Supply Chain Contract Design under Financial Constraints and Bankruptcy Costs

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We study contract design and coordination of a supply chain with one supplier and one retailer, both of which are capital constrained and in need of short-term financing for their operations. Competitively priced bank loans are available, and the failure of loan repayment leads to bankruptcy, where default costs may include variable (proportional to firm’s sales) and fixed costs. Without default costs, it is known that simple contracts (e.g., revenue-sharing, buyback and quantity discount) can coordinate and allocate profits arbitrarily in the chain. With only variable default costs, buyback contracts remain coordinating and equivalent to revenue-sharing contracts, but are pareto dominated by revenue-sharing contracts when fixed default costs are present. Thus, for general bankruptcy costs, contracts without buyback terms are of most interest.

Quantity discount contracts fail to coordinate the supply chain, since a necessary condition for coordination is to proportionally reallocate debt obligations within the channel. With only variable default costs and with high fixed default costs exhibiting economies of scale, revenue-sharing contracts with working capital coordination continue to coordinate the chain. Unexpectedly, with fixed default costs and no economies of scale, the decentralized supply chain under a revenue-sharing contract with working capital coordination might have higher expected profit than the centralized chain. Our results provide support for the use of revenue-sharing contracts with working capital coordination for decentralized management of supply chains when there are bankruptcy risks and default costs.

Key words: Newsvendor, Supply Contract, Supply Chain Coordination, Bankruptcy/Default Costs, and Working Capital Management.

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1. Introduction

It is not uncommon in a supply chain that either the supplier and/or the retailer is the subsidiary of the other or they are both subsidiaries of the same parent company. For example, Target Brands
and Target Stores are subsidiaries of Target Corporation, Visteon was a previous subsidiary of Ford (spun off in 2000), Motorola Mobility is a subsidiary of Google, Nokia Mobile is a subsidiary of Microsoft, and so on. Often the parent company manages regular intra-company transfers of funds among itself and its subsidiaries to re-allocate the working capital for different purposes, e.g., risk concerns, tax reduction, profitability, and so on. In this paper, we will argue that such practice is strategically advantageous from a supply chain coordination perspective in the presence of bankruptcy risks and costs.

In fact, the transfer of funds between supply chain partners is observed beyond just subsidiary-parent style supply chains. When Visteon faced financial distress in 2005, Ford decided to provide $1.7 billion to save Visteon from bankruptcy by purchasing 250 million shares of Visteon’s stock at the price of $6.9 per share. (A parallel story is recounted for another pair of supply chain partners, Delphi and General Motors.) Although Visteon was no longer a subsidiary of Ford at that time, Ford helped with the funds since Visteon was recognized by Ford as a strategic supplier.

In contrast, when the video retailer Blockbuster faced financial distress in the mid-to-late 2000s, its suppliers, prominent Hollywood studios, rather than providing financing help, cut off their trade credit provisions to Blockbuster. As stated in Blockbuster’s Form 10-Q in August 2009, “Given our liquidity limitations and uncertainty surrounding our ability to finance our obligations ... If the studios further tighten their credit terms or if studios eliminate their provision of credit to us altogether, this could result in up-front cash commitments that we may be unable to sustain on a long-term basis ...” Despite the revenue-sharing contracts between Blockbuster and the studios to better align inventory risks and operational costs of the supply chain parties, we clearly observed a coordination failure in the presence of a financial distress event in this chain. Our paper argues that active working capital coordination among supply chain parties is needed in addition to supply chain contracts to effectively handle bankruptcy risks and optimize supply chain performance.

In this paper, we study contract design and coordination in a one-supplier-one-retailer supply chain in the presence of bankruptcy risks and costs due to capital constraints of the firms. Hereafter, and for ease of exposition, the supplier and retailer are referred to as supply chain parties (party singular). Based on the number of bankruptcy exposed firms in the supply chain and with or without coordinated working capital management, we classify supply chains into three types: two
supply chain parties without coordinated working capital management (two independent firms),
two parties with coordinated working capital management, and one firm with centralized control
of all decisions including working capital management. The first two cases are referred to as *decentralized supply chain* or *decentralized system*, and the third case is referred to as *centralized supply chain* or *centralized system*. In the decentralized system, the parties manage financial and material
flows via a supply contract. The supply chain literature is particularly concerned about “coordinating” contracts that achieve “first best” for the decentralized system, i.e., the total profit of the
decentralized supply chain equals that of the centralized one.

A classic example of a coordinating supply chain contract is the revenue-sharing contract. Block-
buster and major studios signed such contracts in 1998. Before that, studios sold videotapes via a
traditional wholesale price contract to Blockbuster and other small retailers for $65 per tape, with
retailers collecting $3 per rental. With the revenue-sharing contract, Blockbuster paid studios 40%
of its rental revenue in exchange for a reduction in the unit price from $65 to $8. The contract helped
Blockbuster gain market share, while the studios ensured high levels of availability of their videos to
the customers. The revenue-sharing contract effectively aligned the interests of supply chain parties
in this instance, and the overall industry’s profitability increased by 10% to 20% (Mortimer, 2008).

In the existing literature, supply chain contracts are studied without concerns of cash flow con-
straints and threats of bankruptcy. However, such concerns are prevalent in real supply chains. The
previously mentioned Visteon situation is typical for the automotive industry, where undercapital-
ized suppliers often face bankruptcy risks due to continuous price pressures from manufacturers
in a volatile demand environment (for more detail see Swinney and Netessine, 2007). In a recent
presentation, the VP of Global Supply Chain for B/E Aerospace stated that “... bankruptcy risk
of my 2,500 suppliers is my major risk management concern. ...” From the current literature, we
know (see Kouvelis and Zhao 2012) that the bankruptcy risk itself does not change the nature
of the coordinating contracts, as long as any needed financing for the existing capital constraints
is provided through competitively priced bank loans. However, there are no studies to address
coordination issues in the presence of costly defaults.

We address these issues in this paper by assuming our supply chain is operated under a general
contract (subsumes class of quantity discount, buyback and revenue-sharing contracts) in the pres-
ence of capital market imperfections such as significant default costs. Both retailer and supplier are capital constrained, and may need to borrow short-term bank loans to finance their operational requirements. Failure of a party to repay the loan will lead to bankruptcy, i.e., if the realized retail sales are low, the supplier and retailer might not be able to repay the loans and become insolvent.

We assume banks operate in highly competitive financial markets, and all bank loans are competitively pricing risks. To account for the relevant default risks and related costs, the bank charges a premium above the risk-free interest rate. In the event of a default, the bank has the right to seize all remaining sales receipts, but only after covering relevant bankruptcy costs (also referred to as default costs). The default costs may include, but are not limited to, fixed costs and variable costs proportional to the residual value of firm’s assets. These two types of default costs are discussed in detail in corporate finance literature (see Ang et al. 1982 and Tirole 2006), and in the recent operations literature (see Kouvelis and Zhao 2011).

To the best of our knowledge, our paper is the first to study supply contract design with considerations of capital constraints, default costs, and working capital management. Unlike the corporate finance literature that mainly takes a single firm perspective, we study the strategic interactions of supply chain parties. Our research question is how the structure of default costs affects the supply contract design and performance, and whether or not expected default loss may be allocated among supply chain parties in a way that aligns their incentives and achieves the “first best” profits.

Our study contributes to the literature in two ways. First, we show how the structure of default costs (fixed, variable, etc.) interacts with contract terms and affects the supply chain performance. We classify assets of supply chain parties into two categories: sales revenue from the current business, and other assets pledged against loan obligations of the current business. In the case of default, some of default costs incurred are variable (proportional to asset value) and some are fixed (independent of asset value). With only variable default costs, both revenue-sharing and buyback contracts with working capital coordination (aligning loan sizes to be proportional to revenue shares of the parties) continue to coordinate the chain. Quantity discount contracts fail to coordinate, since the retailer has to borrow a loan larger than that in the centralized system. With fixed default costs, however, a buyback contract induces less profits than does a revenue-sharing contract.

The existence of fixed default costs complicates the problem and leads to interesting results.
While the centralized system is preferred with substantial economies of scales effects in the fixed default costs, it is possible for the decentralized system with coordinated working capital management to outperform the centralized system without such effects. The decentralized system takes advantage of the flexibility to better allocate loan responsibilities to each party according to its default costs, thus allowing the party with smaller default costs to borrow more.

Our second contribution is to point out the importance of, and offer effective ways to execute, coordinated working capital management in a decentralized supply chain. Our proposed revenue-sharing contracts through appropriate adjustment of wholesale prices achieve the needed alignment in loan sizes of the two firms. With only variable default costs or with high fixed default costs exhibiting substantial economies of scale, these contracts achieve the “first best” in supply chain performance. More strikingly, with fixed default costs not exhibiting economies of scale, such contracts may even induce better profits than the centralized system.

The paper’s organization is as follows. Section 2 briefly reviews the related literature. In Section 3, we introduce default costs and present profit models of supply chain parties. In Section 4, we show contracts with buyback terms are weakly pareto dominated by contracts without such terms. Based on this result, we focus our further analysis of coordination for general default costs using only revenue-sharing contracts. Section 5 examines the case of only variable default costs, and shows that revenue-sharing contracts with coordinated working capital allocation coordinate the chain, but quantity discount contracts fail to do so. In Section 6, we study the case of fixed default costs. Subsection 6.1 discusses fixed default costs without economies of scale, and shows the decentralized system under well designed revenue-sharing contracts may outperform the centralized one. Then, in subsection 6.2, we analyze fixed default costs with economies of scale, and show coordination via revenue-sharing contracts with working capital adjustment is still possible for some cases. Finally, Section 7 concludes with a summary of our results, insights, and future research suggestions.

2. Literature Review

Our work fits in the broad area of the interfaces of operations and financial decisions, which has recently received substantial interest (representative references include Babich and Sobel 2004, and Ding et al. 2007). We are particularly interested in the impact of cash flow constraints on inventory
decisions and supply chain coordination. Until the last few years, most of the related literature either ignored the impact of short-term financing issues on operational decisions (see Cachon 2003, Cachon and Lariviere 2005, Pasternack 1985, and Moorthy 1987 for more references) or considered financing issues in the absence of default costs (see Buzacott and Zhang 2004, Zhou and Groenevelt 2007, and Kouvelis and Zhao 2012 for more references).

Moorthy (1987) is one of the early works discussing supply chain coordination and shows that all unit quantity discount contracts can coordinate the channel. Pasternack (1985) studies the coordinating nature of buyback contracts. More recently, Cachon and Lariviere (2005) analyze revenue-sharing contracts and establish the equivalence between a buyback and a revenue-sharing contract. Cachon (2003) provides a comprehensive review of supply chain coordination in a supplier selling to a newsvendor retailer setting.

