Sourcing from Suppliers with Financial Constraints and Performance Risk

Christopher S. Tang
Anderson School of Management, UCLA, chris.tang@anderson.ucla.edu

S. Alex Yang
London Business School, sayang@london.edu

Jing Wu
City University of Hong Kong, College of Business

Two innovative financing schemes have emerged in recent years to enable suppliers to obtain financing for production. The first, *purchase order financing* (POF), allows financial institutions to offer loans to suppliers by considering the value of purchase orders issued by reputable buyers. Under the second, which we call *buyer direct financing* (BDF), manufacturers issue both sourcing contracts and loans directly to suppliers. Both schemes are closely related to the supplier's *performance risk* (whether the supplier can deliver the order successfully), which the repayment of these loans hinges upon. To understand the relative efficiency of the two emerging schemes, we analyze a game-theoretical model that captures the interactions between three parties (a manufacturer, a financially constrained supplier who can exert unobservable effort to improve delivery reliability, and a bank). We find that when the manufacturer and the bank have symmetric information, POF and BDF yield the same payoffs for all parties irrespective of the manufacturer's control advantage under BDF. The manufacturer, however, has more flexibility under BDF in selecting contract terms. In addition, even when the manufacturer has superior information about the supplier's operational capability, the manufacturer can efficiently signal her private information via the sourcing contract if the supplier's asset level is not too low. As such, POF remains an attractive financing option. However, if the supplier is severely financially constrained, the manufacturer's information advantage makes BDF the preferred financing scheme when contracting with an efficient supplier. In particular, the relative benefit of BDF (over POF) is more pronounced when the supply market contains a larger proportion of inefficient suppliers, when differences in efficiency between suppliers are greater, or when the manufacturer's alternative sourcing option is more expensive.

Key words: Operations–finance interface, supply risk, purchase order finance, supply chain finance
History: First draft: October 2015. Current version: June 2016.

---

1. Introduction

To reduce production costs, many manufacturers (or intermediaries) source products from small suppliers (or contract manufacturers), who are often located in developing countries. With a lack of access to public debt or equity markets, these suppliers often rely on two channels for external financing. The first channel is asset-based loans offered by banks and secured by suppliers' physical assets, such as inventories and equipment (Buzacott and Zhang 2004). The second is factoring, under which suppliers sell account receivables to financial institutions at a discount for immediate cash payment (Klapper 2006, Sodhi and Tang 2012). However, both channels require suppliers to have certain tangible internal resources, which may not be readily available. Consequently, many new suppliers have to turn down profitable orders from reputable buyers simply because they cannot obtain financing to start production (Tice 2010). Similarly, with balance sheets weakened by the recent financial crisis and many institutions still recovering, even established suppliers may fail to secure sufficient financing to meet increasing orders from buyers (Martin 2010). Inevitably, suppliers' difficulties with obtaining financing affect manufacturers adversely when the latter are left with more expensive sourcing options or, even worse, fail to deliver end products to consumers.

To meet the financing needs of the aforementioned suppliers, two innovative *non-asset-based financing* schemes have recently emerged. The first is known as *purchase order financing* (POF), under which financial institutions lend to suppliers based on purchase orders issued by reputable manufacturers. POF lenders include traditional commercial banks and specialized POF lenders (Martin 2010, Tice 2010). Unlike asset-based loans or factoring, which are backed by tangible assets, the repayment of a POF loan depends on the supplier's successful delivery of the associated purchase order. Because a POF loan is only granted based on purchase orders issued by creditworthy buyers, the major risk associated with POF is not the buyer's credit risk but the supplier's *performance risk*, i.e. that the supplier may fail to deliver the order according to the buyer's specifications on quality, timeliness, or compliance (Gustin 2014).

Under the second scheme, which we call *buyer direct financing* (BDF), the manufacturer acts as both the buyer and the lender and directly finances suppliers for production. BDF has been adopted by manufacturers and supply chain intermediaries in both developed and developing markets. Since 2009, Rolls-Royce has lent over £500 million to small suppliers who were unable to obtain adequate financing through other channels. Similarly, GlaxoSmithKline (GSK) has lent billions of pounds to its suppliers (Watkins 2012). Li & Fung, the global supply chain intermediary, has financed some of its long-term suppliers so that they can initiate production for Li & Fung orders (Fung et al. 2007). BDF can also take the form of procuring raw materials for suppliers. For example, Hanbo Enterprises Holdings, a Hong Kong-based supply chain intermediary specializing in the apparel sector, procures fabrics for its suppliers and treats procurement costs as interest-bearing loans (Cheng 2015).

As both POF and BDF are still taking shape, industry experts are debating whether financial intermediaries (i.e. banks and specialized lenders) or supply chain partners (i.e. manufacturers or supply chain intermediaries) are in a better position to finance suppliers. On the one hand, many critics argue that manufacturers should leave financing to professionals with domain expertise. On the other, because the efficiency of both POF and BDF hinges on supplier performance and because manufacturers have better *control* over and *knowledge* of suppliers (Fung et al. 2007), manufacturers can provide financing more efficiently. For instance, manufacturers can design supply contracts to incentivize suppliers to improve delivery performance by exerting efforts in areas such as quality control and process improvement (Aydin et al. 2011). Also, manufacturers often have better information than banks in terms of suppliers' intrinsic operational efficiency due to previous interactions, extensive auditing, or domain knowledge of particular purchase orders. These observations motivated us to examine two research questions more formally in this paper:

1. By combining the roles of buyer and lender under BDF, which we refer to as the manufacturer's *control advantage*, can the manufacturer better incentivize suppliers to improve their delivery performance under BDF?
2. Does the manufacturer's *information advantage* about suppliers' operational capabilities make BDF a superior financing scheme? And if so, under what circumstances?

To answer the first question, we analyze a Stackelberg game that involves three parties: a manufacturer, a financially constrained supplier who can exert costly and unobservable effort to improve delivery reliability, and a bank operating in a competitive lending market (note that the bank only plays a role in POF). Without access to other financing means, the supplier can only borrow through either POF or BDF to cover his production cost. To focus on the manufacturer's control advantage, we first assume that the manufacturer and the bank have symmetric information about the supplier's operational efficiency. Under this model, we find that when the supplier's asset value is below a certain threshold, the supplier cannot obtain financing through either scheme. Second, when the supplier's asset value exceeds this threshold, POF and BDF yield the same performance in terms of the supplier's delivery reliability and probability, even though BDF gives the manufacturer more flexibility in selecting contract terms. Such flexibility, consistent with anecdotal evidence that manufacturers offer diverse interest rates under BDF, suggests that BDF is particularly valuable in markets where interest rates are regulated, as is the case in many developing countries.

To answer the second question, we extend the above model by considering the case in which the supplier can be either efficient or inefficient in terms of their operational capabilities. The efficient supplier incurs lower (effort) costs than the inefficient supplier in order to achieve the same delivery probability. While the manufacturer knows the supplier's actual type, the bank only knows the distribution. Because the manufacturer knows the supplier's actual type and the bank is not involved under BDF, the performance of BDF remains the same as before. However, POF may become less efficient in this case due to the bank's information disadvantage. Using a signaling game to capture the interactions between all three parties, we find that when the supplier's asset value is sufficiently high, the manufacturer can efficiently use the sourcing contract to signal her private information about the supplier to the bank in a credible manner. As such, the performance of POF does not suffer as a result of the bank's information disadvantage and remains just as attractive as BDF. However, when the supplier is extremely financially constrained, it is inefficient, if not impossible, for the manufacturer to use the sourcing contract to signal her private information to the bank under POF, making BDF the preferred financing scheme. Moreover, we find that BDF is relatively more appealing to the manufacturer when the market has a higher percentage of inefficient suppliers or when the manufacturer's alternative sourcing option is more expensive. This finding highlights that information advantage plays an important role in the manufacturer's advantage in financing suppliers, rationalizing why BDF is mostly offered by manufacturers or intermediaries to long-term suppliers or suppliers with specialized skills.

As an initial attempt to understand the relative efficiency of two innovative financing schemes (POF and BDF) in managing suppliers' endogenous performance risk, our paper reveal two important managerial implications. First, the relative benefit of BDF rests more on the manufacturer's information advantage than her control advantage. Second, by formally analyzing the financial implications of the manufacturer's information advantage, we identify operational and financial environments in which manufacturers may benefit more by financing their suppliers directly.

The rest of this paper is structured as follows. We summarize the related literature in Section 2. Sections 3 and 4 study the optimal sourcing contract when the manufacturer and bank have symmetric information under POF and BDF, respectively. Section 5 extends the model to examine the implications of information asymmetry for POF when the supplier's cost factor is known to the manufacturer but not to the bank. Section 6 discusses when BDF is beneficial under asymmetric information. We conclude the paper in Section 7. All proofs are provided in the Appendix.

2. Related Literature

Focusing on the impact of different supply chain financing schemes on supply risk, our paper is related to three research streams: supply risk management, supply chain finance, and signaling games.

Supply risk management is an important research topic in operations. See Sodhi and Tang (2012), Kouvelis et al. (2011), and, in particular, Tomlin and Wang (2011) for a comprehensive overview of this topic. Similarly to recent papers such as Aydin et al. (2011), Li (2013), Tang et al. (2014), and Hwang et al. (2014), our paper focuses on designing supply contracts to incentivize suppliers to improve operational performance. Another related literature stream focuses on managing financially distressed suppliers. Swinney and Netessine (2009) show that long-term contracts can be used to reduce suppliers' default risk. Babich (2010) characterizes manufacturers' joint subsidy and capacity reservation policies when facing financially distressed suppliers. Dong and Tomlin (2012) and Dong et al. (2015) examine how insurance can interact with operational strategies in mitigating supply risk when the chain is subject to financing costs. Our paper complements the supply risk literature by focusing on the interaction between suppliers' financial constraints and endogenous effort and delivery performance, highlighting that selecting financing schemes properly plays a crucial role in manufacturers' sourcing decisions and profitability.

Our paper is also closely related to the supply chain finance literature, the majority of which focuses on trade credit, i.e. the credit extended by suppliers to buyers. First, Babich and Tang (2012) and Rui and Lai (2015) establish the role of trade credit in deterring suppliers' moral hazard. In addition to our focus on different financing schemes (i.e. POF and BDF), our intention is also different: We examine the relative efficiency of POF and BDF under both endogenous supplier performance risk and information asymmetry. Second, Kouvelis and Zhao (2012) and Yang and Birge (2009) show that trade credit can improve supply chain efficiency by acting as a risk-sharing mechanism. We examine a different setting in which the contract price is contingent on whether the supplier can fulfill the order successfully. Because of this contingency, we show that adding interest rates as an additional lever under BDF does not further mitigate the supplier's performance risk. Other recent papers on trade credit include Chod (2015), Chod et al. (2016), and Peura et al. (2016). Beyond trade credit, recent papers, including Chen and Gupta (2014) and Tunca and Zhu (2014), examine the impact of reverse factoring on stocking levels in the presence of demand risk. Our paper complements such works by serving as the first attempt to examine the implications of different financing schemes for *supply* risk.

Finally, our analysis of POF in the presence of information asymmetry between the manufacturer and bank is formulated as a *signaling game* (Riley 2001, Spence 2002). In the OM literature, Cachon and Lariviere (2001) study how firms can signal their private demand information to their supply chain partners. Bakshi et al. (2015) examine how quality can be signaled through after-sales service contracts. Recent papers in the operations–finance interface literature, including Lai et al. (2011), Schmidt et al. (2015), and Lai and Xiao (2014), study how firms can signal demand information to external investors through inventory decisions. In the same spirit, our model examines how the manufacturer can signal her private information about the supplier's type to the bank. However, we complement the above papers in two ways. First, we examine signaling in the context of *debt financing*, rather than *equity financing*. As such, our results are hinged upon the supplier's asset level. For example, when the supplier's asset level is low, the signal that the manufacturer can send is constrained by the bank's willingness to lend so that the pooling equilibrium may be the stable dominant equilibrium. This result complements those obtained by the aforementioned papers, which find that the pooling equilibrium is more appealing in various other settings. Second, unlike the extant literature, our signaling game involves three parties, resulting a unique signaling mechanism that contributes to both *costless* separating (when the supplier's asset is high) and pooling (when the supplier's asset is low).

3. Sourcing with POF

We start our analysis by focusing on how sourcing contracts and financing schemes can jointly control suppliers' moral hazard. We examine this issue under the POF scheme in this section and then examine the BDF scheme in Section 4. Section 5 extends the model to examine the relative attractiveness of both financing schemes in the presence of both moral hazard and information asymmetry.

3.1. The model

Consider a supply chain comprising three risk-neutral players: a manufacturer (she), a supplier (he), and a bank (it). In the following, we describe the supply chain aspect of the model followed by the financing aspect.

3.1.1. The supply chain. Consider a make-to-order supply chain comprising one manufacturer and one supplier. Focusing on supply risk, the demand faced by the manufacturer is assumed to be known and is normalized to 1 without loss of generality. To satisfy this demand, the manufacturer offers a sourcing contract to the supplier, who incurs a production cost $c > 0$ (raw material, wages, etc.) to execute the order.

Our models capture two salient features that are common among suppliers seeking POF or BDF. First, the supplier is financially constrained. Specifically, we assume that the supplier has no cash on hand and only has fixed assets (e.g. plants and equipment) that are indispensable to his operation. Before the contracting stage that this paper focuses on, the manufacturer audits the supplier's assets. The collateral value of the assets $a \geq 0$ is then revealed to all parties (including the bank). To avoid trivial cases, we assume that a is no greater than the supplier's production cost c ($a \leq c$).

Second, the supplier is inherently unreliable and can only deliver the order with a certain probability. The supplier can improve the delivery probability by exerting costly efforts that are not observable to any other parties (e.g. improving or closely monitoring production processes). Without loss of generality, we scale the base delivery probability to 0. To increase the delivery probability from 0 to e, where $e \in (0, 1)$, the supplier needs to exert effort that is associated with a disutility (cost of effort) ke^2 with $k > 0$. This cost of effort is non-monetary and hence does not enter the supplier's cash flow.[1] The supplier's (effort) cost factor k captures the supplier's operational

[1] This modeling approach is similar to those in many papers in the economics and operations literature (McAfee and McMillan 1986, Porteus 1985). The quadratic function form is a common assumption for tractability (Li 2013) and has no bearing on the qualitative results.

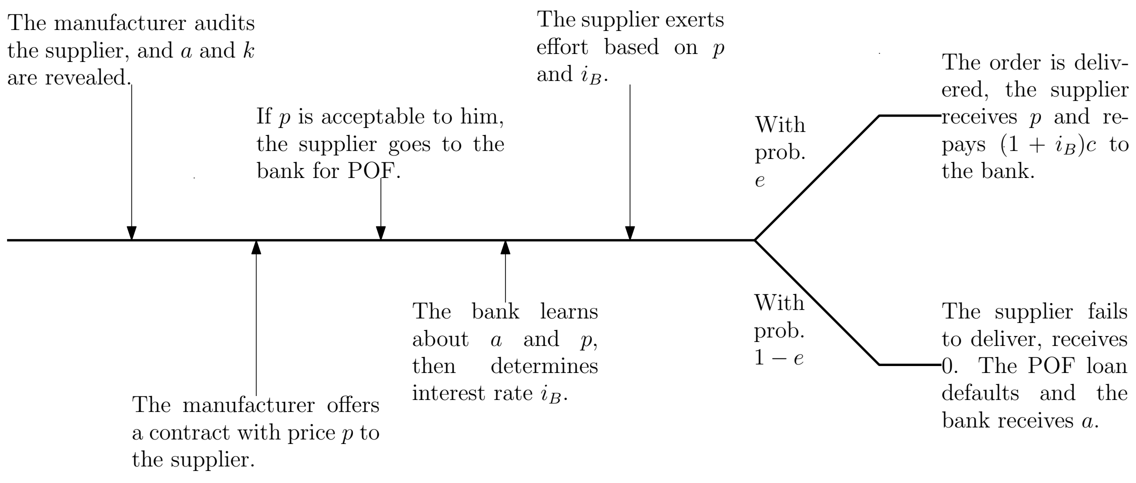
efficiency: A supplier with a lower k can achieve the same delivery probability at a lower cost of effort than a supplier with higher k. To examine the supplier's moral hazard in this section, we assume that k is known to all parties. However, in Section 5, we extend this model to the case where the manufacturer and the supplier know the exact value of k while the bank knows only the distribution.

Acting as the Stackelberg leader, the manufacturer sets the contract terms and the supplier, as the follower, decides whether to accept the supply contract. Without loss of generality, we focus on the following contingent contract: The manufacturer pays the supplier the contract price p upon successful delivery and pays zero otherwise.[2]

In the case where the manufacturer does not source from the supplier, or the supplier fails to deliver, the manufacturer sources the product from an alternative, emergency channel at cost v, which can also be seen as the manufacturer's opportunity cost (foregone revenue). Therefore, the manufacturer's *payoff* Π_M can be measured in terms of the *expected cost savings* generated from sourcing through the unreliable supplier, where

$$\Pi_M = v - [ep + (1-e)v] = e(v-p). \tag{1}$$

Figure 1 Sequence of events under POF when the manufacturer and the bank have symmetric information



[2] In our model, due to the supplier's financial constraint, penalizing the supplier upon failed delivery does not further improve the efficiency of the contract. See Proposition B.1 in the Appendix for the technical details.

3.1.2. Modeling POF. As depicted in Figure 1, after receiving a contract with price p that is acceptable to him, the supplier takes the purchase order to the bank and borrows c in the form of a POF loan to start production.[3] By considering the purchase order with contingent payment p and the collateral value of the supplier's fixed asset a, the bank decides whether to lend c to the supplier and, if so, what interest rate i_B to charge.

