How Inventory Is (Should Be) Financed: Trade Credit in Supply Chains with Demand Uncertainty and Costs of Financial Distress

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As an integrated part of a supply contract, trade credit has intrinsic connections with supply chain contracting and inventory management. Using a stylized model that explicitly captures the interaction of firms’ operations decisions and financial risks, this paper attempts to develop a deeper understanding of trade credit from an operational perspective. Revolving around the question of what role trade credit plays in channel coordination and inventory financing,* we demonstrate that with demand uncertainty, trade credit enhances supply chain efficiency by serving as a risk-sharing mechanism. Two forces determine the optimal trade credit terms: the sales motive (increasing sales through risk-sharing) and the financing motive (minimizing costs of financial distress through financial diversification, that is, employing multiple financing sources). Facing a trade credit contract, the retailer finances his inventory using a portfolio of cash, trade credit, and short-term debt, and the structure of this inventory financing portfolio depends on the retailer’s leverage† and bargaining power. Additionally, our model suggests that financial diversification provides an alternative explanation for the decentralization of some supply chains and the use of factoring in accounts receivable management. Finally, using a sample of firm-level data from Compustat, we find that the inventory financing pattern our model predicts exists in a wide range of firms.

Key words: trade credit; supply chain management; inventory; newsvendor model; supplier financing; costs of financial distress; debt structure; financial constraint

History:

1. Introduction

Appearing in firms’ balance sheets as accounts receivable (on the seller’s side) and accounts payable (on the buyer’s side), trade credit is a type of credit sellers extend to buyers, allowing the latter to purchase goods from the former without immediate payment. Empirical evidence shows that trade credit is an important source of external financing. For example, Rajan and Zingales (1995) report that in a sample of U.S. nonfinancial firms, trade credit amounts to 15 percent of firms’ total assets,

* The term “inventory financing” throughout this paper applies to firms’ decision on how to finance inventory instead of how to use inventory as collateral to gain more loans.

† “Leverage” refers to the use of external financing, including trade credit and bank loans, to supplement investment, such as inventory investment in our model.
whereas debt in current liabilities accounts for only 7.4 percent. Using a sample of large public retailers in North America, we find that accounts payable alone amounts to approximately one sixth of total assets and one third of total liabilities. When examining individual firms, we find that, for example, Wal-Mart had $28.8 billion accounts payable in its balance sheet on January 31, 2009, amounting to 75 percent of its total inventory ($34.5 billion). Circuit City, the consumer electronic retailer that filed for bankruptcy in November 2008, had 48 trade creditors out of its 50 largest unsecured creditors. The three largest trade creditors of Circuit City (Hewlett-Packard, Samsung, and Sony) held total claims of $284 million, accounting for 12 percent of its total liabilities ($2.32 billion). Because of its wide usage, trade credit has long been studied in the areas of economics, finance, and accounting. Researchers have proposed many theoretical explanations for trade credit in various settings; however, despite its intrinsic connection to business operations, especially supply chain contracting and inventory management, trade credit has rarely been examined from an operational perspective.

Common wisdom in operations suggests demand uncertainty and early commitment to order quantities leave the retailer with significant inventory risks, hence forcing the retailer to order less than would be optimal for the supply chain. As a type of inter-firm contracts, trade credit has unique advantages in mitigating this problem: not only are the amount and timing of trade credit closely associated with purchase and inventory decisions, but the repayment of trade credit is contingent on the demand realization, similar to many risk-sharing mechanisms in channel coordination. Therefore, a reasonable conjecture is trade credit is extensively used, at least partially, to reduce the widespread inefficiency in supply chains.

Figure 1 presents a cursory empirical investigation that provides initial supports to our conjecture. In this figure, each point represents the median payable days and inventory days of a subcategory of retailers (the number next to the point represents the North American Industrial Classification System code of this subcategory; for example, 441 represents “Motor Vehicle and Parts Dealer”), and the dotted line represents the linear fit (numbers in the parentheses are t-statistics). The first observation is that retailers carry large amounts of inventory, implying that inventory risks can be significant. The second is that the slope ($\beta = 0.26$, t-stat = 3.01) and coefficient of determination ($R^2 = 47\%$) of this OLS regression clearly suggest that the variation in payable amounts is closely related to that in inventory.

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1 Section 5 explains details of the data set and selection criteria.
Another important observation from Figure 1 is that many firms have payable days longer than one month. Given the fact that firms in our sample normally have easy access to other financing sources, they probably would not use large amounts of trade credit if trade credit is expensive. In contrast, survey data (Ng el al. 1999) alludes that the implicit interest on trade credit is surprisingly high. For example, as an often used trade credit term, “2/10 net 30” (trade credit has to be paid off in thirty days; if paid in ten days, a two percent discount applies), implies an annualized interest of about 44 percent if the early discount is forgone. At a minimum, we can conclude from these conflicting pieces of evidence that the interest on trade credit is widely dispersed; thus two natural questions follow: Why do some companies enjoy cheap trade credit while others face trade credit with high cost? What drives the interest on trade credit?

Despite its wide and common usage, trade credit alone is insufficient to finance inventory, as shown in Figure 1. Hence retailers must employ other internal or/and external sources to finance inventory. Therefore, when discussing how inventory is financed, we are looking at a portfolio that may consist of cash, trade credit, and short-term debt. In this context, questions of interest include: What is the structure of this inventory financing portfolio? How does this structure change according to such factors as the retailer’s and the supplier’s characteristics and the overall efficiency of the financial market?

To answer the above questions, we build a stylized model based on the classical “selling to the newsvendor” setting. The upstream firm, which we call the supplier, behaves as the leader in the Stackelberg game, and the downstream firm (the retailer) as the follower. To explicitly model financial constraints and related costs yet retain our focus on operations, we introduce a perfectly
competitive financial market in which agents (banks and factors) act solely as liquidity providers and make no excess profit. In determining payoffs on different financial claims, we emphasize an important issue associated with the possibility of default: costs of financial distress. Specifically, we assume that upon default, only a proportion ($\alpha$) of the value of the default claim is transferred to the creditor, while the rest ($1 - \alpha$) is lost as distress costs. With this setting, we focus on a particular contract form: the two-part trade credit contract, which is an abstraction of trade credit contracts commonly used in practice. In such a contract, the supplier offers two prices: a unit cash price, which is paid by the retailer to the supplier upon the transfer of the goods, and a unit credit price, which is paid upon the time agreed to by both parties. As our model has a single sales horizon, we assume trade credit is due at the end of the sales horizon. Besides trade credit, firms can use other external sources: the retailer can use a bank loan to finance inventory, and the supplier can either borrow a bank loan or use factoring (selling part of accounts receivable to a third-party factor) in order to finance production and provide trade credit. In the presence of multiple creditors, we assume the order of repayment (seniority) is the bank’s claim is paid off first and then trade credit.

Our model demonstrates that trade credit influences supply chain efficiency through two separate effects. First, similar to many other channel coordination mechanisms, trade credit allows the retailer to share inventory risks with the supplier, hence inducing a higher order quantity from the retailer. This effect, which we call the sales motive, incentivizes the supplier to offer cheap trade credit. Second, through the financing motive, trade credit transfers some of the distress costs from the retailer to the supplier, allowing the former to further increase the order quantity. Unlike the sales motive, the financing motive is a double-edged sword. Although it encourages the supplier to offer trade credit to further boost sales, it also incentivizes the supplier to limit the amount of trade credit by adjusting its price. Combined, these two effects not only explain why the supplier lends to the retailer, but also rationalize why the price of trade credit is dispersed.

Related to inventory management, our model leads to an inventory financing pattern similar to the pecking order theory (Myers 1984) in corporate finance. The retailer first will use internal cash to finance inventory. When internal resource is insufficient, the retailer starts to use external financing, that is, operates with leverage. When moderately leveraged, the retailer will be offered cheap trade credit, which becomes the primary external source in inventory financing. With increasing

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4 The word “bank” is used broadly in this paper; it refers to any financial institution or investors. Similarly, “bank loan” refers to any institutional funding or public debt.
leverage, the retailer will face more expensive trade credit, thereby diversifying external financing between trade credit and a bank loan.

Our studies also illustrate how trade credit affects profit allocation between the supplier and the retailer, and vice versa. When trade credit is unavailable, the supplier, facing a financially constrained retailer, is forced to lower the wholesale price and therefore suffers from the retailer’s financial weakness. By introducing trade credit, however, the supplier can increase the wholesale price and extract more profit from the highly levered retailer. Conversely, the retailer’s reservation profit, or, equivalently, bargaining power influences the trade credit contract the supplier offers. With the retailer’s bargaining power increasing, the sales motive is weakened, and the retailer will face more expensive trade credit and consequently rely more on a bank loan to finance inventory.

Moreover, we find that through financial diversification, factoring can further improve the efficiency of trade credit and alleviate the supplier’s financing pressure. Similarly, properly designed contracts allow a decentralized supply chain to outperform the integrated chain, creating what we call the super-coordination effect. We believe this effect provides an alternative reason (e.g., coordination costs) to explain why vertical integration is not always preferred.

Not only do our studies provide a novel explanation of trade credit, but they also draw implications consistent with previous empirical findings, for example, Giannetti et al. (2008). To provide more support for our theory, we conduct empirical studies using firm-level data from Compustat. We report basic facts on trade credit usage, which suggest that in practice, trade credit may be far more flexible than the rigid contract terms quoted in many empirical studies. To identify the inventory financing pattern our model predicts, we design a test that isolates the effect of leverage on the composition of the inventory financing portfolio. Results show that the amounts of trade credit and short-term debt used to finance inventory change according to the company’s leverage in the exact way our model suggests.

The purpose of this paper is to understand the role trade credit plays in supply chains, thereby motivating two crucial assumptions in our model. First, although the classical newsvendor model is normally used in a single inventory decision setting, it should be viewed in a looser sense under our framework. Admittedly, a multiple-period inventory model might be more realistic; however, we believe that by capturing the effect of demand uncertainty and early commitment on inventory decisions in a concise fashion, a newsvendor-based model serves our purpose precisely. Second, although the most obvious justification for using a single parameter $\alpha$ to model financial distress comes from the direct costs of financial distress, which normally include legal cost, monitoring cost, and so on, $\alpha$ can also be seen in general as a proxy of the efficiency of the financial market, or
agents’ risk-aversion towards default. Our results also show how this assumption, together with the seniority arrangement, captures the incentive for financial diversification.

Lying in the interface of operations and finance, our work is closely related to many areas in both subjects, including supply chain contracting and inventory management in operations, and trade credit in finance. In the area of supply chain contracting, Lariviere and Porteus (2001) provide an in-depth study of the classical price-only contract, which can be seen as a special case of our model, without trade credit and distress costs. For general literature on supply chain contracting, Cachon (2003) provides a thorough review.

The literature in inventory management is extensive. Representative works include Zipkin (2000) and Porteus (2002). In terms of a firm’s optimal inventory policy when receiving certain trade credit terms, we can trace back at least to Haley and Higgins (1973), who study how a company makes order quantity and payment time decisions simultaneously under an EOQ model. Recently, Gupta and Wang (2009) extend the above result by introducing stochastic demand, and show that with exogenous wholesale price and trade credit terms, the firm should follow a state-dependent base-stock policy, the parameters of which are determined by trade credit terms. Buzacott and Zhang (2004) examine a related model of a firm’s inventory decision when the company uses asset-based financing and the bank is a strategic player.