For a capital constrained retailer without default costs, Buzacott and Zhang (2004) discuss asset-based financing, and analyze how a strategically behaving bank decides the interest rate of the loan to the retailer. However, the authors do not consider coordination issues in their work. Kouvelis and Zhao (2012) study trade credit contracts for a capital constrained retailer, with the retailer obtaining financing from the bank and/or the supplier. Analyzing a Stackelberg leading supplier selling to a newsvendor setting, the paper considers bankruptcy risks, but assume costless default.

Yang and Birge (2009) study how the retailer, facing a default cost proportional to sales revenue, decides an optimal portfolio of financing resources, including bank credits and trade credits from the supplier. Kouvelis and Zhao (2011) study the retailer’s ordering problem under a wholesale price-only contract and in the presence of general default costs, including costs proportional to sales revenue, proportional to the pledged collateral to the loan, and fixed administrative costs. However, in both Yang and Birge (2009) and Kouvelis and Zhao (2011), the supplier is a profit maximizing Stackelberg leader in the supply chain, and in both papers there is no discussion of supply chain coordination issues under default costs. Our current paper explicitly focuses on the contract design and coordination issues in the presence of bankruptcy risks and costs for both the retailer and supplier, and brings to focus working capital management considerations among supply chain parties.
3. Model Description, Assumptions and Notation

In the decentralized supply chain the retailer (he) orders a single product from the supplier (she) prior to the sales season to satisfy future uncertain demand. The sequence of events is (see Figure 1):

1. Prior to the sales season (time 0): the supplier and retailer engage in negotiation for the parameterized contract \((w, \theta, T)\), where \(w\) is the wholesale price, \(\theta\) is the retailer’s revenue share, and \(T\) is the fixed amount of money the supplier transfers to the retailer at the end of the sales season. Upon contract agreement, the retailer places an order of quantity \(q\) and transfers the amount \(wq\) to the supplier. Then, the supplier produces the order for the retailer. If necessary, the supplier and retailer independently borrow competitively priced bank loans to finance their production and ordering decisions, respectively.

2. At the end of the sales season (time 1): the retailer transfers \(1 - \theta\) shares of sales revenue to the supplier, and the supplier transfers \(T\) amount of money to the retailer. Next, the supplier and retailer repay their debt obligations to the bank. Any party who defaults has to declare bankruptcy, and the bank gains control of the defaulting party’s remaining wealth after covering bankruptcy proceedings and all other relevant default costs.

**Remark 1.** As described above, we assume contractually agreed transfer payments between the supply chain parties, e.g., fixed money transfer from the supplier to the retailer and share of revenue from the retailer to the supplier, occur prior to bankruptcy proceedings. It is reasonable to assume that supply chain parties have enough time to finish high priority business transactions with their counterparties prior to bankruptcy, since periods of financial distress may last for a few years (for specific such examples, see Warner 1977 and Altman 1984). In most cases, bankruptcies result in a reorganization and the firms continue to be in business after reorganization (e.g., as described in Altman 1984, “... after the firm has declared bankruptcy and is attempting to operate and manage...”)
a return to financial health”). Then, in order to maintain good relationships in the long-term, firms will satisfy contractual agreements with key supply chain partners before declaring bankruptcy.

Let random variable $\xi$ be the demand on $[0, \infty)$. The probability density function is $f(\cdot)$, cumulative distribution function (CDF) is $F(\cdot)$, and complementary CDF is $\bar{F}(\cdot) = 1 - F(\cdot)$. Let $F$ be differentiable, increasing and $F(0) = 0$. The failure rate is $z(\cdot) = \frac{f(\cdot)}{\bar{F}(\cdot)}$ on $[0, \infty)$. We restrict our attention to distributions of an increasing failure rate (IFR), i.e., $z(\xi_2) \geq z(\xi_1)$ for $0 \leq \xi_1 < \xi_2 < \infty$.

Let the bank’s interest rate on a loan offered be $R$. Exogenous parameters are $r_f$, the risk-free interest rate in the period from time 0 to 1, $p$, the retail price at time 1, and $c$, the unit production cost at time 0. We ignore the salvage values of unsold items and goodwill loss for unmet demand. To avoid trivial cases, let $p > c(1 + r_f)$. For ease of exposition, we assume the supplier’s and retailer’s opportunity cost of capital is $r_f$, normalize the retail price $p = 1\text{,}$ and let the risk-free rate $r_f = 0$.

If necessary, we use subscripts $r$, $s$, $c$, and $d$ to denote the retailer, supplier, centralized system, and decentralized system, respectively. Major notation is summarized in Table 1, and modeling assumptions are listed in Table 2. Note that assumption $A_5$ eliminates moral hazard possibilities in loan repayment, i.e., supply chain parties purposefully hide money against loan repayment or contractual obligations. Assumptions $A_5$ and $A_2$ eliminate the possibility the supplier with limited cash on hand fails to fulfill the buyback obligation in the case of low demand realization. She has to borrow an adequate bank loan at time 0 to avoid breaking the contract agreement at time 1. Otherwise, under full information, the retailer will know this at time 0, and will agree to their transaction only if the supplier borrows adequately to cover her obligations.

### 3.1. A General Contract $(w, \theta, T)$

We consider a supply chain of a supplier and a retailer facing uncertain demand under a general contract $GC(w, \theta, T)$ (for notational simplicity, hereafter, we simply refer to it as contract $(w, \theta, T)$), where $0 \leq w \leq 1$ is the wholesale price, $0 \leq \theta \leq 1$ is the retailer’s revenue share, and $T \geq 0$ is a fixed money transfer from the supplier to the retailer at time 1 (we briefly discuss in Section 4 the case $T \leq 0$, the fixed money transfer from the retailer to the supplier). Let the retailer’s ordering quantity be $q \geq 0$. In terms of assumed product flows in the contract, at time 0 there is a flow of $q$ units from the supplier to the retailer, and at time 1 the remaining inventory of $(q - \xi)^+$ units can

\[ \xi' = p\xi, \quad q' = pq, \quad w' = \frac{w}{p}, \quad\text{and} \quad c' = \frac{c}{p}. \]

Our model with $\xi'$, $q'$, $w'$, $c'$, and $p = 1$ is the same as the original model.
Table 1  Notation

c: Supplier’s production cost prior to the sales season, \( c(1 + r_f) < p = 1 \) (and for \( r_f = 0, \ c < p \)),
\( \xi \): Random variable, the future uncertain demand,
y: Working capital prior to the sales season,
q: Retailer’s order quantity prior to the sales season,
R: Bank’s interest rate determined after competitively pricing the risks associated with the loan,
k: Default threshold, i.e., the minimal realized demand for a party to fully repay its loan obligation,
w: Contract parameter, supplier’s wholesale price,
\( \theta \): Contract parameter, the retailer’s revenue share from the sales,
T: Contract parameter, fixed money transfer from the supplier to retailer after demand realization,
\( \pi \): The expected profit of a firm,
\( \delta \): The repayment from a firm to the bank before default costs at time 1 (a random variable),
\( \Delta \): The bank’s expected repayment from a firm, i.e., the expectation of \( \delta \) minus default costs,
B: The default cost of a party as a function of demand realization and contract parameters,
L: The loan amount of a party as a function of ordering quantity and contract parameters,
C: The expected default loss of a party as a function of contract parameters.

Table 2  Assumptions

A1: The bank, retailer, supplier, and centralized system are risk neutral;
A2: Full information, i.e., both the working capital of the retailer and supplier and demand information are common knowledge to the three parties;
A3: All bank loans are competitively priced, and the bank is assumed to face no default risk;
A4: Both the supplier and retailer have long-term capital structure that is solely equity financed (for exposition convenience);
A5: There are no moral hazard issues, i.e., supply chain parties have no ex-ante intention to break the contractual agreement, and will ex-post repay their loan obligations to the extent possible.

be returned to the supplier. Compensation for returned units is captured via adjusting \( T \), as we will further explain. While \( \theta \) is assumed to be independent of \( q \), both \( w \) and \( T \) can be functions of \( q \). But for ease of exposition, we generally omit their dependence on \( q \).

Our general contract represents the three well studied types of coordinating contracts in the literature, by appropriately assigning \( w, \theta \) and \( T \) values and time 1 returned items. If \( w(q) \) is a properly specified function, \( \theta = 1 \) and \( T = 0 \), we get a quantity discount contract. If \( w = c\theta \) and \( T = 0 \), we get a revenue-sharing contract. We next show the general contract can be reduced to a buyback contract \( BC(w, b) \), where the wholesale price is \( w \), the buyback price is \( b \), and all remaining inventory, \((q - \xi)^+\), is returned. In \( BC(w, b) \), at time 0, the product flow is \( q \) units from the supplier to the retailer, and cash flow is \( wq \) from the retailer to the supplier. At time 1, the product flow is \((q - \xi)^+\) from the retailer to the supplier, and cash flow is \( b(q - \xi)^+ \) from the supplier to the retailer.

For our contract \((w, \theta, T)\), the time 0 product flow \( q \) and cash flow \( wq \) match those of the buyback contract \( BC(w, b) \). Let \( \theta = 1 - b \) and \( T = (1 - \theta)q = bq \). Note that the time 1 net cash flow from the supplier to the retailer is \( T - (1 - \theta) \min(\xi, q) = bq - b \min(\xi, q) = b(q - \xi)^+ \), i.e., the supplier buys back the retailer’s remaining inventory \((q - \xi)^+\) at a unit price \( b \). At time 1, both contracts have
the same product flows. Then, the general contract \((w, 1 - b, bq)\) induces the same product flows and cash flows as does the buyback contract \(BC(w, b)\), i.e., they are equivalent\(^2\).

In our contract \((w, \theta, T)\), the supplier to retailer money transfer \(T(q)\), with \(T(0) = 0\), is assumed to be an increasing and concave function of \(q\) (i.e., \(T'(q) \geq 0\) and \(T''(q) \leq 0\)). That is, the supplier does not want the money transfer to increase too fast in \(q\) to avoid the placement of unrealistically large quantities by the retailer. This assumption is satisfied by the buyback contract where \(T = (1 - \theta)q\).

Our performance comparison benchmark is the centralized supply chain: a single firm controls the total working capital of the channel, and serves as a single decision maker on all relevant decisions. The centralized system is a capital constrained newsvendor. Please refer to Figure 2.

