

Working Capital, Inventories and Optimal Offshoring*

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Abstract

In addressing the precipitous drop in trade volumes in the recent crisis, the real and financial explanations have sometimes been juxtaposed as competing explanations. However, they can be reconciled by appeal to the time dimension of production and the working capital demands associated with offshoring and vertical specialization of production. We explore a model of manufacturing production chains with offshoring where firms choose their time profile of production and where inventories, accounts receivable, and productivity are procyclical and track financial conditions.

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“When our grandfathers owned shops, inventory was what was in the back room. Now it is a box two hours away on a package car, or it might be hundreds more crossing the country by rail or jet, and you have thousands more crossing the ocean”

[Chief Executive Officer of UPS quoted in Friedman (2005) *The World is Flat* (p. 174)]

1 Introduction

Inventory investment is known to be highly procyclical, and accounts for a large proportion of the change in GDP over the business cycle. In their survey for the Handbook of Macroeconomics, Ramey and West (1999) show that over the nine post-war recessions in the United States up to 1991, the average peak-to-trough decline in inventories is nearly 70% of the peak-to-trough decline in GDP. Since output is the sum of sales and the change in inventories, the procyclicality of inventory investment sits uncomfortably with the textbook treatment of inventories as a buffer stock used to smooth sales. Blinder (1986) and Blinder and Maccini (1991) note that far from inventories serving to smooth sales to keep pace with production, production is *more volatile* than sales.

A useful perspective in understanding the cyclical nature of inventories is from the balance sheet of a firm. Production takes time, and inventories are the assets of the firm that reflect the time gap between incurring costs and booking revenue from sales. The longer is the production process, the larger are the inventories on the firm’s balance sheet.

The rapid growth of trade in intermediate goods and offshoring provides the perfect setting for the study of the time dimension of production. Grossman and Rossi-Hansberg (2006, 2008) argue that offshoring is now so prevalent that the classical theory of trade in finished goods should be augmented by the theory of the trade in *tasks*. In the same spirit, recent advances in our understanding of offshoring have focused on their technological and informa-

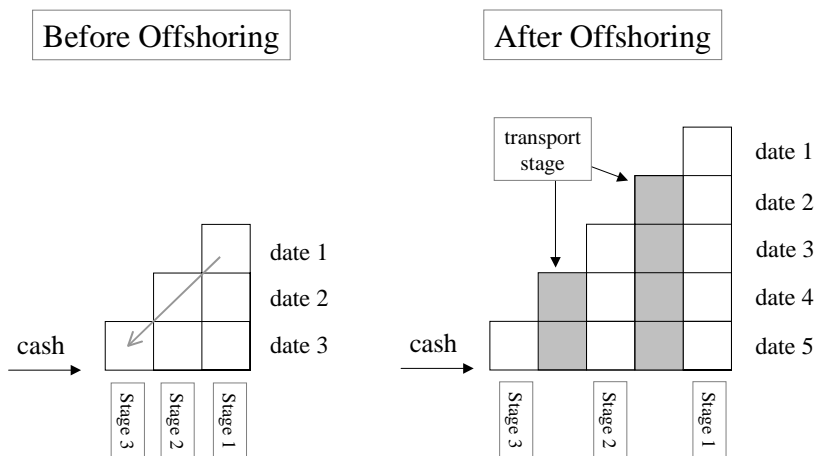


Figure 1. The left hand panel illustrates the inventories needed in a three-stage production process at one site. The right hand panel illustrates the increased inventories resulting from offshoring the second stage of production.

tional determinants, such as the specialization between routine and complex tasks (Antras, Garicano and Rossi-Hansberg (2006)), robustness to quality variability (Costinot, Vogel and Wang (2011)) or the complementarity of production processes (Baldwin and Venables (2010)).

In this paper, we take a different tack and explore the time dimension of offshoring and its consequences for the management of working capital. Although the production process is largely determined by technological realities, the firm nevertheless has considerable scope to choose its production time profile. Offshoring provides a good illustration of the discretion that firms have in this regard.

Figure 1 illustrates the effect of offshoring for a firm with a three-stage production process, with each stage taking one unit of time. The left panel depicts the firm without offshoring, while the right panel shows the time profile when the second production stage is located offshore, entailing a lengthening of the production process due to time taken for transport of intermediate goods to the remote location and back. For the purpose of illustration, we suppose that the transport stage takes the same length of time as is necessary

for a single production stage. Amiti and Weinstein (2011) argue that the transport stage could be as long as two months when taking account of the paperwork involved in shipping.

In Figure 1, offshoring extends the firm’s production chain from three periods to five. There are two notable effects of offshoring on the firm’s financial position, both of which point to greater financing need for the firm. We dub the two effects the *inventory effect* and the *working capital effect*.

We discuss each in turn. First, the *inventory effect* refers to the increase in the firm’s steady state balance sheet due to the increase in steady state inventories. The horizontal block of cells in the bottom row of the two panels in Figure 1 represent the inventories of various “vintages” on the firm’s balance sheet. Before the offshoring, the firm holds three vintages of inventories, reflecting the three stages of production. The oldest inventories are three periods old. Next are two period-old inventories that have gone through two stages of production, and then there are the youngest inventories that have undergone just the first stage of production. Under offshoring, the firm holds inventories of *five* vintages, including inventories that are in transit (grey-shaded cells). We can interpret the opening quote of the UPS chief executive from Tom Friedman (2005) as pointing to just such inventories. They are not buffer stock, but instead reflect the active operation of the global supply chain.

Second, as well as the increase in the firm’s balance sheet in steady state, there is also a fixed cost element initially to build up the longer supply chain. The reason is the greater *working capital* needed to lengthen the chain, which entails a *one-off* increase in the firm’s financing need. In Figure 1, the firm must incur production costs before the first cash flow materializes. In the left panel, the first cash flow comes at the end of date 3, and so the firm must finance itself for three periods before cash flow materializes. If each step in the production process incurs cost w , then the firm needs to finance the “triangle” cost of $6w$, given by the sum $w + 2w + 3w$ before the first

cash flow arrives. This initial expenditure is akin to a fixed investment, since such an investment gives the firm access to the cash flows that come in steady state. In the right hand panel, the firm must finance a larger triangle before the first cashflow materializes. If we suppose that the transport cost is also w , then the firm must pay an initial cost of $15w$ (given by the sum $w + 2w + \dots + 5w$) before the first cash flow. Since the triangle is increasing in the *square* of the chain length, the working capital need can be very large for long production chains.

Both the inventory effect and working capital effect associated with offshoring entail greater financing demand on the firm that must be met from the firm's own equity or by borrowing from financial markets or banks. During periods when financing is easily obtained, we would expect firms to lengthen their production chains to reap the benefits of globalization. However, an abrupt tightening of credit will exert disruptions to the operation of the global supply chain and lead to a drop in offshoring activity and trading volumes.¹ The contractionary effect of financing constraints during the recent crisis have been documented by Chor and Manova (2009), who show that sectors requiring greater financing saw greater declines in trading volume, and by Amiti and Weinstein (2011) who use micro-level data from Japan to show that banks with tighter financing constraints impose greater dampening effect on exports of firms reliant on those banks.