The research on trade credit, viewed mainly as a financing decision, largely attributes to financial economists. Among various theoretical investigations, Schwartz (1974) proposes the financing motive theory, which states that when sellers have easier access to capital markets than their customers, they tend to pass along this cheaper credit to their customers using trade credit. Emery (1984) extends this theory by introducing different borrowing and lending rates as a financial market imperfection. In the same vein, our model explains that the relatively strong financial position of the upstream firm partially stems from the fact that in a supply chain, the downstream firm faces demand uncertainty directly. Our work is also closely related to a new stream of literature that focuses on the role of trade credit in default and liquidation. Frank and Maksimovic (1998) and Longhofer and Santos (2003), for example, argue that suppliers have an advantage in liquidating goods in case of their buyers’ default, whereas Wilner (2000) and Cuñat (2007) suggest that suppliers are more willing to offer help when their customers are in trouble (e.g., due to liquidity shocks), given their desire to continue business with those customers in the future. Our model, however, highlights that the advantage for suppliers has roots in that the possibility of default enables trade credit to act as a risk-sharing mechanism, possibly benefiting suppliers through larger sales. Other prevailing theories for trade credit include: transaction cost (Ferris 1981), peak load smoothing
(Emery 1987), price discrimination (Brennan et al. 1988), information asymmetry (Smith 1987), debt enforcement (Cuñat 2007), and quality control (Long et al. 1993, Kim and Shin 2007). To test the above theories, researchers have conducted numerous empirical tests. Among them, Petersen and Rajan (1994, 1997) use a set of small business survey data to compare different theories, concluding that trade credit is likely to serve multiple purposes. Ng et al. (1999) conduct a survey of trade credit terms on a set of large companies. Giannetti et al. (2008) relate trade credit to product characteristics and document several important empirical regularities, some of which lend support to our model.

As an additional research stream, the interface of operations and finance has recently received fast-growing attention. Many of the papers in this stream, including Li et al. (2005), Babich and Sobel (2004), and Xu and Birge (2004, 2006, 2008), focus on the joint operational and financial decision-making in individual companies and motivate different departures from the seminal irrelevance result of operational and financial decisions in Modigliani and Miller (1958).

Some recent papers start to look at how financial constraints and financing sources influence supply chain performance. Zhou and Groenevelt (2008) study the case when the supplier provides financial subsidies to a financially constrained retailer. Dada and Hu (2008) study a cash-constrained retailer’s optimal ordering quantity when a bank, as the Stackelberg leader, tries to maximize profit. Gupta (2008) tries to determine the optimal rate of trade credit, when the wholesale price is given. Lai et al. (2009) discuss whether a cash constrained supplier should operate in pre-order or consignment mode. Kouvelis and Zhao (2009), whose work shares some similarities with ours, compare supplier financing with bank financing and conclude that supplier financing is superior. Our model, however, by introducing distress costs and the interaction of multiple creditors, is able to explain a broader range of phenomena, including the structure of the inventory financing portfolio, the rationale for the existence of both cheap and expensive trade credit, and the roles of factoring and decentralization in supply chains.

Our paper contributes to the literature in several ways. First, we show that trade credit as a supply chain mechanism improves supply chain efficiency and provides more flexibility in profit allocation. Second, by modeling demand uncertainty and its influence on firms’ borrowing rates explicitly, we endogenize the financing motive theory. Third, our model predicts the structure of the inventory financing portfolio, which is validated by our empirical tests. This result can be related to two important static capital structure theories: the trade-off theory (Modigliani and Miller 1958, Miller 1977) and the pecking order theory. Fourth, we show that financial diversification may serve
as an alternative reason for why vertical integration is not always preferred, as well as for why companies use factoring as a means to manage accounts receivable.

The rest of the paper is organized as follows: in the next section, we lay out the basic setting that models a supply chain with financial constraints and distress costs. Using the integrated chain and the decentralized chain with price-only contract as benchmarks, we identify the negative effect of financial constraints and distress costs on supply chains. In section 3, we introduce a two-part trade credit contract and study the retailer’s response to this contract. Section 4 studies the optimal trade credit contract, the influences of such factors as the retailer’s internal resource and bargaining power on the profits of different parties in the supply chain, the structure of the inventory financing portfolio, and the usage and price of trade credit, as well as how factoring and decentralization benefit the supply chain. Section 5 presents both basic facts about trade credit usage in the retail industry and empirical tests on the composition of inventory financing portfolio. Section 6 concludes the paper and proposes possible extensions.

2. The Basic Setting and Benchmarks
We consider a simple supply chain consisting of a supplier (S, with pronoun, “she”) and a retailer (R, with pronoun, “he”), between whom a single type of goods is produced and transferred.\(^5\) Figure 2 illustrates the sequence of events.

**Figure 2** Sequence of Events

At the beginning of the first period, the supplier proposes a supply contract (price, credit terms, etc.), based on which the retailer determines an order quantity \(x\). The supplier then starts to

\(^5\) Although most retailers sell goods provided by multiple suppliers, in some industries, an exclusive supplier is common; for example, auto dealers normally purchase from a single manufacturer.
produce at a unit cost $c$, which is expended at the end of the first period. At the same time, the goods produced are delivered to the retailer, who starts to sell them at price $p > (1 + r_f)c$ during the second period ($r_f$ is the risk-free rate during the second period; without loss of generality, we assume $r_f = 0$ in this paper). As in the classical “selling to the newsvendor” model, the retailer faces a stochastic demand $\xi$ with support $[0, +\infty)$, cumulative distribution function (CDF) $F(\cdot)$. Other notations of the probability distribution include: complimentary CDF (CCDF) $\bar{F}(\cdot)$, probability density function (PDF) $f(\cdot)$, failure rate $h(\cdot)$, and generalized failure rate $g(\cdot)$. Dealing with a problem similar to that in Lariviere and Porteus (2001), we also assume $\xi$ has an increasing generalized failure rate distribution (IGFR). All unmet demand is lost, and all leftover inventory is salvaged at price $s = 0$. No penalty with lost demand is incurred. At the end of the second period, all revenues are realized.

Unlike the classical model, we assume both the supplier and the retailer face financial constraints, thereby, when seeking for external financing (e.g., a bank loan), neither is unable to borrow at a constant interest rate. Specifically, we assume at the beginning of the first period, the supplier and retailer have cash $K_s$ and $K_r \geq 0$ respectively. Without loss of generality, we assume firms can use nothing but future revenue to back external financing, and the cash position serves as a proxy of the total amount of internal resource the firm can use to finance inventory. Similar to Xu and Birge (2004), we assume that when the realized revenue is insufficient to cover the amount due, the firm defaults on the claim and all realized revenue of the firm is liquidated, $(1 - \alpha)$ of which is lost as distress costs and the rest of which goes to the creditors. Besides this imperfection, we assume the existence of a perfectly competitive financial market and the absence of tax effects. Throughout this paper, we assume complete information, that is, every party knows and agrees on the demand distribution, and each other’s cash position. Although the demand distribution is common knowledge, we assume the realized demand is not contractible. In addition, we assume all parties are risk neutral (or all probability distributions are given under a risk-neutral or equivalent martingale measure). Under those assumptions, the bank loan should be priced so the bank’s (discounted) expected payoff equals the borrowed amount.

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6 When the firm has other collaterals, it might first borrow a secured loan against the collaterals, which is different from the unsecured financing on which we want to focus here.

7 This assumption relates to some complicated issues in the bankruptcy process. First, we assume only the short-term claim used in procurement goes into default. We do not assume the firm as a whole is liquidated, leaving the collateral by which other claims are secured untouched. Because such an assumption requires us to consider how interests should be allocated among different creditors, it is beyond the scope of this paper. A default could also lead to restructuring and reorganization of the firm, however, to fully address this possibility, the firm’s continuing activity needs to be modeled explicitly, which again is beyond the scope of this paper. The above two issues of the seniority of claims and the possibility of continued operations are both quite important and will be addressed in future work.

8 As an exception, section 4.3 assumes that the supplier can contract on the realized demand while the bank cannot.
With this framework, we start by exploring some basic properties of the integrated chain, which is not only used in the traditional supply chain literature as a benchmark to evaluate the decentralized chain’s performance, but also serves as the basic building block of our model with trade credit.

### 2.1. Loan Pricing, Debt Capacity, and Distress-Adjusted Distribution

Under the above setting, the chain faces a newsvendor problem with initial cash position $K_c = K_s + K_r$. At the beginning of the first period, the chain decides to produce $x_c$ units, and sells the products during the second period. Clearly, when $K_c \geq cx_c$, internal cash is sufficient and the centralized firm is indifferent between borrowing or not. Considering the transaction cost related to the loan (which we do not model explicitly), we assume the firm does not borrow in this case. However, when the total procurement cost $cx_c > K_c$, the firm borrows a bank loan with the amount of $D_c = cx_c - K_c$. The payment the bank receives is a function of the realized demand $\xi$ and the default threshold $\theta_c$: when $\xi \geq \theta_c$, no default occurs, and the bank receive the face value of the claim $p\theta_c$; when $\xi < \theta_c$, the bank loan defaults, and the bank receives $\alpha p\xi$, that is, the total realized revenue after distress costs. As we assume the financial market is competitive, the expected net present value of the loan is zero; therefore, the above quantities need to satisfy the following equation, which we refer to as the default threshold constraint:

$$p\theta_c F(\theta_c) + \alpha p \int_0^{\theta_c} \xi dF(\xi) = D_c = (cx_c - K_c)^+.$$  

(1)

The above equation clearly states that the firm’s default risk (quantified by $\theta_c$) is endogenously determined by the firm’s operational decision ($x_c$). An important concept related to borrowing amount is debt capacity, which is defined as the amount a firm can borrow up to the point where firm value no longer increases. In our context, we define debt capacity as the maximum amount of debt that sales can possibly support. Given this definition, we can link debt capacity with default threshold in the following result:

**Lemma 1.** If demand $\xi$ is IGFR, and its moments have $E(\xi^n) < \infty$, $\forall n \in \frac{1}{1-\alpha}$, there exists a finite debt capacity $p\theta_{dc}$, where $\theta_{dc}$ satisfies $g(\theta_{dc}) = \frac{1}{1-\alpha}$.

In the following sections, we focus on demand distributions satisfying IGFR, (or increasing failure rate, IFR in sections 3 and 4), and we only consider the order quantity that results in default threshold $\theta$ with $g(\theta) \leq \frac{1}{1-\alpha}$.