Under this POF loan contract, if the supplier delivers successfully, he receives payment p from the manufacturer, pays the principal and interest $(1+i_B)c$ to the bank, and keeps the rest. If delivery is not successful, the supplier receives no payment, the POF loan defaults, the bank liquidates the supplier's fixed assets and recovers a, and the supplier is left with nothing.[4] Therefore, the supplier's objective is to maximize his expected payoff Π_S, where

$$\Pi_S = e[p-(1+i_B)c]-(1-e)a-ke^2. \tag{2}$$

As shown, Π_S consists of three parts: the expected gain upon successful delivery (after paying off the loan plus interest) $e[p-(1+i_B)c]$, the expected loss of assets to the lender in the event of delivery failure $(1-e)a$, and the cost of effort ke^2. As our model is mainly motivated by made-to-order products, we assume that once the goods are produced, the supplier has to sell them to the manufacturer. Therefore, without loss of generality, we normalize his outside option to 0, i.e. the supplier accepts a contract only when $\Pi_S \geq 0$.

Finally, to focus on the supplier's performance risk, we assume that the manufacturer has no credit risk and will pay the supplier as long as the order is delivered successfully. The bank is assumed to operate in a competitive lending market, and hence it sets the interest rate so that the lending amount c equals its expected payoff discounted at the bank's cost of capital, which is normalized to zero.

3.1.3. The first-best benchmark. Before we analyze the Stackelberg game as depicted in Figure 1, we first establish the first-best solution by analyzing a centralized controlled supply chain. Without the need to consider payment to the supplier and deal with financing within a centralized, controlled system, the expected savings associated with sourcing from an internal supplier are equal to $\Pi_C = v-[c+ke^2+(1-e)v]$.

LEMMA 1. *In a centralized chain, the manufacturer sources from the supplier if and only if* $\frac{v^2}{4k} \geq c$. *The resulting delivery probability is* $\frac{v}{2k}$, *and the corresponding chain payoff is* $\frac{v^2}{4k}-c$.

[3] As the cost of effort is non-monetary, the supplier does not need to finance this cost. In addition, we assume that the supplier borrows the whole production cost c through POF for ease of exposition. We can alternatively assume that the supplier borrows two loans: one secured by his fixed asset a and the other $(c-a)$, against the purchase order. All our results remain unchanged.

[4] As shown in Lemma B.1 in the Appendix, under a given p, it is in the supplier's interests to use all of his assets as collateral in order to lower his financing cost.

It follows from Lemma 1 that, in order to avoid trivial cases, we assume that $k > \frac{v}{2}$ and $c < \frac{v^2}{4k}$ throughout this paper. Combining the assumption $c < \frac{v^2}{4k}$ with that about the supplier's asset level $a \in [0, c]$, we focus in this paper on the case where (c, a) satisfies the following assumption.

ASSUMPTION 1. *The supplier's cost c and his asset level a satisfy:* $0 \leq a \leq c \leq \frac{v^2}{4k}$.

3.2. The supplier's effort under POF

We now solve the Stackelberg game as depicted in Figure 1 by using backward induction. First, given any contingent price p and interest rate i_B, by considering the first-order condition of (2), the supplier's best response is given as:

$$e(p, i_B) = \frac{p - (1 + i_B)c + a}{2k}. \tag{3}$$

By substituting (3) into the supplier's payoff Π_S given in (2), it is easy to check that:

$$\Pi_S = \frac{[p - (1 + i_B)c + a]^2}{4k} - a. \tag{4}$$

Hence, the supplier's participation constraint, i.e., $\Pi_S \geq 0$, can be written as:

$$p \geq (1 + i_B)c + 2\sqrt{ka} - a. \tag{5}$$

3.3. The bank's interest rate under POF

Observing the contract price p selected by the manufacturer, the bank can anticipate the supplier's effort $e(p, i_B)$ as given in (3). Operating in a competitive lending market, the bank sets its interest rate i_B to break even in expectation. In other words, under the interest rate i_B that it offers, the bank's expected payoff, $e[(1 + i_B)c] + (1 - e)a$, equals to the lending amount (c).[5] Substituting e given in (3), the bank's break-even condition can be satisfied if and only if $p \geq p^{BL} \equiv \sqrt{8k(c - a)}$, which we refer as the bank's lending (BL) constraint. This condition suggests that in order for the bank to lend under POF, the contingent price p selected by the manufacturer has to be sufficiently high relative to $(c - a)$, the supplier's *net financing need.* When the BL constraint is satisfied, the equilibrium interest rate for any given p becomes:

$$i_B(p) = \frac{p - \sqrt{p^2 - 8k(c - a)}}{2c} + \frac{a}{c} - 1. \tag{6}$$

[5] In the presence of multiple solutions to the equation, competition should push the bank to offer the lowest interest rate.

3.4. The manufacturer's optimal contract under POF

Substituting the equilibrium interest rate in (6) to the supplier's best response, (3) becomes:

$$e(p) = \frac{p + \sqrt{p^2 - 8k(c-a)}}{4k} \tag{7}$$

and the supplier's acceptance (SA) constraint (5) can be rewritten as:

$$p + \sqrt{p^2 - 8k(c-a)} \geq 4\sqrt{ka}, \tag{8}$$

which we refer to as the *joint acceptance* constraint, as it specifies the condition under which the bank will lend and the supplier will find it profitable to participate.[6]

Anticipating the supplier's best response e given in (7) and the joint acceptance condition (8), the manufacturer's payoff given in (1) can be re-written as:

$$\Pi_M = \frac{p + \sqrt{p^2 - 8k(c-a)}}{4k}(v-p) \cdot \mathbb{1}_{\left\{p+\sqrt{p^2-8k(c-a)} \geq 4\sqrt{ka}\right\}}. \tag{9}$$

The manufacturer aims to select the optimal contract price $p^S \in [0, v]$ that maximizes her payoff given in (9). The optimal contract and corresponding equilibrium outcome can be summarized in Proposition 1 and illustrated in Figure 2.[7]

Proposition 1. *When (c, a) satisfy Assumption 1, the optimal sourcing contract p^S under POF and the corresponding equilibrium outcomes can be described as follows:*

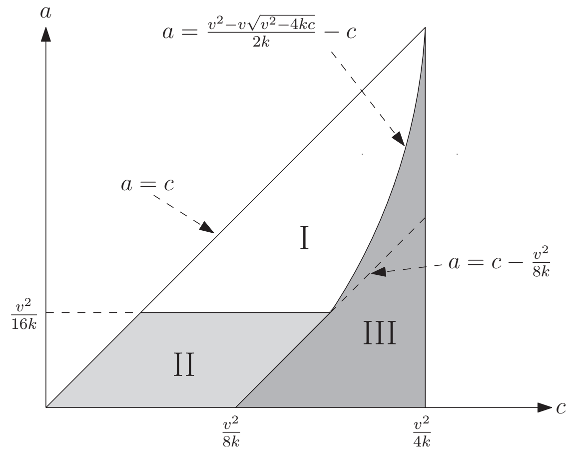
1. *When $a \geq \max\left(\frac{v^2}{16k}, \frac{v^2 - v\sqrt{v^2-4kc}}{2k} - c\right)$ (Region I in Figure 2), the manufacturer offers $p^S = \sqrt{\frac{k}{a}}(c+a) \equiv p^{SA}$, the bank lends to the supplier at interest rate $i_B^S = \left(\sqrt{\frac{k}{a}} - 1\right)\left(\frac{c-a}{c}\right)$, and the equilibrium delivery probability $e^S = \sqrt{\frac{a}{k}}$. Also, the manufacturer's and supplier's payoffs are given as $\Pi_M^S = v\sqrt{\frac{a}{k}} - c - a$ and $\Pi_S^S = 0$, respectively.*
2. *When $a \in \left[c - \frac{v^2}{8k}, \frac{v^2}{16k}\right]$ (Region II in Figure 2), the manufacturer offers $p^S = \frac{v}{2} + \frac{4k(c-a)}{v}$, the bank lends to the supplier at interest rate $i_B^S = \left(\frac{4k}{v} - 1\right)\left(\frac{c-a}{c}\right)$, and the equilibrium delivery probability $e^S = \frac{v}{4k}$. Also, $\Pi_M^S = \frac{v^2}{8k} - (c-a)$ and $\Pi_S^S = \frac{v^2}{16k} - a$.*
3. *When $a < \max\left(c - \frac{v^2}{8k}, \frac{v^2 - v\sqrt{v^2-4kc}}{2k} - c\right)$ (Region III in Figure 2), the manufacturer does not source from the supplier ($p^S = 0$, $i_B^S = \infty$, $e^S = 0$), and $\Pi_M^S = \Pi_S^S = 0$.*

As shown in Proposition 1, when the supplier's asset value a is relatively large compared to the loan c (Region I in Figure 2), the supplier has a stronger incentive to exert more effort to increase

[6] As the paper focuses on the domain of real numbers, for (8) to hold, it implicitly requires the bank's lending constraint, i.e., $p \geq p^{BL}$ to be satisfied.

[7] To avoid confusion regarding the use of $*$ for optimal quantities under different scenarios, we use superscript S to represent the corresponding *optimal* quantities under POF with *symmetric* information between the manufacturer and the bank. Similarly, we use superscript B for optimal quantities under BDF (in Section 4) and superscript A for POF with *asymmetric information* (Section 5).

Figure 2 **Illustration of different regions under the optimal POF contract.**



his delivery probability in order to protect his assets. Recognizing this, it is optimal for the manufacturer to set the contract price at p^{SA}, the lowest price that is acceptable to the supplier. As the supplier's asset value a decreases, the supplier's delivery probability in equilibrium also declines. The decline in both a and the delivery probability leads to a higher interest rate i_B.

Next, consider the case where the supplier's asset value a drops below $\frac{v^2}{16k}$ but the net financing need $(c - a) \leq \frac{v^2}{8k}$ (Region II). As the supplier's asset value a is low, the supplier has little to lose and hence is less incentivized to exert effort to increase delivery probability. Anticipating this, the bank increases the interest rate charged under POF. To offset the increasing financial burden borne by the supplier, the manufacturer offers p^S such that the supplier's net margin, $(p^S - (1 + i_B)c)$, remains constant, leading also to a constant delivery probability.

Finally, when the supplier's net financing need $(c - a)$ is sufficiently large (Region III), it is too costly for the manufacturer to offer a price that is acceptable to herself as well as satisfies (8). To elaborate, consider the case where $c - a \geq \frac{v^2}{8k}$ (the lower part of Region III). By analyzing (8), we note that when $a < \frac{c}{3}$, (8) holds if and only if $p \geq p^{BL}$. However, $c - a \geq \frac{v^2}{8k}$, p^{BL} is greater than v. Clearly, in this region, any contract that induces the bank to lend is not economical for the manufacturer. Similarly, when both a and $c - a$ are relatively large (the upper part of Region III), the lowest price acceptable to the supplier, p^{SA} is greater than v. Hence, sourcing from the reliable supplier is simply unprofitable.

Moreover, it is easy to check from Proposition 1 that both the equilibrium delivery probability e^S and the total supply chain payoff $(\Pi_M^S + \Pi_S^S)$ are lower than the corresponding quantities under the first-best benchmark in Lemma 1. It is well known that when the supplier's asset level is sufficiently high, the manufacturer can design a contract to achieve the first-best benchmark and extract all profit (Laffont and Martimort 2009, §4.2). However, when the supplier is financially constrained, the results stated in Proposition 1 imply that the supplier's financial constraint reduces the delivery probability and supply chain profitability. The efficiency loss increases as the supplier becomes more financially constrained.[8]

Besides the impact of the supplier's asset value a, the supplier's effort cost factor k also directly influences the optimal contract and equilibrium outcomes.

COROLLARY 1. *In equilibrium, the manufacturer's contract price* p^S *and the bank's interest rate* i_B^S *increase in the supplier's cost factor* k*. However, the equilibrium delivery probability* e^S*, manufacturer's payoff* Π_M^S*, and supplier's payoff* Π_S^S *decrease in* k*.*

As shown in Corollary 1, as the supplier becomes less efficient (i.e. a higher cost factor k), the manufacturer needs to offer a higher contract price p^S to compensate for the higher interest rate i_B^S charged by the bank. Nevertheless, the equilibrium delivery probability e^S is decreasing in k. In other words, when the manufacturer sources from an inefficient supplier, she still faces a higher supply risk despite paying a higher contract price.

4. Joint Sourcing and Financing under BDF

As shown in Proposition 1, both the total supply chain payoff and delivery probability are both lower under POF relative to the first-best benchmark. Is such inefficiency caused by the fact that under POF, the sourcing contract and lending terms are determined separately by the manufacturer and the bank? As we know from the trade credit literature, supply chain efficiency can be improved through demand risk sharing when the manufacturer determines both the wholesale price and credit terms (Kouvelis and Zhao 2012, Yang and Birge 2009). Does the same logic apply in our setting with supply risk? In this section, we examine whether BDF, under which the manufacturer controls both the contract price and interest rate, improves supply chain efficiency relative to POF.

Under BDF, the bank does not play a role and the manufacturer determines both the contingent price p and interest rate i_M (for lending c to the supplier). Upon successful delivery, the manufacturer deducts the principal and interest $(1+i_M)c$ from p and pays the rest to the supplier. When the supplier fails to deliver, the manufacturer does not pay the supplier and seizes the supplier's assets a to partially recover the (defaulted) loan. To compare BDF and POF directly, we assume that the manufacturer's cost of capital is also zero, the same as the bank's.

The interaction between the supplier and manufacturer under BDF is analogous to that under POF. First, under given (p, i_M), the supplier's best response $e(p, i_M)$ and his acceptance condition are given in (3) and (5), respectively, with i_B being replaced by i_M. Anticipating this, the manufacturer chooses p and i_M jointly to maximize her payoff $\Pi_M = e(v-p) + [e(1+i_M)c + (1-e)a - c]$,

[8] According to Proposition 1, the supplier's payoff decreases in his asset value a, which plays a similar role as a limited liability constraint (Laffont and Martimort 2009, §3.3, Sappington 1983). When the supplier can dispose (part of) his asset prior to contracting, the manufacturer can design proper mechanisms to induce suppliers to maintain and declare his full asset value (Lewis and Sappington 2000).

the sum of the expected operational savings and her financing earnings from the BDF loan, subject to (3) and (5), with i_B being replaced by i_M.

PROPOSITION 2. *When (c, a) satisfy Assumption 1, the optimal sourcing contract (p^B, i_M^B) under BDF and the corresponding equilibrium outcomes can be described as follows:*

1. *When $a > \max\left(\frac{v^2}{16k}, \frac{v^2 - v\sqrt{v^2-4kc}}{2k} - c\right)$, (p^B, i_M^B) is optimal if and only if $p^B - (1+i_M^B)c = 2\sqrt{ka} - a$.*
2. *When $a \in \left[c - \frac{v^2}{8k}, \frac{v^2}{16k}\right]$, (p^B, i_M^B) is optimal if and only if $p^B - (1+i_M^B)c = \frac{v}{2} - a$.*
3. *When $a < \max\left(c - \frac{v^2}{8k}, \frac{v^2 - v\sqrt{v^2-4kc}}{2k} - c\right)$, the manufacturer does not source from the supplier.*

For all three cases, the equilibrium delivery probability e^B and the manufacturer's and supplier's payoffs (Π_M^B and Π_S^B) associated with the optimal BDF contract (p^B, i_M^B) are identical to their counterparts under POF as presented in Proposition 1.

Proposition 2 asserts that BDF does not improve supply chain efficiency relative to POF even though the manufacturer has a certain control advantage (his ability to jointly optimize the contingent payment and interest rate). The reason is as follows. In both POF and BDF, the supplier's incentive to exert effort is determined solely by the difference between his payoff when the order is delivered and that when the order is not delivered, i.e. $[p - (1+i)c] - (-a)$, as reflected in (3). Under POF, the contingent nature of the supply contract already equips the manufacturer with a lever to maximize the above difference. Under BDF, while the manufacturer can pull both p and i_M, the eventual force is still only $[p - (1+i_M)c]$, rendering the additional lever i_M redundant in terms of further improving supply chain efficiency. In this sense, this equivalence is consistent with the Irrelevance Theorem in Modigliani and Miller (1958).

While BDF and POF yield the same supply chain efficiency, Proposition 2 reveals that BDF offers the manufacturer more flexibility in setting the contract price and interest rates jointly. Specifically, p^B and i_M^B can induce optimal performance as long as $p^B - (1+i_M^B)c$ stays constant. This flexibility is consistent with anecdotal evidence that some manufacturers offer low interest rates in some BDF programs. For example, GSK lends money to its suppliers at the same interest rate that GSK pays the bank (Watkins 2012), while Hanbo finances its suppliers at an interest rate that is effectively lower than the bank rate (Cheng 2015). Such flexibility can also be valuable for the manufacturer as a means of circumventing regulations. For instance, when the supplier's asset value is low, the interest rate under POF has to be set very high to compensate for the associated risk. However, in certain markets, regulations may cap interest rates at certain levels, rendering POF infeasible. However, under BDF, the manufacturer can facilitate financing by lowering the contract price and interest rate simultaneously. Additionally, our model of POF assumes a perfect competitive lending market. However, in less competitive lending markets, POF can also create an additional double marginalization, making BDF more attractive. Therefore, we should expect manufacturers to consider financing suppliers directly in emerging economies where the financial market is less open. Finally, taking factors such as costs of capital and the cost associated with loan administration and asset liquidation into consideration, one could argue that the bank will have lower costs due to its economies of scale and domain expertise in the above areas. These factors could potentially make POF more attractive than BDF. This is consistent with anecdotal evidence that only large manufacturers or intermediaries with a large supply base lend directly to their suppliers.