The time dimension of production and the financing of working capital provide the conceptual link between the approach that emphasizes financial constraints with those focused on real variables, such as Eaton, Kortum, Neiman and Romalis (2009) and Alessandria, Kaboski and Midrigan (2009, 2010). Not only are the financial and real explanations consistent they are arguably two sides of the same coin, as Alessandria et al. (2009, 2010) draw attention to the role of inventories in the amplification of the downturn. One

¹The *Financial Times* headline "Crisis and climate force supply chain shift" on 9 August 2009 neatly summarizes the consolidation of globally extended supply chains. On July 15, it carried a similar article with the title "Reaggregating the supply chain".

main task in this paper will be to show how the real and financial explanations are linked through the time dimension of production.

Well before the crisis, Kashyap, Lamont and Stein (1994) had documented the sensitive nature of inventories to financial conditions, especially to shocks that reduced bank credit supply. The severe banking sector contraction associated with the 2008 crisis can be expected to have exerted very severe brakes on the practice of offshoring and the associated increase in trading volume. The impact on trade is especially large due to the growth in vertical specialization and trade in intermediate goods documented by Yi (2003). Bems, Johnson and Yi (2011) show that gross trade fell more than value-added trade, implying that the demand declines hit vertically specialized sectors harder, reinforcing the case for the role of production chains in explaining recent events.

In a vertically integrated production process, the units could belong to the same firm, or to different firms. To address the boundary of the firm, we must appeal to the contracting environment (as done, for example, by Antras and Chor (2011)). In this paper, we will not address the boundary of the firm. Nevertheless, the boundary of the firm will leave its mark on a firm's balance sheet. When the transactions are *between* firms rather than *within* firms, the time dimension of production will be reflected in the firms' accounts receivable and accounts payable. Receivables appear on the asset side of the balance sheet alongside inventories, while payables appear as liabilities. Figure 2 plots the annual changes in receivables, payables and inventories of non-financial corporate businesses in the United States and shows clearly how receivables, payables and inventories move in unison with the business cycle.

Before presenting our model of offshoring, we examine a preliminary model of supply chains without offshoring that will supply the main intuitions of the time dimensions of production. The preliminary model is deliberately stark so as focus attention on the time cost of production and the role

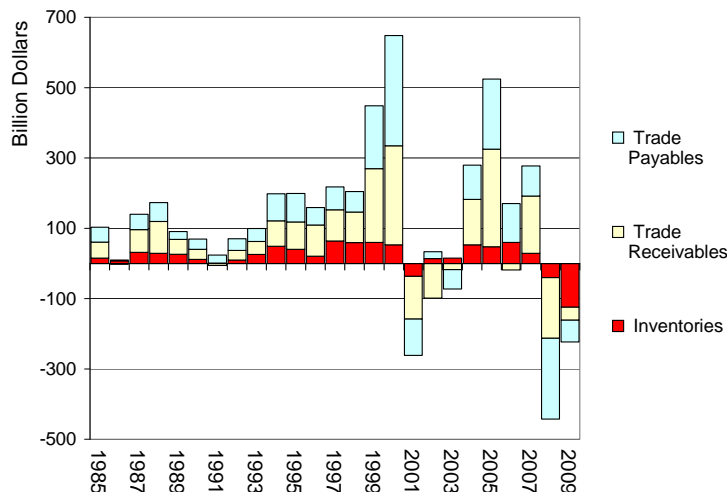


Figure 2. Annual change in receivables, payables and inventories of U.S. Non-Financial Firms (Source: Federal Reserve, Flow of Funds, Table F102)

of financing conditions in sustaining supply chains. In this model, the only “friction” is that production takes time. Even so, fluctuations in credit conditions can have a large impact on output and productivity. In particular, we show how aggregate productivity of the economy fluctuates over the cycle in line with financial conditions, with productivity dropping in downturns. Although our mechanism is very different, the apparent productivity fluctuations over the cycle is in the same spirit as Buera and Moll (2011) where total factor productivity of an economy with heterogeneous firms fluctuates with financial constraints. In our preliminary model, productivity fluctuates due to the cyclical variation in the length of the supply chain.

Our model of offshoring builds on the benchmark model of supply chains by holding fixed the technology, but allowing the length of the supply chain to be the choice variable. The rationale is that the degree of “roundaboutness” of production (in the terminology of Böhm-Bawerk (1884)) cannot easily be varied in the short run, and the firm must adjust its supply chain by varying the extent of offshoring. We show that the optimal choice of supply chain

length depends critically on financial conditions, yielding a credit demand function of firms for the purpose of financing the supply chain. Finally, we close the model by deriving a credit supply function, and conduct comparative statics exercises with respect to financial shocks. We find that a financial shock that reduces credit supply will result in sharply higher loan risk premiums and a contraction in the degree of offshoring undertaken by the firms.

2 Benchmark Model

We begin with an elementary model of supply chains without offshoring. Our model is deliberately stark in order to isolate the time dimension of production and the role of inventory and working capital. The only substantial decision is the ex ante choice of the length of the production chain. There are no product or labor market distortions. The only “friction” is that production takes time.

There is a population of L workers and L firms each owned by a penniless entrepreneur. Each firm is matched with one worker. Production takes place through chains of length n , so that there are L/n production chains in the economy. We assume L is large relative to n , so that the economy consists of a large number of production chains.

Within each production chain, there is a downstream firm, labeled as firm 1, that sells the final output. The other firms produce intermediate inputs in the production of the final good. Firm n supplies its output to firm $n - 1$, who in turn supplies output to $n - 2$, and so on. Each step of the production process takes one unit of time, where time is indexed by $t \in \{0, 1, 2, \dots\}$.

Although each step of the production process is identified with a firm, this is for narrative purposes only. Our model is silent on where the boundary of the firm lies along the chain. Some of the consecutive production stages could lie within the same firm, while some consecutive stages could be in different

firms. If the production chain lies within the firm, claims on intermediate goods will show up on a firm's balance sheet as inventories. If the production chain lies across firms, then they show up as accounts receivable. What matters for us is the *aggregate* financing need, rather than the allocation of financing into inventories and accounts receivable.

The wage rate is w per period and wage cost cannot be deferred and must be paid immediately. Labor is provided inelastically, so that total labor supply is fixed at L . There is no physical capital.

The cashflow to the chain is given in the table below. At the beginning of date 1, firm n begins production and sends the intermediate good to firm $n - 1$ at the end of date 1, who takes delivery and begins production at the beginning of date 2, and so on. Meanwhile, at the beginning of date 2, firm n starts another sequence of production decisions by producing its output, which is sent to firm $n - 1$, and so on.

		Firms					cumulative
		1	2	\dots	$n - 1$	n	cashflow
date t	1					$-w$	$-w$
	2				$-w$	$-w$	$-3w$
	\vdots			\dots	$-w$	$-w$	\vdots
	$n - 1$		$-w$	\dots	$-w$	$-w$	\vdots
	n	$-w$	$-w$	\dots	$-w$	$-w$	$-\frac{1}{2}n(n+1)w$
	$n + 1$	$y(n) - w$	$-w$	\dots	$-w$	$-w$	
	\vdots	\vdots	\vdots		\vdots	\vdots	

The first positive cashflow to the chain comes at date $n + 1$ when firm 1 sells the final output for $y(n)$. The cash transfer upstream is instantaneous, so that all upstream firms are paid for their contribution to the output.