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9 In Lemma 8, we explicitly show that in the presence of distress costs the chain should borrow the minimum amount to cover production costs. This result is consistent with the pecking order theory (Myers 1984), which states that a firm prefers internally generated cash over external financing.
Reexamining equation 1, we define the marginal discount factor of the loan as \( \frac{\partial D(\theta)}{\partial \theta} = \bar{F}(\theta)(1 - (1 - \alpha)g(\theta)) \). Let \( F_d(\theta; \alpha) = \bar{F}(\theta)(1 - (1 - \alpha)g(\theta)) \), for \( \theta \in [0, g^{-1}(\frac{1}{1-\alpha})] \) (the subscript \( d \) is short for distress, as this function is only relevant with the possibility of default), we have \( D(\theta) = p \int_0^{\theta} F_d(\xi; \alpha) d\xi \). Obviously, this function shares many common features with a regular CCDF, including \( F_d(0; \alpha) = 1 \), and \( F_d(\theta; \alpha) \) is monotonically decreasing in \( \theta \). Moreover, at \( \alpha = 1 \), this function degenerates to the regular CCDF \( \bar{F}(\theta) \). Therefore, we call this function the \( \alpha \)-adjusted CCDF. Similarly, we define the \( \alpha \)-adjusted PDF \( f_d(\theta; \alpha) = -\frac{\partial F_d(\theta; \alpha)}{\partial \theta} \) and \( \alpha \)-adjusted failure rate \( h_d(\theta; \alpha) = f_d(\theta; \alpha)/\bar{F}_d(\theta; \alpha) \). Even though the distress adjusted distribution is a function of both \( \theta \) and \( \alpha \), we prefer to see \( \alpha \) as a parameter that defines the function instead of a variable of the function. Therefore, we use \( ' \) to represent \( \frac{\partial}{\partial \theta} \) for any function related to the distress adjusted measure. For example, we use \( f_d'(\theta; \alpha) \) to represent \( \frac{\partial f_d(\theta; \alpha)}{\partial \theta} \).

**Lemma 2.** \( F_d(\theta; \alpha), f_d(\theta; \alpha) \) and \( h_d(\theta, \alpha) \) defined above have the following properties:

1. \( F_d(\theta; \alpha) \) increases in \( \alpha \);
2. For \( \theta \) with \( h'(\theta) \geq 0 \) and \( g(\theta) \leq 1 \), \( f_d(\theta; \alpha) \) and \( h_d(\theta; \alpha) \) decrease in \( \alpha \); and
3. For \( \theta \) with \( h'(\theta), h''(\theta) \geq 0 \) and \( g(\theta) \leq 1 \), \( h_d'(\theta; \alpha) \) decreases in \( \alpha \).

When \( \alpha = 1 \), all distress-adjusted quantities degenerate to their regular counterparts, so, many properties of the original distribution can be transferred to the distress-adjusted version with some slight changes. For example, if we have \( h'(\theta) \geq 0 \) and \( h''(\theta) \geq 0 \), we can readily show that \( h_d(\theta; \alpha) \geq 0 \) for all \( \alpha \in [0, 1] \).

We can view \( F_d(\theta; \alpha) \) as a new probability measure, governing the lower tail of the demand distribution when the default is relevant. Clearly, distress costs work as if the demand distribution shifts toward 0, so that the CCDF decreases faster, the support shrinks to \( [0, g^{-1}(\frac{1}{1-\alpha})] \), and the probability density becomes larger for \( \theta \in [0, g^{-1}(1)] \). As seen in the following sections, by introducing this function, not only can we provide certain notation simplifications, but we can also explain many results and conditions more intuitively.

### 2.2. The Optimal Inventory Decision for the Integrated Chain

After exploring the above properties, we move to solve the optimization problem faced by the integrated chain, which can be discussed in two cases. First, when the order quantity \( x_c < \frac{\kappa_c^{nb}}{c}, \theta_c = 0 \).

Therefore, if \( K_c > \kappa_c^{nb} = c\bar{F}^{-1}(c/p) \), we have \( x^*_c = \bar{F}^{-1}(c/p) \), the optimal amount of the traditional newsvendor problem. In the second case, when \( x_c \geq \frac{\kappa_c^{nb}}{c} \), we can write the chain’s optimization problem as:

\[
\max_{x_c, \theta_c} \int_0^{x_c} \bar{F}(\xi) dF(\xi) - (c/p)x_c - (1 - \alpha)\delta(0, \theta_c)
\]
s.t. \[ p \int_{0}^{\theta_c} \tilde{F}_d(\xi; \alpha) d\xi = cx_c - K_c, \]

where \( \delta(a, b) = \int_{a}^{b} (\xi - a) dF(\xi) \). The first two terms of the objective function are the same as the classical newsvendor problem, whereas the third term corresponds to the distress costs carried by the chain and is related to \( x_c \) only indirectly through \( \theta_c \). Combining the two cases leads to the following optimality condition:

**Proposition 1.** (Lai et al. 2009 Proposition 2) The optimal solution \((x^*_c, \theta^*_c)\) satisfies:

1. when \( K_c \in [0, \kappa^{nb}_c) \), \((x^*_c, \theta^*_c)\) satisfies: \( p\tilde{F}(x^*_c) = c \frac{\overline{F}(\theta^*_c)}{\overline{F}(\theta^*_c)} \), and \( cx_c^* = K_c + p \int_{0}^{\theta^*_c} \tilde{F}_d(\xi; \alpha) d\xi \), and
2. when \( K_c \in [\kappa^{nb}_c, +\infty) \), \( x^*_c = \overline{F}^{-1}(c/p) \) and \( \theta^*_c = 0 \),

where \( \kappa^{nb}_c = c \overline{F}^{-1}(c/p) \).

**Corollary 1.** When \( K_c \in [0, \kappa^{nb}_c) \), \( x^*_c \) and \( \pi^*_c \) increase in \( K_c \) and \( \alpha \); \( \theta^*_c \) decreases in \( K_c \) and \( \alpha \).

Note that without distress cost \((\alpha = 1)\), \( x^*_c \) degenerates to the classical newsvendor solution, even with the financing constraint, which agrees with the irrelevance result in Modigliani and Miller (1958).

**Figure 3** Optimal Order Quantity \( x_c \), Bankruptcy Threshold \( \theta_c \), and Profit \( \pi_c \) as Functions of \( K_c \)

Figure 3 illustrates the above results. We assume \( c = 0.5 \), \( p = 1 \), \( \xi \sim \text{Unif}[0, 1] \), and \( \alpha = 0.5 \) (we use this set of parameters in all following numerical results). The x-axis represents the chain’s cash position normalized by \( \kappa^{nb}_c \). Clearly, with limited \( K_c \), the optimal quantity \( x^*_c \) is less than the traditional newsvendor quantity, as if the existence of distress costs makes the agent risk averse. Intuitively, this deviation allows us to explore other organizational (or contractual) structures that could potentially achieve better performance. We leave related issues to section 4.3.
2.3. The Decentralized Chain with Price-Only Contract and a Bank Loan

As another benchmark, in this section we assume the supplier only offers a price-only contract with cash payment. Under this contract, the retailer, facing a unit wholesale price \( w \), decides on an order quantity \( x_w \) and pays the supplier \( wx_w \) in cash upon delivery. Operating in a make-to-order mode, the supplier has no risk; therefore, the supplier’s cash position \( K_s \) is irrelevant to this decision. The problem the retailer faces is the same as that for the integrated chain, except for \( w \) as the wholesale price. The supplier’s problem can be discussed under two scenarios depending on the retailer’s financial constraint. First, if the retailer’s response to \( w \) is to order \( x_w \) with \( wx_w < K_r \), no external financing is used, and the retailer’s optimal response with the optimality condition \( \pi_w \). In this case, when \( K_r > \kappa_w^{nb} = px_w^{nb} \bar{F}(x_w^{nb}) \), with \( x_w^{nb} \) satisfying \( p \bar{F}(x_w^{nb})(1 - g(x_w^{nb})) = c \), the optimal solution is the same as in the classical price-only contract, that is, \( x_w = x_w^{nb} \), \( w = p \bar{F}(x_w^{nb}) = u^{nb} \).

On the other hand, when \( wx_w \geq K_r \), external financing may be needed. Substituting \( w = p \bar{F}(x_w)(1 - (1 - (1 - (1 - (1 - (1 - (1 - (1 - (1 - (1 - (1 - (1 - (1 = \frac{K_r / p + \int_0^{\theta_d} \bar{F}_d(\theta_w;\alpha) d\xi - cx_w}{F_d(\theta_w;\alpha)} \). Analysis on this program leads to the following results:

**Proposition 2.** \((w^*, x_w^*, \theta_w^*)\) are optimal if and only if
1. when \( K_r \in [0, \kappa_w] \), \((x_w^*, \theta_w^*)\) satisfies \( x_w^* \bar{F}(x_w^*) = (\theta_w^* + C(\theta_w^*)) \bar{F}(\theta_w^*) \) and

\[
\bar{F}(x_w)(1 - g(x_w)) = \left(\frac{c}{p}\right) \frac{\bar{F}(\theta_w)}{F_d(\theta_w;\alpha)} \left[1 + (1 - \alpha)g(\theta_w)\right](\theta_w + C(\theta_w)) \frac{\bar{F}(\theta_w)}{F_d(\theta_w;\alpha)},
\]

and \( w^* = p \bar{F}(x_w^*)(1 - (1 - (1 - (1 - (1 - (1 - (1 - (1 - (1 - (1 - (1 - (1 - (1 - (1 = \frac{K_r / p + \int_0^{\theta_d} \bar{F}_d(\theta_w;\alpha) d\xi - cx_w}{F_d(\theta_w;\alpha)} \).

2. when \( K_r \in [\kappa_w^{nb}, \kappa_w] \), \( x_w^* \bar{F}(x_w^*) = K_r / p, w^* = p \bar{F}(x_w^*), \text{ and } \theta_w^* = 0, \text{ and }

3. when \( K_r \in [\kappa_w^{nb}, \infty) \), \( x_w^* = x_w^{nb}, w^* = p \bar{F}(x_w^*), \theta_w^* = 0, \text{ and }

where \( x_w^{nb} \) and \( \kappa_w^{nb} \) are defined as above, and \( \kappa_w = px_w \bar{F}(x_w) \), where \( x_w \) satisfies \( \bar{F}(x_w)(1 - g(x_w)) = (c/p)[1 + (1 - (1 - (1 - (1 - (1 - (1 - (1 - (1 - (1 - (1 - (1 - (1 - (1 - (1 = \int_0^{\theta_d} \bar{F}_d(\theta_w;\alpha) d\xi - cx_w}{F_d(\theta_w;\alpha)} \).

**Corollary 2.** Under the optimal contract \((w^*, x_w^*, \theta_w^*)\), the monotonicity results of the optimal contract and profits \((\pi_w^* \text{ as the supplier’s profit, } \pi_w^* \text{ as the retailer’s profit, and } \pi_w = \pi_w^* + \pi_w^* \text{ as the chain’s profit}) summarized in Table 1.