3.2. The Expected Profit and Expected Default Loss of the Retailer

The retailer borrows a bank loan \(L_r = (wq - y_r)^+\) for his purchase needs at time 0. Using the interest rate \(R_r\) as the decision variable to control associated risks, the banks would demand \(L_r(1 + R_r)\) as a repayment promise. Let the actual repayment from the retailer be \(\delta_r\), a random variable depending on demand realization. If the retailer defaults on the loan, the bank incurs bankruptcy costs \(B_r\). Thus, the expected amount the banks receive is \(\Delta_r = \mathbb{E}[\delta_r - B_r \mathbf{1}_{bnkr}]^+\), where the indicator function \(\mathbf{1}_{bnkr} = 1\) if the retailer goes bankrupt and 0 otherwise. The banks are perfectly competitive and their rate of return is assumed to be zero. Then, for them to extend the loan of size \(L_r\) at rate \(R_r\), the following equilibrium condition must hold:

\(^2\)We ignore the salvage values for notational convenience. In the more general case that parties have different salvage values, our general contract needs to specify the product flows accordingly and explicitly, to simulate an existing contract in the literature. However, the introduction of the salvage value will not change our main insights.
\[ \Delta_r = \mathbb{E}[\delta_r - B_r \mathbbm{1}_{bnkr}]^+ = L_r. \]  

Note that \( \mathbb{E}[\delta_r - (\delta_r - B_r \mathbbm{1}_{bnkr})^+] \) is the part of assets that the retailer loses but the bank cannot receive due to the existence of \( B_r \), which we refer to as expected bankruptcy (default) loss. Let 

\[ C_r = \mathbb{E}[\delta_r - (\delta_r - B_r \mathbbm{1}_{bnkr})^+] = \mathbb{E}[\delta_r] - \Delta_r. \]

Then, \( \mathbb{E}[\delta_r] = C_r + L_r \) from (1). As a result, the retailer’s expected profit is 

\[
\pi_r(q, w, \theta, T) = \mathbb{E}[\theta \min(\xi, q) + T] - \frac{wq - L_r}{T} - \mathbb{E}[\delta_r] = \theta \mathbb{E}[\min(\xi, q)] + T - wq - C_r,
\]

where the second equality holds from \( L_r - \mathbb{E}[\delta_r] = -C_r \).

The actual repayment \( \delta_r \) will be the minimum between what is promised to the banks \( (L_r(1 + R_r)) \) and the money the retailer has on hand at the repayment time \( (\theta \min(\xi, q) + T) \), which is fraction of the revenue \( \theta \min(\xi, q) \) plus contract payment \( T \) from the supplier. That is, \( \delta_r = \min(L_r(1 + R_r), \theta \min(\xi, q) + T) \). No loan will be offered if the quantity \( q \) is insufficient to repay the loan even assuming infinite demand. Therefore, whenever there exist loan transactions, \( R_r \) and \( q \) together must satisfy \( L_r(1 + R_r) \leq \theta q + T \). As a result, one can simplify the expression for repayment as

\[ \delta_r = \min[L_r(1 + R_r), \theta \xi + T]. \]

The retailer’s bankruptcy condition is \( L_r(1 + R_r) > \theta \xi + T \). Then, his default threshold is

\[ k_r = \frac{1}{\theta}[L_r(1 + R_r) - T]^+, \]

i.e., he will go bankrupt if the realized demand is below this threshold. When \( k_r = 0, \mathbbm{1}_{bnkr} \equiv 0 \) and the bank will receive \( L_r(1 + R_r) \) for sure so that (1) implies that \( R_r = 0 \) and (2) implies that \( C_r = 0 \). Thus, (1) becomes trivial and the retailer’s profit is reduced to the situation without cash constraints. Then, we focus on \( k_r > 0 \) in this section, and we can simplify \( \delta_r \) into

\[
\delta_r = \theta \min(\xi, k_r) + T \quad \text{and} \quad (\delta_r - B_r \mathbbm{1}_{bnkr})^+ = \begin{cases} 
(\theta \xi + T - B_r)^+, & \text{if } \xi < k_r, \\
\theta k_r + T, & \text{otherwise.}
\end{cases}
\]

The default cost \( B_r \) follows a stylized assumption in corporate finance literature that the default cost is incurred as a proportion of the bankrupt firm’s total residual assets. For a reference to the
associated structural modeling work, see the classical debt pricing models of Leland (1994) and Leland and Toft (1996), and the references therein. Several models in the operations literature follow the proportional default cost assumption, such as Xu and Birge (2004) and Lai et al. (2009).

Note that the above default cost is not related to other factors such as the loan size, the repayment size, the short amount, etc. That is, the more residual assets a bankrupt firm has, the more default cost it will incur, no matter how much the firm borrows or how much is left unpaid.

Some criticism of the proportional to residual assets default costs is pointed out in Elkamhi et al. (2012): “Although empirical work tends to report estimates as proportions of bankrupt firm value (or near this value), there may in reality be a mixture of fixed and proportional costs. For example, court and attorney fees are likely to be fairly similar across firms, while asset sale discounts may vary in proportion to firm size. See, for example, Warner (1977) and Bris, Welch, and Zhu (2006).” The recent work of Kouvelis and Zhao (2011) includes both fixed costs and proportional costs.

In our model, the retailer’s total remaining asset, given default, is $\xi \theta + T + O_r$, where the first term is the sales revenue and $O_r$ denotes the value of all other assets pledged against the loan obligations. The total remaining asset incurs the total value loss $B_r = \alpha \xi \theta + \beta_r' r$. It is a combination of fixed and proportional costs. That is, the retailer loses $0 \leq \alpha \leq 1$ portion of his share of sales revenue $\xi \theta$; $0 \leq \epsilon_r \leq 1$ portion of the other assets, and $\beta_r' \geq 0$ bankruptcy administrative fees (e.g., court and attorney fees). (Here we assume that the fixed money transfer $T$ does not directly lose value.) Note that $\epsilon_r O_r$ and $\beta_r'$ are independent of the current sales and are treated as fixed costs. Let $\beta_r = \beta_r' + \epsilon_r O_r$ be the retailer’s fixed costs. Then,

$$B_r = B(\xi, \theta, \beta_r) \equiv \alpha \xi \theta + \beta_r.$$  
(5)

Here we intentionally omit the subscript $r$ from the function $B$, since this function applies to the supplier and centralized system as well, as long as we use the variables corresponding to those parties. We apply the same logic for the repayment function $\Delta$, bankruptcy threshold function $k$, and expected default loss function $C$.

Substituting $(\delta_r - B_r 1_{bnkr})^+$ into (1) yields the retailer’s expected repayment to the bank:

$$\Delta_r = \Delta(k_r, \theta, \beta_r, T) \equiv \int_0^{k_r} [\xi \theta + T - B(\xi, \theta, \beta_r)]^+ dF(\xi) + \int_{k_r}^{\infty} (\theta k_r + T) dF(\xi).$$  
(6)
Note that equation (1), i.e., $\Delta(k_r, \theta, \beta_r, T) = L_r$, implicitly defines the retailer’s bankruptcy threshold $k_r$ as a function of $\theta, \beta_r, T,$ and $L_r$. Then, let $k_r = k(\theta, L_r, \beta_r, T)$. Note that this definition of $k_r$ does not conflict with (4), which is used by the bank to determine the corresponding interest rate.

Substituting $\delta_r$ into (2) and applying (1) yield the retailer’s expected default loss:

$$C_r = C(\theta, L_r, \beta_r, T) \equiv \theta \int_0^{k_r} \bar{F}(\xi)d\xi + T - L_r = \theta \int_0^{k(\theta, L_r, \beta_r, T)} \bar{F}(\xi)d\xi + T - L_r.$$  

Again, we will see in Sections 3.3 and 3.4 that the functions $B$, $\Delta$, $k$, and $C$ can be applied to the supplier and centralized system as well, as long as we use the variables corresponding to those parties. Therefore, we omit the corresponding subscripts from those functions.

As a summary, the retailer decides an optimal quantity to maximize $\pi_r$ in (3), subject to (1) through which banks competitively price the loan by choosing a proper interest rate $R_r$.

### 3.3. The Expected Profit and Expected Default Loss of the Supplier

We now analyze the supplier’s cash flows in a similar way. Let the supplier’s loan size at time 0 be $L_s$. The banks would demand $L_s(1 + R_s)$ as a repayment promise, using the interest rate $R_s$ as the decision variable. The supplier’s actual repayment is a random variable $\delta_s$. If the supplier defaults, the bank incurs bankruptcy costs $B_s$ so that the expected amount the banks receive is $\Delta_s = \mathbb{E}[\delta_s - B_s 1_{\text{bnkr}}]^+$, where $1_{\text{bnkr}} = 1$ if the supplier goes bankrupt and zero otherwise. For the perfectly competitive banks to extend the loan $L_s$ at rate $R_s$, the following equilibrium condition must hold:

$$\Delta_s = \mathbb{E}[\delta_s - B_s 1_{\text{bnkr}}]^+ = L_s.$$  

Note that $\mathbb{E}[\delta_s - (\delta_s - B_s 1_{\text{bnkr}})^+]$ is the expected bankruptcy (default) loss that the supplier loses but the bank cannot receive. Let

$$C_s = \mathbb{E}[\delta_s - (\delta_s - B_s 1_{\text{bnkr}})^+] = \mathbb{E}[\delta_s] - \Delta_s.$$  

Then, $\mathbb{E}[\delta_s] = C_s + L_s$ from (8). As a result, the supplier’s expected profit of the equity holders is

$$\pi_s(q, w; \theta, T) = \frac{\mathbb{E}[(1 - \theta) \min(\xi, q) - T]}{\text{Total revenue from the retailer at time 1}} - \frac{[(cq - wq) - L_s]}{\text{Net cost at time 0}} - \frac{\mathbb{E}[\delta_s]}{\text{Repayment to the bank at time 1}}$$

$$= (1 - \theta)\mathbb{E}[\min(\xi, q)] - T - cq + wq - C_s,$$  

where the second equality holds from $L_s - \mathbb{E}[\delta_s] = -C_s$. 
We now discuss the supplier’s loan size $L_s$. The supplier’s total assets after receiving payment $wq$ from the retailer is $y_s + wq$. Her total liabilities are $cq$, the production cost, plus the net money transfer $T - (1 - \theta)\min(\xi, q)$ to the retailer. As we have already explained, all contractually agreed transfer payments between supply chain parties occur prior to bankruptcy proceedings. To avoid the moral hazard issues (see assumption $A_5$), the supplier needs $T$ cash on hand, for her buyback responsibility if $\xi = 0$, on top of $cq$. Therefore, the supplier’s loan is $L_s = [T + cq - (wq + y_s)]^+$. 

