel B of Table 5 reports the calibration results. The estimated capital share α is 0.93, a value between those suggested in Christiano (1988) and Belo and Lin (2012). The inventory carrying costs amount to 5% of a firm's inventory holdings per quarter, which falls within the range estimated by Richardson (1995). The fixed inventory adjustment cost f_0 is required to be 0.117. The value is approximately equivalent to 5% of average quarterly revenue.

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

[25] During 1980-1986, a tax rate of 46% is applied on the corporate income bracket over $100,000.

5.2 Simulated Moments under JIC

I simulate the JIC economy for 5050 quarters, drop the first 50 observations to limit the effect of the initial condition, and then construct the annual quantity from the quarterly.

Table 6 reports the simulated moments from the JIC environment. Panel A shows the selected moments used for calibration. Panel B presents non-targeted moments for cash saving, inventory investment, capital investment and external financing.[26]

Table 6: **Moments under the JIC System**
Table 6 reports the simulated moments from the JIC environment. Panel A shows the moments used for calibration. Panel B presents non-targeted moments for cash, inventory, capital and external financing.

Moments	Data (1980)	JIC
Panel A: Moments Used for Calibration		
average capital to revenue ($k_{t-1}/F_t(z,k,N)$)	0.55	0.55
average cash ratio ($c_t/(k_t+c_t+s_t)$)	0.098	0.097
average inventory ratio ($s_t/(k_t+c_t+s_t)$)	0.193	0.200
Panel B: Other Moments		
(i) cash saving ($\Delta c_t/sales_t$)		
standard deviation	0.09	0.10
correlation with sales	-0.01	-0.03
(ii) inventory investment ($\Delta s_t/sales_t$)		
standard deviation	0.05	0.07
correlation with sales	0.24	0.08
(iii) capital investment ($I_{k,t}/sales_t$)		
average ratio ($I_{k,t}/at_t$)	0.076	0.075
standard deviation	0.11	0.15
correlation with sales	0.12	0.56
(iv) external financing		
average ratio (e_t/at_t when $e_t<0$)	0.027	0.013
standard deviation ($e_t/sales_t$ when $e_t<0$)	0.05	0.03

Overall, the model performs very well in matching data moments. The calibration targets the average capital to revenue ratio, average cash to asset ratio and average inventory to asset ratio. These model moments match their data counterparts almost exactly.

[26] External financing includes both debt and equity issuance. It is constructed as the sum of the sale of common and preferred stock (item *sstk*) and the issuance of long-term debt (item *dltis*) net of its reduction (item *dltr*) from the data. I drop the first five observations since the IPO year for each firm to remove the IPO effects on external financing.

Many of the non-targeted moments from the model are also quantitatively similar to the corresponding data moments. The within-firm standard deviations of cash saving, inventory investment and capital investment to revenue implied by the model are very close to those in the data. The model-implied correlations of cash saving, inventory investment and capital investment with sales are also qualitatively consistent with the data, although relatively, the model-implied inventory investment is less correlated with sales while the model-implied capital investment is more highly correlated with sales.

The model also has implications for the properties of external financing. Relative to the data, the external borrowing ratio conditional on financing externally is slightly lower, accounting for 1.3% of total assets, and less volatile, with a standard deviation of 0.03.

5.3 Quantifying the Impact of JIT

In this subsection, I examine the quantitative implications of the JIT model to see whether it has the potential to explain the cash hoarding phenomenon. To estimate the effect of JIT, I set all parameters in the JIT environment to their values in the JIC environment. The results are reported in the column (2) of Table 7.

Under JIT, firms on average have a cash-asset ratio of 23.8%, compared to 9.7% under JIC. This result suggests that if all firms in the economy switched their system from JIC to JIT, they would increase their cash ratio by 14.1 percentage points, or hold cash balance roughly 2.5 times as large as that in the JIC environment. In addition, unlike under JIC, cash saving under JIT is positively correlated with sales, in line with the correlation observed in the data. This change reflects the replacement of inventory by cash as working capital when firms switch over to JIT.