5. The Impact of the Manufacturer's Private Information on POF

The above analysis reveals that BDF does not enable the manufacturer to obtain extra benefits despite her *control advantage*. However, in practice, aside from her control advantage, the manufacturer often also has an *information advantage* over the bank when dealing with suppliers. Indeed, in many instances, the manufacturer has more intimate knowledge of the supplier than the bank because the manufacturer has conducted business with the supplier before and/or has better domain knowledge for evaluating the supplier's operational efficiency.[9]

In this section and the next, we examine if and when the manufacturer's information advantage makes BDF the preferred financing scheme. To do so, we extend the base model to the case where the manufacturer knows more than the bank about the supplier's operational efficiency as captured by his cost factor k. Following the classic approach to modeling information asymmetry in economics (Riley 2001, Spence 2002) and operations management (Cachon and Lariviere 2001), we consider the case where the supplier is one of two possible types: an *efficient* one ($\tau = H$) with cost factor $k = k_H$ or an *inefficient* one ($\tau = L$) with cost factor k_L, where $k_L > k_H > 0$. The manufacturer (and the supplier himself) knows the exact cost factor of the particular supplier ($k = k_H$ or k_L), while the bank only knows the (prior) probability distribution of the supplier's type: The supplier is efficient with probability λ and type L with probability $(1-\lambda)$. Here, λ can be interpreted as the proportion of suppliers that are efficient in the market. Therefore, intuitively, λ is generally higher in a developed country than an emerging market. To reflect the supplier's type in the notation, we use subscript $\tau \in \{H, L\}$ to represent the corresponding quantity under type-τ supplier. For example, p_H^S (or p_L^S) represents the optimal contract price as characterized in Proposition 1 under $k = k_H$ (or k_L).

[9] For example, Li & Fung audits suppliers extensively before conducting business with them. Through such audits, the company acquires in-depth knowledge about the supplier's operations excellence (facilities, equipment, lean, quality improvement), human capital strengths (employee development and training programs), and compliance with environmental and safety regulations. These factors are often not assessed thoroughly by banks. Another source of information advantage originates from the manufacturer's better understanding of the operational specifics of a particular purchase order.

Because there is no information asymmetry about the supplier's exact type τ between the manufacturer and the supplier (and because the bank is not involved under BDF), the optimal contract and equilibrium outcomes under BDF remain the same as in Proposition 2, with k being replaced by k_τ (i.e. the cost factor of the exact supplier's type). Therefore, it suffices to focus our analysis on POF in the presence of information asymmetry between the manufacturer and the bank.

5.1. The signaling game under POF

Following the sequence of events under POF as depicted in Figure 1, we model the interaction between the manufacturer, the bank, and the supplier as a signaling game that can be described as follows.[10] First, as the party with perfect information about the supplier's exact type, the manufacturer (the *sender* of the signal) first offers a supply contract with price p (the *signal*) to the supplier. Second, the supplier takes the contract to obtain POF financing from the bank (the *receiver* of the signal). Third, upon observing the signal p, the bank forms a posterior belief about the supplier's type using Bayes' rule and offers financing terms accordingly. We use μ to denote the *posterior* probability that the supplier is efficient. In essence, the sequence of events is the same as depicted in Figure 1 with the exception that after observing the signal p selected by the manufacturer, the bank updates its belief about the supplier's type.

As in the signaling games literature, we adopt the Perfect Bayesian Equilibrium (PBE) as the relevant equilibrium concept. A PBE includes a sequentially rational strategy profile and the bank's posterior belief. The strategy profile consists of the contingent price (p_τ) offered by the manufacturer to a type-τ supplier, the interest rate ($i_{B,\tau'}$) offered by the bank under its belief that the supplier is of type τ', and the supplier's delivery probability e_τ selected by a type-τ supplier in response to p_τ and $i_{B,\tau'}$.

Focusing only on pure strategy equilibria, only two types of PBE arise from the above signaling game: separating equilibria (the contract price depends on the supplier's type) and pooling equilibria (the contract price is the same for both types of suppliers). In the remainder of this section, we discuss the underlying logic and existence conditions for both types of equilibria (Section 5.2 for separating equilibria and Section 5.3 for pooling equilibria). In Section 5.4, we establish the stable dominant equilibrium and the corresponding optimal sourcing contract.

Finally, to avoid trivial cases where the manufacturer will not source from any supplier regardless of his type under symmetric information, we confine our analysis in this section and the next to the following range of (c, a).

Assumption 2. *The supplier's cost c and his asset value a satisfy:*

$$\max\left(0,\, c - \frac{v^2}{8k_H},\, \frac{v^2 - v\sqrt{v^2 - 4k_H c}}{2k_H} - c\right) \le a \le c \le \frac{v^2}{4k_H}. \tag{10}$$

[10] The reader is referred to (Riley 2001, Spence 2002) for details regarding ways to analyze signaling games.

Note that the above condition corresponds to the *union* of Regions I and II in Figure 2 for the case when $k = k_H$. According to Proposition 1, Assumption 2 ensures that the manufacturer will at least source from the efficient ($\tau = H$) supplier under symmetric information.

5.2. Separating equilibria under POF

In the context of a signaling game, the contract prices in a separating equilibrium satisfy two properties. First, the contract price offered by the manufacturer p_τ depends on the supplier's exact type $\tau = H, L$, so that $p_H \neq p_L$. Second, the contract price p_τ serves as a credible signal to the bank so that, upon observing p_τ, the bank believes that the supplier's actual type is τ. In other words, upon observing p_τ, $\tau = H, L$, the bank's posterior probability that the supplier is efficient ($\mu = 1$) if it observes p_H and ($\mu = 0$) if it observes p_L.

5.2.1. The supplier's effort. To establish a separating equilibrium, we first examine the best response $e_\tau(p, i_{B,\tau'})$ of a supplier of type τ when the manufacturer offers price p and the bank offers interest rate $i_{B,\tau'}$ under the belief that the supplier's type is τ', where $\tau,\ \tau' \in \{H,\ L\}$. Because there is no information asymmetry between the manufacturer and the supplier, the supplier's response to any given price p and interest rate $i_{B,\tau'}$ is exactly the same as in Section 3.2. By considering (3) and (5), the corresponding supplier's best response can be written as:

$$e_\tau(p, i_{B,\tau'}) = \frac{p - (1 + i_{B,\tau'})c + a}{2k_\tau} \cdot \mathbb{1}_{\left\{p \geq \left(1 + i_{B,\tau'}\right)c + 2\sqrt{k_\tau a} - a\right\}}, \tag{11}$$

where the supplier's acceptance constraint (5) is embedded in the indicator function $\mathbb{1}_x$.

5.2.2. The bank's interest rate Anticipating the supplier's best response $e_\tau(p, i_{B,\tau'})$, the bank sets the interest rate $i_{B,\tau'}$ that is based on its belief of the supplier's type τ'. By considering (6) and replacing k with $k_{\tau'}$, i.e. the supplier's cost factor based on the bank's belief, the bank's interest rate can be written as:

$$i_{B,\tau'}(p) = \begin{cases} \frac{p - \sqrt{p^2 - 8k_{\tau'}(c-a)}}{2c} + \frac{a}{c} - 1 & \text{if } p \geq \sqrt{8k_{\tau'}(c-a)}; \\ \infty & \text{otherwise.} \end{cases} \tag{12}$$

5.2.3. The manufacturer's problem Let us define the manufacturer's payoff function when the supplier's actual type is $\tau \in \{H, L\}$, when the bank's belief about the supplier type is $\tau' \in \{H, L\}$, and when the manufacturer offers price p. By using (11) and (12) in the same manner as in Section 3.4, we can determine the manufacturer's payoff akin to (9). Specifically, the manufacturer's payoff $\Pi_M(\tau, p, \tau') = e_\tau(p, i_{B,\tau'}(p)) \cdot (v - p)$ can be rewritten as:

$$\Pi_M(\tau, p, \tau') = \frac{p + \sqrt{p^2 - 8k_{\tau'}(c-a)}}{4k_\tau}(v - p) \cdot \mathbb{1}_{\left\{p + \sqrt{p^2 - 8k_{\tau'}(c-a)} \geq 4\sqrt{k_\tau a}\right\}}. \tag{13}$$

Similarly to the symmetric information case as stated in (8), the indicator function in (13) captures the condition for the contract price p to be *jointly acceptable* to both the supplier and the bank. Note that the manufacturer's payoff under the symmetric information case, as studied in Proposition 1, is simply $\Pi_M(\tau, p, \tau)$ with k being replaced by k_τ for $\tau \in \{H,\ L\}$ and $p_\tau^S = \arg\max = \Pi_M(\tau, p, \tau)$.

5.2.4. Separating equilibria By analyzing the manufacturer's payoff given in (13), we can characterize the separating equilibria under POF as follows.

LEMMA 2. *A supplier type-specific contract price pair (p_H, p_L) is part of a separating PBE if and only if:*

1. *the contract price offered to an inefficient supplier (i.e. $\tau = L$) is p_L, where $p_L = p_L^S$, and*
2. *the contract price offered to an efficient supplier ($\tau = H$) is p_H, where p_H satisfies:*

$$\Pi_M(L, p_L^S, L) \geq \Pi_M(L, p_H, H); \tag{14}$$

$$\Pi_M(H, p_H, H) \geq \max_{p \neq p_H} \Pi_M(H, p, L). \tag{15}$$

Lemma 2 reveals the basic economic rationale for a price pair to be an equilibrium one.[11] Consider two scenarios. First, when the manufacturer faces an inefficient supplier ($\tau = L$), given $k_L > k_H$ and (13), we have $\Pi_M(\tau, p, H) \geq \Pi_M(\tau, p, L)$ for $\tau \in \{H, L\}$. Hence, under the same price p, regardless of the supplier's exact type τ, the manufacturer is always (weakly) better off if the bank believes that the supplier is efficient ($\tau = H$). As the bank knows this, the manufacturer has no incentive to go the extra mile to convince the bank that she is facing an inefficient supplier. Therefore, she can simply offer p_L^S, which is optimal under symmetric information. Observing this, the bank already knows that the supplier is inefficient.

On the other hand, when the manufacturer faces an efficient supplier ($\tau = H$), to ensure that p_H is a credible signal, it has to satisfy (14), which guarantees that the manufacturer would be worse off by setting the price at p_H if the supplier was indeed inefficient (i.e. $\tau = L$); otherwise, the manufacturer would have the incentive to deceive the bank by offering p_H to an inefficient supplier. In addition, the manufacturer must have the incentive to signal that the supplier is efficient. This is ensured by (15), which says that the manufacturer's payoff under p_H (and the bank's belief that the supplier is efficient) must be greater than her payoff under any other price and the bank's belief that the supplier is inefficient ($\tau' = L$).

5.3. Pooling equilibria under POF

In a pooling equilibrium, the manufacturer offers the same price p_W to the supplier, regardless of his actual type ($\tau \in \{H, L\}$).[12] Finding the price p_W uninformative, the bank's posterior belief is the same as its prior one, i.e. $\mu = \lambda$, and it offers interest rate $i_{B,W}$ accordingly.

[11] Lemma 2 gives the most general conditions for a price pair to be part of a separating PBE (i.e., under any off-equilibrium belief). Later, as we show in Proposition 3, most, if not all, of the separating equilibrium can be eliminated when imposing common refinements (i.e., Parato dominance and Intuitive Criterion). The relationship between Lemma 3 and Proposition 3 is similar.

[12] The subscript W represents "weighted." With slight abuse of notation, in the rest of this section, we use $\tau = W$ to represent the corresponding quantities when the bank's posterior belief is the same as its prior so that $\mu = \lambda$.

For any given price p_W and interest rate $i_{B,W}$, a type-τ supplier's best response e_τ is given in (11) with p being replaced by p_W and $i_{B,\tau'}$, by $i_{B,W}$. With the belief that the supplier's cost factor is k_H with probability λ and k_L with probability $1-\lambda$, it can be shown that the bank sets the interest rate $i_{B,W}$ similarly to in Section 5.2:

$$i_{B,W} = \frac{p_W - \sqrt{p_W^2 - 8k_W(c-a)}}{2c} + \frac{a}{c} - 1, \tag{16}$$

where $k_W \equiv \left(\frac{1-\lambda}{k_L} + \frac{\lambda}{k_H}\right)^{-1}$. Here, the term k_W can be interpreted as the cost factor associated with a weighted average supplier. Plugging p_W and $i_{B,W}$ into (11), we can determine the corresponding $e_\tau(p_W, i_{B,W})$. Combining this observation with the fact that the manufacturer's payoff equals $e_\tau(p_W, i_{B,W}) \cdot (v - p_W)$, we can determine the manufacturer's payoff under the pooling equilibria (akin to (13) and (9)) as:

$$\Pi_M(\tau, p_W, W) = \frac{p_W + \sqrt{p_W^2 - 8k_W(c-a)}}{4k_\tau}(v - p_W) \cdot \mathbb{1}_{\left\{p_W + \sqrt{p_W^2 - 8k_W(c-a)} \geq 4\sqrt{k_\tau a}\right\}}, \quad \tau \in \{H, L\}. \tag{17}$$

By considering (17), we can establish the following result:

Lemma 3. *A contract price p_W is part of a pooling PBE if and only if:*

$$\Pi_M(\tau, p_W, W) \geq \max_{p \neq p_W} \Pi_M(\tau, p, L), \ \textit{for } \tau = H, L. \tag{18}$$

Intuitively, as p_W is not informative, p_W forms a pooling PBE as long as the manufacturer is better off by offering p_W under the bank's belief that $\mu = \lambda$ than offering any other prices under the bank's belief that the supplier is inefficient.

5.4. The sourcing contract under the stable dominant equilibrium

As commonly observed in the signaling game literature, Lemmas 2 and 3 establish multiple separating and pooling PBE. Applying both Pareto dominance and the Intuitive Criterion (Cho and Kreps 1987) for equilibrium refinement, for each (c, a) that satisfies Assumption 2, we identify a unique equilibrium, which we shall refer to as the *stable dominant equilibrium*, as characterized in the following proposition. Notice that this equilibrium can neither be eliminated by the Intuitive Criterion nor Pareto dominated by other equilibria and is hence the focal equilibrium in the remainder of this paper.[13]

Proposition 3. *For any (c, a) that satisfies Assumption 2, under POF the contract prices under the stable dominant equilibrium are:*

[13] In our setting, as the bank breaks even in all equilibria and the supplier only passively reacts to the sourcing contract, Equilibrium A Pareto dominates Equilibrium B if and only if the manufacturer's payoffs when facing the efficient and inefficient suppliers are both higher in Equilibrium A than in Equilibrium B. This is also consistent with the common usage of Pareto dominance in the signaling literature (Bolton and Dewatripont 2005).

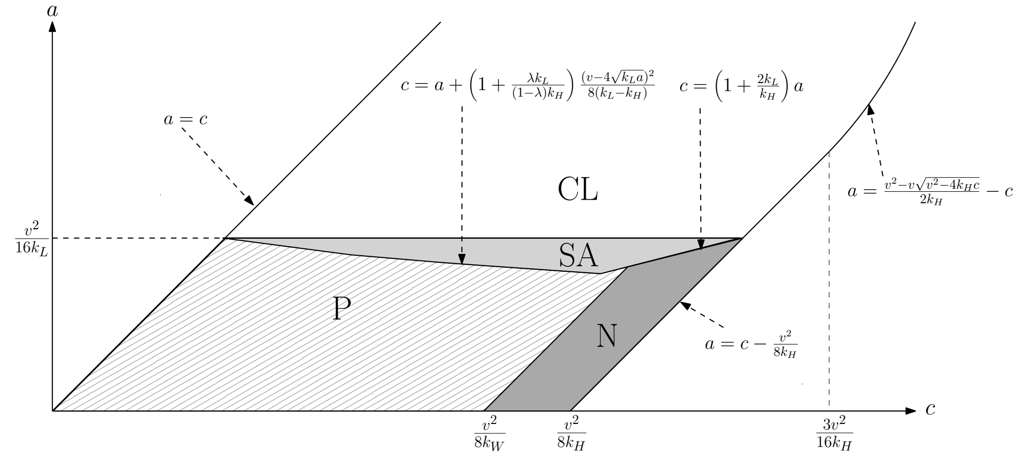
1. *When* $a \geq \frac{v^2}{16k_L}$ *(Region CL in Figure 3), the manufacturer offers the same supply contract as characterized in Proposition 1:* $p_H^A = p_H^S$*, and* $p_L^A = p_L^S$*.*

2. *When* $a < \frac{v^2}{16k_L}$ *and* $c - a \in \left[\left(1 + \frac{\lambda k_L}{(1-\lambda)k_H}\right)\frac{(v-4\sqrt{k_L a})^2}{8(k_L - k_H)},\ \left(\frac{2k_L}{k_H}\right)a\right]$ *(Region SA in Figure 3), the manufacturer offers* $p_L^A = p_L^S$ *if the supplier is inefficient and* $p_H^A = p_{L,H}^{SA} - \epsilon$ *if the supplier is efficient, where* $p_{L,H}^{SA} \equiv 2\sqrt{k_L a} + \frac{k_H(c-a)}{\sqrt{k_L a}}$ *and* $\epsilon > 0$ *is sufficiently small.*

3. *When* $c - a \in \left(0,\ \left(1 + \frac{\lambda k_L}{(1-\lambda)k_H}\right)\frac{(v-4\sqrt{k_L a})^2}{8(k_L - k_H)}\right) \cup \left(\left(\frac{2k_L}{k_H}\right)a,\ \frac{v^2}{8k_W}\right)$ *(Region P in Figure 3), the manufacturer offers* $p_H^A = p_L^A = p_W^* \equiv \frac{v}{2} + \frac{4k_W(c-a)}{v}$ *to both types of supplier.*

4. *When* $c - a > \max\left\{\left(\frac{2k_L}{k_H}\right)a,\ \frac{v^2}{8k_W}\right\}$ *(Region N in Figure 3), the manufacturer does not source from either type of supplier.*

Figure 3 Regions of the stable dominant PBE.