The actual repayment $\delta_s$ will be the minimum between what is promised to the banks ($L_s(1 + R_s)$) and the money the supplier has on hand at the repayment time ($wq + y_s + L_s - cq + (1 - \theta)\min(\xi, q) - T$). Note that $wq + y_s + L_s - cq$ is the remaining cash the supplier has at time 0 (after borrowing $L_s$ and investing $cq$) and $T - (1 - \theta)\min(\xi, q)$ is her net transfer amount to the retailer. It holds that $wq + y_s + L_s - cq + (1 - \theta)\min(\xi, q) - T = (1 - \theta)\min(\xi, q)$ for $L_s > 0$. That is, $\delta_s = \min(L_s(1 + R_s), (1 - \theta)\min(\xi, q))$. No loan will be offered if the quantity $q$ is insufficient to repay the loan even assuming infinite demand. Therefore, whenever there exist loan transactions, $R_s$ and $q$ together must satisfy $L_s(1 + R_s) \leq (1 - \theta)q$. As a result,

$$\delta_s = \min[L_s(1 + R_s), (1 - \theta)\xi].$$

The retailer’s bankruptcy condition is $L_s(1 + R_s) > (1 - \theta)\xi$. Then, her default threshold is

$$k_s = \frac{1}{1 - \theta}L_s(1 + R_s),$$

i.e., she will go bankrupt if the realized demand is below $k_s$. When $k_s = 0$, $1_{\text{bnkr}} \equiv 0$ and the bank will receive $L_s(1 + R_s)$ for sure. From (8), $R_s = 0$ and from (9), $C_s = 0$. Thus, the bank’s equation (8) becomes trivial and the supplier’s profit is reduced to the situation without cash constraints. Then, we focus on $k_s > 0$ in this section. In this case, we can simplify $\delta_s$ into

$$\delta_s = (1 - \theta)\min(\xi, k_s) \quad \text{and} \quad (\delta_s - B_s1_{\text{bnkr}})^+ = \begin{cases} ((1 - \theta)\xi - B_s)^+, & \text{if } \xi < k_s, \\ (1 - \theta)k_s, & \text{otherwise}. \end{cases}$$

If the supplier defaults, her remaining asset from the current business is $wq + y_s + L_s - cq + (1 - \theta)\min(\xi, q) - T = (1 - \theta)\min(\xi, q) = (1 - \theta)\xi$ (recall we require $\xi < q$ when default happens). Let $O_s$ be her other assets pledged towards the loan. Then, her total remaining asset is $\xi(1 - \theta) + O_s$. Let $B_s = \alpha\xi(1 - \theta) + \epsilon_sO_s + \beta_s' = \alpha\xi(1 - \theta) + \beta_s$, where $\alpha$ is the percentage loss of her share of sales.
revenue, \( \epsilon_s \) is the percentage loss of the other assets, \( \beta' s \) is the bankruptcy administrative cost, and 
\( \beta_s = \beta'_s + \epsilon_s O_s \) is her fixed cost. It is reasonable for the supplier to have the same \( \alpha \) as the retailer, 
as she shares revenue with the retailer and is subject to the same percentage loss. Notice that
\[
B_s = \alpha \xi (1 - \theta) + \beta_s = B(\xi, 1 - \theta, \beta_s),
\]
where the function \( B \) is defined in (5), with corresponding variables for the supplier.

Substituting \( (\delta_s - B_s 1_{\text{bnkr}})^+ \) into (8) yields the supplier’s expected repayment to the bank:
\[
\Delta_s = \int_0^{k_s} [\xi (1 - \theta) - B(\xi, 1 - \theta, \beta_s)]^+ dF(\xi) + \int_{k_s}^\infty (1 - \theta) k_s dF(\xi) = \Delta(k_s, 1 - \theta, \beta_s, 0),
\]
where the function \( \Delta \) is defined in (6). Note that equation (8), i.e., \( \Delta(k_s, 1 - \theta, \beta_s, 0) = L_s \), implicitly defines \( k_s \) as a function of \( 1 - \theta, \beta_s, 0 \), and \( L_s \). Since defined through the same function \( \Delta \), this function is just the function \( k \) defined in Section 3.2 for the retailer, i.e., \( k_s = k(1 - \theta, L_s, \beta_s, 0) \).

Substituting \( \delta_s \) into (9) and applying (8) yield the supplier’s expected default loss:
\[
C_s = (1 - \theta) \int_0^{k_s} \bar{F}(\xi) d\xi - L_s = (1 - \theta) \int_0^{k(1 - \theta, L_s, \beta_s, 0)} \bar{F}(\xi) d\xi - L_s = C(1 - \theta, L_s, \beta_s, 0),
\]
where the function \( C \) is defined in (7).

In summary, the contract \( (w, \theta, T) \) is jointly determined/negotiated by the retailer and supplier. The \( q \) is determined by the retailer, and thus is not a free variable to the supplier. The supplier has to influence \( q \) through negotiating on the contract terms. Also, the supplier’s problem is subject to (8) through which the bank competitively prices the loan (by choosing the proper interest rate \( R_s \)).

3.4. The Expected Profit and Expected Default Loss of the Centralized System
The centralized system has the channel working capital \( y_r + y_s \). At time 0, the centralized system needs to borrow \( L_c = (cq - y_r - y_s)^+ \) for the production requirement, with the bank’s interest rate \( R_c \). The actual repayment is a random variable \( \delta_c \), and if the centralized system defaults, the bank incurs bankruptcy costs \( B_c \). Then, the expected amount the banks receive is \( \Delta_c = \mathbb{E}[\delta_c - B_c 1_{\text{bnkr}}]^+ \), where \( 1_{\text{bnkr}} = 1 \) if the centralized system goes bankrupt and 0 otherwise. For competitive banks to extend the loan of size \( L_c \) at rate \( R_c \), the following equilibrium condition must hold:
\[
\Delta_c = \mathbb{E}[\delta_c - B_c 1_{\text{bnkr}}]^+ = L_c.
\]
Note that $\mathbb{E}[\delta_c - (\delta_c - B_c 1_{bnkr})^+]$ is the expected bankruptcy (default) loss that the centralized system loses but the bank cannot receive. Let

$$C_c = \mathbb{E}[\delta_c - (\delta_c - B_c 1_{bnkr})^+] = \mathbb{E}[\delta_c] - \Delta_c. \quad (15)$$

Then, $\mathbb{E}[\delta_c] = C_c + L_c$ from (14). As a result, the centralized system’s expected profit is

$$\pi_c(q, c, 1, 0) = \mathbb{E}[\min(\xi, q)] - (cq - L_c) - \mathbb{E}[\delta_c] = \mathbb{E}[\min(\xi, q)] - cq - C_c, \quad (16)$$

where the second equality holds from $L_c - \mathbb{E}[\delta_c] = -C_c$.

The actual repayment $\delta_c$ will be the minimum between what is owed to the banks ($L_c(1 + R_c)$) and on hand cash of the centralized system at the repayment time ($\min(\xi, q)$). No loan will be offered if the quantity $q$ is insufficient to repay the loan even assuming infinite demand. Therefore, whenever there exist loan transactions, $R_c$ and $q$ together must satisfy $L_c(1 + R_c) \leq q$. As a result, we can simplify the expression for repayment as

$$\delta_c = \min(L_c(1 + R_c), \xi).$$

The centralized system’s bankruptcy condition is $L_c(1 + R_c) > \xi$. Then, the default threshold is

$$k_c = L_c(1 + R_c). \quad (17)$$

When $k_c = 0$, $1_{bnkr} \equiv 0$ and the bank will receive $L_c(1 + R_c)$ for sure. From (14), $R_c = 0$ and from (15), $C_c = 0$. Thus, (14) becomes trivial and the centralized system’s profit is reduced to the case without cash constraints. Then, we focus on $k_c > 0$ in this section. We have

$$\delta_c = \min(\xi, k_c) \quad \text{and} \quad (\delta_c - B_c 1_{bnkr})^+ = \begin{cases} (\xi - B_c)^+, & \text{if } \xi < k_c, \\ k_c, & \text{otherwise}. \end{cases}$$

Note that the centralized system’s other assets pledged towards the loan are $O_c = O_r + O_s$. Then, its total asset exposure is $\xi + O_c$. Let the default cost of the centralized system $B_c = \alpha \xi + \epsilon_c O_c + \beta'_c = \alpha \xi + \beta_c$, where $\alpha$ percent of the sales revenue is lost, $\beta'_c$ is the bankruptcy administrative cost, $\epsilon_c$ being the percentage loss of the other assets, and $\beta_c = \beta'_c + \epsilon_c O_c$ is the fixed cost. Here note that we use the same percentage loss $\alpha$ for the sales revenue as the supplier and retailer. Notice that

$$B_c = \alpha \xi + \beta_c = B(\xi, 1, \beta_c),$$
where the function $B$ is defined in (5).

Substituting $(\delta c - Bc 1_{\text{bnkr}})^+$ into (14) yields the expected repayment to the bank:

$$\Delta_c = \int_0^{k_c} \left[ \xi - B(\xi, 1, \beta_c) \right]^+ dF(\xi) + \int_{k_c}^\infty k_c dF(\xi) = \Delta(k_c, 1, \beta_c, 0),$$

(18)

where the function $\Delta$ is defined in (6). Note that equation (14), i.e., $\Delta(k_c, 1, \beta_c, 0) = L_c$, implicitly defines $k_c$ as a function of 1, $\beta_c$, 0, and $L_c$. Since defined through the same function $\Delta$, this function is just the function $k$ defined in Section 3.2 for the retailer, i.e., $k_c = k(1, L_c, \beta_c, 0)$.

Substituting $\delta c$ into (15) and applying (14) yield the expected default loss:

$$C_c = \int_0^{k_c} \bar{F}(\xi) d\xi - L_c = \int_0^{k(1, L_c, \beta_c, 0)} \bar{F}(\xi) d\xi - L_c = C(1, L_c, \beta_c, 0),$$

(19)

where the function $C$ is defined in (7).

3.5. New Features in Supply Chain Contract Design and Coordination

The operations literature proposes various supply contracts which achieve “first best” for the supply chain while allowing different degrees of profit sharing between the retailer and supplier. However, factors such as capital constraints and default costs are generally ignored. In this section, we examine contract design and coordination under such concerns.