My model also explains the decline in inventory. It predicts that firms on average have inventory ratios of 7.8% in the post-adoption period, which is a 12% reduction relative to the 20% inventory ratio under the JIC system. The reason for the low but non-zero

Table 7: **Implications under the JIT System**

Table 7 presents data moments during 2000-2006 and model moments for two JIT economies with different degrees of financial friction. Panel A summarizes the parameter values used in each economy. In Panel B, Column (1) reports the data moments computed based on a sample of manufacturing firms over the period 2000-2006 from Compustat. Column (2) reports the simulated moments generated in the benchmark JIT model. Column (3) reports the simulated moments under the JIT environment with lower borrowing costs.

	(1) Data (2000-2006)	(2) JIT	(3) JIT with lower borrowing costs
Panel A: Parameters			
linear costs of external finance (λ_1)		0.025	**0.0088**
Panel B: Moments			
(i) cash			
average cash ratio (c_t/at_t)	0.246	**0.238**	**0.097**
std. dev. of cash saving ($\Delta c_t/sales_t$)	0.08	0.13	0.09
corr. with sales ($\Delta c_t/sales_t$)	0.04	0.05	0.10
(ii) inventory			
average inventory ratio (s_t/at_t)	0.085	**0.078**	0.100
std. dev. of inventory investment ($\Delta s_t/sales_t$)	0.04	0.08	0.08
corr. with sales ($\Delta s_t/sales_t$)	0.13	0.08	0.08
(iii) capital investment			
average investment ratio ($I_{k,t}/at_t$)	0.059	0.075	0.085
std. dev. of capital investment ($I_{k,t}/sales_t$)	0.12	0.16	0.17
corr. with sales ($I_{k,t}/sales_t$)	0.08	0.57	0.58
(iv) external financing			
average external financing (e_t/at_t)	0.078	0.018	0.296
std. dev. ($e_t/sales_t$)	0.17	0.05	0.13

inventory holdings is the existence of fixed inventory adjustment costs. Although the stockout motive for inventory holdings is absent under JIT, to economize on the fixed costs, firms choose to carry some level of inventory forward instead of replenishing the stock before production at the beginning of each period.

The simulated capital investment ratio slightly overshoots its data counterpart, 7.5% vs. 5.9%. 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 reduced their capital investment.

As for the external financing, the magnitude and variation generated in the model are smaller than those in the data. One potential explanation for those differences is that firms' access to external finance has become easier and cheaper over time.

Note that given many factors that possibly affect firms' real and financial decisions have been changing over the last three decades, I do not expect the JIT model to provide a perfect reproduction of the data moments observed in the 2000s. However, Table 7 shows that JIT performs reasonably well, and suggests that keeping all other factors constant, the marginal effects of JIT on cash and inventory ratios are a 14.1% increase and a 12.2% decrease, respectively.

5.4 The Importance of Financial Frictions on Cash Hoarding

In the previous subsection, I quantify the marginal effect of JIT on cash holdings. I next run an experiment by relaxing financial frictions and examine how low the external borrowing costs are required to be in order to offset the full impact of JIT on cash increase.

I recalibrate the linear cost of external finance λ_1 in the JIT environment, such that the firm holds the same level of cash ratio as under JIC. All other parameter values remain the same as those in the JIT economy. The results are summarized in the column (3) of Table 7.

According to Table 7, to neutralize the effect of JIT on cash, the borrowing cost needs to be reduced from 2.5% per quarter to 0.88% per quarter. The relaxed financial friction lowers the value of financial flexibility provided by internal cash and encourages firms to resort to external financing. It results in a drop in the average cash ratio by 14.1 percentage points and an increase in the external financing ratio from 1.8% to 29.6%. In the meanwhile, it drives up the volatility of external financing, but dampens the variation in cash saving.

Moreover, cheaper external financing leads firms to invest more in inventory and physical capital. Compared to the benchmark *JIT* economy, the average inventory and capital investment ratios rise by 2.2 percentage points and 1 percentage point, respectively. But the related second moments do not change much.