We illustrate the above results with a numerical example. As Figure 4 shows, when \( K_r \) increases, \( x_w^* \) increases to the traditional price-only quantity \( x_w^{nb} \); the retailer borrows less, reducing default
Table 1  Monotone Results under the Optimal Price-Only Contract

<table>
<thead>
<tr>
<th>$K_r$</th>
<th>$w^*$</th>
<th>$x_w^*$</th>
<th>$\theta_w^*$</th>
<th>$\pi_w^*$</th>
<th>$\pi_s^*$</th>
<th>$\pi_c^*$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$(0, \kappa_w^b)$</td>
<td>↑</td>
<td>↑</td>
<td>↓</td>
<td>↑</td>
<td>-</td>
<td>↑</td>
</tr>
<tr>
<td>$(\kappa_w^b, \kappa_w^{nb})$</td>
<td>↓</td>
<td>↑</td>
<td>0</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
</tr>
<tr>
<td>$(\kappa_w^{nb}, \infty)$</td>
<td>→</td>
<td>→</td>
<td>0</td>
<td>→</td>
<td>→</td>
<td>→</td>
</tr>
</tbody>
</table>

Figure 4  Optimal Wholesale Contract with Bank Loan

The sudden drop of $x_w^*$ corresponds to the region $K_r \in [\kappa_w^b, \kappa_w^{nb}]$, where the retailer stops borrowing ($\theta_w^* = 0$) and only orders the amount allowed by his internal cash. In the right panel, the profits suggest that with a price-only contract, the retailer’s financial constraint actually hurts the supplier more than the retailer himself when the retailer has very limited internal resource. Moreover, the non-monotonicity in the retailer’s profit may incentivize the retailer to limit his cash position. As shown later, trade credit contract fixes this problem.

3. The Two-Part Trade Credit Contract

As section 2 shows, the existence of financial constraints and distress costs aggregates the inherent shortcoming of the price-only contract and further reduces supply chain efficiency. Trade credit, however, might alleviate these problems in two ways. First, the limited repayment power of the retailer allows the payoff of trade credit to depend on the realized demand. Trade credit, in this case, serves as a risk-sharing mechanism, which resembles many well-studied supply chain contracts. Second, trade credit can reduce the distress costs the retailer bears and further increase the retailer’s order quantity. To describe this logic qualitatively, we define an abstract contract that generalizes real-world trade credit contracts.

First, note that in practice, two basic forms of trade credit are often used: net terms (one-part terms) and two-part terms. Net terms have one parameter: the net period, which specifies when the full payment is due after delivery. Two-part terms are more complex and involve three
parameters: the discount period \((t_1)\), the net period \((t_2)\), and the discount percentage \((d_{tc})\). Upon delivery \((t = 0)\), a discount \(d_{tc}\) applies if the buyer pays within \(t_1\) days, and full payment is due at \(t_2\). According to Ng et al. (1999), most companies have a net period of 30 days, and the most commonly used two-part terms are \("2/10 net 30\)”. Combining the above two forms, we define the following stylized two-part trade credit contract:

**Definition 1.** A **two-part trade credit contract** consists of the following two elements:

1. A unit cash price \(w_1\) if the retailer chooses to pay cash upon delivery; and
2. A unit credit price \(w_2\), due at the end of the second period. The actual amount the supplier receives depends on the retailer’s cash availability and the realized demand \(\xi\).

Clearly, \(w_1\) and \(w_2\) should satisfy \(c \leq w_1 \leq w_2 \leq p\). The case with \(w_1 = w_2\) corresponds to net terms, and the case with \(w_1 < w_2\) to two-part terms with discount \(d_{tc} = 1 - \frac{w_1}{w_2}\). Note that despite its broad usage, trade credit is not the only form of supplier financing. For example, automobile manufacturers often finance their dealers through different programs. Our model can also cover these situations.

To respond to this contract, the retailer determines the order quantity paid by cash \(x_1\) (part of the cash amount \(w_1x_1\) may be financed by a bank loan) and credit \(x_2\) (the supplier will have accounts receivable with amount of \(w_2x_2\) in balance sheet). When \(x_2\) is confined at 0, this problem is equivalent to that in Lariviere and Porteus (2001).

### 3.1. How the Contract Works: Payoffs and Seniority

Note that the two-part trade credit contract is incomplete at this point. When receiving both trade credit and a bank loan, the retailer faces two creditors. Moreover, when providing trade credit, the supplier is exposed to demand risks as well. If she has sufficient cash, she can provide the trade credit out of her own pocket. However, with limited cash, the supplier may use an external source to finance production and provide trade credit to the retailer. Unlike the retailer, the supplier has another alternative. Upon the delivery of the goods, instead of receiving cash, the supplier receives accounts receivable with amount \(w_2x_2\) from the retailer. As a common means to manage accounts receivable (see Mian and Smith Jr. 1992 and Klapper 2006), the supplier might sell a portion of the accounts receivable to a third-party factor for immediate cash (factoring). Whether the supplier chooses to use a bank loan or factoring, the amount borrowed or factored, together with the cash the supplier has, should be sufficient to cover the total production cost.

As described above, we can have at most three financial claims when trade credit is offered:
the retailer’s bank loan, trade credit, and the supplier’s bank loan (or the receivable factored).\footnote{Note that the accounts receivable the supplier owns effectively provides credit support for his loan. Even though the supplier might use bank loan and factoring at the same time, these two claims should have the same seniority and hence are equivalent to an aggregated claim. Therefore, in the following analysis, we only consider the case where at most one of these two claims is used.}

Therefore, to complete the contract, we must determine the distress costs incurred when each of the claim defaults, and the seniority arrangement, that is, the order of repayment of different financial claims. Here we assume that in the event of default, all claims have the same recovery rate $\alpha$, that is, a portion of $(1 - \alpha)$ is lost as distress costs.\footnote{Some literature (e.g., Frank and Maksimovic 1998) argues that the supplier should have a higher recovery rate upon default as the supplier has channels ready to re-sell the products. This argument, however, does not hold in our case. As we assume the unsold goods have no salvage value and the recovery rate refers only to the cost incurred during the default, it is reasonable to assume suppliers and financial institutions incur the same cost.}

Furthermore, for a single default, the distress cost only incurs once. For example, when the trade credit payment the supplier receives is insufficient to cover the supplier’s bank loan, we assume the supplier’s bank will take over this payoff directly from the retailer, and the distress cost only occurs here.

As an important issue in debt financing, seniority has been studied by financial economists and legal scholars extensively. For related works, see Schwartz (1997), Mann (1997), Longhofer and Santos (2000), and references therein. In this paper, we confine ourselves to a specific seniority arrangement, where the retailer’s bank loan is strictly senior to trade credit. Not only is this arrangement consistent with common practice (see Schwartz 1997), we also find it the most efficient.\footnote{In a separate paper (Yang and Birge 2009), we address seniority-related issues more thoroughly, including how different restrictions in seniority influence the supply chain contract, and the supply chain performance. In particular, we show that the risk-sharing inventive of trade credit is maximized when bank loan is strictly senior to trade credit.}

This relationship also implies the retailer’s bank loan is senior to the supplier’s bank loan (or the claim held by the factor), as the supplier will not receive any trade credit until the retailer’s bank loan is paid off. More specifically, we define the following default thresholds: $\theta_{rb}$ for the retailer’s bank loan, $\theta_{tc}$ for trade credit, and $\theta_{sb}$ for the supplier’s bank loan (or $\theta_f$ for factoring), and they follow: $\theta_{rb} \leq \theta_{sb} \leq \theta_{tc}$. For each party’s payoff, when $\xi \in [0, \theta_{rb})$, all three claims default, the retailer’s bank gets $\alpha p \xi$, and the supplier’s bank and the supplier get nothing; when $\xi \in [\theta_{rb}, \theta_{sb})$, only the supplier’s bank loan and the trade credit default, the supplier’s bank gets $\alpha p (\xi - \theta_{rb})$, and the supplier’s retained profit is 0; when $\xi \in [\theta_{sb}, \theta_{tc})$, only trade credit defaults, and the supplier’s retained profit is: $\alpha p (\xi - \theta_{sb})$; when $\xi \in [\theta_{tc}, +\infty)$, no claim defaults. When the supplier uses factoring, we assume the contract is structured such that the factor’s claim is senior to the supplier’s claim, the $\theta_{sb}$ is replaced by $\theta_f$, and everything else stays the same.

Figure 5 further illustrates how seniority and payoff work under the current contract. As shown,
the x-axis represents the realized demand $\xi$ and the y-axis represents total revenue. Default thresholds and order quantity are marked based on our seniority arrangement, and the darkened area represent distress costs, which will be lost if corresponding claims default. The left panel shows the case where only a bank loan and trade credit are used. The right panel represents the case where the supplier also factors part of receivable. Comparing the right graph with the left one, total distress costs are reduced through financial diversification. In the following sections, we will discuss this issue in greater detail.

3.2. The Retailer’s Response

Given the seniority arrangement, we move to the retailer’s response on a given trade credit contract $(w_1, w_2)$, which can be discussed in two scenarios. First, when $w_1 x_1 < K_r$, that is, no bank financing is used. Obviously, for the optimal response, the retailer does not use trade credit either, that is, $x_2 = 0$. Therefore, the retailer’s problem again reduces to the classical newsvendor problem, which leads to $x_1^* = F\left(\frac{w_1}{p}\right)$.

Second, when $w_1 x_1 \geq K_r$, bank financing may be used, depending on the trade credit contract the supplier offers. In this case, we can write out the retailer’s optimization problem as:

$$\max \int_{\theta_{rb}}^{x_1+x_2} F(\xi) d\xi$$

s.t. $w_1 x_1 - K_r - p \int_{\theta_{rb}}^{0} F_d(\xi; \alpha) d\xi = 0$; $w_2 x_2 - p(\theta_{tc} - \theta_{rb}) = 0$; $\theta_{tc} \geq \theta_{rb} \geq 0$.

This program has four decision variables: $x_1$, $x_2$, $\theta_{rb}$, and $\theta_{tc}$. The first constraint determines that the bank loan breaks even, and determines the bank loan default threshold $\theta_{rb}$. The second

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13 This result can be shown by contradiction. Suppose $w_1 x_1 + \epsilon_1 = K_r$, and $x_2 = \epsilon_2$, where $\epsilon_1, \epsilon_2 > 0$. As $w_1 \leq w_2$, the retailer can improve his solution by letting $x_1' = x_1 + \min(\epsilon_2, \epsilon_1/w_1)$, and $x_2' = \max(0, \epsilon_2 - \epsilon_1/w_1)$. Clearly, the new solution $(x_1', x_2')$ can achieve the same service level with a lower cost, and the new quantities $(x_1', x_2')$ have either $x_2' = 0$ ($\epsilon_2 \leq \epsilon_1/w_1$), or $w_1 x_1' = K_r$. 

constraint determines the trade credit threshold $\theta_{tc}$. Note that as the retailer only responds to $(w_1, w_2)$, the supplier’s bank loan threshold $\theta_{sb}$ (or factoring threshold $\theta_f$) is irrelevant. Also, as distress costs are not priced explicitly in trade credit, the retailer should respond to the credit price $w_2$ as if no distress costs exist. Combining these two scenarios (when $w_1x_1 < K_r$ or $w_1x_1 \geq K_r$), we can prove the following conditions for the retailer’s optimal response:

**Proposition 3.** For a given two-part trade credit contract $(w_1, w_2)$, if $\xi$ has IFR, depending on the retailer’s cash position $K_r$, the retailer’s response $(x_1^*, x_2^*)$ and the corresponding $(\theta_{rb}^*, \theta_{tc}^*)$ is optimal if and only if:

