Sustaining Production Chains Through Financial Linkages

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The importance of sectoral linkages and complementarities for economic development are timeless themes, discussed in the classics of the subject such as Wassily Leontief (1936) and Albert O. Hirschman (1958). In the same spirit, development economists have studied the technological challenges in sustaining complex production processes. The O-ring theory of Michael Kremer (1993) and the role of intermediate goods and complementarity discussed by Antonio Ciccone (2002) and Charles I. Jones (2011) are examples.

As well as technological constraints, incentive and hold-up problems that operate within the production chain may also restrict complex production processes. A glaring example is the breakdown of production chains in the post-Soviet economies in the 1990s. Olivier Blanchard and Kremer (1997) and Dalia Marin and Monika Schnitzer (2005) attribute the drastic fall in output to hold-up problems and the recursive nature of the rent-seeking along the production chain that undermined pre-existing production chains of the Soviet-era command economy.

In the same spirit, our focus will be on the incentive problems faced by firms in a production chain and the financial counterparts of the relationships between firms as suppliers and customers. Firms hold large interlocking claims and obligations through inter-firm credit, with accounts receivable exceeding 20% of corporate assets in many countries (on which more below). However, far from being a measure of inefficiency, such large claims may have an economic rationale. The chain of interlocking claims and obligations that arise from delays in settling transactions bind the interests of individual firms with that of the production chain as a whole and thereby mitigate the hold-up problems. In this sense, financial linkages through delayed payments serve as the "glue" that ties firms together in the supply chain. The downside, however, is that firms need more working capital to participate in production, and such resources are not always available to developing or transition economies.

We model "recursive moral hazard" that places limits on the complexity of production chains. In this setting, delayed payments that build up implicit inter-firm credit relationships can mitigate incentive problems, and the efficient benchmark can be achieved with sufficient stock of working capital. In this setting, the invoice price incorporates a repayment component for the implicit credit and hence can be substantially higher than the underlying fundamental transaction prices. Our results suggest that disentangling the real and financial components in the invoice price is important in understanding the cohesiveness of supply chains.

I. Production Chain

Consider the economy depicted in Figure 1. $N+1$ firms operate in a production chain where firm 0 sells the final output and firm $i+1$ supplies intermediate output to firm i. Each step of the production process takes one time period. Firm i incurs wage cost w_i, which cannot be deferred. The final good generates per period revenue $q > 0$, but there is a probability each period that the cash flow stops due to product failure. If all firms exert high effort, the product fails with probability π^H each period. If one or more exert low effort, the failure probability rises to π^L, where $\pi^L > \pi^H$. Cash flows before transfers are given in Figure 1.

The efficient benchmark is when the production chain is subject only to the technological break-even constraint, without any incentive problems within the chain. Viewed from date 0, the expected present value of wage costs for the

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		Firms				
		0	1	$\cdots$	$N-1$	N
date t	0					$-w_N$
	1				$-w_{N-1}$	$-w_N$
	$\vdots$			$\cdots$	$-w_{N-1}$	$-w_N$
	$N-1$		$-w_1$	$\cdots$	$-w_{N-1}$	$-w_N$
	N	$-w_0$	$-w_1$	$\cdots$	$-w_{N-1}$	$-w_N$
	$N+1$	$q-w_0$	$-w_1$	$\cdots$	$-w_{N-1}$	$-w_N$
	$N+2$	$q-w_0$	$-w_1$	$\cdots$	$-w_{N-1}$	$-w_N$
	$\vdots$	$\vdots$	$\vdots$		$\vdots$	$\vdots$

FIGURE 1. CASHFLOWS IN PRODUCTION CHAIN BEFORE TRANSFERS

production chain is given by

$$\frac{w_n}{\pi^H} + ... + \left(1-\pi^H\right)^N \frac{w_0}{\pi^H} \tag{1}$$

while expected output of the production chain is

$$\left(1-\pi^H\right)^{N+1} \frac{q}{\pi^H} \tag{2}$$

The technological break-even condition is that the net present value be non-negative:

$$\left(1-\pi^H\right) q \geq \sum_{k=0}^{N} \frac{w_k}{\left(1-\pi^H\right)^k} \tag{3}$$

Using (3) as the efficient benchmark, we examine "recursive moral hazard" in the chain using a multi-layered version of the contracting model of Bengt Holmstrom and Jean Tirole (1997). A firm either exerts high effort or low effort. Low effort yields private benefit, but is detrimental to the success of the final output. Firm i receives p_i every period from firm $i-1$ for its output and pays p_{i+1} to firm $i+1$ for its input. Low effort results in private benefit of bw_i for firm i, where $b > 0$ is common to all firms and assumed to be large so that $b > \pi^L - \pi^H$. If firm i shirks today, the probability of product failure increases to π^L once the final good goes on sale $i+1$ periods ahead. When firm i has exerted high effort at every date in the past, the expected payoff from exerting high effort at all subsequent dates is

$$\left(p_i - p_{i+1} - w_i\right) \sum_{\tau=0}^{\infty} \left(1-\pi^H\right)^\tau \tag{4}$$

The incentive compatibility constraint against a one period deviation to low effort by firm i is

$$p_i \geq p_{i+1} + (1+b_i)\, w_i \tag{5}$$

where

$$b_i \equiv b \cdot \frac{\pi^H}{\left(\pi^L - \pi^H\right)\left(1-\pi^H\right)^i} \tag{6}$$

The working paper version of this article (Kim and Shin (2010)) contains the derivations, as well as showing that (5) is sufficient to deter other deviations from high effort.