In summary, financial frictions generate the coexistence of external borrowing and cash saving, and the intensity of financial frictions is an important factor in understanding the composition of sources of funds (internal vs. external) for expenses.

5.5 JIT and the Rise in Corporate Cash

In section 5.3, I estimate the marginal effect of JIT on cash holdings. The next step is to quantify the fraction of the cash increase observed in the data that is attributed to 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* by CFO Research Services, nearly two-thirds of manufacturing firms had implemented JIT by 2008.

5.5.1 A Weighted-average Approach

I assume that shifting from JIC to JIT requires a one-time fixed cost and that the switchover is irreversible. The one-period fixed cost is heterogenous among firms and stochastic. In 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 19.2% ($\frac{1}{3} \times 9.7\% + \frac{2}{3} \times 23.8\%$) and 11.9% ($\frac{1}{3} \times 20\% + \frac{2}{3} \times 7.8\%$), respectively.

Table 8 summarizes the results, with Panel A reporting the data moments and Panel B reporting the model counterparts. In the data, the average cash ratio has increased by 14.8 percentage points since 1980, from 9.8% to 24.6%. During the same period, the average inventory ratio has decreased by 10.8 percentage points, from 19.3% to 8.5%. Panel B suggests that the implementation of JIT can explain a large share of the observed cash and inventory changes, 64% of the cash increase and 75% of the input inventory reduction.

Table 8: **The Role of JIT in Explaining the Rise in Corporate Cash**
Table 8 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 2000-2006, as well as the changes of cash and inventory ratios between those two periods. In Panel B, Column (1) reports the simulated moments generated under the JIC environment. Column (2) considers an economy in which two-thirds of the firms implement JIT, and adjusts the results with a weighted-average approach. Column (3) computes the difference between Column (2) 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 (2000-2006)	Change
Average cash	9.8%	24.6%	14.8%
Average inventory	19.3%	8.5%	-10.8%
Panel B: **Weighted-Average**	(1)	(2)	(3)
	JIC	Adjusted Results	Change
Average cash	9.7%	19.2%	**9.5**%
Average inventory	20.0%	11.9%	**-8.1**%
Panel C: **Self-Selection**	(1)	(2)	(3)
	JIC	Adjusted Results	Change
Average cash	9.5%	17.8%	**8.3**%
Average inventory	19.8%	11.3%	**-8.5**%

5.5.2 Controlling for Self-selection

In the above subsection, I assume 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-time fixed cost, C, is identical to all firms and modelling the adoption decision to control for the induced self-selection bias.

In 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 a decision on JIT implementation. 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.[27]

Assessing the contribution of JIT requires information on the one-time adoption cost C. I set $C = 7.39$ such that two-thirds of firms become JIT users within 112 periods (i.e. 28 years) after firms are allowed to choose between JIC and JIT.[28,29] Among those adopters, a large portion are large firms who can more easily afford the costs of adoption. This model implication is consistent with the empirical findings suggested in White et al. (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 column (2) in Panel C of Table 8. Those moments are computed using the simulated data in the 28^{th} year since JIT becomes available. After controlling for self-selection, JIT contributes 56% and 78% of the observed rise in cash and reduction in inventory.

5.6 Comparison with Risk-based Explanation

In the previous subsections, I investigate whether JIT is related to the 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 et al. (2009)). I then conduct a comparison between the risk-based explanation (precautionary motive for cash savings) and the one I propose in this paper (transaction motive).

To this end, I reset the standard deviation σ under JIC to 0.20 (equivalent to 0.30 at the annual frequency), and keep all other parameters the same as their values in the

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

[28] I calibrate C to match the adoption rate in the data. More specifically, I simulate a sample of 3000 firms for 212 periods, by starting from the same initial state $\{z_1, k_1, c_1, s_1\}$ and drawing 3000 sequences of revenue shocks ε_z from the same distribution $N(0, \sigma_z^2)$. For the first 100 periods (i.e. 25 years), all firms are restricted to operating under JIC. From the period 101, firms are allowed to select between JIC and JIT. Once they switch over, firms operate under JIT permanently. Prospective adopters make adoption decisions in each period.