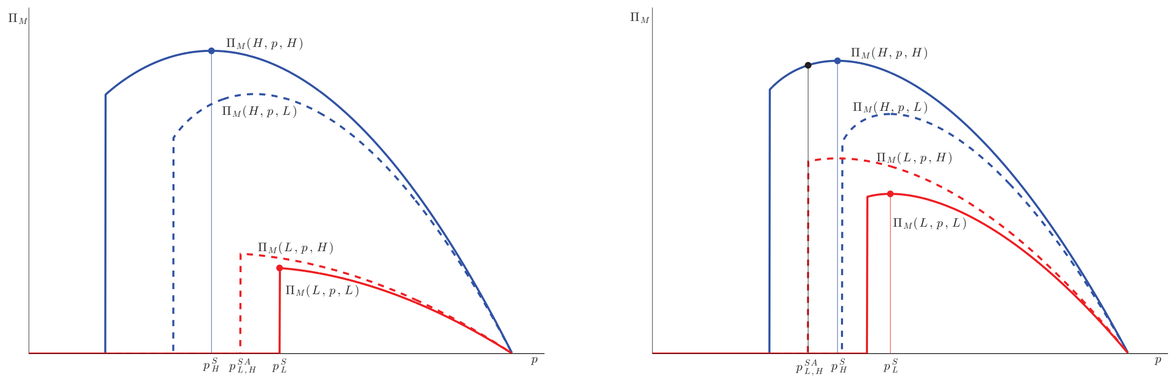
Notes. CL represents *costless* separating; SA represents separating based on the *supplier's acceptance* constraint, P represents *pooling*, N represents that *no* equilibrium exists. The illustration is generated using $\frac{k_L}{k_H} = 1.5$ and $\lambda = 0.5$.

Figure 3 depicts the four scenarios as characterized in Proposition 3. First, when the supplier's asset value a is relatively high (Region CL in Figure 3), the manufacturer can simply offer the same contract as under symmetric information (Proposition 1) because such contract prices $(p_H^S,\ p_L^S)$ can already signal the supplier's type. To see this, observe from Figure 4(a) that in this region, the price offered to the efficient supplier, p_H^S, is already lower than $p_{L,H}^{SA}$, which, as derived from the indicator function in (13), is the lowest price that an inefficient supplier ($\tau = L$) would accept even if the bank mistakenly believed that he was efficient ($\tau' = H$). As such, the manufacturer's payoff under asymmetric information is identical to that under symmetric information. In other words, signaling is *costless* to the manufacturer.

Second, where the supplier's asset value a is slightly below $\frac{v^2}{16k_L}$ and the net financing need $(c-a)$ is medium (Region SA), unlike in Region CL, the bank will no longer treat p_H^S as a credible signal that the supplier is efficient. The reason for this is illustrated in Figure 4(b), which shows that in this region, as long as the bank believes that he is efficient, the supplier is willing to accept p^S_H, i.e. $p^S_H > p^{SA}_{L,H}$. Moreover, Figure 4(b) also shows that $\Pi_M(L, p^S_H, H) > \Pi_M(L, p^S_L, L)$. Thus, the incentive compatibility constraint (14) is violated, rendering (p^S_H, p^S_L) no longer part of a separating PBE. As such, while it is still cost-efficient for the manufacturer to separate the two types of suppliers, she has to do so by deviating the contract offered to a efficient supplier from p^S_H, the optimal one under symmetric information. Specifically, the least-costly signal that the manufacturer can send is to offer $p^{SA}_{L,H} - \epsilon$ to an efficient supplier. Recall that $p^{SA}_{L,H} - \epsilon$ is the highest price an inefficient supplier will not accept, even if the bank believes that he was efficient. Therefore, in Region SA, the manufacturer signals that the supplier is efficient by making the contract unacceptable to an inefficient one.

Figure 4 Illustration of manufacturer's payoff as a function of price p under different (τ, τ') for $\tau, \tau' \in \{H, L\}$.

(a) Region CL (b) Region SA



Notes. $p^S_\tau = \arg\max_p \Pi_M(\tau, p, \tau)$ for $\tau = H,\ L$. $p^{SA}_{\tau,\tau'} = 2\sqrt{k_\tau a} + \frac{k_{\tau'}(c-a)}{\sqrt{k_\tau a}}$ for $\tau,\ \tau' = H,\ L$.

As the supplier's asset a drops further while the net financing need $c - a$ remains not too high (Region P in Figure 3), the stable dominant equilibrium is a pooling one. In equilibrium, the manufacturer simply offers p^*_W, regardless of the supplier's type. In response, the bank treats all suppliers as having cost factor k_W and hence offers a single interest rate according to (16) to all suppliers. Interestingly, the prevalence of the pooling equilibrium lays in the exact mechanism that the manufacturer separates the two types in Region SA, i.e., offering a price that is only acceptable to the efficient supplier. This mechanism, however, is constrained. For example, observe from the indicator function in (13), when $c \geq \left(1 + \frac{2k_L}{k_H}\right) a$, which separates Region P from SA for larger c, a supplier, regardless of his type, is willing to accept a contract as long as the bank believes that he is efficient.[14] As such, the manufacturer is unable to offer a contract that is only acceptable to the efficient supplier, rendering separation impossible. When $c < \left(1 + \frac{2k_L}{k_H}\right) a$, the situation is less extreme. However, in that part of Region P, the manufacturer needs to deviate the price that she offers to an efficient supplier significantly from the optimal one under symmetric information. As such, pooling is more cost-efficient.

Finally, where a is small and $(c-a)$ is large (Region N), neither pooling nor separating equilibria exist and hence the manufacturer does not source from the supplier, regardless of his type. To elaborate, when $c - a > \frac{v^2}{8k_W}$, under the belief that the supplier's cost factor is the weighted average one, the bank is not willing to lend unless the manufacturer offers a price greater than v, which is clearly not economical. Therefore, no pooling equilibrium exists. On the other hand, separating equilibrium does not exist for the same reason as we explained in Region P when $c \geq \left(1 + \frac{2k_L}{k_H}\right) a$.

In summary, due to the three-party supply chain setting and the specific mechanism that the manufacturer relies on for separation, i.e., the supplier's acceptance constraint, the manufacturer's information advantage has bifurcating impacts on the performance of POF. On the one hand, when the supplier's asset level is not too low, signaling the supplier's cost factor through the sourcing contract is actually costless. However, as the supplier's asset level drops, signaling the true type of the supplier quickly becomes too costly, leading to two scenarios: First, when $c - a$ is low, the manufacturer offers the pooling price and the bank treats both types of suppliers as the weighted average; and second, when $c - a$ is high, no equilibrium exists that allows the manufacturer to source from the efficient supplier, and hence the manufacturer has to give up a valuable sourcing opportunity.

6. The Benefit of BDF under Information Asymmetry

Armed with the stable dominant equilibrium associated with the signaling game under POF as stated in Proposition 3, we now examine the conditions under which BDF is more appealing than POF when the manufacturer has an information advantage over the bank.

Because the bank is not involved under BDF, the information asymmetry between the manufacturer and the bank has no impact on the performance of BDF. In other words, even with information asymmetry, the manufacturer's and supplier's payoffs under BDF remain the same as in Proposition 2 (with the exception that k is replaced with k_H or k_L). Because these payoffs under BDF, in both symmetric and asymmetric information cases, are the same as in Proposition 1 under POF for the symmetric information case, the benefit of BDF for the manufacturer (relative to

[14] The mechanism is similar to what we discussed for Region III in Proposition 1 and Figure 2 under the symmetric information case. There, we show that, when $c \geq 3a$, the supplier accepts any contract as long as the bank is willing to lend. Note that by setting $k_L = k_H$, $c \geq \left(1 + \frac{2k_L}{k_H}\right) a$ degenerates to $c \geq 3a$, connecting the symmetric and asymmetric information cases.

POF) that can be attributed to information asymmetry is captured by the difference in her payoffs between Propositions 1 and 3. Also, we note that the information asymmetry does not adversely influence the performance of POF when the manufacturer faces an inefficient supplier.[15] In other words, when facing an inefficient supplier, the manufacturer's information advantage does not lead to any additional benefit for her in financing the supplier. Therefore, in the rest of this section, we focus on the scenario in which the manufacturer sources from efficient suppliers. Such a focus is also supported by anecdotal evidence that many manufacturers only offer BDF to suppliers with good track records.

When facing an efficient supplier ($\tau = H$), Proposition 3 reveals that the manufacturer may need to bear certain costs under POF due to information asymmetry. Therefore, the higher the signal cost that the manufacturer has to bear under POF when she has private information, the more appealing BDF will be. According to the optimal contract characterized in Proposition 3, we examine the following three scenarios.

First, when (c, a) lies within Region CL in Figure 3, Proposition 3 asserts that the manufacturer can send a costless and credible signal to the bank under POF so that the manufacturer will obtain the same payoff as if there were no information asymmetry. Consequently, as in the symmetric information case (Sections 3 and 4), the manufacturer still obtains the same payoff under both BDF and POF. In other words, even with an information advantage, BDF does not result in a higher payoff for the manufacturer.

Second, when (c, a) lies within Region N, Proposition 3 implies that the manufacturer should not source from the efficient supplier under POF while she should do so under BDF (as stated in Proposition 2). Hence, under information asymmetry, BDF may be the only financing option when the supplier is poor (low a) and the production cost is high.

Third, when (c, a) lies within Regions SA or P, the second and third statements in Proposition 3 suggest that while POF remains a feasible option, the manufacturer needs to bear additional costs, either because it is costly for her to send a credible signal to the bank that the supplier is efficient in the separating equilibrium (Region SA), or she has to compensate the supplier for the higher interest rate charged by the bank as it assumed that the supplier is of average efficiency in the pooling equilibrium (Region P). To quantify the benefit of the manufacturer's information advantage under BDF (instead of POF) when (c, a) lies within Regions SA or P, we examine the term $\Delta_M = \Pi_M^B - \Pi_M^A$, where Π_M^B is the manufacturer's payoff under BDF as stated in Proposition 2 and Π_M^A is the manufacturer's payoff under POF as stated in Proposition 3.

[15] As established in Corollary B.1 in the Appendix, when facing an inefficient supplier, the manufacturer's payoff under asymmetric information is identical to that under symmetric information in Regions CL, SA, and N in Proposition 3, and is higher in Region P. In addition, the inefficient supplier's payoffs under the symmetric information is no greater than that under asymmetric information.

Proposition 4. *Consider the case where the manufacturer has an information advantage over the bank. When the supplier's cost c and asset level a lie within Region SA or Region P, BDF is strictly preferable to POF, i.e. $\Delta_M > 0$. In addition, the benefit of BDF relative to POF (Δ_M) increases when the supplier's asset value a decreases, when the supplier's cost factor k_H decreases, when the percentage of efficient suppliers in the market λ decreases, or when the manufacturer's outside option v increases.*

Combining the results as stated in Proposition 4 (for the case where (c, a) lies within Regions SA or P) with the discussion above (for the case where (c, a) falls in Regions CL and N), we can examine the conditions under which BDF is preferable as follows. First, BDF is more beneficial to the manufacturer when the supplier's asset value a is low. Therefore, it is more beneficial for the manufacturer when she focuses her financing capacity on helping her most financially constrained suppliers, as well as offering financing to a supplier when the value of the supplier's assets shrinks, such as during an economic downturn. This result provides a plausible explanation for the emergence of BDF during financial crises. For example, during the 1997 Asian Financial Crisis, Li & Fung offered direct financing to its cash-strapped suppliers in Indonesia (Tang 2006).

Second, BDF is more appealing to the manufacturer when the efficient supplier's cost factor k_H is low, i.e. when the supplier is more cost efficient. Therefore, it could be more beneficial to directly lend to efficient suppliers who need help with acquiring new equipment to improve their operational efficiency.

Third, BDF is more valuable for the manufacturer when the market consists of mostly inefficient suppliers (i.e. when λ is low). Note that as λ decreases, k_W becomes larger, leading to two implications: The manufacturer offers a higher contract price p_W^* (Region P) or fails to source from the supplier (Region N). As such, BDF is an effective financing scheme for manufacturers who source from developing markets comprised predominantly of inefficient suppliers.

Fourth, the benefit of POF also increases as her outside option v becomes more expensive. When v is larger, we can see from Figure 3 that Regions SA, P, and N expand. Furthermore, Proposition 3 reveals that under POF, it is more likely that the manufacturer will incur signaling costs or not source from the supplier. As such, BDF becomes more appealing to the manufacturer when the supplier is more specialized and the alternative sourcing option is particularly expensive (i.e. when v is high). Consistent with the anecdotal evidence, manufacturers that work with specialized suppliers, such as Rolls-Royce and GSK, are among the pioneers of directly financing their suppliers.

Finally, while we mainly focus on the benefits of BDF for the manufacturer, owing to her leader position in the supply chain, BDF can also improve profitability for the efficient supplier, as formalized in the following result.

COROLLARY 2. *Consider the case where the manufacturer has an information advantage over the bank. When the supplier's cost c and asset level a lay within Region SA or Region N, an efficient supplier strictly prefers BDF to POF.*

Intuitively, in Region N, the presence of information asymmetry prohibits the efficient supplier from obtaining a supply contract under POF that he could secure under BDF otherwise. Hence, the efficient supplier would directly benefit from BDF. Next, by comparing the results as stated in Proposition 2 (under BDF) and Proposition 3 (under POF), it can be shown that in Region SA, the contract price under POF is lower than that under BDF. This is because the manufacturer must, in order to signal credibly to the bank that the supplier is indeed efficient, offer a lower contract price under POF. As such, the supplier's payoff is also adversely affected. In summary, the above result suggests that BDF can also benefit the efficient supplier under information asymmetry, achieving a win–win situation for both parties in the supply chain.

7. Conclusion

POF and BDF are both recently emerged schemes aiming to help financially constrained suppliers secure financing for production. Different from more traditional financing channels such as asset-based loans and factoring, which are secured by tangible assets, repayment under both POF and BDF hinges on successful delivery by the supplier. As such, the efficiency of the two schemes depends crucially on the lender's control over and knowledge of the supplier's performance risk.

Using a three-party model that captures the interaction between a manufacturer, a supplier, and a bank, we find that without an information advantage, the manufacturer's control advantage alone does not make BDF a more attractive financing scheme. In other words, when facing supply risk, the additional lever of interest rates does not necessarily further mitigate the supplier's moral hazard due to the intrinsic contingent nature of a typical sourcing contract.

While the manufacturer's control advantage does not translate directly into an advantage of BDF, the impact of the manufacturer's information advantage on the relative benefits of BDF over POF is bifurcating. On the one hand, when the supplier's asset level is not too low, the manufacturer can signal her private information about the supplier to the bank through the sourcing contract without incurring an additional cost. In this case, POF is as efficient as BDF. However, when the supplier's asset level is low, signaling private information under POF becomes too costly for the manufacturer, if not impossible. In the case where BDF has an advantage over POF, we also find that this relative advantage increases when the manufacturer's outside option is expensive, the average efficiency of suppliers is low, or the heterogeneity of suppliers is high.

Our finding reveals that the advantage of BDF is more likely to be related to the manufacturer's information advantage, which is consistent with anecdotal evidence that BDF is more commonly observed in developing countries or where manufacturers deal with specialized suppliers. By contrast, in industries where buyers do not necessarily possess more accurate information about suppliers than banks, such as when a retailer orders from a new supplier for the first time, POF remains an attractive financing scheme; this is also consistent with anecdotal evidence (Tice 2010).

As the first attempt at understanding the relative efficiency of POF and BDF, our paper is not without limitations. On the modeling side, extensions such as repeated interaction, multiple suppliers, and endogenous supplier asset level, could be promising directions for future research. In addition, due to data availability, our results are connected only with anecdotal evidence. However, should data become available, empirical research may be conducted to verify the various predictions that the paper generates.

References

Aydin, G., V. Babich, D. Beil, Z. Yang. 2011. Decentralized supply risk management. *The Handbook of Integrated Risk Management in Global Supply Chains* 387–424.

Babich, V. 2010. Independence of capacity ordering and financial subsidies to risky suppliers. *Manufacturing & Service Operations Management* **12**(4) 583–607.

Babich, V., C. S Tang. 2012. Managing opportunistic supplier product adulteration: Deferred payments, inspection, and combined mechanisms. *Manufacturing & Service Operations Management* **14**(2) 301–314.

Bakshi, N., S.-H. Kim, N. Savva. 2015. Signaling new product reliability with after-sales service contracts. *Management Science* **61**(8) 1812–1829.

Bolton, P., M. Dewatripont. 2005. *Contract theory*. MIT press.

Buzacott, J.A., R.Q. Zhang. 2004. Inventory management with asset-based financing. *Management Science* **50**(9) 1274–1292.