Firms borrow by rolling over one period loans. The risk-free interest rate is zero, and is associated with a storage technology that does not depreciate

in value. Although the risk-free rate is zero, the firms' borrowing cost will reflect default risk and a risk premium in the credit market. Once the output is marketed from date $n + 1$, there is a constant hazard rate $\varepsilon > 0$ that the chain will fail with zero liquidation value so that lenders suffer full loss on their loans to the chain. Before date $n + 1$, there is no probability of failure, and firms can borrow at the risk-free rate of zero. But starting from the loan repayable at date $n + 1$, they must borrow at the higher rate $r > \varepsilon$, which reflects the default risk ε as well as the risk premium, which will be endogenized by introducing a financial sector in Section 4. For now, we treat the borrowing rate r as given. Firms have limited liability, so that once a production chain fails, the firms in the chain can re-group costlessly to set up another chain of same length by borrowing afresh.

Before the first cash flow materializes to the chain from the sale of the final product, the chain must finance the initial set-up cost of $\frac{1}{2}n(n + 1)w$. We can decompose this sum into the steady state inventory nw that must be carried by the firm in steady state and the initial "triangle" of working capital of $\frac{1}{2}n(n - 1)w$. Firms start with no equity and all financing is done by raising debt. Thus, the total initial financing need of the production chain of length n is given by

$$\frac{n(n + 1)w}{2} \tag{1}$$

From the lenders' perspective, the cash flow is negative until date n , but then they start receiving interest repayment on the outstanding stock of loans. Figure 3 compares the profile of lenders' cash flows conditional on survival of the chain. The light line gives the cash flow profile by lending to a production chain of length n , while the dark line gives the profile from lending to a chain of length $n' > n$.

Note that the outstanding loan amount is of the order of the *square* of the length of the production chain, since the initial set-up cost of the chain is the "triangle" until the final product is marketed. For the firms, the choice of the length of the production chain trades off the marginal increase in productivity

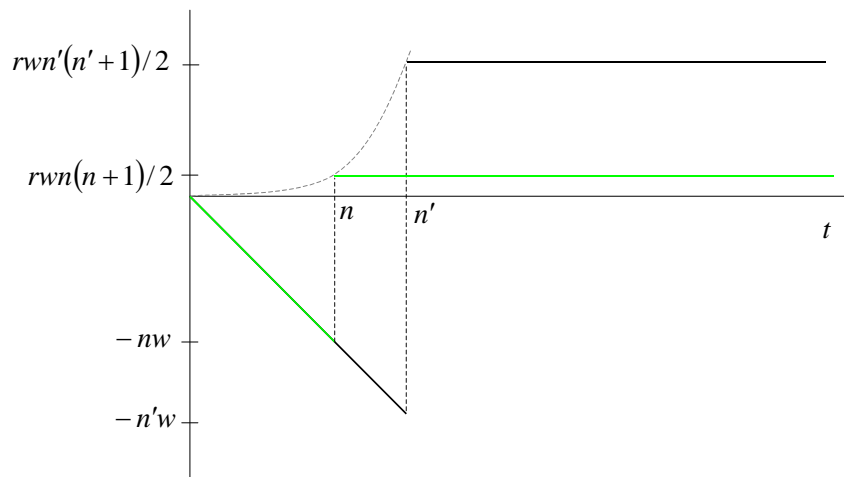


Figure 3. Profile of lenders' cash flow from lending to a production chain of length n (light line) and to a chain of length n' (dark line)

from lengthening the chain against the increased cost of financing working capital.

There are L/n production chains, so that the aggregate working capital demand in the economy, denoted by K , is

$$\begin{aligned}
 K &= \frac{1}{2}n(n+1)w \times \frac{L}{n} \\
 &= \frac{n+1}{2}wL
 \end{aligned}
 \tag{2}$$

The production chain consisting of n firms has output $y(n)$. The output per firm (equivalent to output per worker) is $y(n)/n$. We will adopt the following production function

$$\frac{y(n)}{n} = n^\alpha, \quad (0 < \alpha < 1)
 \tag{3}$$

The formulation of productivity in our model harks back to Böhm-Bawerk's (1884) notion of "roundabout production", where intermediate goods are used as inputs in further intermediate goods. Our assumption that $0 < \alpha < 1$ captures the feature that:

“[t]he indirect method entails a sacrifice of time but gains the advantage of an increase in the quantity of the product. Successive prolongations of the roundabout method of production yield further quantitative increases though in diminishing proportion.”²

The parameter α is the only “deep” technological parameter in our model, as the borrowing rate on working capital will be solved in Section 4 by clearing the credit market. Taking r as given for the moment, we solve for total credit demand, production chain length, and the wage rate. We take the stance of the coalition of firms in maximizing the joint surplus. We may take the solution as the upper bound to any equilibrium solution that incorporates inefficiencies that may arise from incentive problems (see Blanchard and Kremer (1997) and Kim and Shin (2012) for analyses of incentive problems within chains).

The firm coalition’s problem at date 0 is to choose n to maximize the expected surplus net of wage costs and all financing costs. Since the borrowing cost is zero until date n and is r from date $n + 1$, the firm coalition’s problem at date 0 is to choose n to maximize:

$$\sum_{t=n+1}^{\infty} (1 - \varepsilon)^{t-n} (n^\alpha L - wL - rK) \quad (4)$$

which boils down to the problem of maximizing the per period surplus:

$$\begin{aligned} \Pi &= n^\alpha L - wL - rK \\ &= n^\alpha L - wL \left(1 + \frac{r(n+1)}{2}\right) \end{aligned} \quad (5)$$

The first-order condition for n gives

$$n = \left(\frac{2\alpha}{wr}\right)^{\frac{1}{1-\alpha}} \quad (6)$$

²Bohm-Bawerk (1884), p 88 of 1959 English translation by G. Huncke, Libertarian Press.

We assume that firms bid away their surplus by competing for workers, so that the wage rate is determined by the zero profit condition:

$$n^\alpha = w \left(1 + \frac{r(n+1)}{2}\right) \quad (7)$$

We can then solve the model in closed form. The wage w is

$$w = 2 \left(\frac{\alpha}{r}\right)^\alpha \left(\frac{1-\alpha}{2+r}\right)^{1-\alpha} \quad (8)$$

Optimal chain length is

$$n = \frac{\alpha}{1-\alpha} \left(1 + \frac{2}{r}\right) \quad (9)$$

so that productivity per worker is

$$\left(\frac{\alpha}{1-\alpha}\right)^\alpha \left(1 + \frac{2}{r}\right)^\alpha \quad (10)$$

and total output Y is

$$Y = n^\alpha L = \left(\frac{\alpha}{1-\alpha}\right)^\alpha \left(1 + \frac{2}{r}\right)^\alpha L \quad (11)$$

Note that the wage, productivity and output are declining in the borrowing rate r , which incorporates the risk premium $r-\varepsilon$. The reason for the negative impact of the borrowing rate on real variables in spite of the absence of the standard intertemporal savings decision arises from the decline in the length of production chains in the economy as financing cost increases.

Finally, the total credit used by all production chains in the economy is

$$\begin{aligned} K &= \frac{n+1}{2} w L \\ &= \left(\frac{\alpha}{1-\alpha}\right)^\alpha \left(1 + \frac{2}{r}\right)^\alpha \left(\frac{\alpha}{r} + \frac{1-\alpha}{2+r}\right) L \end{aligned} \quad (12)$$

Note that total financing need is increasing linearly in chain length n , since the financing need is the “triangle” whose size increases at the rate of the *square* of the chain length.

We may interpret K as the *aggregate credit demand* in the economy. Credit demand is declining in the borrowing rate r . Once we introduce a financial sector in Section 4, the borrowing rate r can be solved as the market clearing rate that equates K with total credit supply.