[29] The lump sum cost $C = 7.39$ is equivalent to 120% of the average total asset under JIC. This number can measure both the direct costs of system adoption and the indirect costs of adapting to the new system.

Table 9: **JIT-based vs. Risk-based Explanations for Cash Hoarding**
Table 9 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 2000-2006	JIT-based Explanation (JIT)	Risk-based Explanation (JIC)
Panel A: Parameters			
standard deviation of shock (σ)		0.10	0.20
Panel B: Moments			
(i) cash (c_t/at_t)			
mean	0.246	**0.238**	**0.122**
standard deviation	0.09	0.10	0.18
(ii) inventory (s_t/at_t)			
mean	0.085	**0.078**	**0.152**
standard deviation	0.03	0.08	0.12

benchmark JIC.[30] Results are reported in the last column of Table 9.

In the JIC economy with a doubled risk, firms have an average cash ratio of 12.2%, raising the ratio by 2.5 percentage points from the JIC-benchmark case. Relative to JIT-implementation, 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 savings 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 (use of funds). The firm therefore has a low incentive to save. 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: The standard deviations of cash and inventory ratios overshoot their data counterparts by a factor of 2 and 4 respectively.

My findings on cash are in line with the results found in Boileau and Moyen (2010).

[30] 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 standard deviation of sales growth measured with the sample used in this paper increased from 0.26 in the 1980s to 0.32 in the post-2000 period, and the risk measure used in this paper went 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 of the shock twice as large as the value used in the JIC benchmark.

They focus on a risk-based explanation. They consider two possible channels through which risk affects cash holdings, by modelling 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). This paper reaches the same conclusion, but extends the understanding of what the "liquidity needs" are. It models cash as working capital and implies that even in the absence of uncertainty, firms would hold cash to facilitate transactions.

5.7 Robustness

In this subsection, I evaluate the robustness of the main results to different parameterizations by considering the curvature of revenue function (θ) and the elasticity of substitution between capital and materials ($\frac{1}{1+\eta}$).

I change one parameter at a time, holding other pre-determined parameters at the values in Table 5. I then re-calibrate capital share (α), fixed inventory adjustment costs (f_0) and inventory depreciation rate (δ_s) in the JIC environment to match target moments. With the alternative calibrations, I re-examine model predictions on cash and inventory ratios in the JIT environment. Results are reported in Table 10.

The fourth column presents the results for the case of $\theta = 0.7$. As the revenue function becomes more concave, firms respond by raising less cash when they switch from JIC to JIT. This result occurs for the following reason. Implementing JIT provides firms with cheaper materials by reducing carrying costs of inventory holdings, firms therefore scale up their operations by using more materials and capital to produce goods. However, a drop in θ discourages firms from further expansion, and the cash required to purchase materials is therefore lower.

The fifth column shows that the change in the average cash ratio increases with the degree of substitutability between capital and materials. This effect arises because cheaper materials, as a result of using JIT, lead firms to (i) increase production (using

Table 10: **Robustness**

Table 10 summarizes model moments under different parameterizations: (i) benchmark case, (ii) $\theta = 0.7$ and (iii) $\eta = 1$. Panel A presents target moments under JIC, and Panel B reports simulated moments under JIT.