The constraint (5) captures the *recursive moral hazard* in our model. The payment to firm i must be sufficiently large so as to induce it not to shirk, but the payment to firm i also incorporates the rent captured by its supplier firm, $i+1$.

The optimal contract solves for the prices $\{p_i\}$ that maximize the expected profit of firm 0, subject to the incentive compability constraints (5) and participation constraints of all upstream firms. Equivalently, the optimal contract solves a chain of overlapping bilateral contracting problems, where firm i acts as principal with respect to firm $i+1$, but acts as agent with respect to firm $i-1$.

When firms pay their suppliers immediately, the participation constraints are satisfied automatically whenever incentive compability (5) holds (see Kim and Shin (2010) for details). Therefore, the solution is given by payments $\{p_i\}$ that maximize the expected profit for firm 0 subject only to the incentive compatibility constraints. Recursive substitution in (5) gives

$$p_i = \sum_{k=i}^{N} (1 + b_k)\, w_k \tag{7}$$

The prices $\{p_i\}$ are higher than production costs, reflecting rents for all upstream firms. Production of the final good is feasible only when $\left(1 - \pi^H\right) q \geq p_1 + w_0$, and the optimal contract minimizes p_1 subject to the constraints. Equation (7) illustrates well how long production chains are difficult to sustain, not only because of the technological/logistical concerns but also because of the viability of production in the face of incentive problems.

In particular, there is now the possibility that the production chain is viable technologically, but is not sustainable due to recursive moral hazard and the resulting rise in the price of intermediate goods. Even if the break-even constraint (3) is satsified, the production chain becomes unviable when expected revenue $\left(1 - \pi^H\right) q$ is insufficient to meet the costs that incorporate the rents along the chain, given by $w_0 + \sum_{k=1}^{N} (1 + b_k)\, w_k$. Since $b_k > 0$ for all k, the gap between the technologically efficient organization of production and the incentive compatible organization of production can be very large when the terms $\{b_k\}$ are large.

II. Achieving Efficiency Through Delay

Delay in payments can mitigate the incentive problems within the production chain by building up interlocking claims and obligations. The downside is that firms need substantial working capital to cope with long delays.

Consider delays in the payment where firm $i-1$ pays firm i after a delay of d_i periods. In return, firm $i-1$ pays for this delay by amortizing its accounts payable (its debt to firm i) by means of a perpetuity with constant payment $a_i\, p_i$. The "a" stands for "amortization". The idea is that the steady state payments between firms incorporates an implicit repayment flow for the trade credit that has been granted between firms. The amortization payment will be the acturially fair repayment for the trade credit granted between firms.

The *invoice price* is the sum of the underlying sale price and the amortization cost, given by $(1 + a_i)\, p_i$. With amortization payments, the incentive compatibility constraint is given by $(1 + a_i)\, p_i \geq (1 + a_{i+1})\, p_{i+1} + (1 + b_i)\, w_i$, or

$$p_i \geq \frac{1}{1 + a_i} \sum_{k=i}^{N} (1 + b_k)\, w_k \tag{8}$$

The optimal contract solves for $\{p_i\}$ and $\{a_i\}$ that maximize firm 0's profit subject to incentive compatibility (IC) and participation (IR) constraints for upstream firms. Delayed payments mean that the IC and IR constraints are now linked. If the IR constraint is slack, it is possible to relax the IC constraint by accumulation of larger accounts receivable.

The participation constraint requires firms to break even in expected terms. Firm i's cash flows are the combination of three risky perpetuities. It has wage cost $-w_i$ per period, starting immediately, it has revenue $(1 + a_i)\, p_i$ per period, starting after a delay of d_i periods, and it has input cost $-(1 + a_{i+1})\, p_{i+1}$ per period, starting with a delay of $d_{i+1} - 1$ periods. Thus, the expected net present value of firm i's cash flows is

$$\begin{aligned} V_i \equiv\ & -\frac{w_i}{\pi^H} + \left(1 - \pi^H\right)^{d_i} \frac{(1 + a_i)\, p_i}{\pi^H} \\ & - \left(1 - \pi^H\right)^{d_{i+1}-1} \frac{(1 + a_{i+1})\, p_{i+1}}{\pi^H} \end{aligned}$$

The participation constraint for firm i is that $V_i \geq 0$.