1. when $K_r \in (\kappa_r^{pb}(w_1), +\infty)$, $x_1^* = \tilde{F}(w_1/p)$, $x_2^* = \theta_{rb}^* = \theta_{tc}^* = 0$,
2. when $K_r \in (\kappa_r^{cb}(w_1, w_2), \kappa_r^{pb}(w_1))$, $x_1^*$ and $\theta_{rb}^*$ satisfy $p\tilde{F}(x_1^*) = \frac{w_1}{1 - (1 - \alpha)g(\theta_{rb}^*)}$, and $w_1x_1^* = K_r + p\int_0^{\theta_{rb}^*} \tilde{F}_d(\xi; \alpha)d\xi$; and $x_2^* = 0$, $\theta_{tc}^* = \theta_{rb}^*$, and
3. when $K_r \in [0, \kappa_r^{cb}(w_1, w_2))$, $\theta_{rb}^*$ satisfies $\tilde{F}_d(\theta_{rb}^*; \alpha) = w_1/w_2$, $x_1^* = K_r/w_1 + (p/w_1)\int_0^{\theta_{rb}^*} \tilde{F}_d(\xi; \alpha)d\xi$, $(x_2^*, \theta_{tc}^*)$ satisfy: $w_2\tilde{F}(\theta_{tc}^*) = p\tilde{F}(x_1^* + x_2^*)$, and $w_2x_2^* = p(\theta_{tc}^* - \theta_{rb}^*)$,

where $\kappa_r^{pb}(w_1) = w_1\tilde{F}(\frac{w_1}{p})$, and $\kappa_r^{cb}(w_1, w_2) = w_1x_1^* - p\int_0^{\theta_{rb}^*} \tilde{F}_d(\xi; \alpha)d\xi$, where $(x_1^*, \theta_{rb}^*)$ is uniquely determined by: $w_1 = w_2\tilde{F}_d(\theta_{rb}^*; \alpha)$, and $p\tilde{F}(x_1^*) = \frac{w_1}{1 - (1 - \alpha)g(\theta_{rb}^*)}$.

Obviously, the first two sets of conditions describe scenarios in which no trade credit is used, and the third set of conditions describes the scenario in which trade credit might be needed. In the third set, $p\tilde{F}(x_1^* + x_2^*) = w_2\tilde{F}(\theta_{tc}^*)$ suggests the marginal revenue at the optimal total quantity $x_1 + x_2$ should equal the marginal cost at that point. The fact that the retailer’s marginal cost $w_2\tilde{F}(\theta_{tc}^*)$ decreases with order quantity $x_2$ explicitly explains how trade credit behaves as a risk-sharing mechanism. The condition that determines $\theta_{rb}^*$ can also be written as: $\frac{w_1}{1 - (1 - \alpha)g(\theta_{rb}^*)} = w_2\tilde{F}(\theta_{tc}^*)$, which describes that at $\theta_{rb}$, the marginal cost of one extra unit purchased with the bank loan (the left-hand side) equals to the marginal cost of starting to use trade credit (the right-hand side).

As the marginal cost of using a bank loan increases as $x_1$ (or equivalently $\theta_{rb}$) increases, and the marginal costs of trade credit decreases at the same time, the retailer switches from the bank loan to trade credit. Further, the early discount $d_{tc} = 1 - w_1/w_2 = 1 - \tilde{F}(\theta_{rb}^*; \alpha)$, and if and only if $w_1 = w_2$, we have $\theta_{rb}^* = 0$, and no bank loan will be used.

Although the above conditions describe the retailer’s optimal response, Using them as constraints in the supplier’s optimization problem is inconvenient. Therefore, we modify these conditions by considering two scenarios. First, under the condition $w_1x_1 < K_r$, the interior optimum simply satisfies the first set of optimality conditions of Proposition 3; that is, $w_1 = p\tilde{F}(x_1^*)$, $x_2^* = 0$, and $\theta_{rb}^* = \theta_{tc}^* = 0$. Under this response, the supplier has no default risk (as $x_2^* = 0$ and no trade credit is
used); therefore, the supplier faces the classical problem with the price-only contract, which leads to \( x^*_1 = x^{nb}_w \) with \( x^{nb}_w \) satisfying \( p\bar{F}(x^{nb}_w)(1 - g(x^{nb}_w)) = c \). Clearly, \( K_r > K^{nb}_w \) is necessary (yet not sufficient) for this solution.

Second, when \( w_1x_1 \geq K_r \), the retailer faces the second or third set of optimality conditions of Proposition 3. Note that when \((w^*_1, w^*_2)\) becomes decision variables, the second set of optimality conditions can be seen as a special case of the third set by setting \( w^*_1 = w^*_2\bar{F}_d(\theta^*_r, \alpha) \). Rearrange and consolidate the third set of conditions of Proposition 3 into the following conditions:

\[
x_1(\theta_{tc} - \theta_{rb}) \bar{F}(\theta_{rb}; \alpha) - x_2\left[\frac{K_r}{p} + \int_{0}^{\theta_{rb}} \bar{F}(\theta_{rb}; \alpha) d\xi\right] = 0;
(\theta_{tc} - \theta_{rb}) \bar{F}(\theta_{tc}) - x_2\bar{F}(x_1 + x_2) = 0.
\]

Let \( x_t = x_1 + x_2 \). The above constraints can be further simplified the following equation, which we call the trade credit financing constraint:

\[
(\theta_{tc} + C(\theta_{rb})) \bar{F}(\theta_{tc}) - x_t\bar{F}(x_t) = 0. \tag{2}
\]

Note that in the constraint, as \( \xi \) is IGR, \( x_t \bar{F}(x_t) \) is concave, first increasing with \( x_t \) and then decreasing. With fixed \( \theta_{rb} \) and \( \theta_{tc} \), the objective function (as illustrated below) decreases in \( x_t \). Therefore, if more than one \( x_t \) satisfies the constraint for the given \((\theta_{rb}, \theta_{tc})\), the supplier should pick the smaller one, that is, the \( x_t \) that satisfies \( g(x_t) \leq 1 \). In the following analysis, we confine our discussion to this region.

With the simplified constraint, we then focus on \( \theta_{rb} \) and \( \theta_{tc} \) as the only independent decision variables when solving the supplier’s problem. The following lemma summarizes how \( w_1, w_2, d_{tc}, \) and \( x_t \) (\( x_1 \) and \( x_2 \)) are connected to \( \theta_{tc} \) and \( \theta_{rb} \) through Proposition 3.

**Lemma 3.** If \( \xi \) has IFR, \( d_{tc} \) increases in \( \theta_{rb} \), \( w_2 \) decreases in \( \theta_{rb} \) and \( \theta_{tc} \), \( w_1 \) decreases in \( \theta_{rb} \) and \( \theta_{tc} \), \( x_t \) increases in \( \theta_{rb} \) and \( \theta_{tc} \), \( x_1 \) increases in \( \theta_{rb} \) and \( \theta_{tc} \), and \( x_2 \) increases in \( \theta_{tc} \).

### 4. The Optimal Contract and Extensions

Given the retailer’s response, this section studies the optimal trade credit contract the supplier provides. We start by assuming the supplier has sufficient cash to finance production, and she will not factor any accounts receivable (or equivalently, she could factor all receivable). In this case, the supplier’s objective is to maximize \( \pi_s = \int_{0}^{\theta_{tc}} \bar{F}(\xi) d\xi - (c/p)x_t - (1 - \alpha)[\delta(0, \theta_{rb}) + \delta(\theta_{rb}, \theta_{tc})] \), with equation 2 and \( \theta_{tc} \geq \theta_{rb} \geq 0 \) as constraints. Note that the supplier’s program with price-only contract can be seen as a special case of this program by setting \( \theta_{rb} = \theta_{tc} \). We start analyzing the optimal solution by examining the partial derivatives:

\[
\frac{\partial \pi_s}{\partial \theta_{rb}} = -(c/p) \frac{\partial x_t}{\partial \theta_{rb}} + (1 - \alpha)[\bar{F}(\theta_{rb})(1 - g(\theta_{rb})) - \bar{F}(\theta_{tc})],
\]
\[
\frac{\partial \pi_s}{\partial \theta_{tc}} = \bar{F}(\theta_{tc}) - \left(\frac{c}{p}\right) \frac{\partial x_t}{\partial \theta_{rb}} - (1 - \alpha) (\theta_{tc} - \theta_{rb}) f(\theta_{tc}),
\]

where \( \frac{\partial x_t}{\partial \theta_{rb}} \) and \( \frac{\partial x_t}{\partial \theta_{tc}} \) are defined by equation 2 and satisfy:

\[
\begin{aligned}
0 &< \frac{\partial x_t}{\partial \theta_{rb}} = \frac{C'(\theta_{rb}) \bar{F}(\theta_{tc})}{\bar{F}(x_t)(1 - g(x_t))}; \\
\frac{\bar{F}(\theta_{tc})}{\bar{F}(x_t)} &< \frac{\frac{\partial x_t}{\partial \theta_{tc}}}{\frac{\bar{F}(\theta_{tc})(1 - (\theta_{tc} + C(\theta_{rb})) h(\theta_{tc}))}{\bar{F}(x_t)(1 - g(x_t))}}.
\end{aligned}
\]

According to the partial derivatives, two forces drive the optimal solution. The first one (the sales motive), which corresponds to the first part of both partial derivatives, is directly related to operational profit. For \( \theta_{rb} \), lowering \( \theta_{rb} \) only increases production costs (as \( \frac{\partial x_t}{\partial \theta_{rb}} > 0 \)), leaving revenue untouched; hence, the profit decreases. Fixing \( \theta_{rb} \), as \( \frac{\partial x_t}{\partial \theta_{tc}} < \frac{\bar{F}(\theta_{tc})}{\bar{F}(x_t)(1 - g(x_t))} \) for \( x_t < x_{mb}^* \), increasing \( \theta_{tc} \) always increases the profit. The second one (the financing motive) is associated with costs of financial distress. When \( \theta_{tc} \) increases, the supplier needs to carry more distress costs embedded in trade credit. Therefore, total distress costs increase with \( \theta_{tc} \). In contrast, the influence of \( \theta_{rb} \) on distress costs is non-monotone. When \( \theta_{rb} \) is much smaller than \( \theta_{tc} \), that is, \( \bar{F}(\theta_{rb})(1 - g(\theta_{rb})) > \bar{F}(\theta_{tc}) \), increasing \( \theta_{rb} \) reduces total distress costs through diversification of the bank loan and trade credit (financial diversification). After reaching optimal diversification, total distress costs start to increase with \( \theta_{rb} \). This analysis leads to the following two results:

**Lemma 4.** For an optimal solution, if \( \theta_{rb}^* > 0 \), we have \( \theta_{tc}^* > \theta_{rb}^* \), and \( x_2^* > 0 \).

**Lemma 5.** When \( \alpha = 1 \), \( \theta_{rb}^* = 0 \).

In other words, Lemma 4 demonstrates that as the sales motive always presents, trade credit should always be used. Also, the solution under the trade credit contract strictly dominates the solution under the price-only contract. Lemma 5 formalizes the fact that without distress costs, the reason for financial diversification no longer exists, thereby eliminating the use of the bank loan. The general case acts in accordance with the following result.