The ratio K/Y could be interpreted as the credit to GDP ratio, and has the simple form as below, which also declines with the borrowing rate.

$$\frac{K}{Y} = \frac{\alpha}{r} + \frac{1 - \alpha}{2 + r} \quad (13)$$

Since credit is a stock while output is a flow, the choice of the time period is important in interpreting the ratio K/Y . In our model, this ratio is given meaning by setting the unit time interval to be the time required to finish one stage of production.

2.1 Total Factor Productivity

If we treat working capital as a factor of production, we can give a reduced-form representation of total output, but where the total factor productivity term is not a constant, but instead depends on financial conditions.

Such an exercise is of interest given Valerie Ramey's (1989) study of modeling inventories as a factor of production. Indeed, we can give a Cobb-Douglas representation as follows. Note from (11) that total output can be written as

$$\begin{aligned} Y(K, L) &= n^\alpha L \\ &= \left(\frac{2K}{wL} - 1 \right)^\alpha L \\ &= \left(\frac{2}{w} - \frac{L}{K} \right)^\alpha K^\alpha L^{1-\alpha} \end{aligned} \quad (14)$$

Imposing a Cobb-Douglas functional form for working capital will result in a misspecified production function, where total factor productivity depends on endogenous variables.

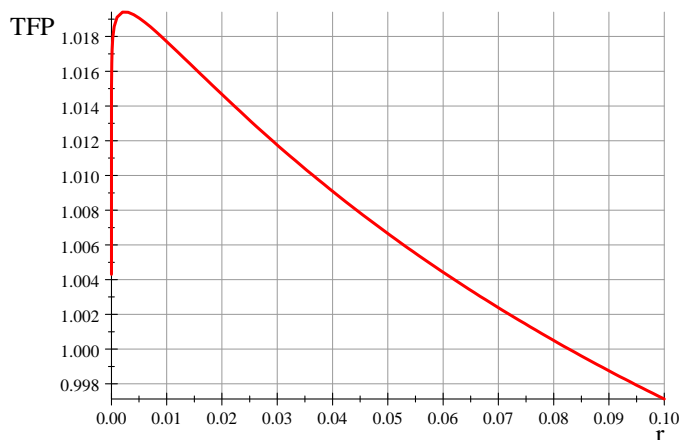


Figure 4. Total factor productivity as a function of the market interest rate ($\alpha = 0.033$)

Figure 4 plots the TFP term in the production function as a function of the borrowing rate r when $\alpha = 0.033$. The TFP term is not well-defined when $r = 0$, since both expressions inside the brackets in (14) shoot off to infinity. However, for reasonable ranges for r , the TFP term is decreasing in the borrowing rate.

To an outside observer who imposes a Cobb-Douglas production function on the economy, they would observe that productivity undergoes shocks as financial conditions change. When financial conditions are tight and the risk premium in the borrowing rate increases, they will also observe that total factor productivity falls. This is in spite of the fact that our model has none of the standard distortions or frictions to product or labor markets, or indeed any intertemporal choice. The only “friction” in our model is that production takes time.

This feature of our model where the TFP depends on financial conditions is in a similar spirit to the finding in Buera and Moll (2011), who show that the aggregate TPF of an economy with heterogeneous firms that are differentially affected by collateral constraints will also exhibit sensitivity to financial conditions. Our mechanism is very different from that of Buera

and Moll (2011), and the lesson from our paper is that vertical specialization of production may give rise to productivity effects that are not captured by a representative firm production function.

2.2 Sales and Value Added

Although our model is very simple, some of the variables have empirical counterparts that are not discussed in standard macro models with representative firms. One example is the ratio sales to value-added implied by our model. Consider the sales of each firm in the chain. From the zero profit condition, each firm's sale is the cost of production, including the cost of working capital.

$$\begin{aligned}
 p_n &= w + rwn \\
 p_{n-1} &= w + rw(n-1) + p_n \\
 p_{n-2} &= w + rw(n-2) + p_{n-1} \\
 &\vdots \\
 p_1 &= w + rw + p_2
 \end{aligned} \tag{15}$$

By recursive substitution,

$$\begin{aligned}
 p_n &= w(1 + rn) \\
 p_{n-1} &= 2w(1 + rn) - wr \\
 p_{n-2} &= 3w(1 + rn) - wr(1 + 2) \\
 &\vdots \\
 p_1 &= nw(1 + rn) - wr(1 + 2 + \dots + (n-1))
 \end{aligned} \tag{16}$$

Therefore total sales are

$$\sum_{k=1}^n p_k = w(1 + rn) \left(\sum_{k=1}^n k \right) - wr \sum_{k=1}^{n-1} k(n-k) \tag{17}$$

Using the algebraic identity:

$$\sum_{k=1}^{n-1} k(n-k) = \frac{1}{6}n(n-1)(n+1)$$

total sales in the chain are

$$\sum_{k=1}^n p_k = \frac{1}{2}nw(nr+1)(n+1) - \frac{1}{6}nrw(n-1)(n+1) \quad (18)$$

Total value added in the chain is

$$\begin{aligned} p_1 &= nw(1+rn) - wr \sum_{k=1}^{n-1} k \\ &= nw(nr+1) - \frac{1}{2}nrw(n-1) \end{aligned} \quad (19)$$

Hence, the sales to value-added ratio is

$$\begin{aligned} \frac{\sum_{k=1}^n p_k}{p_1} &= (n+1) \frac{\frac{1}{3}r + \frac{2}{3}nr + 1}{r + nr + 2} \\ &= \frac{(r+2\alpha)(r+\alpha(1+r)+3)}{3r(1-\alpha)(r+2)} \end{aligned} \quad (20)$$

Figure 5 plots the sales to value-added ratio given by (20) when $\alpha = 0.033$. We see that the sales to value-added ratio is decreasing in the borrowing rate r , reflecting the shorter production chains when financial conditions are tighter.

Although our model is not sufficiently developed to take to the data, it is illuminating to get some bearing on the empirical magnitudes for the sales to value-added ratio for US manufacturing firms. The U.S. Census Bureau publishes an annual survey of manufacturing firms and provides estimates of the total value of shipments and value-added of the manufacturing sector. Figure 6 plots the recent movements in total shipments and value-added, where both series have been normalized to be 1 in 2000. The total value of shipments for the manufacturing sector in 2000 was 4.21 trillion dollars, and value-added was 1.97 trillion dollars.