By competitively pricing the loans, banks do not claim any profits from the supply chain. From equations (3), (10), and (16), the total profits of the decentralized and centralized supply chains are given in (20) and (21), respectively:

$$\pi_r(q, w, \theta, T) + \pi_s(q, w, \theta, T) = \mathbb{E}[\min(\xi, q)] - cq - [C(\Theta, L_r(q), \beta_r, T) + C(1 - \theta, L_s(q), \beta_s, 0)],$$

(20)

$$\pi_c(q, c, 1, 0) = \mathbb{E}[\min(\xi, q)] - cq - C(1, L_c(q), \beta_c, 0).$$

(21)

As is implied from (20) and (21), without default costs, the decentralized and centralized systems perform identically under coordinating contracts which induce the decentralized system to order the same $q$ as the centralized one. While the default costs, particularly fixed ones $\beta_r$ and $\beta_s$, interact with contract terms through the expected default loss function $C$ and affect the expected profits of the decentralized system, the fixed default cost $\beta_c$ affects the expected profits of the centralized system as well. This not only makes contract designs of the decentralized system challenging, but can even change the relative values of the optimal profits of the decentralized and centralized systems.
More specifically, we show as in the traditional literature, the optimal profit of the centralized system serves as an upper bound to the optimal profit of the decentralized system, when there are no fixed default costs (see Section 5) and when fixed default costs exist but $\beta_c$ is substantially less than $\beta_r + \beta_s$ (see Section 6.2). In such cases, we say that coordination is achieved if the contract used in the decentralized system results in decisions which generate the optimal profits of the centralized system. However, in Section 6.1, we show the decentralized system may outperform the centralized one when fixed default costs exist but $\beta_c = \beta_r + \beta_s$. For such cases, we are not searching any more for “coordinating” contracts in the above sense, but for contracts that result in a set of the decentralized supply chain optimal actions that are Nash equilibrium, i.e., no supply chain party has a profitable unilateral deviation from these optimal actions (see page 230, Cachon 2003).

Throughout the paper, unless stated explicitly, we use comparatives in the weak sense. Also, we assert that a contract is more efficient (or has a larger efficiency) than another one if it can generate larger expected profits in the decentralized supply chain.

In our next analysis, we work with a generalized form of the default cost function defined in (5):

$$B(\xi, \theta, \beta) = g(\xi)\theta + \beta,$$

where $g(\xi) \geq 0$ with $g(0) = 0$ and $0 \leq g'(\xi) \leq 1$.

4. **Contracts ($w, \theta, T$) with Non-Zero Transfer Payment $T$**

4.1. **Positive Fixed Transfer Payment $T > 0$ (Buyback Contracts)**

We first discuss the general contracts with a fixed transfer payment $T > 0$ from the supplier to the retailer at time 1, which can be interpreted as a buyback related term. The buyback term has two effects on the retailer: 1. In order to honor the buyback, the supplier charges a larger wholesale price than the production cost $c$, and thus the retailer has to borrow a larger loan principal than under the centralized system, which leads to the over-borrowing effect; and 2. The buyback amount can be used as the collateral at time 1 to secure the retailer’s loan. This is referred to as the collateral effect. However, similar to the sales revenue, this buyback collateral may lose some of its value in the case of default, which influences the retailer’s expected default loss and expected profit.

Recall both $w$ and $T$ can be functions of $q$. Without loss of generality, let $w(q) = \omega(q) + \gamma$, where $\gamma \geq 0$ is a constant independent of $q$. Let $q_d(w(q_d), \theta, T(q_d)) = \arg \max_{q \geq 0} \pi_r(q|w(q), \theta, T(q))$ be the
retailer’s optimal ordering quantity under a contract \((w(q), \theta, T(q))\). Then,

\[
\text{PROPOSITION 1. For IFR demand distributions and a contract } (w(q), \theta, T(q)) \text{ where } T(q) \text{ satisfies } 0 \leq q T(q) \leq T(q), \text{ there exists a counterpart revenue-sharing contract } (\hat{w}(q) - \frac{T(q)}{q}, \theta, 0) \text{ with } \hat{w}(q) = \omega(q) + \gamma \text{ and } \gamma \geq \gamma, \text{ i.e., the same or increased (shifted by a positive constant) wholesale price, so that}
\]

1. \( q_d(\hat{w}(q_d) - \frac{T(q_d)}{q_d}, \theta, 0) = q_d(w(q_d), \theta, T(q_d)), \text{ i.e., the retailer’s optimal ordering quantity under the revenue-sharing contract } (\hat{w}(q) - \frac{T(q)}{q}, \theta, 0) \text{ is the same as that under the contract } (w(q), \theta, T(q)); \)
2. \( (w(q), \theta, T(q)) \) is (weakly) pareto dominated by \((\hat{w}(q) - \frac{T(q)}{q}, \theta, 0)\). That is, both the retailer and supplier are (weakly) better-off under the contract \((\hat{w}(q) - \frac{T(q)}{q}, \theta, 0)\), i.e.,

\[
\pi_r(q_d, \hat{w}(q_d) - \frac{T(q_d)}{q_d}, \theta, 0) \geq \pi_r(q_d, w(q_d), \theta, T(q_d));
\]
\[
\pi_s(q_d, \hat{w}(q_d) - \frac{T(q_d)}{q_d}, \theta, 0) \geq \pi_s(q_d, w(q_d), \theta, T(q_d)).
\]

For the case of \(\beta_r = 0\), we have \(\gamma = \gamma\) and \(\hat{w}(q) = w(q)\). Furthermore, the equalities in the above two inequalities hold, and the two contracts are equivalent to each other.

For the contract \((w(q), \theta, T(q))\), let us first consider the contract \((w(q) - \frac{T(q)}{q}, \theta, 0)\). We can show that whenever the retailer under the contract \((w(q) - \frac{T(q)}{q}, \theta, 0)\) orders the optimal quantity under \((w(q), \theta, T(q))\), the retailer will be better-off and the supplier’s expected profits are the same under the two contracts. The driving factor for \((w(q), \theta, T(q))\) to be less efficient is that \(T(q)\) may lose value in the retailer’s bankruptcy. When comparing the buyback contract \((w(q), \theta, T(q))\) to the contract \((w(q) - \frac{T(q)}{q}, \theta, 0)\), the retailer pays an extra \(T(q)\) at time 0. Then, at time 1, the supplier pays back the \(T(q)\) to the retailer when buying the retailer’s leftover inventory. We refer to it as the \textit{overcharge-then-payback} mechanism of the buyback contract \((w(q), \theta, T(q))\). From (6) and (22), if \(\beta_r = 0\), then \(T(q)\) is separable from other terms in \(\Delta_r\). From (1), there will be no difference whether \(T(q)\) happens at time 0 to reduce \(L_r\) or happens at time 1 to reduce \(\Delta_r\). That is, this mechanism is still efficient and the two contracts are equivalent to each other (Cachon and Lariviere, 2005).

However, if \(\beta_r > 0\), this mechanism may cause profit-loss, since part of the buyback collateral may have to cover the retailer’s fixed default cost. That is, the reduced collateral amount at time 1 does not offset the increased loan obligation at time 0 any more. Then, the bank charges a higher rate and the retailer ends up with smaller expected profit under the original buyback
contract \((w(q), \theta, T(q))\) than the revenue-sharing contract \((w(q) - \frac{T(q)}{q}, \theta, 0)\).

The above observations hold under the assumption that the retailer orders the same quantities under \((w(q), \theta, T(q))\) and \((w(q) - \frac{T(q)}{q}, \theta, 0)\). It is, however, possible that the retailer may order a different quantity under \((w(q) - \frac{T(q)}{q}, \theta, 0)\) than under \((w(q), \theta, T(q))\). Case 1 of Proposition 1 shows that to ensure the retailer orders the same quantity under \((w(q) - \frac{T(q)}{q}, \theta, 0)\) as that under \((w(q), \theta, T(q))\), the supplier might have to appropriately increase the wholesale price from \(w(q) = \omega(q) + \gamma\) to \(\hat{w}(q) = \omega(q) + \gamma\) where \(\hat{\gamma} \geq \gamma\). We refer to this appropriately adjusted wholesale price revenue-sharing contract \((\hat{w}(q) - \frac{T(q)}{q}, \theta, 0)\) as the counterpart revenue-sharing contract of the buyback contract \((w(q), \theta, T(q))\). Note that if \(\beta_r = 0\), then \(\hat{\gamma} = \gamma\) and \((w(q) - \frac{T(q)}{q}, \theta, 0)\) is equivalent to \((w(q), \theta, T(q))\).

Case 2 of Proposition 1 shows that both the retailer and supplier will receive (weakly) better profits under \((\hat{w}(q) - \frac{T(q)}{q}, \theta, 0)\) than those under the contract \((w(q), \theta, T(q))\). As a result, we conclude that \((w(q), \theta, T(q))\) is (weakly) pareto dominated by, and less efficient than, the counterpart revenue-sharing contract \((\hat{w}(q) - \frac{T(q)}{q}, \theta, 0)\).

### 4.2. Negative Fixed Transfer Payment \(T < 0\) (Partial Down Payment)

We now discuss what happens if the retailer only pays part of \(wq\) as down payment at time 0. If so, the supplier will require the retailer to pay the remaining amount at time 1, i.e., \(T \leq 0\). Then, the smaller down payment at time 0 forces the supplier to borrow a larger loan, and the retailer’s remaining payment at time 1 serves as a collateral to secure the supplier’s loan. The retailer also needs to carefully plan and borrow against his time 1 payment obligations. Under our full information assumption \(A_2\), if the retailer does not borrow enough, the supplier will know it at time 0 and demand from the retailer to do so prior to engaging in any transactions. Our observations are parallel to those made for \(T > 0\) in Proposition 1, but now differentiating on cases for \(\beta_s > 0\) or \(\beta_s = 0\). The following lemma summarizes our results.

**Lemma 1.** Let \(T(q) < 0\). Consider the contracts \((w(q), \theta, T(q))\) and \((w(q) - \frac{T(q)}{q}, \theta, 0)\). We have

1. \(q_d(w(q) - \frac{T(q)}{q_d}, \theta, 0) = q_d(w(q), \theta, T(q_d))\), i.e., the retailer’s optimal ordering quantity under the revenue-sharing contract \((w(q) - \frac{T(q)}{q}, \theta, 0)\) is the same as that under the contract \((w(q), \theta, T(q))\);

2. \((w(q), \theta, T(q))\) is (weakly) pareto dominated by \((w(q) - \frac{T(q)}{q}, \theta, 0)\). More specifically, the retailer

\(^3\)Note that concave functions \(T(q)\) are a subset of functions satisfying \(0 \leq qT'(q) \leq T(q)\).
gets the same optimal expected profit under both contracts, and the supplier gets (weakly) better optimal expected profit under the contract \((w(q) - \frac{T(q)}{q}, \theta, 0)\), i.e.,

\[
\begin{align*}
\pi_r(q_d, w(q_d) - \frac{T(q_d)}{q_d}, \theta, 0) &= \pi_r(q_d, w(q_d), \theta, T(q_d)), \\
\pi_s(q_d, w(q_d) - \frac{T(q_d)}{q_d}, \theta, 0) &\geq \pi_s(q_d, w(q_d), \theta, T(q_d)).
\end{align*}
\] (23)

If \(\beta_s = 0\), the equality in inequality (23) holds and the two contracts are equivalent to each other.