Letting (8) hold with equality and setting $V_i = 0$ for all firms, we can solve for the optimal pattern of delays $\{d_i\}$ and transactions prices $\{p_i\}$ along the chain in recursive fashion, backward from firm N. The solution for the pattern of delays $\{d_i\}$ and transactions prices $\{p_i\}$ can be obtained in closed form as follows.

$$d_i = \frac{\ln\left[\sum_{k=i}^{N} \frac{w_k}{\left(1-\pi^H\right)^{k-i}}\right] - \ln\left[\sum_{k=i}^{N} (1+b_k) w_k\right]}{\ln\left(1-\pi^H\right)}$$

$$p_i = \sum_{k=i}^{N} \frac{1}{\left(1 - \pi^H\right)^{k-i+1}} w_k$$

When $i = 0$ we have $p_0 = q$, giving the efficient benchmark. Say that the production chain is *technologically viable* whenever the benchmark efficiency condition (3) holds. Say that the production chain is *sustainable* if the expected profit of firm 0 is non-negative under the optimal

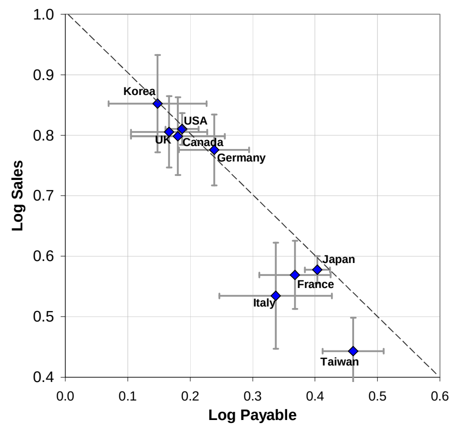

FIGURE 2. COEFFICIENTS OF OLS REGRESSIONS OF (10) (SOURCE: KIM AND SHIN (2010))

contract. We thus have the following proposition.

PROPOSITION 1: *For any technologically viable production chain, there is a profile of delays* $\{d_i\}_{i=1}^N$ *such that the production chain is sustainable.*

The introduction of accounts receivable and payable reduces total rents along the production chain enabling longer production chains to be feasible. Indeed, Proposition 1 suggests that the technologically efficient outcome is achievable provided firms have enough working capital by accumulating inter-firm credit inside the chain.

Our framework highlights the distinction between the *invoice price* $(1 + a_i)\, p_i$ and the *fundamental price* p_i. The invoice price incorporates the implicit cost of servicing debt between firms. The difference between accounts receivable and payable must be financed by the firm's working capital. It can be shown that

$$a_i p_i = a_{i+1} p_{i+1} + \beta_i w_i \tag{9}$$

where $\beta_i = b_i - (\pi^H / (1 - \pi^H))$. The working capital necessary to sustain the production chain is captured in β_i, which in turn reflects the severity of the recursive moral hazard b_i. Thus, longer production chains entail greater demands on working capital, and firms that are higher up in the production chain are burdened more by the need to hold working capital.

PROPOSITION 2: *Working capital is higher for firms that are further upstream.*

Michael Gofman (2009) finds evidence supporting this proposition for several manufacturing sectors in the United States.

III. Cobb-Douglas Representation

The working paper version of this article derives the following Cobb-Douglas representation of receivables.

$$\ln[\text{receivable}] = \alpha + \varepsilon \ln\left[\text{payable}\right] + (1 - \varepsilon) \ln[\text{sales}] \tag{10}$$

Firms' receivables are stakes in the project as a whole. If firm i is large relative to firm $i+1$, receivables are explained mainly by firm i's *sales* rather than by its *payables*. For this reason, the elasticity ε is lower in those production chains where firm size increases rapidly going downstream.

The working paper version of this article investigates results of country-level cross-section OLS regressions of (10) for manufacturing firms in Canada, France, Germany, Italy, Japan, Korea, Taiwan, U.K. and U.S. Figure 2 plots the coefficients with the standard errors indicated by the crosses.

The estimates for most countries lie on, or close to the diagonal line in Figure 2, suggesting that the Cobb-Douglas representation with constant returns to scale may be a promising basis for more detailed investigations. Japan, Taiwan and Italy have higher coefficients for log payable than for Korea, U.S., Canada and the U.K.

According to our model of inter-firm credit, if firm i is large relative to its supplier $i+1$, then its stake in the chain is explained by its own value-added rather than the input costs and rents that are earmarked for its upstream suppliers, implying a low value of ε. According to this interpretation, firms in Korea and the U.S. are more vertically integrated than in Japan, Taiwan and Italy. More detailed investigations may yield additional insights.

IV. Concluding Remarks

We have explored the hypothesis that financial relationships serve as the "glue" that bind firms into a chain. Our framework sheds light on the puzzle of why firms persist in maintaining large stocks of both accounts payable and receivable at the same time, even though some industries have substantial discounts for prompt cash settlement (see the survey evidence in Chee K. Ng, , Janet Smith and Richard Smith (1999)). Our approach also sheds light on why accounts payable and receivable are so large on corporate balance sheets. Raghuram Rajan and Luigi Zingales (1995, p. 1428) report that accounts receivable are 18% of total assets for U.S. firms, with higher numbers for Germany (27%), France (29%), Japan (23%), and the United Kingdom (22%).

The message of our paper is that industrial structure and corporate finance are inextricably linked.

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