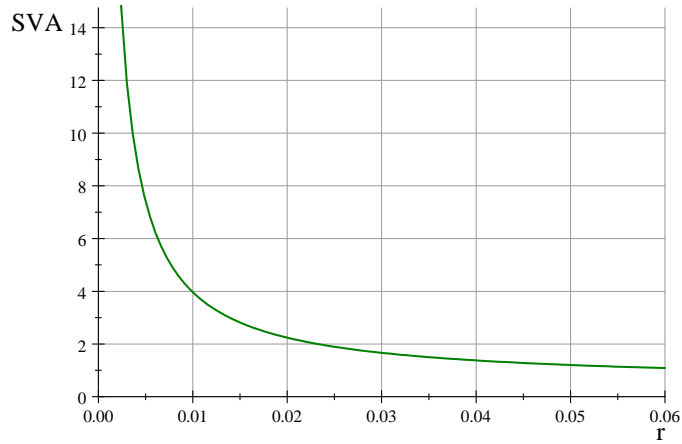


Figure 5. Plot of the ratio of sales to value-added of the economy as a function of the borrowing rate r ($\alpha = 0.033$)

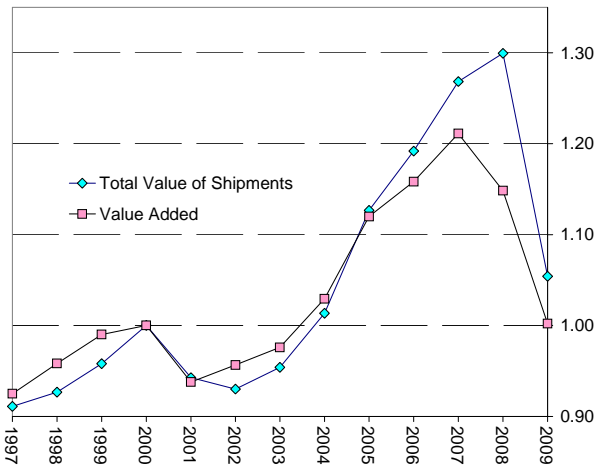


Figure 6. Total shipments and value-added of U.S. Manufacturing firms (2000 = 1)
(Source: U.S. Census Bureau)

We see that the two series do not always move in step. Total sales (value of shipments) is more procyclical than value-added, where sales overtake value-added from below in 2005, but then fall much more in 2009. The ratio of total shipments to value-added for the manufacturing sector lies in the range of 2.0 to 2.4. The ratio rises strongly in the period before the crisis but crashes in 2009, consistent with the basic picture given by our model in Figure 5.

3 Production Chains with Offshoring

We now develop our model of offshoring by changing some key features of the benchmark model above.

First, in line with the intuition that the degree of “roundaboutness” of production will not be easily changed in the short run, we fix the production chain length. Instead, the choice of the firm is to decide whether to perform a particular task at home or send it offshore to a destination where the task can be done more effectively.

Assume there is a large number of multi-national firms, with a presence in all countries. Given the large number of multi-national firms, all markets are competitive and the profit of each multi-national firm is zero. There is no restriction on free trade and labor can move freely across countries.

Assume that there are \bar{n} stages to the production chain and \bar{n} countries. Each country has an absolute advantage in precisely one stage of the production process. The absolute advantage derives from the location, not the worker, so that if any worker moves to the country with absolute advantage in a particular task, the new worker is able to produce at the higher productivity for that task. There is a constant $b > 0$ such that the country with the absolute advantage in production stage i has an effective labor input of $1 + b$ compared to the effective labor input of 1 in any other country for that task.

The output of a production chain depends on the amount of offshoring done to utilize the most effective inputs. Specifically, the output of a production chain is given by

$$\left(\sum_{i=1}^{\bar{n}} x_i \right)^\alpha \quad (0 < \alpha < 1) \quad (21)$$

where $x_i = 1 + b$ if the production of the i th stage takes place in the country with the absolute advantage in stage i while $x_i = 1$ if the production takes place anywhere else. Thus, if a firm offshores s stages of the production chain to the country with the absolute advantage in that process, output is given by

$$y(s) = (\bar{n} + bs)^\alpha \quad (22)$$

The firm's decision is to choose s , the extent of offshoring.

Offshoring entails two costs - the cost of transport and the financing cost due to the lengthening of the production chain. We assume that transport requires labor services just as for production. Offshoring also incurs financing costs due to the time needed to transport intermediate goods. Transportation by ship to a foreign country takes much longer than delivery within the same country. According to Amiti and Weinstein (2011), overseas shipping could take two months. To formalize this in a simplest way, we assume that if an intermediate good is transported to another country, transport takes one unit of time, which is the same as the time needed for production of an intermediate good. Within the same country, we assume that transport happens instantaneously.

As in the benchmark model, wages cannot be deferred and firms that engage in intermediate good production or overseas transport need working capital to pay wages. Assume wage for each stage of intermediate good and transportation service is paid at the beginning of the production stage. Wage per unit of time is w . We maintain the assumption that firms have no equity so that working capital is financed with debt at borrowing rate r .

The financing requirement depends on the extent of offshoring, as offshoring lengthens the production process. If all production happens within a country, the production process consists of \bar{n} stages and takes \bar{n} periods. If intermediate goods are always transported across borders to the next stage, and the final product returns to the home country, the production process takes $2\bar{n}$ periods in total. If offshoring takes place s times, the production process takes $\bar{n} + s$ periods. Total financing requirement for the world economy, denoted by K , is then

$$\begin{aligned} K &= \frac{1}{2}(\bar{n} + s)(\bar{n} + s + 1)w \times \frac{L}{(\bar{n} + s)} \\ &= \frac{\bar{n} + s + 1}{2}wL \end{aligned} \quad (23)$$

where L is the world labor force. The per period interest cost for the world economy is

$$r \frac{\bar{n} + s + 1}{2}wL \quad (24)$$

The profit of a multinational firm is given by

$$\begin{aligned} \Pi &= (\bar{n} + bs)^\alpha zL - wzL - rzK \\ &= (\bar{n} + bs)^\alpha zL - wzL \left(1 + \frac{r(\bar{n} + s + 1)}{2} \right) \end{aligned} \quad (25)$$

where z is the proportion of the world workforce employed by firm. The firm maximizes profit by choosing s . Since the firms' profits are driven down to zero, the share z will not play any meaningful role in our model. The first-order condition for s yields

$$\bar{n} + bs = \frac{1}{w^{\frac{1}{1-\alpha}}} \left(\frac{2b\alpha}{r} \right)^{\frac{1}{1-\alpha}} \quad (26)$$

and the zero profit condition is

$$\begin{aligned} (\bar{n} + bs)^\alpha &= w \left(1 + \frac{r(\bar{n} + s + 1)}{2} \right) \\ &= w \left(1 + \frac{r}{2}(1 + \bar{n}) + \frac{r}{2}s \right) \end{aligned} \quad (27)$$

From (26) and (27) we can solve the model in closed form. The extent of off-shoring is

$$s = \frac{\alpha}{1 - b\alpha} \left(1 + \bar{n} \left(1 - \frac{1}{b} \right) + \frac{2}{r} \right) - \frac{\bar{n}}{b} \quad (28)$$

The wage rate is

$$w = 2 \frac{b\alpha}{r} \left(\frac{1 - b\alpha}{2 + r \left(1 + \bar{n} \left(1 - \frac{1}{b} \right) \right)} \right)^{1-\alpha} \quad (29)$$

Note that both s and w are decreasing in the borrowing cost r . Thus, the extent of offshoring depends on financial conditions, where a tightening of credit will reduce offshoring and result in a concomitant reduction in trade volume. The reduction in trade volume will be higher for more elaborate production processes with a greater vertical specialization. The empirical evidence in Bems, Johnson and Yi (2011) is consistent with such a prediction.

Finally, since total financing K is given by $(\bar{n} + s + 1) wL/2$ it is increasing in s and w . Therefore, the global demand for credit is decreasing in the borrowing cost r .

4 Closing the Model with Credit Supply

So far, we have treated the borrowing rate r as given. We now close the model by building a financial sector and modeling the credit supply by banks. The borrowing rate r is then determined as the rate that clears the credit market.

Before describing the model of credit supply in more detail, it is useful to note the salient features of banking sector credit supply in order that our model may capture the financial frictions more faithfully.