Note that the wholesale purchase payment \(wq\) is split between an upfront and a remnant payment. The remnant payment is paid at time 1 under the \(T(q) < 0\) buyback contract, but is paid at time 0 under the revenue-sharing contract. Under our assumptions of full information and all contractual agreements are executed prior to bankruptcy, it is guaranteed the retailer makes an equal amount payment. Then, Case 1 of Lemma 1 concludes that the retailer’s optimal ordering quantities are the same under the buyback contract and its counterpart revenue-sharing contract.

Using the same logic, Case 2 of Lemma 1 concludes that the retailer’s optimal expected profits are the same under the two contracts. However, for the supplier, in the case of the buyback contract, she may have to borrow more at time 0 and use as a collateral payment to that loan the amount to be received at time 1. In the case of fixed default cost \(\beta_s > 0\), this collateral might be subject to lose some of its value, and might not be covering some of the overborrowed amount at time 0. As a result, if \(\beta_s > 0\), then the supplier will receive smaller expected profits, and the contract \((w(q), \theta, T(q))\) is pareto dominated by \((w(q) - \frac{T(q)}{q}, \theta, 0)\). Otherwise, the supplier will receive the same expected profits under the two contracts, and the two contracts are equivalent to each other.

Combining Proposition 1 for \(T \geq 0\) and Lemma 1 for \(T \leq 0\), we get the results below.

**Lemma 2.** For contracts \((w(q), \theta, T(q))\) with a fixed money transfer \(T(q) \neq 0\) at time 1 and \(T'(q) \geq 0\) and \(T''(q) \leq 0\) if \(T(q) \geq 0\), there exists a counterpart revenue-sharing contract \((\hat{w}(q) - \frac{T(q)}{q}, \theta, 0)\) which induces the same retailer’s ordering quantity as \((w(q), \theta, T(q))\), and both parties in the decentralized system are (weakly) better-off under \((\hat{w}(q) - \frac{T(q)}{q}, \theta, 0)\) than under \((w(q), \theta, T(q))\).

Our analysis in Section 4 clearly shows that for any general contract \((w(q), \theta, T(q))\) with \(T(q) > 0\) or \(T(q) < 0\), we can always find an equivalent or pareto dominant counterpart revenue-sharing contract (with \(T(q) = 0\)). Thus, in search for pareto dominant coordinating contracts in Sections
5 and 6, we do not consider fixed transfer payment, i.e., $T = 0$. Therein, for ease of exposition, we drop the term $T$ in all relevant functions. We want to point out that our two parameter contracts are more general than the revenue-sharing contracts in the literature, due to the fact that the wholesale price might be a function of the retailer’s ordering quantity.

5. Coordinating Contracts for the Case of Only Variable Default Costs

We study the case that the retailer, supplier, and centralized system do not have fixed bankruptcy costs at all, i.e., $\beta_r = \beta_s = \beta_c = 0$. As mentioned before, we only need to study contracts with $T = 0$. For simplicity, the contract $(w, \theta, 0)$ going forward is denoted as $(w, \theta)$. Let $q_c$ be the optimal production quantity of the centralized system and $L_c(q_c) > 0$. Then,

**Proposition 2.** For IFR demand distributions and for any $q \geq 0$, we have

$$C(\theta, L_r(q), 0) + C(1 - \theta, L_s(q), 0) \geq C(1, L_c(q), 0),$$

where the equality holds if and only if

$$\frac{L_r(q)}{\theta} = \frac{L_s(q)}{1 - \theta} = \frac{L_c(q)}{1},$$

Condition (25) is a necessary, and also sufficient if $L_c(q_c) > 0$, condition to coordinate the chain. That is, let $(\bar{w}(q), \theta)$ be the contract according to (25) and $q_d(w(q_d), \theta) = \arg \max_{q \geq 0} \pi_r(q|w(q), \theta)$ be the retailer’s optimal quantity under a given contract $(w(q), \theta)$ in the decentralized system. Then,

$$\begin{cases}
q_d(\bar{w}(q_d), \theta) = q_c \\
\pi_r(q_d(\bar{w}(q_d), \theta), \bar{w}(q_d), \theta) + \pi_s(q_d(\bar{w}(q_d), \theta), w(q_d), \theta) \leq \pi_c(q_c, c, 1), \quad \text{for all } w(q) \geq 0, \\
\pi_r(q_d(\bar{w}(q_d), \theta), \bar{w}(q_d), \theta) + \pi_s(q_d(\bar{w}(q_d), \theta), \bar{w}(q_d), \theta) = \pi_c(q_c, c, 1) \\
\pi_r(q_d(\bar{w}(q_d), \theta), \bar{w}(q_d), \theta) = \theta \pi_c(q_c, c, 1).
\end{cases}$$

As a result, $(\bar{w}(q), \theta)$ is the optimal contract among the contracts $(w(q), \theta)$ with $w(q) \geq 0$ and $0 \leq \theta \leq 1$ and coordinates the chain with arbitrary profit allocation between the supplier and retailer.

The case of supply chains without any financial constraint, i.e., $L_r(q) = L_s(q) = L_c(q) = 0$, is a special case of Proposition 2. In the case that $L_c(q_c) > 0$, i.e., the centralized system has bankruptcy risks, under condition (25), the retailer’s and supplier’s profits are proportional to the centralized system’s profit (except for a constant term). Then, the retailer’s optimal ordering quantity is also $q_c$. Furthermore, since both the expected default losses of the retailer and the supplier are
proportional to the expected default loss of the centralized system, the expected profit of the decentralized system with the retailer ordering \( q_c \) equals that of the centralized system. Therefore, the revenue-sharing contract \((w, \theta)\) achieves coordination.

From Proposition 2, it is clear that (25) is the necessary condition for supply chain coordination. In other words, the only possible way for a contract to coordinate is to allocate the channel’s total debt to each party proportional to his/her revenue share.

Note that condition (25) implies \( L_r + L_s = L_c \). We have shown that for a given revenue share, a party’s expected default losses \( C \) are increasing and convex in the loan amount (see proof of Proposition 2). As a result, if \( L_r(q) + L_s(q) > L_c(q) \) for any \( q \geq 0 \) with \( L_c(q) > 0 \), then the strict inequality in (24) holds, and the optimal expected profit the decentralized system can possibly achieve will be strictly smaller than the optimal profit of the centralized one. We refer to this coordination failure case as due to over-borrowing effects, and it explains the coordination failure of quantity discount contracts in bankruptcy cost settings. We have the following lemma:

**Lemma 3.** For IFR demand distributions, in the case that the centralized system has default risks, i.e., \( cq_c > y_r + y_s \), any quantity discount contract with \( w > c \) fails to coordinate.

Under quantity discount contracts, since \( w > c \), only the retailer borrows, i.e., \( L_s(q) = 0 \) for any \( q \geq 0 \). If \( L_c(q) = cq - y_r - y_s > 0 \), then we have \( L_r(q) = (wq - y_r)^+ = wq - y_r > L_c(q) > 0 \) and thus \( L_r(q) + L_s(q) > L_c(q) \). Due to the larger loan size, the decentralized system incurs larger expected default loss and gets smaller expected profit, and quantity discount contracts fail to coordinate.

From condition (25), we have \((\bar{w}(q), \theta) = (c\theta - \frac{\theta(y_r + y_s) - y_r}{q}, \theta)\). From Proposition 2, we know that for IFR demand distributions, the revenue-sharing contract \((\bar{w}(q), \theta)\) coordinates the supply chain. Thus, for a retailer with small \( y_r \) but large revenue share \( \theta \), i.e., \( y_r < \theta(y_r + y_s) \), the wholesale price the retailer receives is smaller than \( c\theta \), and vice versa. However, we can equivalently interpret the proposed revenue-sharing contractual mechanism as that the wholesale price is always \( c\theta \), but the working capital positions of the two supply chain parties are adjusted to be proportional to the party’s revenue share. Effectively, it ensures implementation of the necessary condition (25).

**Remark 2.** Our model does not include any fixed production cost \( K \). In fact, including such fixed cost does not change our results and insights in Proposition 2. Note that \( L_c = cq - y_r - y_s + K \),
\[ L_r = wq - y_r, \text{ and } L_s = cq - wq - y_s + K. \] Then, \[ L_r = \theta L_c \Leftrightarrow wq - y_r = c\theta q - \theta(y_r + y_s) + \theta K \Leftrightarrow \]

\[ w = c\theta - \frac{\theta(y_r + y_s - K) - y_c}{q} \] (thus, we can verify that \( L_s = (1 - \theta)L_c \)). As a result, the working capital adjustment for the retailer is \( \theta(y_r + y_s - K) - y_r \). Similar argument applies for other kinds of costs, as long as such costs can be appropriately shared among supply chain parties (so that a party’s loan size is proportional to its revenue share).

**Remark 3.** Since \( \beta_r = 0 \) in this section, Proposition 1 implies that the contract \((c\theta - \frac{\theta(y_r + y_s - K) - y_c}{q}, \theta)\) is the counterpart revenue-sharing contract of the buyback contract with a positive fixed payment term \((c\theta - \frac{\theta(y_r + y_s - K) - y_c}{q} + (1 - \theta), \theta, (1 - \theta)q)\), and both contracts coordinate the supply chain. Note that here \( T = (1 - \theta)q \), i.e., the supplier buybacks all of the retailer’s leftover inventory at unit price \( 1 - \theta \) (see Section 3.1).

## 6. With Fixed Default Costs

### 6.1. Fixed Default Costs: No Economies of Scale

We now study the case that firms face fixed default costs due to bankruptcy administrative costs and/or pledging other assets towards the loan obligations. Recall that \( \beta_r = \epsilon_r O_r + \beta'_r, \beta_s = \epsilon_s O_s + \beta'_s \) and \( \beta_c = \epsilon_c (O_r + O_s) + \beta'_c \). Then, \( B(\xi, \theta, \beta_r) = g(\xi)\theta + \beta_r \) for the retailer, \( B(\xi, 1 - \theta, \beta_s) = g(\xi)(1 - \theta) + \beta_s \) for the supplier, and \( B(\xi, 1, \beta_c) = g(\xi) + \beta_c \) for the centralized system. We focus on the case that \( \beta_c = \beta_r + \beta_s \), i.e., no economies of scale effects for the fixed default costs. Note that \( B(\xi, 1, \beta_c) = B(\xi, \theta, \beta_r) + B(\xi, 1 - \theta, \beta_s) \), i.e., no economies of scale effects for the total default costs as well.