Cachon, G. P, M. A Lariviere. 2001. Contracting to assure supply: How to share demand forecasts in a supply chain. *Management science* **47**(5) 629–646.

Chen, Y., D. Gupta. 2014. Trade-finance contracts for small-business suppliers and the effect of third-party financing. *Available at SSRN 2486757* .

Cheng, P. 2015. Personal Communication. Chairman of Hanbo Enterprise.

Cho, I., D. M Kreps. 1987. Signaling games and stable equilibria. *The Quarterly Journal of Economics* 179–221.

Chod, J. 2015. Inventory, risk shifting, and trade credit. Working paper, Boston College.

Chod, J., N. Trichakis, G. Tsoukalas. 2016. A signaling theory of in-kind finance. Working paper, Boston College.

Dong, L., S. Y. Tang, B. Tomlin. 2015. Production chain disruptions: Inventory, preparedness, and insurance. Working Paper.

Dong, L., B. Tomlin. 2012. Managing disruption risk: The interplay between operations and insurance. *Management Science* **58**(10) 1898–1915.

Fudenberg, D., J. Tirole. 1991. *Game theory*. MIT press Cambridge, MA.

Fung, V. K, W. K Fung, Y. J. R Wind. 2007. *Competing in a flat world: building enterprises for a borderless world*. Pearson Prentice Hall.

Gustin, D. 2014. Purchase order finance, the tough nut to crack. URL `http://spendmatters.com/tfmatters/purchase-order-finance-the-tough-nut-to-crack/`. Accessed at August 20, 2015.

Hwang, W., N. Bakshi, V. DeMiguel. 2014. Simple contracts for reliable supply: Capacity versus yield uncertainty. *London Business School, Working paper* .

Klapper, L. 2006. The role of factoring for financing small and medium enterprises. *Journal of Banking and Finance* **30**(11) 3111–3130.

Kouvelis, P, L. Dong, O. Boyabatli, R. Li. 2011. *Handbook of integrated risk management in global supply chains*, vol. 1. John Wiley & Sons.

Kouvelis, P., W. Zhao. 2012. Financing the newsvendor: supplier vs. bank, and the structure of optimal trade credit contracts. *Operations Research* **60**(3) 566–580.

Laffont, J., D. Martimort. 2009. *The theory of incentives: the principal-agent model*. Princeton university press.

Lai, G., L. Debo, L. Nan. 2011. Channel stuffing with short-term interest in market value. *Management Science* **57**(2) 332–346.

Lai, G., W. Xiao. 2014. Signals to partially informed investors: Inventory distortion and realization of stock-based payment. *Available at SSRN* .

Lewis, T. R, D. EM Sappington. 2000. Contracting with wealth-constrained agents. *International Economic Review* **41**(3) 743–767.

Li, C. 2013. Sourcing for supplier effort and competition: Design of the supply base and pricing mechanism. *Management Science* **59**(6) 1389–1406.

Martin, A. 2010. The places they go when banks say no. *New York Times* .

Mas-Colell, A., M. D. Whinston, J. R Green. 1995. *Microeconomic theory*. Oxford university press New York.

McAfee, R Preston, John McMillan. 1986. Bidding for contracts: a principal-agent analysis. *The RAND Journal of Economics* 326–338.

Modigliani, F., M.H. Miller. 1958. The cost of capital, corporation finance and the theory of investment. *American Economic Review* **48**(3) 261–297.

Peura, H., S. A. Yang, G. Lai. 2016. Trade credit in competition: a horizontal benefit. *Manufacturing & Service Operations Management* Forthcoming.

Porteus, E. L. 1985. Investing in reduced setups in the eoq model. *Management Science* **31**(8) 998–1010.

Riley, J. G. 2001. Silver signals: Twenty-five years of screening and signaling. *Journal of Economic Literature* **39**(2) 432–478.

Rui, H., G. Lai. 2015. Sourcing with deferred payment and inspection under supplier product adulteration risk. *Production and Operations Management* **24**(6) 934–946.

Sappington, D. 1983. Limited liability contracts between principal and agent. *Journal of Economic Theory* **29**(1) 1–21.

Schmidt, W., V. Gaur, R. Lai, A. Raman. 2015. Signaling to partially informed investors in the newsvendor model. *Production and Operations Management* **25**(3) 383–401.

Sodhi, M., C.S. Tang. 2012. *Managing Supply Chain Risks*. Springer, New York.

Spence, M. 2002. Signaling in retrospect and the informational structure of markets. *American Economic Review* 434–459.

Swinney, R., S. Netessine. 2009. Long-term contracts under the threat of supplier default. *Manufacturing & Service Operations Management* **11**(1) 109–127.

Tang, C. S. 2006. Perspectives in supply chain risk management. *International Journal of Production Economics* **103**(2) 451–488.

Tang, S. Y, H. Gurnani, D. Gupta. 2014. Managing disruptions in decentralized supply chains with endogenous supply process reliability. *Production and Operations Management* **23**(7) 1198–1211.

Tice, C. 2010. Can a Purchase Order Loan Keep Your Business Growing? URL `http://www.entrepreneur.com/article/207058`. Accessed at March 10, 2015.

Tomlin, B., Y. Wang. 2011. Operational strategies for managing supply chain disruption risk. P. Kouvelis, O Boyabatli, L. Dong, , R Li, eds., *The Handbook of Integrated Risk Management in Global Supply Chains*. Wiley Online Library, 79–101.

Tunca, T.I., W. Zhu. 2014. Buyer Intermediation in Supplier Finance. University of Maryland working paper.

Watkins, S. 2012. Top UK firms lend billions to struggling suppliers as they are forced to act as banks. URL `http://www.thisismoney.co.uk/money/news/article-2220517/Top-UK-firms-lend-billions-suppliers-forced-act-banks.html`. Accessed at February 28, 2015.

Yang, S. A., J. R. Birge. 2009. How Inventory is (Should Be) Financed: Trade Credit in Supply Chains with Demand Uncertainty and Costs of Financial Distress. *SSRN eLibrary* doi:10.2139/ssrn.1734682.

Appendix A: Proofs

Proof of Lemma 1. In a centralized chain, the system's payoff $\Pi_c = v - [(1-e)v + c + ke^2]$, which is maximized at $e = \frac{v}{2k}$. By substituting e into Π_c, it is easy to check that the corresponding optimal payoff is equal to $\frac{v^2}{4k} - c$. For the centralized system to be viable, the optimal payoff has to be non-negative, i.e. $\frac{v^2}{4k} \geq c$, as desired. $\square$

Proof of Proposition 1. We prove the results by using e as the decision variable (instead of p). In preparation, let us transform the constraints in terms of e (instead of p). First, by considering (7) and (8), the joint acceptance constraint (8) (or the indicator function as stated in (9)) holds if and only if $4ke \geq 4\sqrt{ka}$ or, equivalently, $e \geq \sqrt{\frac{a}{k}}$.

Second, we can apply (7) to express p in terms of e so that $p = 2ke + \frac{c-a}{e}$. By using this expression of p, it is easy to check that the boundary constraint $p \leq v$ holds if and only if $e \in [\underline{e}, \bar{e}]$, where $\underline{e} = \frac{v}{4k} - \frac{\sqrt{v^2-8k(c-a)}}{4k}$, $\bar{e} = \frac{v}{4k} + \frac{\sqrt{v^2-8k(c-a)}}{4k}$.

By substituting $p = 2ke + \frac{c-a}{e}$ into the manufacturer's payoff (9) along with the transformed constraints in terms of e, the manufacturer's problem can be rewritten as:

$$\max_{e} \Pi_M = e(v-p) = ev - 2ke^2 - (c-a) \tag{19}$$

$$\text{s.t. } e \geq \sqrt{\frac{a}{k}} \tag{20}$$

$$e \in [\underline{e}, \bar{e}]. \tag{21}$$

We now solve this problem by mapping out the optimal solution within different regions of (c, a). In preparation, recall from Assumption 1 that (c, a) lies within the region $0 \leq a \leq c \leq \frac{v^2}{4k}$. Also, combine the boundary constraint and the bank's lending constraint so that $v \geq p \geq \sqrt{8k(c-a)}$. Hence, (c, a) must lie within the region that has $v \geq \sqrt{8k(c-a)}$, or, equivalently, $a \geq c - \frac{v^2}{8k}$. By considering the intersection of these two regions, we now present the optimal solution e^* to the manufacturer's problem as follows.

First, observe that the unconstrained solution to the manufacturer's problem is given as $e = \frac{v}{4k}$. Now observe that $\frac{v}{4k} \in (\underline{e}, \bar{e})$. Therefore, if $\frac{v}{4k} \geq \sqrt{\frac{a}{k}}$ (or, equivalently, when $a \leq \frac{v^2}{16k}$), then $e = \frac{v}{4k}$ satisfies all of the constraints. Thus, it is the optimal solution. By combining the region that has $a \leq \frac{v^2}{16k}$ with the feasible region stated above, we can conclude that $e = \frac{v}{4k}$ is optimal when (c, a) lies in Region II as stated in Figure 2. Correspondingly, $\Pi_M = \frac{v^2}{8k} - (c-a) > 0$ and $\Pi_S = \frac{v^2}{16k} - a \geq 0$.

It remains to examine the case where $\frac{v}{4k} < \sqrt{\frac{a}{k}}$. There are two scenarios to consider:

1. If $\sqrt{\frac{a}{k}} \leq \bar{e}$ or, equivalently, when $a \geq \frac{v^2 - v\sqrt{v^2-4kc}}{2k} - c$, then the boundary solution $e = \sqrt{\frac{a}{k}}$ is the optimal solution that satisfies all constraints. By combining the region that has $a \leq \frac{v^2 - v\sqrt{v^2-4kc}}{2k} - c$ with the feasible region stated above, we can conclude that $e = \sqrt{\frac{a}{k}}$ is the optimal solution when (c, a) lies in Region I as shown in Figure 2. Correspondingly, $\Pi_M = v\sqrt{\frac{a}{k}} - c - a \geq 0$ and $\Pi_s = ke^2 - a = 0$.

2. If $\sqrt{\frac{a}{k}} > \bar{e}$ or, equivalently, when $a < \frac{v^2 - v\sqrt{v^2-4kc}}{2k} - c$, then there is no e that can satisfy both constraints (i.e. $e \geq \sqrt{\frac{a}{k}}$ and $e \leq \bar{e}$). Thus, the manufacturer does not source from the supplier. By combining the region that has $a < \frac{v^2 - v\sqrt{v^2-4kc}}{2k} - c$ for $a \geq \frac{v^2}{16k}$ with the constraint $c - a \leq \frac{v^2}{8k}$ stated above, we can conclude that there is no feasible solution e for the manufacturer's problem when $a < \max\left(c - \frac{v^2}{8k}, \frac{v^2 - v\sqrt{v^2-4kc}}{2k} - c\right)$ (Region III as shown in Figure 2).

Finally, for Regions I and II, p follows directly from $p = 2ke + \frac{c-a}{e}$, and (6) i_B, Π_S and Π_M can also be directly derived from e. $\square$

Proof of Corollary 1. This corollary follows directly from Proposition 1. First, it is easy to verify that the desired monotonicity holds for each of the three regions in Proposition 1. For example, when $a > \frac{v^2}{16k}$ and $c < v\sqrt{\frac{a}{k}} - a$ as in Region I, $e^S = \sqrt{\frac{a}{k}}$ and $p^S = 2\sqrt{ka} + (c-a)\sqrt{\frac{k}{a}}$. $i_B = \left(\sqrt{\frac{k}{a}} - 1\right)\left(\frac{c-a}{c}\right)$, $\Pi^S_M = v\sqrt{\frac{a}{k}} - c - a$, and $\Pi^S_S = 0$. Thus, we have $\frac{\partial p^S}{\partial k} > 0$, $\frac{\partial i^S_B}{\partial k} > 0$, $\frac{\partial e^S}{\partial k} < 0$, $\frac{\partial \Pi^S_S}{\partial k} = 0$, and $\frac{\partial \Pi^S_M}{\partial k} < 0$, ad desired. □

Proof of Proposition 2. In BDF, the bank is not involved and the manufacturer's problem can be formulated as: $\max_{p,i_M} \Pi_M = \max_{p,i_M} \{e(v-p) + [e(1+i_M)c + (1-e)a - c]\}$, subject to the supplier's participation constraint given in (5); i.e. $p \geq (1+i_M)c + 2\sqrt{ka} - a$.

We now prove the results by using e as the decision variable (instead of p). In preparation, let us transform the constraints in terms of e (instead of p). First, by considering the supplier's best response given in (3) (with i_B being replaced by i_M), we can express p as a function of e, i.e. $p = 2k \cdot e + (1+i_M)c - a$. Second, by using this expression of p, it is easy to check that the supplier's participation constraint given in (5) can be rewritten as $e \geq \sqrt{\frac{a}{k}}$. By using this simplified supplier's participation constraint and by substituting this expression of p into the manufacturer's payoff, we can transform the above manufacturer's problem as follows:

$$\max_{e,i_M} \Pi_M = \max_{e,i_M} \{-2ke^2 + ve - (c-a)\}, \text{ subject to } e \geq \sqrt{\frac{a}{k}}. \tag{22}$$

Observe that i_M does not appear in the objective function Π_M and the manufacturer can select any interest rate i_M satisfying $p = 2ke + (1+i_M)c - a$.

By considering the first-order condition along with the constraint $e \geq \sqrt{\frac{a}{k}}$, it is easy to check that the supplier's optimal effort is $e^B = \max\{\frac{v}{4k}, \sqrt{\frac{a}{k}}\}$. Similarly to the proof for Proposition 1, depending on region that (c,a) lies within, we have the following three scenarios.

1. When (c,a) lies in Region I as depicted in Figure 2 so that $0 \leq a \leq c \leq \frac{v^2}{4k}$ (Assumption 1) and $a > \frac{v^2}{16k}$ and $c < v\sqrt{\frac{a}{k}} - a$, it is easy to check that $\sqrt{\frac{a}{k}} \geq \frac{v}{4k}$ in Region I. Therefore, the optimal $e^* = \sqrt{\frac{a}{k}}$. Correspondingly, $\Pi^B_M = -2k(e^B)^2 + ve^B - (c-a) = v\sqrt{\frac{a}{k}} - c - a$ and $\Pi^B_S = k(e^B)^2 - a = 0$. The manufacturer offers (p^B, i_M) such that $p^B = 2ke^B + (1+i_M)c - a = 2\sqrt{ak} + (1+i_M)c - a$.

2. When (c,a) lies in Region II as depicted in Figure 2 so that $0 \leq a \leq c \leq \frac{v^2}{4k}$ (Assumption 1) and $a \in \left[c - \frac{v^2}{8k}, \frac{v^2}{16k}\right)$, it is easy to check that $\sqrt{\frac{a}{k}} < \frac{v}{4k}$ in Region II. Therefore, we have $e^B = \frac{v}{4k}$. Correspondingly, $\Pi^B_M = -2k(e^B)^2 + ve^B - (c-a) = \frac{v^2}{8k} - (c-a)$, $\Pi^B_S = \frac{v^2}{16k} - a$. The manufacturer offers (p^B, i^B_M) such that $p^B = 2ke^B + (1+i_M)c - a = \frac{v}{2} + (1+i_M)c - a$.

3. When (c,a) lies in Region III as depicted in Figure 2, let us first examine the condition under which the manufacturer will source from the supplier, i.e. the condition under which $\Pi^B_M \geq 0$. By using the fact that $\Pi_M = -2ke^2 + ve - (c-a)$, we can conclude that $\Pi^B_M \geq 0$ if and only if $e \in [\underline{e}, \bar{e}]$, where $\underline{e} = \frac{v}{4k} - \frac{\sqrt{v^2 - 8k(c-a)}}{4k}$, $\bar{e} = \frac{v}{4k} + \frac{\sqrt{v^2 - 8k(c-a)}}{4k}$. By using the same argument as presented in the proof of Proposition 1, we know that there is no e that can satisfy both constraints (i.e. $e \geq \sqrt{\frac{a}{k}}$ and $e \leq \bar{e}$) within Region III. In other words, when (a,c) lies in Region III, the manufacturer's payoff is always negative. Consequently, the manufacturer will not source from the supplier. □

Proof of Lemma 2. We first show that any (p_H, p_L) satisfying the conditions is part of a separating PBE. Based on the definition of a PBE, there is no restriction on the off-equilibrium belief (Fudenberg and Tirole 1991, Mas-Colell et al. 1995). Therefore, we specify the bank's off-equilibrium belief as follows: For $p \neq p_H$, the bank believes that the supplier is inefficient, i.e. $\mu = 0$.

Under such an off-equilibrium belief, p_L^S is the rational choice for the manufacturer if the supplier is inefficient as $p_L^S = \arg\max_p \Pi_M(L, p, L)$ (so that if the bank believes the supplier is inefficient, p_L^S is the manufacturer's optimal choice) and $\Pi_M(L, p_L^S, L) \geq \Pi_M(L, p_H, H)$ (so that the manufacturer has no incentive to misrepresent an inefficient supplier as an efficient one).

Symmetrically, p_H is also the rational choice for the manufacturer facing an efficient supplier as $\Pi_M(L, p_L^S, L) \geq \Pi_M(L, p_H, H)$ (so that p_H serves as a credible signal that the supplier is efficient) and $\Pi_M(H, p_H, H) \geq \max_{p \neq p_H} \Pi_M(H, p, L)$ (so that it is indeed profitable for the manufacturer to signal that the supplier is efficient instead of being perceived as an inefficient one).

In addition, it is clear that the bank's belief is consistent with Bayes' rule. Therefore, (p_H, p_L) is indeed part of a separating PBE.