We have already noted the findings of Kashyap, Lamont and Stein (1994) and Amiti and Weinstein (2009), who (in different contexts) have pointed to the pivotal role of the banking sector in determining the credit conditions for trade finance. Adrian, Colla and Shin (2011) investigate the nature of

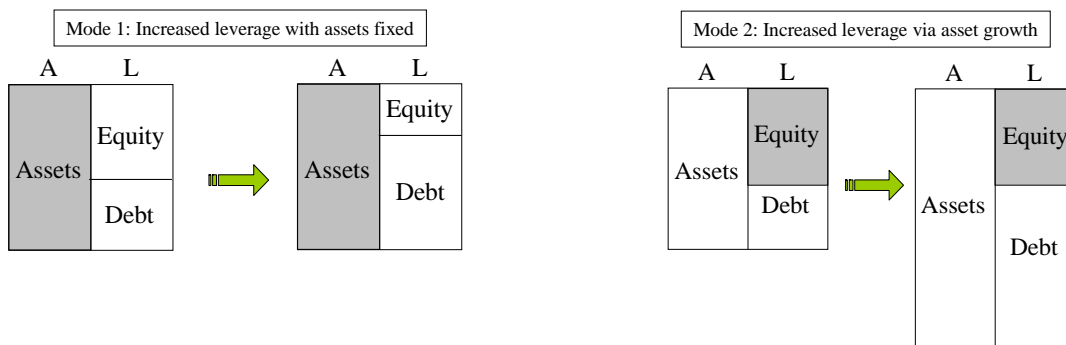


Figure 7. **Two Modes of Leveraging Up.** In the left panel, the firm keeps assets fixed but replaces equity with debt. In the right panel, the firm keeps equity fixed and increases the size of its balance sheet.

the financial frictions that operated in the recent crisis, where the banking sector behavior is described in more detail. Here, we will focus on adapting some key features of the banking sector into our model of offshoring and production chains.

The banking sector is special in several respects, compared to the non-financial corporate sector. In textbook discussions of corporate financing decisions, the set of positive net present value (NPV) projects is often taken as being exogenously given, with the implication that the size of the balance sheet is fixed. Leverage increases by substituting equity for debt, such as through an equity buy-back financed by a debt issue, as depicted by the left hand panel in Figure 7.

However, the left hand panel in Figure 7 turns out not to be a good description of the way that the banking sector leverage varies over the financial cycle. For banks, however, leverage fluctuates through changes in the total size of the balance sheet with equity being the pre-determined variable. Hence, leverage and total assets tend to move in lock-step, as depicted in the right hand panel of Figure 7.

Figure 8 is the scatter plot of the quarterly change in total assets of the sector consisting of the five US investment banks examined in Adrian and

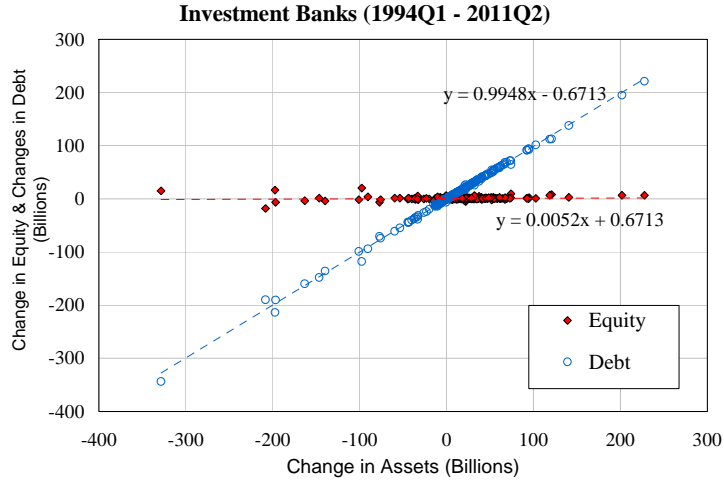


Figure 8. Scatter chart of $\{(\Delta A_t, \Delta E_t)\}$ and $\{(\Delta A_t, \Delta D_t)\}$ for changes in assets, equity and debt of US investment bank sector consisting of Bear Stearns, Goldman Sachs, Lehman Brothers, Merrill Lynch and Morgan Stanley between 1994Q1 and 2011Q2 (Source: SEC 10Q filings).

Shin (2010) where we plot both the changes in assets against equity, as well as changes in assets against debt. More precisely, it plots $\{(\Delta A_t, \Delta E_t)\}$ and $\{(\Delta A_t, \Delta D_t)\}$ where ΔA_t is the change in total assets of the investment bank sector at quarter t , and where ΔE_t and ΔD_t are the change in equity and change in debt of the sector, respectively.

We see from Figure 8 that US investment banks conform to the right hand panel of Figure 7 in the way that they manage their balance sheets. The fitted line through $\{(\Delta A_t, \Delta D_t)\}$ has slope very close to 1, meaning that the change in assets in any one quarter is almost all accounted for by the change in debt, while equity is virtually unchanged. The slope of the fitted line through the points $\{(\Delta A_t, \Delta E_t)\}$ is close to zero. Both features capture the picture of bank balance sheet management given by the right hand panel in Figure 7.³

³The slopes of the two fitted lines sum to 1 due to the linearity of covariance and the balance sheet identity $A = E + D$.

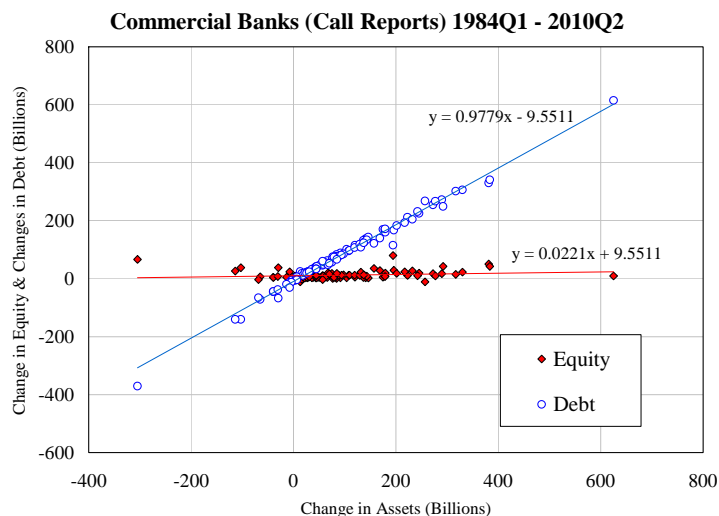


Figure 9. Scatter chart of $\{(\Delta A_t, \Delta E_t)\}$ and $\{(\Delta A_t, \Delta D_t)\}$ for changes in assets, equity and debt of US commercial bank sector at t between 1984Q1 and 2010Q2 (Source: FDIC call reports).

Commercial banks show a similar pattern to investment banks in the way they manage their balance sheets. Figure 9 is the analogous scatter plot of the quarterly change in total assets of the US commercial bank sector which plots $\{(\Delta A_t, \Delta E_t)\}$ and $\{(\Delta A_t, \Delta D_t)\}$ using the FDIC Call Reports. The sample period is between Q1:1984 and Q2:2010. We see essentially the same pattern as for investment banks, where every dollar of new assets is matched by a dollar in debt, with equity remaining virtually unchanged. In other words, bank lending rises and falls dollar for dollar through a change in debt financing, while equity remaining largely unchanged. A consequence of this feature is that equity should be seen as the pre-determined variable when modeling bank lending, and we can see banks as choosing their leverage given the fixed level of bank equity. This is the approach we will take here.