Unexpectedly, for this case of fixed default costs the decentralized supply chain might have smaller expected default losses, and thus induce larger expected profit than the centralized supply chain. This is formally established in the following proposition. Recall \( q_c \) is the optimal production quantity of the centralized system, and we denote a contract \((w(q), \theta, 0)\) by \((w(q), \theta)\) for simplicity.

**Proposition 3.** We have the following results:

1. For \( q \geq 0 \) with \( L_c(q) > 0 \), there might exist combinations of revenue shares and corresponding loans for the two parties, \((\theta, L_r(q), \beta_r)\) and \((1 - \theta, L_s(q), \beta_s)\), with \( L_r(q) + L_s(q) = L_c(q) \) so that

\[
C(\theta, L_r(q), \beta_r) + C(1 - \theta, L_s(q), \beta_s) < C(1, L_c(q), \beta_c);
\] (26)

2. There might exist contracts \((\tilde{w}(q), \theta)\) so that
\[
\pi_r(q_d(\hat{w}(q_d), \theta), \hat{w}(q_d), \theta) + \pi_s(q_d(\hat{w}(q_d), \theta), \hat{w}(q_d), \theta) > \pi_c(q_c, c, 1),
\]

where \( q_d(\hat{w}(q_d), \theta) = \arg\max_{q \geq 0} \pi_r(q|\hat{w}(q), \theta) + \pi_s(q|\hat{w}(q), \theta) \) is the retailer’s optimal ordering quantity in the decentralized system. Thus, the decentralized system may end up with larger expected profit than the centralized system, especially if \( q_d(\hat{w}(q_d), \theta) = \arg\max_{q \geq 0} \pi_r(q|\hat{w}(q), \theta) + \pi_s(q|\hat{w}(q), \theta) \), i.e., \( \hat{w}(q), \theta \) induces the retailer to order the optimal quantity of the decentralized system.

Note that by substituting \( B(\xi, \theta, \beta_r) = g(\xi)\theta + \beta_r \) into equation (6) and \( B(\xi, 1 - \theta, \beta_s) = g(\xi)(1 - \theta) + \beta_s \) into equation (12), we observe the fixed default costs \( \beta_r \) and \( \beta_s \) cannot be perfectly aligned with revenue shares \( \theta \) and \( 1 - \theta \) (except for specific value \( \theta = \frac{\beta_r}{\beta_r + \beta_s} \)) and with corresponding sizes of the retailer and supplier. In fact, such misalignment may benefit the decentralized system for non-convex expected default loss functions \( C \).

In other words, in the decentralized system, we have the flexibility to better allocate loan responsibilities to each party according to its default cost, e.g., to allow the party with smaller default costs to borrow more. The loan flexibility might be easier to be implemented in parent-subsidiary or subsidiary-subsidiary (of the same parent company) supply chains through a well designed contract with coordinated working capital. However, other chains can implement such schemes through third parties (potentially banks) agreeing to serve as working capital coordinators.

According to Case 1 of Proposition 3 for an arbitrary \( q \) with \( L_c(q) > 0 \), if the retailer independently orders the optimal quantity of the centralized system, (26) implies that it is possible for the revenue-sharing contract that induces such a retailer’s order to result in larger total expected profit of the decentralized system than that of the centralized one. Of course, if the contract induces the retailer to order the quantity that maximizes the total expected profit of the decentralized system, the performance of the decentralized system can be even better, as Case 2 of Proposition 3 implies. (For the details on the existence of such contracts, please refer to Section EC.1 in the Appendix.)

We further study our modified revenue-sharing contract \( \hat{w}(q), \theta = (c\theta - \frac{\theta(y_r + y_s) - y_r}{q}, \theta) \), which implements the loan alignment condition (25) of Proposition 2 holds. Although such contracts may not be the optimal contracts that maximize the total profits of the decentralized system, the decentralized system may still outperform the centralized system. (Please refer to Figure EC.6 in Section EC.1 in the Appendix for a graphical interpretation of such a case.) We have the following
proposition for decentralized systems operated under the revenue-sharing contracts $(\bar{w}(q), \theta)$.

**Proposition 4.** Consider IFR demand distributions with $z''(\cdot) \geq 0$, i.e., $z(\cdot)$ is increasing and convex. Let $g''(\cdot) \geq 0$. Under the contract $(\bar{w}(q), \theta)$, there exist $\bar{q}(\theta, \beta_r, \beta_s) \leq \bar{q}(\theta, \beta_r, \beta_s)$ so that

1. For $q \leq \bar{q}(\theta, \beta_r, \beta_s)$, we have $C(\theta, L_r(q), \beta_r) + C(1 - \theta, L_s(q), \beta_s) \leq C(1, L_c(q), \beta_c)$;
2. For $q \geq \bar{q}(\theta, \beta_r, \beta_s)$, we have $C(\theta, L_r(q), \beta_r) + C(1 - \theta, L_s(q), \beta_s) \geq C(1, L_c(q), \beta_c)$;
3. If $q_c \leq \bar{q}(\theta, \beta_r, \beta_s)$, the contract $(\bar{w}(q), \theta)$ might induce

$$\pi_r(q_d(\bar{w}(q_d), \theta), \bar{w}(q_d), \theta) + \pi_s(q_d(\bar{w}(q_d), \theta), \bar{w}(q_d), \theta) > \pi_c(q_c, c, 1),$$

where $q_d(\bar{w}(q_d), \theta) = \arg\max_{q \geq 0} \pi_r(q|\bar{w}(q), \theta)$ is the retailer’s optimal ordering quantity. Thus, the decentralized system under $(\bar{w}(q), \theta)$ might end up with larger expected profit than the centralized system, especially if $q_d(\bar{w}(q_d), \theta) = \arg\max_{q \geq 0} \pi_r(q|\bar{w}(q), \theta) + \pi_s(q|\bar{w}(q), \theta)$, i.e., the contract $(\bar{w}(q), \theta)$ induces the retailer to order the optimal quantity of the decentralized system.

The definitions of the two thresholds $\bar{q}(\theta, \beta_r, \beta_s) \leq \bar{q}(\theta, \beta_r, \beta_s)$ are in the proof of Proposition 4 in the Appendix. According to the proposition, the decentralized system has smaller expected default loss for $q \leq \bar{q}(\theta, \beta_r, \beta_s)$, and larger expected default loss for $q \geq \bar{q}(\theta, \beta_r, \beta_s)$, than the centralized one. Note that in Case 3 of Proposition 4, if $C(\theta, L_r(q_c), \beta_r) + C(1 - \theta, L_s(q_c), \beta_s) < C(1, L_c(q_c), \beta_c)$, then even if the retailer’s quantity that maximizes his own profit, $q_d$, is not precisely the quantity that maximize the total profit of the decentralized system, but the two quantities are close enough, the conclusion that the decentralized system outperforms the centralized one still holds.

The stated conditions in the proposition hold for many settings. The increasing and convex failure rate $z''(\cdot) \geq 0$ characterizes many commonly used distributions, e.g., uniform, exponential, power, Weibull with the shape parameter greater than or equal to two, and truncated normal meet this needed requirement (see Kouvelis and Zhao 2012, and Zhou and Groenevelt 2007).

Proposition 4 sharpens the result of Proposition 3 by clarifying that working capital coordination as described in condition (25) is not sufficient to optimized decentralized supply chain profits, especially when $q_c \geq \bar{q}(\theta, \beta_r, \beta_s)$. Although we correct the misalignment of revenue shares and loan sizes of supply chain parties through the use of the modified revenue-sharing contract $(\bar{w}(q), \theta)$, the misalignment between fixed default costs $\beta_r$ and $\beta_s$ and revenue shares $\theta$ and $1 - \theta$ is still there. Particularly, from equations (6) and (12), the misalignment increases in $k_0$ and $k_s$, which increase
in \( q \). Cases 1 and 2 of Proposition 4 indicate that the above misalignment benefits the decentralized system when \( q \) is small, and hurts it when \( q \) becomes large.

## 6.2. Fixed Default Costs: With Economies of Scale

We now extend our discussion from Section 6.1 to the more general case \( 0 \leq \beta_c < \beta_r + \beta_s \). We refer to this property of default costs as exhibiting economies of scale effects.

### 6.2.1. The Same Fixed Default Costs Across Parties: \( \beta_r = \beta_s = \beta_c = \beta > 0 \)

We start from the simple case of \( \beta_r = \beta_s = \beta_c = \beta > 0 \). Then, \( B(\xi, \theta, \beta) = g(\xi)\theta + \beta \) for the retailer, \( B(\xi, 1 - \theta, \beta) = g(\xi)(1 - \theta) + \beta \) for the supplier, and \( B(\xi, 1, \beta) = g(\xi) + \beta \) for the centralized system. We have \( B(\xi, \theta, \beta) + B(\xi, 1 - \theta, \beta) > B(\xi, 1, \beta) \), i.e., the decentralized system has a larger default cost for each demand realization. That is, the economies of scale effects apply to total default costs.

Recall that \( q_c \) is the optimal production quantity of the centralized system and let \( k_c^\circ = k(1, L_c, \beta) \big|_{q=q_c} \) be the corresponding default threshold. We focus on the case that \( L_c(q_c) > 0 \) (or alternatively, \( k_c^\circ > 0 \)), i.e., the centralized system has bankruptcy risk.