	Data (1980)	Benchmark $\theta = 0.75$, $\eta = 2$	$\theta = 0.7$	$\eta = 1$
Panel A: **Targets under JIC**				
average capital to revenue	0.55	0.55	0.55	0.55
average cash ratio	0.098	0.097	0.098	0.099
average inventory ratio	0.193	0.200	0.189	0.194
Panel B: **Predictions under JIT**	Data (2000-2006)			
(i) cash				
average cash ratio	0.246	**0.238**	**0.213**	**0.265**
std. dev. of cash saving	0.08	0.13	0.13	0.13
(ii) inventory				
average inventory ratio	0.085	**0.078**	**0.088**	**0.065**
std. dev. of inventory investment	0.04	0.08	0.09	0.08
(iii) capital investment				
average investment ratio	0.059	0.075	0.067	0.062
std.dev. of capital investment	0.12	0.16	0.13	0.15

more materials and capital) and (ii) substitute away from capital into materials. As the degree of substitution rises (η drops), firms increase their material usage even more, which further drives up the average material order size. To facilitate the purchase, firms need more cash.

Overall, the results exhibit robustness. That is, the model predicts quantitatively similar changes in the average cash and inventory ratios once firms switchover from JIC to JIT, despite different parameterizations. This validates the power of JIT inventory systems in explaining the rise in cash balances.

6 Conclusion

In the past three decades, the U.S. manufacturing sector has gradually shifted resources from inventory to cash. In this paper, I propose an explanation— the implementation of JIT inventory system — to understand the observed high substitution rate between cash and inventory, and in turn to shed light on 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 64% of the cash increase and 75% 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 over half of the accumulated cash can be rationalized as a normal and positive investment.

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A Appendix

A.1 Corporate Cash Holdings by Sector

Figure A1 plots the dynamics of the average cash and inventory ratios in different sectors. The increase in the average cash ratio at the aggregate level (all non-financial and non-utility industries) has begun since 1980. The same pattern is only found in manufacturing, with other sectors either starting accumulating cash at much later dates or not experiencing a cash increase at all. In addition, the constant average cash and inventory ratio prevails in most sectors, except for agriculture and wholesale.

A.2 Variable Definitions

Following Bates et al. (2009), I construct the sample from Compustat and define the variables used in the cash and inventory regressions as follows:

Cash is defined as the ratio of cash and short-term investments over total assets;

Inventory is the ratio of total inventories over total assets;

Firm size is the natural logarithm of total assets;

Risk is computed as the standard deviation of operating cash flow to asset ratio in the past five periods, with operating **cash flow** defined as earnings after interest, dividends and tax but before depreciation;

Market-to-book ratio is the sum of market value and debt over total assets;

Net working capital is equal to working capital net of cash and inventory over total assets;

Capital investment is the ratio of capital expenditure over total assets;

Leverage is the sum of long-term debt and debt in current liabilities normalized by total assets;