4.1 Bank Credit Supply

Credit in the economy is intermediated through banks. We assume that workers (as investors) cannot lend directly to entrepreneurs, and must lend through the banking sector. Banking sector equity E is fixed, with equity ownership evenly distributed among the worker population. The banks maximize profit subject only to a Value-at-Risk (VaR) constraint that limits the probability of bank failure. Specifically, the VaR constraint stipulates that the probability of bank failure has to be no higher than some (small) threshold level $\gamma > 0$. We do not derive microfoundations for the Value-at-Risk constraint for the bank here, but merely note that banks say they follow it, and the regulators say that they ought to follow it. We will simply take the rule as given and follow the consequences of such behavior for credit supply and lending standards.

In keeping with the overall theme of the paper, the particular model of credit risk that drives the VaR constraint will be the Vasicek (2002) model, adopted by the Basel Committee for Banking Supervision (BCBS (2005)). Due to an aggregation result across banks to be shown below, it is without loss of generality to consider the banking sector as being a single bank.

The notation to be used is as follows. The bank lends out amount C (for “credit”) at date t at the lending rate r , so that the bank is owed $(1 + r)C$ in date $t + 1$ (its notional assets). The lending is financed from the combination of equity E and debt funding L , where L encompasses deposits raised from workers. The cost of debt financing is f so that the bank owes $(1 + f)L$ at date $t + 1$ (its notional liabilities). We assume that the workers are risk-neutral so that the funding rate f is the actuarially fair compensation for the probability γ that the bank fails, so that $1 + f = 1 / (1 - \gamma)$.

We now appeal to the hazard rate $\varepsilon > 0$ of failure by of production chain, introduced in Section 2. Entrepreneurs have limited liability, and so the failure of the chain results in credit losses for the bank. The correlation in defaults across loans follows the Vasicek (2002) model. Production chain j

succeeds (so that the loan is repaid) when $Z_j > 0$, where Z_j is the random variable

$$Z_j = -\Phi^{-1}(\varepsilon) + \sqrt{\rho}S + \sqrt{1-\rho}X_j \quad (30)$$

where $\Phi(\cdot)$ is the c.d.f. of the standard normal, S and $\{X_j\}$ are independent standard normals, and ρ is a constant between zero and one. S has the interpretation of the economy-wide fundamental factor that affects all chains, while X_j is the idiosyncratic factor for chain j . The parameter ρ is the weight on the common factor, which limits the extent of diversification that investors can achieve. Note that the probability of default is given by

$$\begin{aligned} \Pr(Z_j < 0) &= \Pr\left(\sqrt{\rho}S + \sqrt{1-\rho}X_j < \Phi^{-1}(\varepsilon)\right) \\ &= \Phi\left(\Phi^{-1}(\varepsilon)\right) = \varepsilon \end{aligned} \quad (31)$$

which is consistent with our assumption that each chain has a constant hazard rate of failure of ε .

Banks are able to diversify their loan book by lending small amounts to a large number of separate production chains. Conditional on S , defaults are independent. The bank can remove idiosyncratic risk by keeping C fixed but diversifying across chains - that is, by increasing number of borrowers that it lends to but reducing the face value of individual loans. In the limit, the realized value of assets is function of S only, by the law of large numbers. The realized value of the bank's assets at date 1 is given by the random variable $w(S)$ where

$$\begin{aligned} w(S) &\equiv (1+r)C \cdot \Pr(Z_j \geq 0|S) \\ &= (1+r)C \cdot \Pr\left(\sqrt{\rho}S + \sqrt{1-\rho}X_j \geq \Phi^{-1}(\varepsilon) | S\right) \\ &= (1+r)C \cdot \Phi\left(\frac{S\sqrt{\rho}-\Phi^{-1}(\varepsilon)}{\sqrt{1-\rho}}\right) \end{aligned} \quad (32)$$

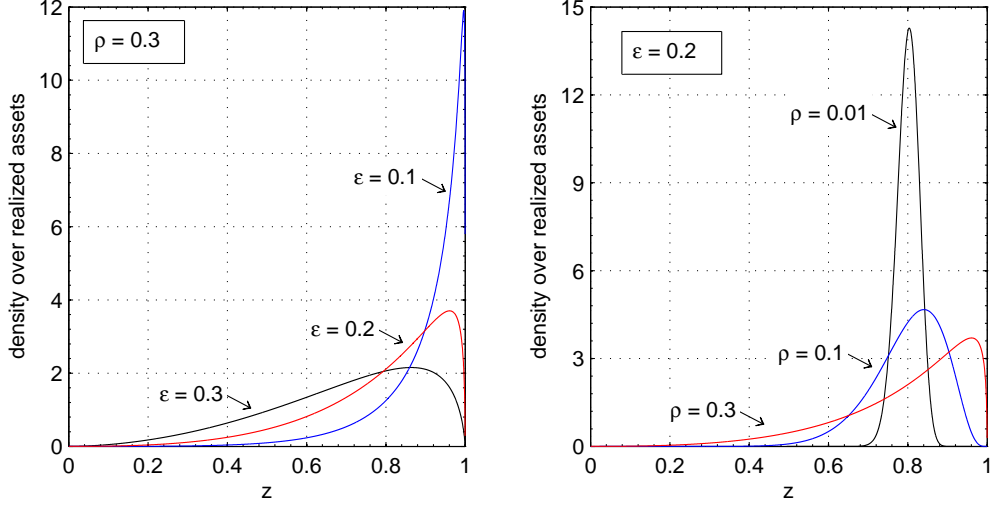


Figure 10. The two charts plot the densities over realized assets when $C(1+r) = 1$. The left hand charts plots the density over asset realizations of the bank when $\rho = 0.1$ and ϵ is varied from 0.1 to 0.3. The right hand chart plots the asset realization density when $\epsilon = 0.2$ and ρ varies from 0.01 to 0.3.

Then, the c.d.f. of $w(S)$ is given by

$$\begin{aligned}
 F(z) &= \Pr(w \leq z) \\
 &= \Pr(S \leq w^{-1}(z)) \\
 &= \Phi(w^{-1}(z)) \\
 &= \Phi\left(\frac{1}{\sqrt{\rho}}\left(\Phi^{-1}(\epsilon) + \sqrt{1-\rho}\Phi^{-1}\left(\frac{z}{(1+r)C}\right)\right)\right) \quad (33)
 \end{aligned}$$

The density over the realized assets of the bank is the derivative of (33) with respect to z . Figure 10 plots the densities over asset realizations, and shows how the density shifts to changes in the default probability ϵ (left hand panel) or to changes in ρ (right hand panel). Higher values of ϵ imply a first degree stochastic dominance shift left for the asset realization density, while shifts in ρ imply a mean-preserving shift in the density around the mean realization $1 - \epsilon$.