Next, we prove that (p_H, p_L) that does not satisfy the conditions does not correspond to a separating PBE. To prove this, we basically show that (p_H, p_L) does not correspond to a separating PBE if any one of the three conditions, i.e. $p_L = p_L^S$, (14), and (15), is violated.

First, assume $p_L \neq p_L^S$. As $p_L^S = \arg\max_p \Pi_M(L, p, L)$, and $\Pi_M(L, p_L^S, H) > \Pi_M(L, p_L^S, L)$, the manufacturer is always better off offering p_L^S to an inefficient supplier than some other price p_L, regardless whether the bank believes that the supplier is efficient or not. Therefore, offering p_L other than p_L^S is not rational for the manufacturer, violating the sequential rationality requirement for a PBE.

Second, assume that (14) does not hold, i.e. $\Pi_M(L, p_H, H) > \Pi_M(L, p_L^S, L)$. In this case, it is clear that the manufacturer has the incentive to misrepresent an inefficient supplier as an efficient one and, hence, p_H is not a credible signal that the supplier is efficient.

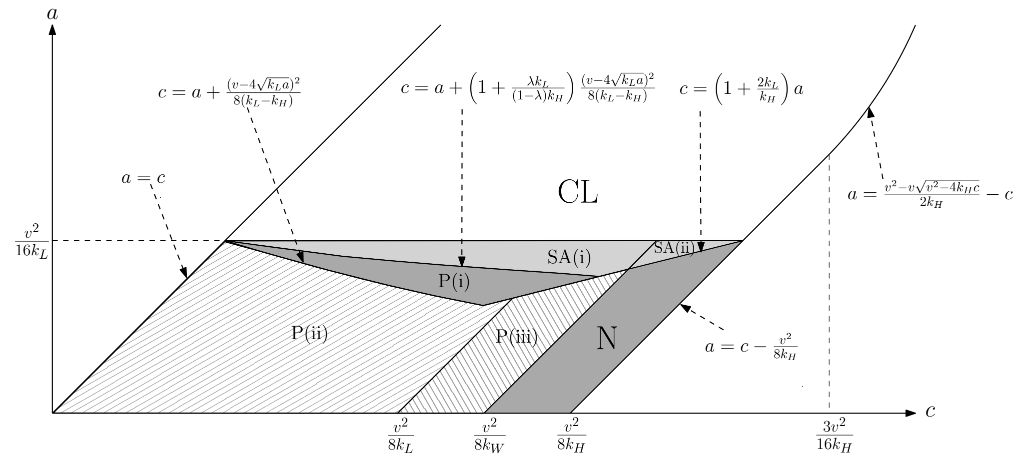
Third, assume that (15) does not hold, i.e. $\Pi_M(H, p_H, H) < \max_{p \neq p_H} \Pi_M(H, p, L)$. In this case, it is clear that the manufacturer will be better off offering some other price to the efficient supplier, even if this leads to the bank's belief that the supplier is inefficient. And as $\Pi_M(H, p, L) \leq \Pi_M(H, p, H)$ for all p, it is also clear that the manufacturer will be better off offering some other price to the efficient supplier, even if this leads to the bank's belief that the supplier is efficient.

Combining the above three cases, we can see that all three conditions are necessarily for (p_H, p_L) to correspond to a separating PBE. □

Proof of Lemma 3. The proof is similar to that of Lemma 2. We first show that p_W that satisfies (18) is part of a pooling PBE. To see this, we specify that the bank's off-equilibrium path belief is that $\mu = 0$ for $p \neq p_W$. Under this belief, it is clear that for both the efficient and inefficient supplier, the manufacturer is better off offering p_W (under which the bank believes that the supplier is a weighted-average one) than any other price (under which the bank believes that the supplier is inefficient). Therefore, offering p_W under the above-specified belief is rational for the manufacturer.

Next, we note that p_W that does not satisfy (18) cannot be part of a pooling PBE, as the manufacturer is better off offering some other price, even if the bank believes that the supplier is inefficient. □

Figure 5 **Illustration of different cases in proof of Proposition 3.**



Notes. Regions CL, SA(i), SA(ii), P(i), P(ii), P(iii), and N correspond to different cases in the proof of Proposition 3 below. The illustration is generated using $\frac{k_L}{k_H} = 1.5$ and $\lambda = 0.5$.

Proof of Proposition 3. In our setting, it is clear that (1) the least costly separating PBE (Proposition B.2) Pareto dominates all other separating PBE and (2) the Pareto-dominant pooling equilibrium (Proposition B.3) Pareto dominates all other pooling PBE. Therefore, in this proof, we only need to apply Pareto dominance and the Intuitive Criterion to the least costly separating PBE and the Pareto-dominant pooling PBE. Specifically, we apply the following processes to identify the stable dominant equilibrium for each (c, a) that satisfies Assumption 2.

Step 1: If neither equilibrium (the least costly separating or the Pareto-dominant pooling) exists, no equilibrium exists, i.e. the manufacturer does not source from either type of supplier.
Step 2: If only one equilibrium exists, then this equilibrium is the stable dominant equilibrium.
Step 3: If both equilibria exist, we examine if the pooling equilibrium survives the Intuitive Criterion. Note that it is straightforward that the least costly separating equilibrium always survives the Intuitive Criterion. If the pooling equilibrium can be eliminated by the Intuitive Criterion, then the separating PBE is the stable dominant equilibrium.
Step 4: if the pooling equilibrium survives the Intuitive Criterion, we compare it with the least costly separating equilibrium and see whether one Pareto dominates the other. If the answer is yes, then the Pareto-dominant equilibrium is the stable dominant equilibrium.

Next, we show that applying these steps in our setting allows us to identify (at most) one stable dominant equilibrium. In particular, we consider the four cases: Case CL, Case SA (with two sub-cases), Case P (with three sub-cases), and Case N. The (c, a) region that corresponds to each sub-cases is illustrated in Figure 5.
Case CL: $a \geq \frac{v^2}{16k_L}$ **(Region CL in Figure 3).** According to Proposition B.2 (Statement 1), in this region, $p_H^A = p_H^S$ and $p_L^A = p_L^S$, and hence, separating is costless. Therefore, it is clear that the least costly separating equilibrium survives the Intuitive Criterion and, hence, is the stable dominant equilibrium.
Case SA: $a < \frac{v^2}{16k_L}$ **and** $c - a \in \left[\left(1+\frac{\lambda k_L}{(1-\lambda)k_H}\right)\frac{(v-4\sqrt{k_L a})^2}{8(k_L-k_H)}, \frac{2k_L a}{k_H}\right]$ **(Region SA in Figure 3).** For (c, a) within this region, consider two further scenarios.

Case SA(i): $c-a \le \frac{v^2}{8k_W}$. According to Proposition B.2 (Statement 2), in the separating equilibrium the manufacturer's payoff when facing an efficient supplier is $\Pi_M(H, p_{L,H}^{SA}-\epsilon, H) = \frac{v\sqrt{k_L a}}{k_H} - \left(\frac{2k_L}{k_H}-1\right)a - c - \delta(\epsilon)$, where $\delta(\epsilon)$ is arbitrarily small for arbitrarily small ϵ. Her payoff facing an inefficient supplier is $\Pi_M(L, p_L^S, L) = \frac{v^2}{8k_L} - (c-a)$. On the other hand, according to Proposition B.3 (Statement 1), in the pooling equilibrium the manufacturer's payoff when facing a type-τ supplier is $\Pi_M(\tau, p_W^*, W) = \frac{v^2}{8k_\tau} - \frac{k_W(c-a)}{k_\tau}$ for $\tau = L, H$. Next, we show that the above pooling equilibrium can be eliminated by the Intuitive Criterion.

Intuitively speaking, the Intuitive Criterion eliminates those PBEs that are built only on "unreasonable" off-equilibrium beliefs. In our setting, to eliminate the above pooling equilibrium, consider the off-equilibrium signal $p_{L,H}^{SA}-\epsilon$. It is easy to verify that $\Pi_M(H, p_W^*, W) < \Pi_M(H, p_{L,H}^{SA}-\epsilon, H)$; therefore, for a manufacturer facing an efficient supplier, the signal $p_{L,H}^{SA}-\epsilon$ is *not* equilibrium dominated by p_W^*. On the other hand, note that $\Pi_M(L, p_W^*, W) > \Pi_M(L, p_{L,H}^{SA}-\epsilon, H) = 0$, and hence, for a manufacturer facing an inefficient supplier, the signal $p_{L,H}^{SA}-\epsilon$ is equilibrium dominated by p_W^*. Let us now apply the Intuitive Criterion, under which one should assume zero probability for the inefficient type when observing the off-equilibrium signal $p_{L,H}^{SA}-\epsilon$. In other words, upon observing $p_{L,H}^{SA}-\epsilon$, the bank's posterior belief should be $\mu = 1$. Under this belief, the manufacturer facing an efficient supplier has the incentive to deviate from p_W^* to $p_{L,H}^{SA}-\epsilon$. Thus, the Intuitive Criterion eliminates the pooling equilibrium.

Case SA(ii): $c-a > \frac{v^2}{8k_W}$. According to Proposition B.3 (Statement 2), no pooling equilibrium exists. Therefore, the least costly separating equilibrium is the stable dominant equilibrium.

Combining Case SA(i) and SA(ii), in Region SA of Figure 3 the least costly separating equilibrium is the stable dominant one.

Case P: $c-a \in \left(0, \left(1+\frac{\lambda k_L}{(1-\lambda)k_H}\right)\frac{(v-4\sqrt{k_L a})^2}{8(k_L-k_H)}\right) \cup \left(\frac{2k_L a}{k_H}, \frac{v^2}{8k_W}\right)$ **(Region P in Figure 3).** For (c, a) within the above region, we consider three further scenarios.

Case P(i): $c-a \in \left(\frac{(v-4\sqrt{k_L a})^2}{8(k_L-k_H)}, \frac{2k_L}{k_H}a\right)$**.** For the pooling equilibrium, the manufacturer's payoff facing a type-τ supplier is $\Pi_M(\tau, p_W^*, W) = \frac{v^2}{8k_\tau} - \frac{k_W(c-a)}{k_\tau}$ for $\tau = L, H$, the same as in Case SA(i) above. For the separating equilibrium, this region corresponds to Statement 2 in Proposition B.2. Therefore, the manufacturer's payoff when facing the efficient supplier is $\Pi_M(H, p_{L,H}^{SA}-\epsilon, H) = \frac{v\sqrt{k_L a}}{k_H} - \left(\frac{2k_L}{k_H}-1\right)a - c - \delta(\epsilon)$, which is also the same as in Case SA(i) above.

Next, we apply the Intuitive Criterion to the pooling equilibrium as in Case SA(i). Differently from in Case SA(i), we cannot find any off-equilibrium signal p that allows us to put restrictions on the off-equilibrium belief, which are necessary to eliminate the pooling equilibrium. To see this, consider the following two scenarios.

1. If the off-equilibrium signal p is not acceptable to the inefficient supplier, even if the bank believes that the supplier is efficient, i.e. p satisfies $p + \sqrt{p^2 - 8k_H(c-a)} < 4\sqrt{k_L a}$ (from the indicator function within equation 13 under $\tau = L$ and $\tau' = H$), it is easy to verify that we have $\Pi_M(H, p, H) \le \Pi_M(H, p_{L,H}^{SA}-\epsilon, H) < \Pi_M(\tau, p_W^*, W)$. Therefore, the above signal p is equilibrium dominated by p_W^* under the pooling belief for both $\tau = H$ and $\tau = L$. Hence, the Intuitive Criterion cannot put any restriction on the off-equilibrium belief at p.

2. If the off-equilibrium signal p is acceptable to the inefficient supplier when the bank believes that the supplier is efficient, i.e. for p that satisfy $p+\sqrt{p^2-8k_H(c-a)}\geq 4\sqrt{k_La}$, we can show that $\Pi_M(H,p,H)\geq \Pi_M(H,p_W^*,W)$ and $\Pi_M(L,p,H)\geq \Pi_M(L,p_W^*,W)$ are equivalent. Therefore, the signal p is either equilibrium dominated under both $\tau=H$ and $\tau=L$ or under neither $\tau=H$ nor $\tau=L$ and, hence, the Intuitive Criterion cannot put any restriction on the off-equilibrium belief at such p either.

Combining the above two cases, we can conclude that the pooling equilibrium survives the Intuitive Criterion.

Finally, we apply our **Step 4** to identify whether one equilibrium Pareto dominates the other. Note that in this region, $\Pi_M(H,p_{L,H}^{SA}-\epsilon,H)<\Pi_M(H,p_W^*,W)$. Similarly, we can show that when facing an inefficient supplier, the manufacturer's payoff in the separating equilibrium, $\Pi_M(L,p_L^S,L)$, is strictly lower than her payoff in the pooling equilibrium, $\Pi_M(H,p_W^*,W)$. Therefore, the pooling equilibrium Pareto dominates the separating one and, hence, is the stable dominant equilibrium.

Case P(ii): $c-a\in\left[0,\min\left\{\frac{v^2}{8k_L},\frac{(v-4\sqrt{k_La})^2}{8(k_L-k_H)}\right\}\right]\cup\left[\frac{2k_La}{k_H},\frac{v^2}{8k_L}\right]$**.** For the pooling equilibrium, the manufacturer's payoff is the same as in Case P(i) above. For the separating equilibrium, this region corresponds to Statement 3 in Proposition B.2, and hence, the manufacturer's payoff facing an efficient supplier is $\Pi_M(H,p^{MI},H)=\frac{v^2}{8k_H}-\frac{k_L}{k_H}(c-a)$. It is easy to see that $\Pi_M(H,p^{MI},H)<\Pi_M(H,p_W^*,W)$. Similarly, we can show that the manufacture's payoff facing an inefficient supplier, $\Pi_M(L,p_L^S,L)$, is also less than $\Pi_M(L,p_W^*,W)$. Therefore, the pooling equilibrium Pareto dominates the separating one. Following the same argument as in Case P(i) above, we can show that the pooling PBE survives the Intuitive Criterion and, hence, is the stable dominant equilibrium.

Case P(iii): $c-a\in\left(\frac{v^2}{8k_L},\frac{v^2}{8k_W}\right)$. This region corresponds to Statement 4 in Proposition B.2, where no separating equilibrium exists. Therefore, the pooling equilibrium is the stable dominant equilibrium.

Combining Cases P(i), P(ii), and P(iii), we have shown that in Region P, the pooling PBE in Proposition B.3 is the stable dominant equilibrium.

Case N: $c-a>\max\left\{\frac{2k_L}{k_H}a,\frac{v^2}{8k_W}\right\}$ **(Region N in Figure 3).** According to Proposition B.2 (Statement 4) and Proposition B.3 (Statement 2), neither separating nor pooling equilibria exist in this region. Therefore, the manufacturer does not source from either type of supplier. □

Proof of Proposition 4. Note that for $a<\frac{v^2}{16k_L}$, under BDF, the manufacturer's payoff facing an efficient supplier is $\Pi_M^B=\frac{v^2}{8k_H}-(c-a)$.

In Region SA of Proposition 3, $\Pi_M(H,p_{L,H}^{SA},H)=\frac{v\sqrt{k_La}}{k_H}-\frac{2k_L}{k_H}a-(c-a)$. Therefore, $\Delta_M=\frac{(v-4\sqrt{k_La})^2}{8k_H}$. Taking partial derivatives of Δ_M with respect to a, v, λ, and k_H, we have $\frac{\partial\Delta_M}{\partial a}=-\frac{(v-4\sqrt{ak_L})}{2k_H}\sqrt{\frac{k_L}{a}}<0$, $\frac{\partial\Delta_M}{\partial v}=\frac{v-4\sqrt{ak_L}}{4k_H}>0$, $\frac{\partial\Delta_M}{\partial\lambda}=0$, and $\frac{\partial\Delta_M}{\partial k_H}=-\frac{(v-4\sqrt{ak_L})^2}{8k_H^2}<0$.

In Region P, $\Pi_M(H,p_W^*,W)=\frac{v^2}{8k_H}-\frac{k_W}{k_H}(c-a)$, $\Delta_M=\left(\frac{k_W}{k_H}-1\right)(c-a)=\frac{\frac{k_L}{k_H}-1}{1+\frac{\lambda}{1-\lambda}\frac{k_L}{k_H}}(c-a)$. Therefore, $\frac{\partial\Delta_M}{\partial a}=-\frac{(1-\lambda)(k_L-k_H)}{\lambda k_L+(1-\lambda)k_H}<0$, $\frac{\partial\Delta_M}{\partial v}=0$, $\frac{\partial\Delta_M}{\partial\lambda}=-\frac{k_L(k_L-k_H)}{(\lambda k_L+(1-\lambda)k_H)^2}(c-a)<0$, and $\frac{\partial\Delta_M}{\partial k_H}=-\frac{(1-\lambda)k_L}{(\lambda k_L+(1-\lambda)k_H)^2}(c-a)<0$. □

Proof of Corollary 2. In Region N, Π_S is strictly positive under Propositions 1 and 2. However, with information asymmetry, the manufacturer does not source from the efficient supplier, leading to $\Pi_S=0$. In Region SA, it is also easy to check that Π_S under Propositions 1 and 2 is strictly greater than Π_S under the contract in Proposition 3, as desired. □

Appendix B: Technical Results and Proofs

B.1. Technical results

This section includes the technical results that are needed for the proofs of the results and statements in the main body of the paper as well as short explanations of some of them.