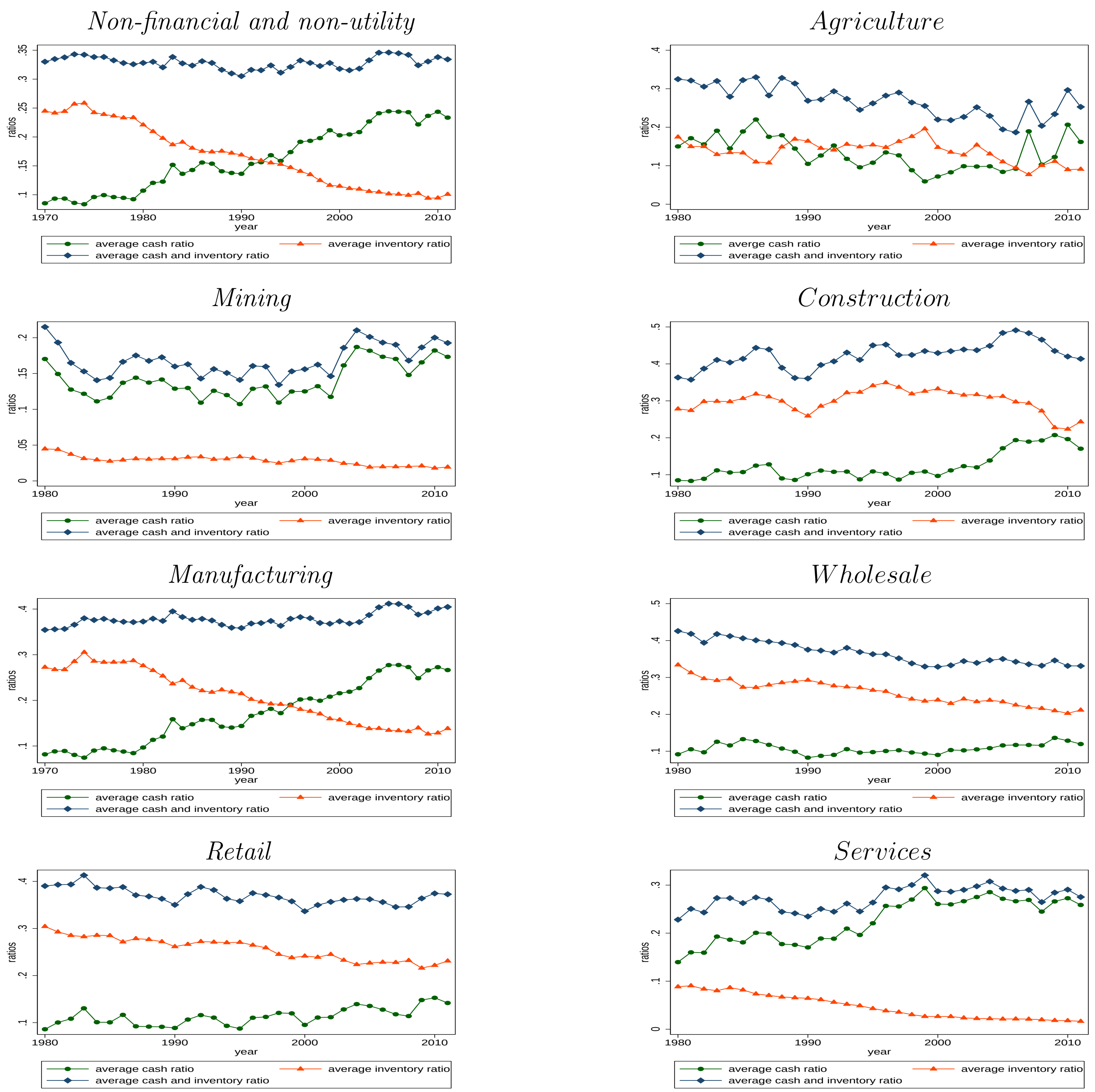

Figure A1: **Average Cash and Inventory Ratios by Sector.** This figure summarizes the average cash-to-asset ratio, average inventory-to-asset ratio and sum of those two ratios over time in (1) All non-financial and non-utility industries; (2) Agriculture; (3) Mining; (4) Construction; (5) Manufacturing; (6) Wholesale; (7) Retail; (8) Services. The sample is constructed from Compustat Fundamentals Annual files.

R&D investment is the ratio of research and development expenses to total assets;

Dividend is a dummy variable taking a value of one if dividend payout (common) is non-zero;

Acquisition is the ratio of acquisition over total asset.

Capital investment (Quarterly) is the ratio of capital expenditure over total asset, with capital expenditure defined as the first difference in gross property, plant and equipment.

Days' sales in inventory is the ratio of inventory over sales multiplied by 365 days.

A.3 Description of the JIT-adopter Sample

Table A1 presents the summary statistics for the relevant variables of the adopters. Relative to an 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.

Table A1: **Summary Statistics for 169 JIT Adopters**

Table A1 presents the descriptive statistics for a sample of 169 JIT adopters. The sample covers the period 1980-2006.

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	0.02	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 A2 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.

Table A2: **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 A3 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.

A.4 WIP Inventory and JIT manufacturing

In Section 3 of the paper, I assume that firms purchase both material and work-in-process (WIP) inventory from suppliers and defining JIT narrowly as JIT purchasing. In reality, WIP inventory is produced within firms due to production inefficiency. 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 WIP inventory to material inventory. As such, once firms adopt

Table A3: **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%

JIT (both purchasing and manufacturing), all input inventory (both material and WIP) will be converted into cash holdings.