As discussed above, we will model the banks as taking its equity E as

given and adjusting the size of its loan book C and funding L so as to keep its probability of default to $\gamma > 0$. Since the bank is risk-neutral and maximizes profit, the VaR constraint binds whenever expected profit to lending is positive. The constraint is that the bank limits lending so as to keep the probability of its own failure to γ . Since the bank fails when the asset realization falls below its notional liabilities $(1 + f)L$, the bank's credit supply C satisfies

$$\Pr(w < (1 + f)L) = \Phi\left(\frac{\Phi^{-1}(\varepsilon) + \sqrt{1-\rho}\Phi^{-1}\left(\frac{(1+f)L}{(1+r)C}\right)}{\sqrt{\rho}}\right) = \gamma \quad (34)$$

Re-arranging (34), we can derive an expression for the ratio of notional liabilities to notional assets for the bank.

$$\frac{\text{Notional liabilities}}{\text{Notional assets}} = \frac{(1 + f)L}{(1 + r)C} = \Phi\left(\frac{\sqrt{\rho}\Phi^{-1}(\gamma) - \Phi^{-1}(\varepsilon)}{\sqrt{1-\rho}}\right) \quad (35)$$

From here on, we will use the shorthand φ to denote this ratio of notional liabilities to notational assets. That is,

$$\varphi(\gamma, \varepsilon, \rho) \equiv \Phi\left(\frac{\sqrt{\rho}\Phi^{-1}(\gamma) - \Phi^{-1}(\varepsilon)}{\sqrt{1-\rho}}\right) \quad (36)$$

φ can be seen as a normalized leverage ratio, lying between zero and one. The higher is φ , the higher is bank leverage and the greater is credit supply.

We can solve for bank credit supply C from (35) and the balance sheet identity $C = E + L$ to give

$$C = \frac{E}{1 - \frac{1+r}{1+f} \cdot \varphi} \quad (37)$$

Figure 11 plots bank credit supply as a function of the lending rate r . It is an upward-sloping curve with an asymptote when the banking sector leverage becomes large.

By combining the credit supply function given above with the credit demand functions for financing working capital, we can solve for the equilibrium

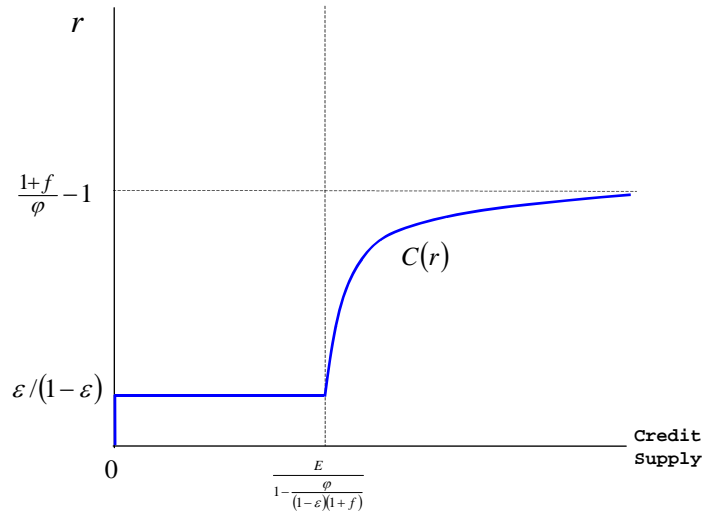


Figure 11. Bank credit supply curve

borrowing rate r as the rate that clears the credit market. Any shock that reduces banking sector credit, such as credit losses that reduce bank equity E or a delveraging episode where banks reduce leverage and lending for given equity E , will result in a shift upward of the credit supply curve, leading to an increase in the borrowing rate r . The increased borrowing rate will then kick in motion the combination of reduced productivity, reduced wages and lower offshoring activity described in Sections 2 and 3.

We summarize our main result as follows.

Proposition 1 *A reduction in banking sector credit results in (1) an increase in the borrowing rate r (2) fall in output Y , (3) fall in productivity per worker, (4) fall in the wage w and (5) fall in the offshoring activity of firms.*

A corollary of (5) is that trade volumes will also fall, with the decline being magnified by the extent of vertical specialization of production as formalized by the length of production chains.

5 Concluding Remarks

Financial shocks that raise the cost of financing can have a substantial impact on macro variables through their impact on the cost of working capital. Our results derive from the feature that production takes time and the operation of a production chain entails heavy demands on financing. One consequence of this feature is that long production chains are sustainable only when credit is cheap, and chains that have become over-extended are vulnerable to financial shocks that raise the cost of borrowing. The financial crisis of 2007-2009 fits this description well.

Our model has been deliberately stark so as to highlight the role of working capital. We have abstracted away from many of the standard ingredients that have been used to model financial frictions in the macro literature. We have no fixed capital, no savings decisions, nor labor supply decisions. Having turned off these intertemporal and labor supply choices, we can isolate the effect of working capital better.

Although much of the discussion of financial frictions in the economy has focused attention on fixed investment, the components of working capital have fluctuated in a much more volatile way in the recent crisis. Figure 12 plots the annual capital expenditure of non-farm, non-financial firms in the United States, taken from the Federal Reserve's Flow of Funds series. Fixed investment fell in 2008 and 2009, but the percentage falls are small (especially in 2008). Inventories fell much more dramatically during the crisis, turning negative in 2008 and especially in 2009.

Our results also relate to the literature on financial frictions and their impact on macro activity. Gilchrist, Yankov, and Zakrajsek (2009) documents evidence that credit spreads have substantial effect on macro activity measures, and Hall (2010, 2011) models fluctuations in fixed investment through financing costs that are amplified by distortions in the product market. Ohanian (2010) is more skeptical about the effect of financial frictions citing the large cash holdings in firms, and the fact that firms rely mostly on internal

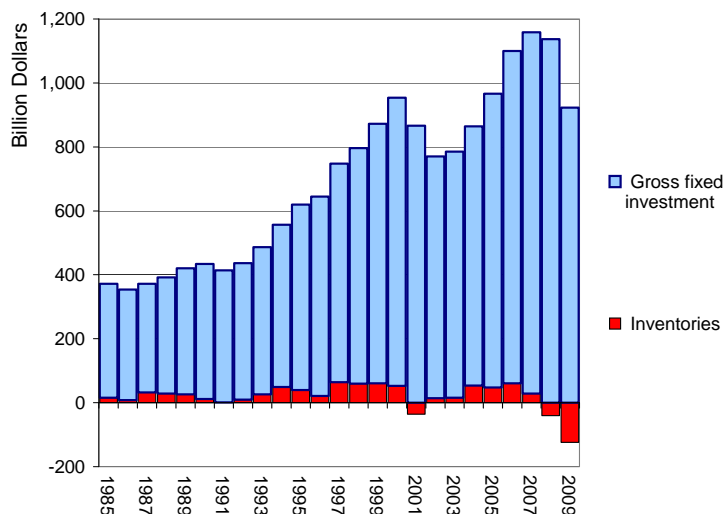


Figure 12. Capital Expenditure of U.S. Non-Financial Firms (Source: Federal Reserve Flow of Funds, Table F102)

funds for fixed investment. The business cycle accounting literature in the manner of Chari, Kehoe and McGrattan (2007) finds lack of clear-cut quantitative evidence on deviations of fixed investment relative to the benchmark model. The contribution of our paper relative to this large literature is to highlight the working capital channel of financial frictions, and show how financing cost can impact output even in a model without physical capital or labor/product market distortions.

Working capital is more familiar to the literature on financial crises, especially those in emerging economies. Calvo, Izquierdo and Talvi (2006) document several stylized facts that appear consistently during financial crises, such as the fact that credit and total factor productivity drop sharply with the onset of the crisis but that employment drops to a lesser extent. Our model addresses these features, and our deliberately stark modeling choices enable a relatively clean identification of the working capital channel of financial shocks. Neumeier and Perri (2005) and Mendoza (2009) have emphasized working capital shortages in their models of fluctuations in emerging eco-

nomics. although their modeling relies on quantitative constraints on firms' financing. Raddatz (2006, 2010) presents cross-section evidence using firm level data that financial shocks affect firm level financing needs as revealed through components of working capital.

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