**Proposition 4.** Without factoring, \( \exists \kappa_{tc}^c \geq \kappa_{df}^c \geq 0 \) such that the optimal contract \((\theta_{rb}^*, \theta_{tc}^*)\) the supplier offers depends on the retailer’s cash position:

1. when \( K_r \in [0, \kappa_{df}^c] \), \( \theta_{rb}^* > 0 \), that is, two-part terms are optimal;
2. when \( K_r \in [\kappa_{df}^c, \kappa_{tc}^c] \), \( \theta_{rb}^* = 0 \), that is, net terms are optimal;
3. when \( K_r \in (\kappa_{tc}^c, \infty) \), \( \theta_{rb}^* = \theta_{tc}^* = 0 \), that is, no external financing is used.

The most important message of Proposition 4 is the structure of the portfolio the retailer uses to finance inventory (inventory financing portfolio), which is illustrated in Figure 6. Three scenarios
in Proposition 4, together with the price-only contract with a bank loan, are presented in four panels, in which the x-axis represents the order quantity and the y-axis represents marginal revenue or marginal cost. Clearly, the optimal order quantity is determined when marginal cost equals marginal revenue. In panel I, the retailer has sufficient internal resource; the contract degenerates to a classical price-only contract. Panel II illustrates the case with insufficient internal resource and only a bank loan. As the retailer’s marginal cost increases with the amount of the bank loan, the supplier has to lower wholesale price, even though the order quantity also decreases. In contrast, trade credit can improve both margin and quantity. When the retailer is under moderate leverage (panel III), the supplier offers cheap trade credit ($w_1 = w_2$). In this case, the retailer forgoes the bank loan, and uses only trade credit. However, one drawback of trade credit is that the supplier cannot transfer all distress costs to the retailer. Therefore, when the retailer has extremely limited internal resource, and therefore operates with a high leverage (panel IV), a discount in trade credit is offered, inducing the retailer to diversify external financing between the bank loan and trade credit. As panel IV shows, line A–C–E represents the marginal cost if the retailer only uses trade credit, and line B–C–D represents the marginal cost when only the bank loan is used (the solid line segments B–C and C–E represent what is actually used, and the dotted ones A–C and C–D are hypothetical.).

The above result is related to the cost of funds hypothesis in Petersen and Rajan (1994) (Figure I). While we predict a similar debt structure, two differences are notable. First, we argue the
amount of internal resource influences the price of trade credit, and therefore cheap trade credit is available. Second, given the retailer’s limited payback power, the marginal cost of trade credit purchase decreases in order quantity, thereby inducing the retailer to order more. These two points allow our model to better explain why large companies, which normally have easy access to financial markets, also use a significant amount of trade credit.

**Corollary 3.** *Ceteris paribus, when* $K_r$ *increases, $w_2^*$ *decreases, $\theta_{rb}^*$ *decreases, $\theta_{tc}^*$ *decreases, $x_t^*$ *decreases, $\pi_r^*$ *increases, $\pi_s^*$ *decreases, and $\pi_c^*$ *decreases.*

Figure 7 and Figure 8 further illustrate Proposition 4 and Corollary 3. In Figure 7, the left panel describes the structure of the inventory financing portfolio when the retailer faces the optimal trade credit contract. The three quantities represent the percentage of the bank loan ($\frac{\theta_{rb}^*}{(K_r/p)+\theta_{tc}^*}$), trade credit ($\frac{\theta_{tc}^*-\theta_{rb}^*}{(K_r/p)+\theta_{tc}^*}$), and cash ($\frac{Kr/p}{(K_r/p)+\theta_{tc}^*}$) in this portfolio. This result lead to the hypothesis tested in section 5. The right panel plots the early discount the retailer receives. As shown, the early discount is offered only to induce financial diversification when the retailer has very limited internal resources ($K_r$).

Figure 7 **Optimal Trade Credit Contract: Usage**

![Figure 7: Optimal Trade Credit Contract: Usage](image)

Figure 8 summarizes the supply chain’s performance under the optimal trade credit contract. The left panel shows that when $K_r$ decreases, instead of lowering the wholesale price (as in the price-only case), the supplier increases the wholesale price ($w_2$), as the probability of default ($F(\theta_{w})$) increases; the order quantity of the chain also increases. Note that the solution is discontinuous at $K_r = \kappa_{tc}$, where both $(x_t^*, \theta_{tc}^*)$ and $(x_{wb}, 0)$ generate the same profit ($\pi_{wb}^*$) for the supplier, the former leads to a higher retailer profit. This jump is caused by the discontinuity of the probability density function at 0. Looking at the right panel, the profits of the retailer and the supplier move
Figure 8  Optimal Trade Credit Contract: Supply Chain Performance

monotonically as $K_r$ increases. Whereas the retailer faces a relatively constant return, the supplier’s profit increases as $K_r$ decreases, correcting the problem with the price-only contract.

Corollary 4. Ceteris paribus, when $\alpha$ increases, $x_t^*$ increases, $\theta_{tc}^*$ increases, $\theta_{rb}^*$ decreases, and both $\pi_r^*$ and $\pi_s^*$ increase.

As discussed in section 2, the magnitude of $\alpha$ could represent the efficiency of the financial market, enforcement costs, or agents’ risk-aversion towards default. Therefore, Corollary 4 can lead to interesting implications and testable hypotheses in trade credit usage and supply chain performance over time or across countries. For example, the above result suggests that during market downturns, inventory is financed by a more diversified portfolio with more debt.

Although the purpose of this paper is not to find a mechanism that achieves coordination, we show through the following lemma that, in general, the two-part trade credit contract cannot obtain the chain optimality.

Corollary 5. $x_w^* \leq x_t^* \leq x_c^*$, and the second equality only holds when $K_r = 0$ and $\alpha = 1$. Compared with the optimal contract under the wholesale price mechanism, the supplier and the chain have a higher profit.

Another important issue related to granting credit is credit limit. In our case, the total amount of trade credit the supplier provides is $p(\theta_{tc} - \theta_{rb})$. Our formulation makes it clear that when a credit limit $L_c$ is set, the supplier’s optimization problem has an extra constraint: $p(\theta_{tc} - \theta_{rb}) \leq L_c$, which will not improve the supplier’s profit. Therefore, in our model, the supplier has no incentive to set an explicit limit on the amount of trade credit offered to the retailer.
4.1. The Retailer’s Bargaining Power

One limitation of the above section is that we implicitly assume the retailer has no bargaining power and will accept any contract the supplier offers. This assumption, however, does not always hold. In this section, we explore how the retailer’s bargaining power, which is modeled as a participation constraint, influences the trade credit terms. If we use $\pi^\text{min}_r$ to represent the retailer’s reservation profit, that is, the minimum profit the retailer will accept, we need:

$$\pi_r = p \int_{\theta_{tc}}^{x_t} \bar{F}(\xi) d\xi - K_r \geq \pi^\text{min}_r.$$

Incorporating this constraint into the optimization program leads to the main result of this section.

**Proposition 5.** Ceteris paribus, when the retailer’s bargaining power $\pi^\text{min}_r$ increases, $w^*_2$ decreases, $\theta^*_r b$ increases, and $x^*_t$ increases.

Figure 9  The Effect of the Retailer’s Bargaining Power ($K_r = 0.5\kappa^\text{tc}$)

Numerical results are presented in Figure 9. The x-axis represents the retailer’s reservation profit $\pi^\text{min}_r$ normalized by $\pi^\text{tc}_r$, his profit under the optimal trade credit contract without the participation constraint. As the left panel suggests, when the retailer’s bargaining power increases, the supplier has to give up her profit by lowering her profit margin, which reduces the sales motive of trade credit; hence, the supplier offers a deeper discount of trade credit, inducing more bank financing. This result is consistent with the finding of Giannetti et al. (2008). The right panel illustrates the order quantity and the chain profit. As the retailer’s reservation profit increases, the supply chain efficiency increases.

Although we discuss separately the effect of bargaining power and leverage, the retailer’s bargaining power should be influenced by the amount of internal resource ($K_r$) the retailer possesses...
when he faces the same market (demand distribution). For example, the retailer may invest part of $K_r$ in an external investment opportunity or use his internal resource to create partial vertical integration (e.g., producing private-label products to meet part of the demand). Therefore, we argue that the retailer’s bargaining power should increase with the amount of internal resource he possesses, or, equivalently, decreases with the retailer’s leverage.

4.2. The Advantage of Factoring

Up until now, we have studied the case where the supplier has sufficient cash to finance production and does not factor any accounts receivable. To complete the analysis, we need to discuss two other scenarios introduced in section 3. First, the supplier can borrow from a bank; second, the supplier can sell part of accounts receivable to a factor. Specifically, we assume the factor belongs to part of the perfectly competitive financial market, hence providing a break-even factoring contract to the supplier. Second, we assume that a factoring contract can be structured such that the part of receivable factored is strictly senior to the other part of receivable the supplier holds. With this arrangement, we are able to compare the supplier’s choice of borrowing versus factoring, which is summarized in the following result:

**Lemma 6.** Fixing $\theta_{rb}$ and $\theta_{tc}$, for any amount of bank loan the supplier may use, factoring the same amount does not decrease the supplier’s profit.

The intuition behind this proposition is that even though factoring and the bank loan are priced in a similar way, factoring is more flexible as it is completely independent of the amount of the retailer’s internal resource, whereas the bank loan is not. Given the advantage of factoring over supplier borrowing, in this section, we confine our discussion to factoring. We can rewrite the supplier’s optimization problem as:

$$\max_{\int_0^{\theta_{tc}} \tilde{F}(\xi) d\xi - (c/p)x_t - (1 - \alpha)[\delta(0, \theta_{rb}) + \delta(\theta_{rb}, \theta_f) + \delta(\theta_f, \theta_{tc})];}
$$

$$\text{s.t. } \frac{K_r + K_s}{p} + \int_0^{\theta_f} \tilde{F}(\xi) d\xi - (c/p)x_t - (1 - \alpha)[\delta(0, \theta_{rb}) + \delta(\theta_{rb}, \theta_f)] \geq 0;$$

$$\quad (\theta_{tc} + C(\theta_{rb}))\bar{F}(\theta_{tc}) - x_t\bar{F}(x_t) = 0;$$

$$\quad \theta_{tc} \geq \theta_f \geq \theta_{rb} \geq 0.$$

We can analyze this program under two scenarios, depending on whether the inequality constraint is binding. When it is not binding, as $\theta_f$ does not play a role in the retailer’s response, the supplier chooses the factoring amount to achieve optimal financial diversification. Setting $\frac{\partial \pi_f}{\partial \theta_f} = 0$ leads to the following result, which suggests that when offering trade credit, the supplier should factor part of accounts receivable but not all of them.
Lemma 7. When $\theta_{tc}^* > 0$, the optimal solution has $\theta_{rh}^* < \theta_{jf}^* < \theta_{tc}^*$.

Combining this case with the scenario when the inequality constraint is binding, we obtain the main results in this section.

Corollary 6. By introducing factoring, the supplier offers more trade credit at lower interests.

Corollary 7. When $K_s$ increases, the supplier factors less amount and offers more trade credit with a cheaper price.