Lemma B.1 *Under a given contract price p, it is optimal for the supplier to pledge his entire asset a as collateral for the POF loan.*

This lemma shows that when the supplier takes a purchase order with contract price p to the bank for a POF loan, even if he has the option to pledge only part of his assets as collateral, it is in his best interest to pledge all of his assets. Intuitively, this is because that a smaller collateral lowers the supplier's incentive to exert effort. Anticipating that, the bank charges a higher interest rate on the loan, which eventually hurts the supplier.

Proposition B.1 *Assume that under POF the manufacturer has the freedom to offer the following contract to the supplier: Upon successful delivery, she pays the supplier payment $p > 0$; if the supplier fails to deliver, she imposes a penalty $p_n \geq 0$ on the supplier. Under the optimal contract in such a form, the manufacturer's and supplier's payoffs and the equilibrium delivery probability are the same as under the optimal contract in Proposition 1.*

This result supports the statement that it is sufficient to consider the contract form we focus on in the paper – the supplier receives p upon successful delivery and 0 otherwise. As shown in the Proposition B.1, charging the supplier a penalty for a failed delivery does not improve contract performance (either profitability or delivery probability).

Proposition B.2 *For (c, a) that satisfies Assumption 2 in the least costly separating equilibrium, the manufacturer offers p_L^S to the inefficient supplier. The manufacturer's payoff is the same as in Proposition 1 with $k = k_L$.*

The contract price p_H^* she offers the efficient supplier ($\tau = H$) is as follows:

1. *For $a \geq \frac{v^2}{16k_L}$, $p_H^A = p_H^S$.*
2. *For $a < \frac{v^2}{16k_L}$ and $c - a \in \left(\frac{(v-4\sqrt{k_L a})^2}{8(k_L - k_H)}, \frac{2k_L a}{k_H}\right)$, $p_H^A = p_{L,H}^{SA} - \epsilon = 2\sqrt{k_L a} + \frac{k_H(c-a)}{\sqrt{k_L a}} - \epsilon$, where $\epsilon > 0$ is sufficiently small.*
3. *For $c - a \in \left[0, \min\left\{\frac{v^2}{8k_L}, \frac{(v-4\sqrt{k_L a})^2}{8(k_L - k_H)}\right\}\right] \cup \left[\frac{2k_L a}{k_H}, \frac{v^2}{8k_L}\right]$, $p_H^A = p^{MI} \equiv \frac{v}{2} + \sqrt{2(k_L - k_H)(c-a)} + \frac{4k_H(c-a)}{v + 2\sqrt{2(k_L - k_H)(c-a)}}$.*
4. *For $c - a > \max\left\{\frac{v^2}{8k_L}, \frac{2k_L a}{k_H}\right\}$, no separating equilibrium exists.*

Proposition B.3 *For (c, a) that satisfies Assumption 2 and $a < \frac{v^2}{16k_L}$, in the Pareto-dominant pooling equilibrium,*

1. *when $c - a \leq \frac{v^2}{8k_W}$, the manufacturer sets $p_W^* = \frac{v}{2} + \frac{4k_W(c-a)}{v}$ for both types of supplier;*
2. *when $c - a > \frac{v^2}{8k_W}$, the manufacturer does not source from any supplier.*

Corollary B.1 *When the supplier is inefficient, the manufacturer's payoff under POF with symmetric information (Proposition 1 with $k = k_L$) are identical to that under asymmetric information in Region CL, SA, and N in Proposition 3, and her payoff under symmetric information is lower than that under information asymmetric in Region P in Proposition 3.*

In addition, the inefficient supplier's payoff under POF with symmetric information (Proposition 1 with $k = k_L$) is identical to that under POF with asymmetric information in all regions under Assumption 2, except for in Region P where $c - a > \frac{v^2}{8k_L}$. In Region P where $c - a > \frac{v^2}{8k_L}$, the supplier's payoff under asymmetric information is higher than that under symmetric information.

B.2. Proofs of technical results

Proof of Lemma B.1. Assume the supplier chooses to put part of asset $a_C \in [0, a]$ as collateral. Similar to the analysis in Section 3, the supplier's payoff is (2), with a replaced by a_C. Taking the first order condition, the supplier's optimal effort level follows (3), with a replaced by a_C. Anticipating this, the bank sets its interest rate i_B according to (6), also with a replaced by a_C. Substituting e and i_B into (2), we have:

$$\Pi_S = \frac{\left[p + \sqrt{p^2 - 8k(c - a_C)}\right]^2}{16k} - a_C \tag{23}$$

Taking derivative of Π_S with respect to a_C, we have:

$$\frac{\partial \Pi_S}{\partial a_C} = -\frac{1}{4} + \frac{p}{4\sqrt{p^2 - 8k(c - a_C)}} > 0. \tag{24}$$

That is, the supplier's payoff increases in the amount of collateral that he pledges. Therefore, he should set a_C at the maximal level, i.e., $a_C = a$. □

Proof of Proposition B.1. First, from the supplier's perspective, due to limited liability, even with a penalty, the supplier effectively still his asset a if he fails to deliver. Therefore, his acceptance constraint $\Pi_s \geq 0$, or equivalently, $ke^2 - a \geq 0$, remains the same as $e \geq \sqrt{\frac{a}{k}}$. By noting that the manufacturer has the right to claim the penalty p_n (against the supplier's asset value a) from the bank upon failed delivery, the effective value of the supplier's asset is now $(a - p_n)$. Therefore, from the bank's perspective, its break-even constraint becomes $e(1 + i_B)c + (1 - e)(a - p_n) = c$.

Next, by considering (7) and the penalty p_n, we can express p in terms of e so that $p = 2ke + \frac{c - a + (1-e)p_n}{e}$. Substituting this into the manufacturer's payoff $\Pi_M = e(v - p) + (1 - e)p_n$, we have $\Pi_M = ev - 2ke^2 - (c - a)$, which is identical to that without penalty p_n, and p_n does not appear in the equation. In other words, the effect of p_n is completely internalized by the increase in i_B.

Maximizing the above Π_M subject to the supplier's participation constraint $e \geq \sqrt{\frac{a}{k}}$. The optimal e should be $e = \max\left(\frac{v}{4k}, \sqrt{\frac{a}{k}}\right)$. Similarly to the proof in Proposition B.1, we consider two cases:

1. for $a \geq \frac{v^2}{16k}$, $e = \sqrt{\frac{a}{k}}$, $\Pi_M = v\sqrt{\frac{a}{k}} - c - a$. Clearly, $\Pi_M \geq 0$ if and only if $c \leq v\sqrt{\frac{a}{k}} - c - a$ or, equivalently, $a \leq \frac{v^2 - v\sqrt{v^2 - 4kc}}{2k} - c$, which is the same as in Statement 1 in Proposition 1 (Region I in Figure 2).
2. For $a < \frac{v^2}{16k}$, $e = \frac{v}{4k}$, and $\Pi_M = \frac{v^2}{8k} - (c - a)$. Note that $\Pi_M \geq 0$ if and only if $a \geq c - \frac{v^2}{8k}$, which is the same as in Statement 2 in Proposition 1 (Region II in Figure 2).

Combining the two regions above where $\Pi_M < 0$, we can see that for $a < \max\left(c - \frac{v^2}{8k}, \frac{v^2 - v\sqrt{v^2-4kc}}{2k} - c\right)$, the manufacturer does not source from the supplier, which is the same as in Statement 3 in Proposition 1 (Region III in Figure 2). Combining these three conditions, we can see that the manufacturer's payoff under the optimal contract with penalty is no greater than that under Proposition 1.

Finally, note that in the above proof, we ignore the bank lending constraint, as the goal of this proof is that adding a penalty into the contract does not improve the manufacturer's payoff, which we have already shown for the relaxed problem above. Therefore, we do not need to consider the constraint. □

Proof of Proposition B.2. First, consider the scenario where $a \geq \frac{v^2}{16k_L}$. Note that according to Proposition 1, the optimal price offered to the efficient supplier is $p_H^S = \sqrt{\frac{k_H}{a}}(c+a)$ for $a \geq \frac{v^2}{16k_H}$ (Statement 1 of Proposition 1), and $p_H^S = \frac{v}{2} + \frac{4k_H(c-a)}{v}$ for $a \in \left[\frac{v^2}{16k_L}, \frac{v^2}{16k_H}\right]$ (Statement 2 of Proposition 1). It is easy to verify that (p_H^S, p_L^S) satisfies conditions (14) and (15) in Lemma 2. Therefore, $p_H = p_H^S$ corresponds to the separating PBE. In addition, as the manufacturer's payoff under p_H^S is the same as the symmetric information case, separating is costless, and therefore, it corresponds to the least costly separating equilibrium.

Next, consider the case where $a < \frac{v^2}{16k_L}$. First, observe that, as above, $p_H = p_H^S$ does not satisfy (14), i.e. at p_H^S, the manufacturer has the incentive to misrepresent an inefficient supplier as an efficient one. Therefore, p_H must deviate from p_H^S for a separating equilibrium to exist. We consider two further scenarios: First, p_H that is not acceptable to an inefficient supplier even when the bank (mistakenly) believes he is efficient, and second, p_H that is acceptable to an inefficient supplier when the bank (mistakenly) believes he is efficient.

Case 1: When p_H is not acceptable to an inefficient supplier even when the bank (mistakenly) believes he is efficient. Intuitively, if such a p_H is acceptable to an efficient supplier, it serves as a credible signal as the bank knows that such a price is not acceptable to an inefficient supplier under any belief. This intuition is illustrated in Figure 4. By examining (13), we can see that such p_H only exists for $a > c\left(1 + \frac{2k_L}{k_H}\right)^{-1}$. To see this, substitute $\tau = L$ and $\tau' = H$ into the indicator function in (13),

$$p + \sqrt{p^2 - 8k_H(c-a)} \geq 4\sqrt{k_L a}, \tag{25}$$

which is equivalent to $p \geq \sqrt{8k_H(c-a)}$ for $a < c\left(1 + \frac{2k_L}{k_H}\right)^{-1}$ and $p \geq p_{L,H}^{SA}$ for $a \geq c\left(1 + \frac{2k_L}{k_H}\right)^{-1}$. Similarly, substituting $\tau = H$ and $\tau' = H$ into the indicator function in (13), the equation is equivalent to $p \geq \sqrt{8k_H(c-a)}$ for $a < \frac{c}{3}$. Combining the two cases, we note that for $a < c\left(1 + \frac{2k_L}{k_H}\right)^{-1}$, the lowest price acceptable to both the inefficient and efficient suppliers is the same, which is $\sqrt{8k_H(c-a)}$. In other words, there exists no price that is only acceptable to the efficient supplier.

For $a \geq c\left(1 + \frac{2k_L}{k_H}\right)^{-1}$, we can verify that among all p_H that is only acceptable to the efficient supplier and satisfies (14), $p_H = p_{L,H}^{SA} - \epsilon$ achieves the highest payoff for the manufacturer facing an efficient supplier.

In addition, we need to characterize the condition under which $p_H = p_{L,H}^{SA} - \epsilon$ to satisfy (15), i.e. $\Pi_M(H, p_H, H) \geq \max_{p \neq p_H} \Pi_M(H, p, L)$. To do that, note that

$$\max_{p \neq p_H} \Pi_M(H, p, L) = \frac{k_L}{k_H} \Pi_M(H, p_L^S, L) = \frac{p + \sqrt{p^2 - 8k_L(c-a)}}{4k_H}(v-p) = \frac{v^2}{8k_H} - \frac{k_L}{k_H}(c-a), \tag{26}$$

and as $p_H = p^{SA}_{L,H} \equiv 2\sqrt{k_L a} + \frac{k_H(c-a)}{\sqrt{k_L a}}$,

$$\Pi_M(H, p_H, H) = \frac{\sqrt{k_L a}}{k_H}\left(v - 2\sqrt{k_L a} - \frac{k_H(c-a)}{\sqrt{k_L a}}\right) = v\frac{\sqrt{k_L a}}{k_H} - \frac{2k_L a}{k_H} - (c-a). \tag{27}$$

Therefore, $\Pi_M(H, p_H, H) \geq \max_{p\neq p_H} \Pi_M(H, p, L)$ if and only if:

$$v\frac{\sqrt{k_L a}}{k_H} - \frac{2k_L a}{k_H} - (c-a) \geq \frac{v^2}{8k_H} - \frac{k_L}{k_H}(c-a), \tag{28}$$

or equivalently,

$$c - a \leq \frac{(v - 4\sqrt{k_L a})^2}{8(k_L - k_H)}. \tag{29}$$

Combining the above conditions, we can see that among all of the p_H that fall in **Case 1**, $p_H = p^{SA}_{L,H} - \epsilon$ is the only candidate for the least costly separating equilibrium, and it is a candidate if and only if $c - a \in \left(\frac{(v-4\sqrt{k_L a})^2}{8(k_L - k_H)}, \frac{2k_L a}{k_H}\right)$.

Case 2: When p_H is acceptable to an inefficient supplier when the bank (mistakenly) believes he is efficient. When p_H is acceptable to both types of suppliers, for both (14) and (15) to be satisfied, we consider the following two scenarios.

First, when $c-a \leq \frac{v^2}{8k_L}$ (it is profitable to source from the inefficient supplier under symmetric information), substitute the corresponding τ and τ' into (14) and (15), p_H must satisfy:

$$\frac{p_H + \sqrt{p_H^2 - 8k_H(c-a)}}{4k_L}(v - p_H) \leq \frac{v^2}{8k_L} - c - a, \tag{30}$$

$$\frac{p_H + \sqrt{p_H^2 - 8k_H(c-a)}}{4k_H}(v - p_H) \geq \frac{k_L}{k_H}\left(\frac{v^2}{8k_L} - c - a\right), \tag{31}$$

where for both conditions to hold, we must have

$$\frac{p_H + \sqrt{p_H^2 - 8k_H(c-a)}}{4k_L}(v - p_H) = \frac{v^2}{8k_L} - c - a, \tag{32}$$

or equivalently,

$$p_H = \frac{v}{2} + \sqrt{2(k_L - k_H)(c-a)} + \frac{4k_H(c-a)}{v + 2\sqrt{2(k_L - k_H)(c-a)}} \equiv p^{MI}, \tag{33}$$

as stated in the Proposition.

Second, for $c - a > \frac{v^2}{8k_L}$ (it is not profitable to source from the inefficient supplier under symmetric information), as $\Pi_M(L, p^S_L, L) = 0$, such a separating equilibrium does not exist.

Consolidating the above conditions, we can see that among all of the p_H that falls in **Case 2**, $p_H = p^{MI}$ is the only candidate for the least costly separating equilibrium and it is a candidate if and only if $c - a \leq \frac{v^2}{8k_L}$.

Combining the results under **Cases 1** and **2** above, it is easy to verify that, when both $p_H = p^{MI}$ and $p_H = p^{SA}_{L,H} - \epsilon$ are parts of to a separating PBE, $\Pi_M(H, p^{SA}_{L,H} - \epsilon, H) > \Pi_M(H, p^{MI}, H)$, i.e. the PBE with $p_H = p^{SA}_{L,H} - \epsilon$ is the least costly PBE, corresponding to Statement 2 in Proposition B.2. When only $p_H = p^{MI}$ is part of a separating PBE, it corresponds to Statement 3 in Proposition B.2. Finally, when neither forms a PBE, no separating PBE exists, corresponding to Statement 4 in Proposition B.2. □

Proof of Proposition B.3. We consider two scenarios.

First, for $c-a \le \frac{v^2}{8k_W}$ we can verify that p_W^* satisfies (18) in Lemma 3, and hence is part of a pooling PBE. Furthermore, note that $p_W^* = \arg\max_p \Pi_M(\tau, p, W)$ for $\tau = H, L$. Therefore, among all potential pooling prices, p_W^* achieves the highest payoff for the manufacturer and hence corresponds to the Pareto-dominant pooling equilibrium.

Second, for $c-a > \frac{v^2}{8k_W}$, note from (17) that the bank only lends to a supplier that it believes is a weighted-average one if $p_W \ge \sqrt{8k_W(c-a)}$. This means that for $c-a > \frac{v^2}{8k_W}$, $p_W > v$, which is clearly not economical for the manufacturer. Therefore, no pooling equilibrium exists. □

Proof of Corollary B.1. According to Proposition 3, we can see that in Regions CL, SA, and N, the inefficient supplier receives the same contract under symmetric or asymmetric information. Therefore, both the manufacturer's and the supplier's payoffs are identical under the symmetric and asymmetric information case.

Next, in Region P, we can verify that $\Pi_M(L, p_W^*, W) > \Pi_M(L, p_L^S, L)$, and hence, information asymmetry benefits the manufacturer when the supplier is inefficient.

Finally, for the inefficient supplier's payoff under asymmetric information, $\Pi_S(L, p_W^*, W)$, we have:

$$\Pi_S(L, p_W^*, W) = e_L(p_W^*, i_{B,W})[p_W^* - (1+i_{B,W})c] - [1 - e_L(p_W^*, i_{B,W})]a - k_L e_L(p_W^*, i_{B,W})^2 \tag{34}$$

$$= k_L e_L(p_W^*, i_{B,W})^2 - a, \tag{35}$$

where $p_W^* = \frac{v}{2} + \frac{4k_W(c-a)}{v}$, and

$$i_{B,W} = \frac{p_W^* - \sqrt{(p_W^*)^2 - 8k_W(c-a)}}{2c} + \frac{a}{c} - 1, \tag{36}$$

and

$$e_L(p_W^*, i_{B,W}) = \frac{p_W^* - (1+i_{B,W})c + a}{2k_L} = \frac{p_W^* + \sqrt{(p_W^*)^2 - 8k_W(c-a)}}{4k_L} = \frac{v}{4k_L} \tag{37}$$

Substituting these quantities into (34), we have $\Pi_S(L, p_W^*, W) = \frac{v^2}{16k_L} - a$, which equals to the supplier's payoff under the symmetric information case when he can secure financing, i.e., $c - a \le \frac{v^2}{8k_L}$.