**Proposition 5.** For IFR demand distributions and under our general contract \( (w(q), \theta) \),

1. For \( q \geq 0 \), the decentralized system has larger expected default loss than the centralized one, i.e.,

\[
C(\theta, L_r(q), \beta) + C(1 - \theta, L_s(q), \beta) \geq C(1, L_c(q), \beta).
\] (27)

2. Let \( q_d(w(q_d), \theta) = \arg \max_{q \geq 0} \pi_r(q|w(q), \theta) \) be the retailer’s optimal quantity under \( (w(q), \theta) \). Then,

\[
\pi_r(q_d(w(q_d), \theta), w(q_d), \theta) + \pi_s(q_d(w(q_d), \theta), w(q_d), \theta) \leq \pi_c(q_c, c, 1), \quad \text{for all } w(q) \geq 0,
\] (28)

i.e., the optimal expected profit of the decentralized system has as an upper bound the optimal profit of the centralized system. More specifically,

i. If \( 0 < \beta < k_c^\circ - g(k_c^\circ) \), the strict inequality in (28) holds for all \( w(q) \geq 0 \), and coordination fails;

ii. If \( \beta \geq k_c^\circ - g(k_c^\circ) \), then for \( (\bar{w}(q), \theta) = (c\theta - \theta(\sigma + g(q)) - \bar{w}, \theta) \) that implements the condition (25),

\[
\begin{align*}
q_d(\bar{w}(q_d), \theta) &= q_c, \\
\pi_r(q_d(\bar{w}(q_d), \theta), \bar{w}(q_d), \theta) + \pi_s(q_d(\bar{w}(q_d), \theta), \bar{w}(q_d), \theta) &= \pi_c(q_c, c, 1) \\
\pi_r(q_d(\bar{w}(q_d), \theta), \bar{w}(q_d), \theta) &= \theta \pi_c(q_c, c, 1).
\end{align*}
\]

As a result, \( (\bar{w}(q), \theta) \) is the optimal contract and coordinates the chain with arbitrary profit allocation between the supplier and retailer.
We interpret the case $0 < \beta < k^o_c - g(k^o_c)$ as “small fixed default costs.” Then, there is a $0 < \xi < k^o_c$ so that $\beta = \xi - g(\xi)$. For $\xi < \xi \leq k^o_c$, we have $\beta < \xi - g(\xi)$ and $B(\xi, 1, \beta) = g(\xi) + \beta < \xi$. For such demand realizations, the centralized system can retain some of the remaining assets’ value after bankruptcy. Since the default costs of each party in the decentralized system are strictly larger for demand realizations leading to bankruptcy, the decentralized system will have smaller total expected profit than the centralized one. That is, economies of scale in default costs allow the centralized system to reduce the expected default loss and increase the expected profits by combining the loans and receiving all sales revenues. Then, for small fixed default costs, our contracts cannot coordinate the decentralized chain, even with coordinated working capital management.

We interpret the case $\beta \geq k^o_c - g(k^o_c)$ as “large fixed default costs.” Given $0 \leq g'(\xi) \leq 1$, we have $\beta \geq \xi - g(\xi)$ for $0 < \xi < k^o_c$. Then, $B(\xi, 1, \beta) = g(\xi) + \beta \geq \xi$ and the centralized system in the case of bankruptcy loses all the remaining value of assets due to default costs. Both parties in the decentralized system fare equally as bad in bankruptcy due to the economies of scale property of the default costs. However, as the centralized system cannot leverage its economies of scale by borrowing larger loans and collecting all the sales revenue, the decentralized system can still achieve the best profits of the centralized system under the proposed revenue-sharing contract.

From Proposition 5, default costs with economies of scale do not automatically lead to coordination failure. For small fixed default costs with economies of scale, the centralized system is more effective in handling default costs, and our proposed revenue-sharing contract $(w, \theta)$ fails to coordinate the decentralized chain. However, high fixed default costs cannot be absorbed by the centralized system, and in that case, both centralized and decentralized chains are equally ineffective in handling default. Then, the supply chain can still be coordinated with the proposed revenue-sharing contract $(\bar{w}(q), \theta)$ and with working capital coordination.

6.2.2. Party Specific Fixed Default Costs: $\beta_r \neq \beta_s$ and $0 \leq \beta_c < \beta_r + \beta_s$

We now study the more general case that $\beta_r \neq \beta_s$ and $0 \leq \beta_c < \beta_r + \beta_s$. From (22), $B(\xi, \theta, \beta_r) = g(\xi)\theta + \beta_r$ for the retailer, $B(\xi, 1 - \theta, \beta_s) = g(\xi)(1 - \theta) + \beta_s$ for the supplier, and $B(\xi, 1, \beta_c) = g(\xi) + \beta_c$ for the centralized system.

**Proposition 6.** For the fixed default costs with economies of scale effects:
1. there exists a threshold $\min(\beta_r, \beta_s) \leq \bar{\beta}_c \leq \beta_r + \beta_s$ so that the centralized system is guaranteed to have larger expected profits than the decentralized system if $0 \leq \beta_c \leq \bar{\beta}_c$.

2. if $\beta_c \geq k^c_o - g(k^o_c)$, $\beta_r \geq \theta(k^c_o - g(k^o_c))$ and $\beta_s \geq (1 - \theta)(k^c_o - g(k^o_c))$, then for $(\bar{w}(q), \theta) = (c\theta - \frac{\theta w_a + w_b}{\theta}, \theta)$ that implements the condition (25),

\[
\begin{align*}
q_d(\bar{w}(q_d), \theta) &= q_c \\
\pi_r(q_d(\bar{w}(q_d), \theta), \bar{w}(q_d), \bar{w}(q_d), \theta) + \pi_s(q_d(\bar{w}(q_d), \theta), \bar{w}(q_d), \theta) &= \pi_c(q_c, c, 1) \\
\pi_r(q_d(\bar{w}(q_d), \theta), \bar{w}(q_d), \theta) &= \theta \pi_c(q_c, c, 1).
\end{align*}
\]

Thus, the decentralized system under our proposed contract $(\bar{w}(q), \theta)$ has the same expected profit as the centralized system. Moreover, such contracts are the optimal contracts if $0 \leq \beta_c \leq \bar{\beta}_c$.

It can be shown that a party’s expected profit decreases in the fixed default cost (see proof of Proposition 3). Consequently, when the fixed default costs exhibit strong economies of scale, i.e., $0 \leq \beta_c \leq \bar{\beta}_c$ where $\bar{\beta}_c$ is a threshold, the centralized system is guaranteed to end up with larger expected profits than the decentralized one. This is Case 1 of Proposition 6.

In Case 2, for $\beta_c \geq k^c_o - g(k^o_c)$, $\beta_r \geq \theta(k^c_o - g(k^o_c))$ and $\beta_s \geq (1 - \theta)(k^c_o - g(k^o_c))$, the retailer and supplier lose all remaining assets in the case of bankruptcy under the contract $(\bar{w}(q), \theta) = (c\theta - \frac{\theta w_a + w_b}{\theta}, \theta)$. The same applies to the centralized system as well. Thus, the centralized system does not gain any benefits by combining the loans, and it has the same expected profit as the decentralized system under the proposed revenue-sharing contract. However, we still need the condition $0 \leq \beta_c \leq \bar{\beta}_c$ to guarantee that such contracts are the optimal contracts. That is, if $\beta_c > \bar{\beta}_c$, the decentralized system may outperform the centralized system, and then $(\bar{w}(q), \theta)$ is possible not the optimal contract that maximizes the expected profit of the decentralized system.

Note that Proposition 5 can be viewed as a special case of Proposition 6. For $\beta_r = \beta_s = \beta_c = \beta$, we have $\beta = \min\{\beta_r, \beta_s\} \leq \bar{\beta}_c \leq 2\beta = \beta_c + \beta_s$ and $\beta_c = \beta \leq \bar{\beta}_c$. Also, $\beta_c \geq k^c_o - g(k^o_c)$, $\beta_r \geq \theta(k^c_o - g(k^o_c))$ and $\beta_s \geq (1 - \theta)(k^c_o - g(k^o_c))$ are reduced to $\beta \geq k^c_o - g(k^o_c)$. Then, Proposition 6 establishes the results of Proposition 5, i.e., the centralized system always has larger expected profits, and the modified revenue sharing contract $(\bar{w}(q), \theta)$ can coordinate the supply chain.

7. Conclusions and Future Research

We study contract design and coordination in a one-supplier-one-retailer supply chain facing uncertain demand. Both the supplier and retailer may be capital constrained and need to borrow com-
petitively priced bank loans for their operational requirements. Failure of loan repayment will lead to bankruptcy. Without default costs, it is known that simple contracts, e.g., revenue-sharing, buyback and quantity discount, can coordinate and arbitrarily allocate profits in our supply chain. However, supply chains with leveraged firms need to address realistic concerns of bankruptcy risks and costly default, and in such cases, the contract design and coordination become challenging. Our study brings to light such concerns and is the first to study the expected default loss that may be both contract- and firm asset-dependent. We study the performance of a general contract \((w, \theta, T)\). By assigning proper values to the parameters, the general contract can be reduced to the traditional revenue-sharing, buyback, and quantity discount contracts. Thus, we are able to inform the performance of these widely used contracts in leveraged and default exposed supply chains, while at the same time address relevant supply chain coordination issues.

First, we discuss contracts with a fixed money transfer \(T\) from the supplier to the retailer \((T > 0)\), or in the reverse direction \((T < 0)\), at time 1. Without fixed default costs, the buyback amount \(T\) will not lose value and cause contract efficiency loss. However, with fixed default costs, since the buyback amount has to be used for covering fixed default costs in the case of low demand realization, the contract is pareto dominated by the counterpart revenue-sharing contract without any buyback term. Thus, we proceed in our analysis with revenue-sharing contracts that have no buyback terms and offer insights for pareto dominant coordinating contracts for general default costs.

In our further analysis of revenue-sharing contracts, we first study the case that there are only variable default costs (i.e., proportional to sales revenue). In this case, the necessary condition to coordinate is to align the loan amounts each supply chain party borrows with their revenue shares, or what we refer to as “coordinated working capital management”. Such working capital coordination is not possible for a quantity discount contract, and thus it fails to coordinate in the presence of default costs. The large wholesale price charged by the supplier necessitates the retailer borrowing a larger loan than the corresponding loan amount in the centralized system (over-borrowing effect), which then increases the expected default loss of the decentralized system.

For the case of fixed default costs but without economies of scale, we establish that it is possible for the decentralized system to achieve (strictly) larger expected profits than the centralized system. For such cases, the decentralized chain uses its flexibility to better allocate the loan responsibilities
among supply chain parties according to their default costs (e.g., the party with lower default costs borrows more). This can happen if a contract induces the retailer to order the quantity that maximizes the total expected profit of the decentralized system, or even if the retailer independently orders the same quantity as does the centralized system.

Then, we analyze the case that fixed default costs exhibit economies of scale effects. When the economies of scale effects are substantial and for high fixed default cost, both supply chain parties and the centralized system lose all of their residual assets in the case of default, which eliminates any opportunity to leverage the economies of scale on default costs in the centralized system. Then, our proposed revenue-sharing contract can still coordinate the chain. However, for small fixed default costs, both parties and the centralized system may retain some remaining asset value after covering the default costs, and the economies of scale property of the default costs favors the centralized system. Then, revenue-sharing contracts fail to coordinate.

In summary, our results illustrate the importance and necessity of coordinating initial cash positions, and/or loan amounts among supply chain parties. Frequently, our proposed revenue-sharing contracts with adjusted wholesale price can be used to effectively achieve the desired working capital coordination.

For supply chain parties with little or no economies of scale effects in the fixed default costs, it might be challenging to find the optimal contracts for the decentralized supply chain. In such situations, how to align the loan responsibilities and revenue shares with fixed default costs for optimal channel performance remains a challenging research question.

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