The above results are best illustrated in Figure 10. First note that two dotted lines, $K_r = \kappa_r^{df}$ and $K_r = \kappa_r^{fc}$, divide the quadrant into three regions characterized in Proposition 4, where $K_s$ is irrelevant. Introducing factoring changes the picture. When $K_r < \kappa_r^{fc,f}$, the curve A–C–E separates regions I and IV, where optimal financial diversification is achieved and the supplier has extra cash after factoring, from regions II and III, where the supplier only factors the amount that is sufficient to finance production. Similarly, B–C–D separates regions I and II, where the retailer, facing two-part terms, finances inventory with the bank loan and trade credit, from regions III and IV, where the retailer uses only trade credit. Note that in regions III and IV, the supplier is willing to offer net terms to the retailer while factoring her receivable at a discount, or, equivalently, borrowing a bank loan at a positive rate. This phenomenon further demonstrates the sales motive, and rationalizes why smaller suppliers are willing to lend to large retailers.
4.3. Coordination and Super-Coordination: Two Examples

As section 2 indicates, costs of financial distress hurt the profits of different parties in the supply chain. Therefore, a natural question to ask is how different traditional supply chain coordination mechanisms perform in the presence of distress costs. In addition, the goal in traditional supply chain management literature is to allow the decentralized chain to match the profit of the integrated chain, that is, to achieve supply chain coordination. However, introducing distress costs complicates this task in two aspects. First, according to Proposition 1, even the profit of the integrated chain suffers from potential distress; therefore, the integrated chain might not be the perfect benchmark. Second, as section 4.2 shows, diversifying financing among different sources can reduce costs of financial distress the whole chain carries. Following this direction, another interesting question arises: Can the decentralized chain, through properly designed supply and financing contracts, outperform the integrated chain? Below we use two examples to provide some insights on the answers to these questions.

The first contract we study is quantity discount (see Lee and Rosenblatt 1986). We can easily show that when financially constrained, the retailer’s optimality conditions facing price \( w(x) \) are

\[
p\hat{F}(x_{qd}) = \left[ w(x_{qd}) + \frac{\partial w}{\partial x_{qd}} x_{qd} \right] \hat{F}_{\hat{d}(\theta_{qd}, \alpha)} \quad \text{and} \quad w(x_{qd}) x_{qd} = K_r + \int_0^{x_{qd}} \hat{F}_{\hat{d}(\xi)} d\xi.
\]

Instead of finding the optimal contract, we focus on a fixed price schedule. We carry the same parameters used in the previous sections \((c = 0.5, p = 1; \xi \sim \text{Unif}[0, 1])\) and assume \( w(x) = 2/3 - x/6. \) Clearly, without financial constraints, this contract coordinates the chain \((x^*_c = 0.5, \pi^*_c = 0.125),\) and the profit is allocated evenly between the supplier and the retailer.

The left panel of Figure 11 presents the numerical results, where the \( x \)-axis represents the retailer’s cash \( K_r \) normalized by \( \kappa^{ab}_c \). Apparently, as the quantity discount contract involves a cash payment from the retailer to the supplier with an amount larger than the total production cost, the cash requirement of the retailer is very high. In fact, to coordinate the chain, the retailer needs more cash than required for the integrated chain. When this requirement cannot be met, the bank loan requires a large premium, hence increasing the marginal cost the retailer faces.

Results on quantity discount clearly suggests that when financially constrained, ex-post risk-sharing has advantages. Therefore, by assuming the supplier can contract on the realized demand \( \xi \) (yet the bank loan cannot), we turn to the second contract studied here: revenue sharing (Cachon and Lariviere 2005). The traditional revenue sharing contract states that upon delivery (at the end of the first period), the retailer pays \( \phi_{cx} \) to the supplier; at the end of the sale horizon (the second period), the retailer pays \( \phi(p - c)\xi \) to the supplier. However, we need to add a new twist when the retailer borrows a risky bank loan. Suppose the retailer’s default threshold is \( \theta_r \), then
after paying off the bank loan ($p\theta_r$), the retailer should pay $p(\phi^{-1} - 1)\theta_r$ (proportional to the revenue share) to the supplier before sharing the revenue. Therefore, the retailer’s objective is to maximize $\int_{\theta_r/\phi}^{x_{rs}} (\xi - \theta_r) dF(\xi) + (x - \theta_r/\phi) \hat{F}(x_{rs})$. Under this arrangement, the retailer’s optimal response satisfies: $p\hat{F}(x_{rs}) = c_{rs} F(\theta_r/\phi)$ and $\phi c x_{rs} = K_r + p \int_{0}^{\theta_r} \hat{F}(\xi; \alpha) d\xi$.

In addition, only receiving $\phi c x_{rs}$ upon delivery, the supplier might borrow a risky loan to finance production. The loan term, however, is complicated. If the fixed payment $p(\phi^{-1} - 1)\theta_r$ from the retailer to the supplier satisfies $\alpha p \int_{\theta_r/\phi}^{\theta_r} (\xi - \theta_r) dF(\xi) + p(\theta_r/\phi - \theta_r) \hat{F}(\theta_r/\phi) > (1 - \phi)c x_{rs} - K_s$, the supplier’s default threshold $\theta_s$ satisfies: $(1 - \phi)c x_{rs} = K_s + \alpha p \int_{\theta_r}^{\theta_s} (\xi - \theta_r) dF(\xi) + p(\theta_s - \theta_r) \hat{F}(\theta_s)$.

For simplicity, we assume this condition is satisfied.

The results are shown in the right panel of Figure 11. Again, we assume a 50-50 profit split ($\phi = 50\%$). Interestingly, when financially constrained, the modified revenue sharing outperforms the integrated with the same amount of cash. The intuition behind this result is that, different from the integrated chain, the decentralized chain allows the retailer and supplier to borrow separately, thereby reducing total distress costs the chain faces through financial diversification. This cursory result suggests that with properly designed supply chain contracts, the decentralized chain can outperform the integrated chain. We call this the super-coordination effect, which may serve as an alternative reason for why supply chains may remain decentralized.

5. Empirical Evidence

With the above theory established, we move to explore how empirical data agree with the predictions our model suggests. We test our theory using North American retailer\textsuperscript{14} data from 1999 to 2008. The data are drawn from the quarterly financial statements in Compustat. We confine all

\textsuperscript{14} In North American Industry Classification System, retailers are represented with code 441 - 454.
samples to retailers with fiscal year end at December 31 or January 31 (around 75% of total retailers satisfy this condition). Our data selection is based on several considerations. First, Compustat consists of public companies that are normally large (of our sample, the median company has total assets of around $424 million). These companies usually have easy access to financial markets and have fewer information issues, hence fitting our model. Second, the most recent data are chosen as the wide usage of information technology weakens the transaction-related motive of trade credit. Third, as retailers represent the end of the entire supply chain and sell goods to end consumers, they normally carry less accounts receivable (our data show that the median receivable days for retailers are fewer than seven), most of which should be related to credit card transactions, allowing us to isolate companies’ role as borrowers. Finally, for two reasons, we select companies whose fiscal years are largely aligned with the calendar year. First, many retailers expect large sales during holiday season (the fourth calendar quarter), hence building large amounts of inventory, which allows us to test the hypothesis; second, this selection minimizes the fiscal-year-end effect. With these criteria, we have 2,127 firm-year samples. Table 2 summarizes some descriptive statistics of our data set.

Table 2 Descriptive Statistics

<table>
<thead>
<tr>
<th></th>
<th>Assets ($ Million)</th>
<th>Balance Sheet Items as a Fraction of Total Assets</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inventory</td>
<td>Cash &amp; Eq</td>
</tr>
<tr>
<td>Mean</td>
<td>2730.0</td>
<td>34.1%</td>
</tr>
<tr>
<td>Q₁</td>
<td>142.1</td>
<td>19.1%</td>
</tr>
<tr>
<td>Q₂</td>
<td>424.5</td>
<td>32.0%</td>
</tr>
<tr>
<td>Q₃</td>
<td>1561.7</td>
<td>47.7%</td>
</tr>
</tbody>
</table>

5.1. How Much Trade Credit Do Retailers Used?

Although trade credit is widely used in industry, its real terms are not well understood in academia. Ng et al. (1999), using a set of survey data, conclude that trade credit exhibits the following three characteristics: first, trade credit terms are normally fixed within an industry; second, the net period of trade credit is generally less than thirty days; third, when a two-part trade credit is offered, the implicit interest is high. Petersen and Rajan (1997) reach a similar conclusion that trade credit is an expensive substitute for institution funding when the latter is unavailable. Some recent empirical papers, however, paint a different picture. For example, Giannetti et al. (2008) suggest that many companies have access to trade credit at low cost. Focusing only on the retail sector, we present some simple statistics of trade credit usage that shed light on the real terms of trade credit.

Figure 12 plots empirical cumulative distributions of payable days (91.25*Average Quarterly Accounts Payable/Cost of Goods Sold) from three different subsets of our sample: all firm-years, all
firm-years with extra cash, and firm-years of 2008. The figure illustrates three important features. First, most companies have long outstanding payable days. For example, the median company’s payable days > 40, which is beyond the net period of most industries reported in Ng et al. (1999). Second, payable days cover a wide range, suggesting the usage and terms of trade credit vary among companies. Third, the usage of trade credit of firm-years with extra cash is similar to that of all firm-years, implying the implicit interest of trade credit is unlikely to be high.

Table 3 summarizes the quartiles of accounts payable days and inventory days (91.25*Average Quarterly Inventory/Cost of Goods Sold) within each subcategory of retailers. The data suggests that even within a subcategory in the retail sector, the usage of trade credit varies greatly. In addition, most subcategories have a median payable days greater than 30. The above two observations further suggest that in practice, trade credit terms can be quite flexible even within a sub-industry, and the net period is not strictly enforced.

<table>
<thead>
<tr>
<th>Subcategory in Retail (North America Industry Classification System)</th>
<th>Num. of Firm-Years</th>
<th>Payable Days</th>
<th>Inventory Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Retailers</td>
<td>2127</td>
<td>27.8</td>
<td>86.0</td>
</tr>
<tr>
<td>Motor Vehicle and Parts Dealers (441)</td>
<td>183</td>
<td>5.7</td>
<td>56.4</td>
</tr>
<tr>
<td>Furniture and Home Furnishings Stores (442)</td>
<td>62</td>
<td>34.1</td>
<td>92.8</td>
</tr>
<tr>
<td>Electronics and Appliance Stores (443)</td>
<td>97</td>
<td>33.3</td>
<td>35.0</td>
</tr>
<tr>
<td>Building Material and Garden Equipment and Supplies Dealers (444)</td>
<td>68</td>
<td>24.4</td>
<td>97.4</td>
</tr>
<tr>
<td>Food and Beverage Stores (445)</td>
<td>156</td>
<td>21.6</td>
<td>34.1</td>
</tr>
<tr>
<td>Health and Personal Care Stores (446)</td>
<td>155</td>
<td>30.2</td>
<td>48.9</td>
</tr>
<tr>
<td>Gasoline Stations (447)</td>
<td>31</td>
<td>8.3</td>
<td>13.0</td>
</tr>
<tr>
<td>Clothing and Clothing Accessories Stores (448)</td>
<td>543</td>
<td>29.5</td>
<td>91.4</td>
</tr>
<tr>
<td>Sporting Goods, Hobby, Book, and Music stores (451)</td>
<td>208</td>
<td>49.3</td>
<td>131.1</td>
</tr>
<tr>
<td>General Merchandise Stores (452)</td>
<td>259</td>
<td>31.3</td>
<td>107.3</td>
</tr>
<tr>
<td>Miscellaneous Store Retailers (453)</td>
<td>109</td>
<td>27.1</td>
<td>84.8</td>
</tr>
<tr>
<td>Nonstore Retailers (454)</td>
<td>256</td>
<td>32.2</td>
<td>55.3</td>
</tr>
</tbody>
</table>
5.2. How Is Inventory Financed?