I model JIC manufacturing and JIT manufacturing as follows. Firms use linear technology, $G_1(N_1) = N_1$, to transform materials into WIP products which are then used to produce final goods with technology $G_2(N_2) = N_2^{\alpha}$ with $0 < \alpha < 1$. The production process is inefficient in the JIC environment, in the sense that newly generated WIP products from materials cannot be converted into final goods immediately. To smooth operations, firms hold both material inventory s_1 and WIP inventory s_2 as working capital. Both types depreciate at the same rate δ_s. JIT manufacturing shortens production time and makes newly generated WIP available for current-period final-good production.

Similar to the model presented in section 4, I assume away uncertainty and 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 inventory holdings in 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 WIP products N_2 to use in production, given the beginning of period material and WIP inventory stocks, s_1 and s_2.

A.4.1 Steady State under JIC-manufacturing

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

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

where

$$s_1' = (1 - \delta_s)(s_1 - N_1 + i_s) \geq 0,$$

$$s_2' = (1 - \delta_s)(s_2 - N_2 + N_1) \geq 0.$$

Rewriting the problem with multipliers, the first order conditions of material use, WIP use, new purchases, material inventory and WIP inventory are given by:

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

$$+\mu_1(s_1 - N_1) + \mu_2(s_2 - N_2)\},$$

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

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

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

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

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

Solving the system of equations above at the steady state gives: $s_1^* = \frac{[\beta^2(1-\delta_s)^2\alpha]^{\frac{1}{1-\alpha}}}{1-\delta_s}$ and $s_2^* = [\beta^2(1-\delta_s)^2\alpha]^{\frac{1}{1-\alpha}}$.

A.4.2 Steady State under JIT-manufacturing

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

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

where

$$s_2 + N_1 \ge N_2,$$

$$s_1' = (1-\delta_s)(s_1 - N_1 + i_s) \ge 0,$$

$$s_2' = (1-\delta_s)(s_2 - N_2 + N_1) \ge 0.$$

The Bellman equation with multipliers can be formulated as

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

$$+\mu_1(s_1 - N_1) + \mu_2(s_2 + N_1 - N_2),$$

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

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

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

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

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

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

A.4.3 Discussion

I first show analytically that the optimal level of material inventory 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,* $s_{1,JIT}^* > s_{1,JIC}^*$.

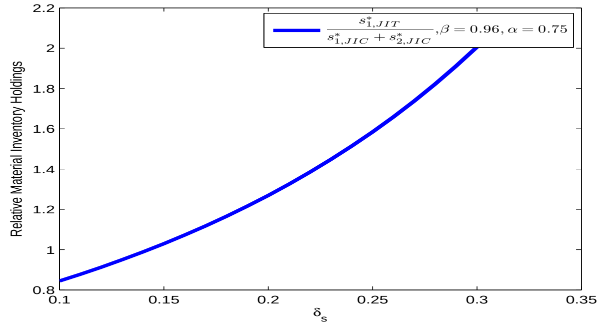

Figure A2: **Relative Material Inventory Holdings after the Adoption of JIT-manufacturing.** This figure plots the model-implied ratio of the steady-state material inventory holdings under JIT manufacturing to the total input inventory holdings (both material and WIP) under JIC manufacturing.

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 WIP inventory. The improved productivity leads firms to invest more resources in production by using more materials. In the absence of JIT purchasing, firms hoard materials to smooth production.

Figure A2 plots the ratio of the optimal material inventory under JIT over the sum of the optimal material and WIP inventory under JIC as a function of inventory depreciation rate δ_s, given the parameter values used in the text, $\beta = 0.96$ and $\alpha = 0.75$ (at annual frequency). As the annual inventory depreciation rate rises from 10% to 30%, the ratio increases from 0.84 to 2. When δ_s is 20%, the value calibrated in the text, the ratio equals to 1.27. That is, as firms switch from JIC to JIT manufacturing, firms allocate approximately the same amount of resources from WIP to material inventory.