On their other hand, for $c-a > \frac{v^2}{8k_L}$ (the right part of Region P), the supplier's payoff is 0 under symmetric information as he cannot secure financing. Thus, his payoff under symmetric information is lower than that under asymmetric information, as desired. □

Appendix C: The impact of the supplier's reservation payoff

In the main body of the paper, for expositional brevity, we have normalized the supplier's reservation payoff to zero. In this Appendix, we relax this assumption by generalizing the supplier's reservation payoff, which is denoted as π_S^o, to be an arbitrary positive number. Aligned with Assumption 1, we make the following technical assumption.

ASSUMPTION 3. $0 \leq a \leq c \leq \frac{v^2}{4k} - \pi_S^o$.

Note that according to Lemma 1, $\frac{v^2}{4k} - c$ is the centralized supply chain's payoff. Clearly, if the supplier's reservation payoff is greater than the chain profit, the supply chain transaction will never occur. In what follows, we show that, after generalizing the supplier's reservation payoff from 0 to a positive value (π_S^o), the main structure in Propositions 1 and 2 continues to hold, and the main insights under the asymmetric information case are expected to hold as well.

C.1. The impact of π_S^o on POF

Similar to the analysis in Section 3, we start with the supplier's payoff function, which is bounded by his reservation payoff π_S^o:

$$\Pi_S = e[p - (1+i_B)c] - (1-e)a - ke^2 \geq \pi_S^o. \tag{38}$$

Facing i_B and p, the supplier solves for the optimal e, which follows:

$$e = \frac{p - (1+i_B)c + a}{2k} \tag{39}$$

which is identical to (3) in Section 3. Substituting this into the supplier's payoff function above, the supplier only accepts the contract when

$$\frac{[p - (1+i_B)c + a]^2}{4k} - a \geq \pi_S^o. \tag{40}$$

or equivalently,

$$p \geq (1+i_B)c - a + 2\sqrt{k(a+\pi_S^o)}. \tag{41}$$

For the bank to break-even, i.e., $e[(1+i_B)c] + (1-e)a = c$, using the equilibrium effort level e, we should have:

$$i_B(p) = \frac{p - \sqrt{p^2 - 8k(c-a)}}{2c} + \frac{a}{c} - 1. \tag{42}$$

which is the same as (6). Thus, (7) also continues to hold. Substituting that into the supplier's acceptance constraint above, we have:

$$p + \sqrt{p^2 - 8k(c-a)} \geq 4\sqrt{k(a+\pi_S^o)}, \tag{43}$$

which is the new *joint acceptance* constraint. The manufacturer's expected payoff subject to the above constraint is:

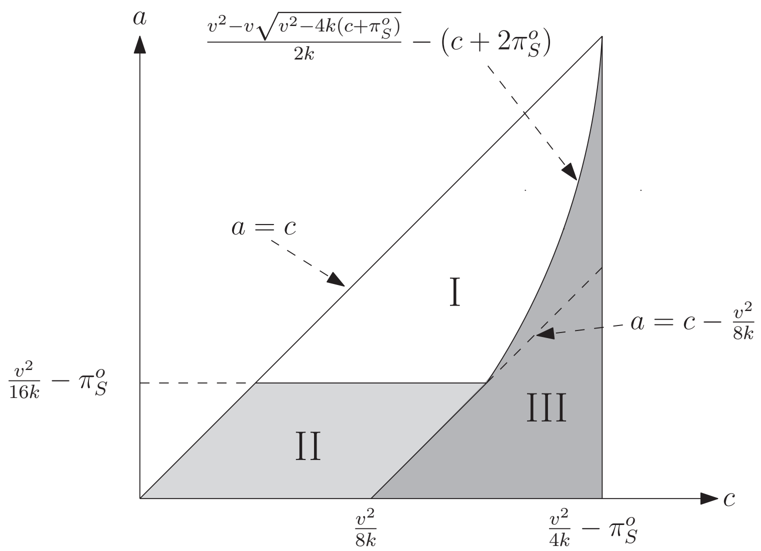
$$\Pi_M = \frac{p + \sqrt{p^2 - 8k(c-a)}}{4k}(v-p) \cdot \mathbb{1}_{\left\{p+\sqrt{p^2-8k(c-a)} \geq 4\sqrt{k(a+\pi_S^o)}\right\}}. \tag{44}$$

By solving for the contract price p that maximizes Π_M, we have the following proposition.

Proposition C.1 *When the supplier's reservation payoff is π_S^o, the optimal sourcing contract p^S under POF and the corresponding equilibrium outcomes are as follows.*

1. *When $a \geq \max\left(\frac{v^2}{16k} - \pi_S^o, \frac{v^2 - v\sqrt{v^2-4k(c+\pi_S^o)}}{2k} - (c+2\pi_S^o)\right)$, the manufacturer offers $p^S = \sqrt{\frac{k}{a+\pi_S^o}}(c+a+2\pi_S^o)$, the bank lends to the supplier at interest rate $i_B^S = \left(\sqrt{\frac{k}{a+\pi_S^o}} - 1\right)\left(\frac{c-a}{c}\right)$, and the equilibrium delivery probability $e^S = \sqrt{\frac{a+\pi_S^o}{k}}$. The manufacturer's payoff is $\Pi_M^S = v\sqrt{\frac{a+\pi_S^o}{k}} - (c+a+2\pi_S^o)$, and the supplier's payoff is $\Pi_S^S = \pi_S^o$.*
2. *When $a \in \left[c - \frac{v^2}{8k}, \frac{v^2}{16k} - \pi_S^o\right]$, the manufacturer offers $p^S = \frac{v}{2} + \frac{4k(c-a)}{v}$, the bank lends to the supplier at interest rate $i_B^S = \left(\frac{4k}{v} - 1\right)\left(\frac{c-a}{c}\right)$, and the equilibrium delivery probability $e^S = \frac{v}{4k}$. Also, $\Pi_M^S = \frac{v^2}{8k} - (c-a)$ and $\Pi_S^S = \frac{v^2}{16k} - a$.*
3. *When $a < \max\left(c - \frac{v^2}{8k}, \frac{v^2 - v\sqrt{v^2-4k(c+\pi_S^o)}}{2k} - (c+2\pi_S^o)\right)$, the manufacturer does not source from the supplier ($p^S = 0$, $i_B^S = \infty$, $e^S = 0$), and $\Pi_M^S = \Pi_S^S = 0$.*

Figure 6 **Illustration of different regions under the optimal POF contract under the supplier's reservation payoff π_S^o.**



Proposition C.1 is illustrated in Figure 6. In comparison, Proposition C.1 (and Figure 6) are analogous to Proposition 1 (and Figure 2). As shown, while the presence of the supplier's reservation payoff π_S^o changes the boundaries of the three regions summarized in the proposition, the relative positions and the economic intuition of these regions remain the same as in Proposition 1. In addition, we can show that the impact of the supplier's operational efficiency, k, which is a focus of our paper, on contract prices and supply chain performance (Corollary 1 in Section 3) continues to hold.

C.2. The impact of π_s^o on BDF

In the presence of a general non-zero supplier reservation profit, the analysis under the BDF scheme is similar to the above, and hence we omit the details in derivation and directly present the results in the following proposition, which is analogous to Proposition 2 in Section 4.

Proposition C.2 *When the supplier's reservation payoff is π_S^o, the optimal sourcing contract (p^B, i_M^B) under BDF and the corresponding equilibrium outcomes are as follows.*

1. *When $a \geq \max\left(\frac{v^2}{16k} - \pi_S^o, \frac{v^2 - v\sqrt{v^2-4k(c+\pi_S^o)}}{2k} - (c+2\pi_S^o)\right)$, (p^B, i_M^B) is optimal if and only if $p^B - (1+i_M^B)c = 2\sqrt{k(a+\pi_S^o)} - a$.*
2. *When $a \in \left[c - \frac{v^2}{8k}, \frac{v^2}{16k} - \pi_S^o\right]$, (p^B, i_M^B) is optimal if and only if $p^B - (1+i_M^B)c = \frac{v}{2} - a$.*
3. *When $a < \max\left(c - \frac{v^2}{8k}, \frac{v^2 - v\sqrt{v^2-4k(c+\pi_S^o)}}{2k} - (c+2\pi_S^o)\right)$, the manufacturer does not source from the supplier ($p^S = 0$, $i_B^S = \infty$, $e^S = 0$), and $\Pi_M^S = \Pi_S^S = 0$.*

For all three cases, the equilibrium delivery probability e^B and the manufacturer's and supplier's payoffs (Π_M^B and Π_S^B) associated with the optimal BDF contract (p^B, i_M^B) are identical to their counterparts under POF, as presented in Proposition C.1.

As shown, the equivalence between POF and BDF in terms of supply chain performance, as well as the additional flexibility under BDF, remains valid in the presence of the general reservation payoff.

C.3. Discussions on the impact of π_s^o under asymmetric information

Combining the above results on the impact of the supplier's reservation payoff π_S^o on POF and the economic rationale behind the signaling results as presented in Section 5, we explain the expected results under signaling with the supplier's reservation payoff π_S^o as follows.

1. When a is high (Region I in Figure 6 for $k = k_L$), facing the contract offered to an efficient supplier, p_H^S, the inefficient supplier's payoff will be lower than his outside option. Thus, in this region, the stable dominant equilibrium under the signaling model should remain to be a costless separating PBE, as shown in Region CL in Figure 3.
2. When a is low but c is also low (Region II in Figure 6 when $k = k_L$), the supply chain performance and the sourcing contract are independent of π_S^o. Therefore, the results in Proposition 3 in Section 5 should continue to hold. Specifically, when a is not very low, the relevant region is SA in Figure 3, i.e., the manufacturer signals the supplier's operational efficiency to the bank at a cost. When a is extremely low, the manufacturer adopts the pooling equilibrium and the bank takes both types of suppliers as the average type (Region P in Figure 3).
3. When a is low and c is high (the right part of Region II in Figure 6 when $k = k_H$), similar to Statement 4 in Proposition 3, the bank is not willing to lend to an "average" supplier and hence POF is not viable – corresponding to Region N in Figure 3.

As explained above, we expect that the main insights highlighted in Section 5 would remain valid when allowing the supplier to have a general reservation payoff.

C.4. Proofs

Proof of Proposition C.1. Similar to the proof of Proposition 1, we prove this result using e as the decision variable (instead of p). First, we express p as a function of e: $p = 2ke + \frac{c-a}{e}$. So the bank lending constraint $p^2 \geq 8k(c-a)$ is always satisfied, and the supplier's participation constraint $p + \sqrt{p^2 - 8k(c-a)} \geq 4\sqrt{k(a+\pi_S^o)}$ becomes:

$$e \geq \sqrt{\frac{a+\pi_S^o}{k}}. \tag{45}$$

The unconstrained optima, on the other hand, is $e = \frac{v}{4k}$. Comparing the two different cases, we can see that the unconstrained optima is only feasible if $\frac{v}{4k} \geq \sqrt{\frac{a+\pi_S^o}{k}}$, or equivalently,

$$a \leq \frac{v^2}{16k} - \pi_S^o. \tag{46}$$

Now consider two cases based on whether the above condition is satisfied (and equivalently, which solution e is relevant).

1. For $a \leq \frac{v^2}{16k} - \pi_S^o$, $e = \frac{v}{4k}$ is relevant. In this region, for $\Pi_M \geq 0$, or equivalently, $p \leq v$, the necessary and sufficient condition is:

$$a \leq c - \frac{v^2}{8k}. \tag{47}$$

2. For $a > \frac{v^2}{16k} - \pi_S^o$, the boundary solution $e = \sqrt{\frac{a+\pi_S^o}{k}}$ is relevant. In this region, $\Pi_M \geq 0$ if and only if:

$$a \leq \frac{v^2 - v\sqrt{v^2 - 4k(c+\pi_S^o)}}{2k} - (c + 2\pi_S^o). \tag{48}$$

Rearranging the above two scenarios leads to the three cases presented in the Proposition. The contract price p^S, interest rate i_B^S, and the payoffs Π_S^S and Π_M^S follow immediately. □

Proof of Proposition C.2. The proof is similar to that of Propositions 2 and C.1, and the details are omitted here. □

Appendix D: The supplier's choice of asset level a in the presence of supplier selection/qualification.

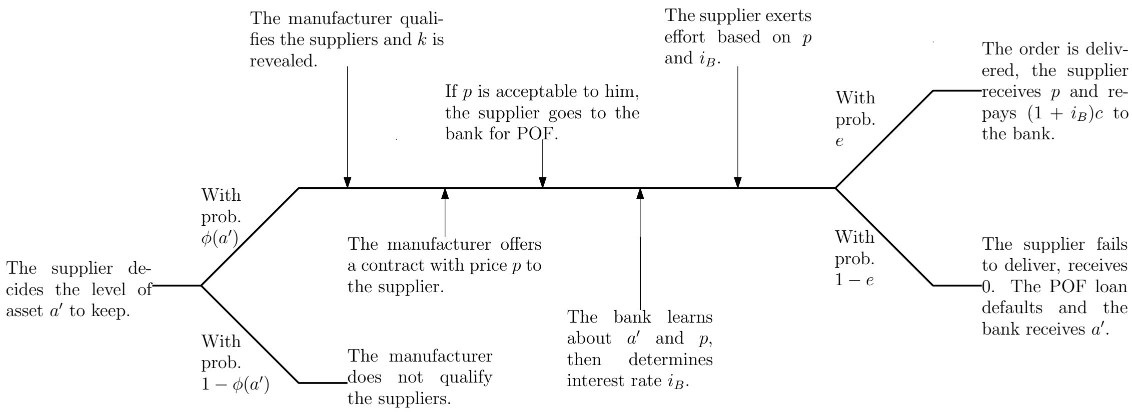
In the main body of the paper, we focus on the contracting game when the manufacturer has already decided to work with the supplier (i.e., the supplier is selected and qualified), and is setting the contract term for a specific purchase order. Consistent with this operational focus, we assume the supplier's asset level a is exogenously given. However, if we extend the scope of the supply chain interaction to a longer horizon, two new decisions may arise.

1. The supplier, with an endowed asset level, may have *the flexibility to adjust his asset level.* In other words, he can choose the level of asset to maintain (and declare) before approaching to the manufacturer.

2. Before the contracting stage, the manufacturer needs to *choose from among multiple suppliers*, and the chosen supplier needs to be *qualified* before entering the contracting stage. The qualification process includes auditing the supplier's operational capability and financial strength.[16] The supplier can only receive a purchase order once he is qualified.

In this appendix, we extend the model in our paper by incorporating both features, and we show that under some reasonable conditions, the supplier has the incentive to maintain (and declare) his entire endowed asset.

Figure 7 Sequence of events under POF when the manufacturer needs to decide the level of asset to maintain.



The sequence of events of the augmented model is illustrated in Figure 7. As shown, in the qualification stage, the supplier with endowed asset level a first decides the level of asset to keep (and declare) before approaching the manufacturer for qualification. Let the asset level he decides to keep be $a' \in [0, a]$. Facing a', the manufacturer qualifies the supplier with probability $\phi(a') \in [0, 1]$. $\phi(a')$ can be seen as a reduced form expression that captures supplier market competition. Once qualified, the supplier is under contractual obligation to maintain this asset level. In addition, as shown in Lemma B.1, knowing a', the manufacturer can use the contract price p to incentivize the supplier to pledge all of his asset as collateral.

Further, in addition to the *monetary* payoff that the supplier receives through the purchase order, i.e., $\Pi_S^S(a)$, which is similar to what is characterized in Proposition 1 or Proposition C.1 (depending on whether

[16] Quality management standard such as ISO 9001 commonly include suppliers' machine details, creditworthiness, etc. as part of supplier audit. See `http://www.iso9001help.co.uk/741.html` as an example.

the supplier's reservation payoff is normalized to zero or not), the supplier may also gains other *non-monetary* benefit by working with the manufacturer, such as reputation, acquiring new technique/knowledge, etc. Let the benefit be $B \geq 0$. Although B does not influence his effort level after entering the contract, it should be taken consideration when the supplier is in the qualification stage. Therefore, when deciding the asset level to maintain before qualification, the supplier solves the following optimization problem:

$$\max_{a' \in [0,a]} \phi(a')[B + \Pi_S^S(a')] \tag{49}$$

Based on our analyses in Section 3 and Appendix C, $\Pi_M^S(a')$ increases in a'. Thus, the manufacturer prefers a supplier with a higher asset level. As such, it is reasonable to assume that $\phi(a')$ increases in a', i.e., the manufacturer is more likely to contract with a supplier with a higher asset level. In essence, this model is similar to Lewis and Sappington (2000), who show that the principal can induce the agents to truthfully reveal their wealth level by assigning a larger probability of being selected to the agent with a higher wealth level.

By analyzing (49), we observe that when $\phi'(\cdot)$ or B is sufficiently large, or when $\Pi_S^S(a')$ does not decrease very quickly in a', it is optimal for the supplier to choose $a' = a$, the highest level of asset available to him. In other words, at the stage that the supplier can decide the asset level to keep, the supplier's expected payoff increases in his kept asset level a', giving him the incentive to maintain an asset level as high as possible. In other words, during the qualification/selection stage, it is in the supplier's interest to maintain and declare his endowed asset level a in order to increase the chance to be selected among competing suppliers.