Previous empirical findings confirm some of the implications drawn from our model. For example, Giannetti et al. (2008) document two important facts consistent with our model: first, many companies receive cheap trade credit; second, companies with market power normally receive a large early discount. In this section, we focus on testing another important implication drawn from our model (Proposition 4 and Corollary 3), which suggests companies finance their inventory with a portfolio of cash, trade credit, and short-term debt, and that the company’s leverage (or distress level) should influence the structure of this portfolio.

However, at least two difficulties exist in testing this hypothesis. First, as argued in section 4.1, across different companies, leverage (level of distress) should be negatively related to bargaining power, which influences trade credit terms and usage in the direction opposite of leverage. Therefore, to isolate those two effects, we focus on (cyclic) changes in leverage within a company, which are unlikely to influence its bargaining power. Intuitively, due to the seasonal nature of the retail industry, a single retailer might operate with different leverage over a year. For example, if a retailer expects the sales during the fourth quarter to be significantly larger than other quarter, he should build up his inventory at the end of the third quarter. However, this retailer’s internal resource is normally invariant over a year. Therefore, this retailer needs to operate with higher than average leverage at the end of the third quarter, and returns to his normal leverage at the end of the fourth quarter. Second, although our model suggests the amounts of cash, accounts payable, and short-term debt retailers use to finance inventory, the actual amounts they use are unobservable from financial statements. Therefore, instead of looking at absolute values, we focus on the changes in accounts payable and short-term debt and how they are related to the change in inventory. This method is similar to the one in Shyam-Sunder and Myers (1999) and Frank and Goyal (2003), both of which test the pecking order theory by regressing net debt issue and net equity issue on an aggregate measure of financial deficit.

Furthermore, we want to identify two groups of firms: one of them operates with moderate leverage, and the other one with high leverage, corresponding the first two scenarios in Proposition 4. Looking at the fourth quarter, we argue that firms with smoother sales over the year should operate under moderate leverage at the end of the third quarter, thereby mainly using cash and trade credit to finance inventory. In contrast, firms with sales in the fourth quarter significantly larger sales in other quarters should be highly levered at the same time, which means that they

15 Here we only focus on short term debt. Given many companies match the maturity of their assets and liability, it is unlikely that long term debt will be used to finance inventory.
will not only use more trade credit, but also a significant amount of short-term debt to finance inventory. With this logic, we divide the sample into two groups by the fourth quarter cost of goods sold as a fraction of the annual cost of goods sold (\(\frac{4Q \text{ COGS}}{\text{Annual COGS}}\)): the high group and low group.

Table 4 summarize statistics of these two group. First note that the median \(\frac{4Q \text{ COGS}}{\text{Annual COGS}}\) in the low group is around 25 percent, that is, the sales in the fourth quarter are roughly the average of annual sales. In the high group, however, the median \(\frac{4Q \text{ COGS}}{\text{Annual COGS}}\) is close to one third of the annual sale. Another observation is both payable and inventory of the high group are larger than those of the low group, suggesting firms in the high group increase their inventory to meet the fourth quarter demand, and are more likely to be highly levered. Also, the high group has lower receivable and cash, which implies the financial constraint is tighter. Comparing the changes from the end of the third quarter to the end of the fourth quarter, the high group reduces inventory and payable more significantly than the low group. Cash in the high group also increases much more than that in the low group. All those results indicate this classification provides an effective way to identify firms with different leverage.

<table>
<thead>
<tr>
<th>Table 4</th>
<th>Summary Statistics (Median) of Firm-years Sorted by (4Q COGS)/(Annual COGS).</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low 4Q COGS/Annual COGS</td>
</tr>
<tr>
<td>Assets ($ Million)</td>
<td>388.6</td>
</tr>
<tr>
<td>4Q COGS/Annual COGS</td>
<td>25.9%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Items as a Fraction of Assets</th>
<th>Low 4Q COGS/Annual COGS</th>
<th>High 4Q COGS/Annual COGS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Payable</td>
<td>15.2%</td>
<td>17.3%</td>
</tr>
<tr>
<td>Receivable</td>
<td>6.4%</td>
<td>3.2%</td>
</tr>
<tr>
<td>Inventory</td>
<td>29.9%</td>
<td>40.3%</td>
</tr>
<tr>
<td>Cash &amp; Eq</td>
<td>3.9%</td>
<td>3.1%</td>
</tr>
<tr>
<td>Ct. Debt</td>
<td>2.0%</td>
<td>1.8%</td>
</tr>
<tr>
<td>∆Payable (4Q - 3Q)</td>
<td>-0.7%</td>
<td>-2.7%</td>
</tr>
<tr>
<td>∆Receivable (4Q - 3Q)</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>∆Inventory (4Q - 3Q)</td>
<td>-0.6%</td>
<td>-6.7%</td>
</tr>
<tr>
<td>∆Cash &amp; Eq (4Q - 3Q)</td>
<td>0.2%</td>
<td>3.4%</td>
</tr>
<tr>
<td>∆Ct. Debt (4Q - 3Q)</td>
<td>0.6%</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

Based on the above considerations, our regression is as follows:

\[
\Delta \text{Payable}^i = \alpha^i_{\text{pay}} + \beta^i_{\text{inv,pay}} \Delta \text{INV}^i + \epsilon;
\]

\[
\Delta \text{Ct. Debt}^i = \alpha^i_{\text{debt}} + \beta^i_{\text{inv,debt}} \Delta \text{INV}^i + \epsilon,
\]

where \(i = H, L\), represents the high and low group, respectively. To test the robustness of the results, we also run separate regressions with the changes of accounts receivable and cash as additional independent variables. Our theoretical results suggest the following hypotheses:

**Hypothesis 1.** \(\beta^H_{\text{inv,pay}} > \beta^L_{\text{inv,pay}} > 0\).
Hypothesis 2. \( \beta_{\text{inv,debt}}^H > \beta_{\text{inv,debt}}^L = 0 \).

Table 5 presents the regression results. The first two columns show the results of the basic regression, and the other columns add \( \Delta \)Receivable and \( \Delta \)Cash & Eq as independent variables. Several important results follow. First, in panel A, when inventory changes, the payable change in the high group (\( \beta > 0.6 \)) and in the low group (\( \beta < 0.4 \)) are both statistically and economically significant, suggesting companies with higher leverage use more accounts payable to finance inventory. In addition, \( R^2 \) in the high group is much larger than that in the low group. Adding changes in cash and receivable as independent variables does not alter this result. Second, in panel B, the influence of inventory change on the level of short term debt is barely significant in the low group (t-stat \( \approx 2 \) and \( R^2 \approx 0 \)), where the influence is much stronger in the high group (t-stat > 8 and \( R^2 > 5\% \)). By adding \( \Delta \)Cash & Eq as an independent variable, the influence in the high group remains the same, whereas that in the low group becomes insignificant (t-stat < 0.5). This finding again suggests that during the regular period, companies use little short-term debt to finance inventory. However, during the period with high leverages, they use some short-term debt, making the inventory financing portfolio more diversified.

### Table 5  Regression of \( \Delta \)Payable and \( \Delta \)Ct. Debt on \( \Delta \)Inventory, \( \Delta \)Receivable and \( \Delta \)Cash & Eq.

<table>
<thead>
<tr>
<th></th>
<th>Panel A: ( \Delta )Payable Regression</th>
<th>Panel B: ( \Delta )Ct. Debt Regression</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L</td>
<td>H</td>
</tr>
<tr>
<td>( \Delta )Inventory</td>
<td>0.37</td>
<td>0.62</td>
</tr>
<tr>
<td>( \Delta )Receivable</td>
<td>0.19</td>
<td>0.19</td>
</tr>
<tr>
<td></td>
<td>(5.51)</td>
<td>(2.98)</td>
</tr>
<tr>
<td>( \Delta )Cash &amp; Eq</td>
<td>0.09</td>
<td>0.21</td>
</tr>
<tr>
<td></td>
<td>(2.99)</td>
<td>(9.33)</td>
</tr>
<tr>
<td>Adjusted ( R^2 )</td>
<td>0.16</td>
<td>0.40</td>
</tr>
</tbody>
</table>

6. Conclusion

This paper addresses an important question that has received little attention in the operations community: As an integrated part of a supply chain contract, what role does trade credit play in a supply chain? Both the analytical model and empirical evidence lead to the conclusion that an essential role of trade credit is to act as a risk-sharing mechanism and mitigate the mismatch of
operational and financial risks among companies in supply chains. On the operational side, demand uncertainty and early commitment results in suboptimal inventory decisions in supply chains. As a contingent claim, trade credit allows the supplier to share part of the inventory risks the retailer otherwise bear alone, hence inducing higher order quantities from the retailer. On the financial side, costs of financial distress, which play an important role in capital structure, limit the retailer’s ability to use external sources to finance inventory. Trade credit, together with other financing contracts, allocates costs of financial distress among different parties more efficiently. Due to its extensive use in practice, trade credit might be the most common risk-sharing mechanism in supply chains.

One important area our model does not address is information asymmetry. To focus on trade credit’s role as a risk-sharing mechanism, we assume complete information. However, information-related issues are unavoidable in supply chain contracts. Introducing information asymmetry can influence the effectiveness of trade credit in different directions. On the one hand, information asymmetry may weaken the risk-sharing role of trade credit, as it does to other supply chain contracts. However, due to its simple form, trade credit may suffer less from information asymmetry than other contracts. On the other hand, trade credit provides a cash flow that is (partially) independent of the existing information flow (orders) and material flow (physical goods delivery) within supply chains. Therefore, it may alleviate some well-documented problems in supply chains. For example, by receiving trade credit payments, the upstream company can infer more about the downstream company’s sales, thereby reducing the bullwhip effect documented in Lee et al. (1997).

This paper can also be extended along other directions. First, although a stylized model is sufficient to answer the essential questions in which we are most interested, a multi-period setting is more appropriate for implementation. Second, although a single-supplier single-retailer chain structure allows us to capture the fundamental reason for why companies use trade credit, extensions to multiple retailers or/and multiple suppliers settings are also of interest. In a working paper, we focus on how suppliers, in their capacity as trade creditors, interact with other creditors in the presence of legal and regulatory constraints. The research also explores how legal regulations should be designed to improve supply chain efficiency.

Related empirical extensions are also promising. As the price of trade credit influences inventory level and the structure of the inventory financing portfolio, understanding trade credit is essential to certain assumptions (e.g., constant and exogenous holding cost) in inventory management models. Although our empirical results confirm that companies use a portfolio of cash, trade credit, and short-term debt to finance inventory, we do not address quantitative issues. An interesting yet
challenging project is to use a structural model to estimate the price of trade credit and the marginal holding cost of inventory. Moreover, as our current research suggests, trade credit is a complex phenomenon and is likely to serve multiple roles in supply chains; therefore, further empirical studies that identify other operations-related roles trade credit plays should also be rewarding.

References


