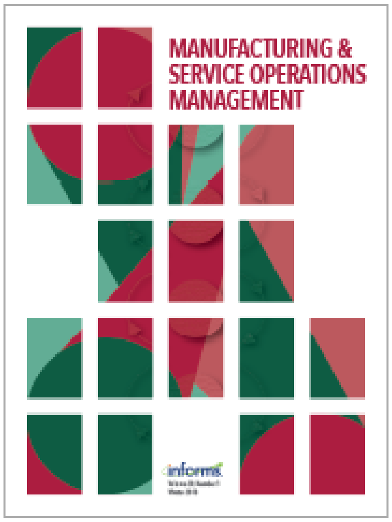

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Operational Investment and Capital Structure Under Asset-Based Lending

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Abstract. *Problem definition*: Banks commonly use asset-based lending (ABL) to provide loans collateralized by a borrower firm's inventory. We study the implications of ABL by examining how banks should determine asset-based loan terms based on firms' operational characteristics (e.g., inventory salvage value and demand uncertainty) and how firms should make inventory stocking and capital structure decisions under asset-based borrowing constraints. *Academic/practical relevance*: Despite its widespread use for lending to small firms and those with large inventory investments, such as retailers, ABL has not been well studied in the literature. *Methodology:* We analyze ABL using a stylized single-period screening game of incomplete information between a business owner and a bank. The bank offers a menu of loans, where each loan offer is characterized by an interest rate and inventory advance rate. The owner then decides the inventory level and the mix of debt and equity with which to finance the firm's operations. Our model captures the practical features of ABL, for example, the bank does not have the full knowledge of the firm's demand prospects, and the inventory advance rate leads to a credit limit that increases in the firm's inventory investment. *Results*: We show that ABL enables the bank to mitigate information asymmetry by screening firms and thereby controlling each firm type's order quantity and leverage. We also obtain hypotheses describing the equilibrium loan contracts, capital structure, inventory investment, and bankruptcy outcomes. For instance, leverage leads to overinvestment resulting from the equity decision being endogenous to the model. Moreover, inventory advance rates are more sensitive to firms' operational characteristics than interest rates. *Managerial implications*: Our study sheds light on the operational and financial implications of ABL by demonstrating how managers should make inventory and capital structure decisions while interacting with asset-based lenders.

Supplemental Material: The online appendix is available at https://doi.org/10.1287/msom.2017.0670.

Keywords: operations–finance interface • inventory management • capital structure • bankruptcy risk • capital market frictions

1. Introduction

We study the problem of a bank providing an asset-based loan to a firm that faces the newsvendor problem. The firm makes an operational investment decision, that is, the amount of inventory to buy to meet random demand, and a capital structure decision, that is, the mix of debt and equity with which to finance its operations. The bank sets the terms of the loan offer under asymmetric information about the demand faced by the firm. This relationship necessitates a number of questions: How does the operational investment of the firm vary with its capital structure? What loan terms should the bank offer to the firm? How is the equilibrium outcome affected by information asymmetry and the operational parameters of the firm, such as its demand uncertainty and price–cost economics? The importance of these questions is well recognized in the literature, but solutions are not readily available in part because this problem falls at the interface of operations management and corporate finance. The models of capital structure in corporate finance typically do not include the details of operational decisions whereas the operations–finance interface models in operations management typically do not include the interaction of a firm with a lender under asymmetric information or endogenous equity decisions. We address these questions in this paper in the context of asset-based lending (ABL), which is a method commonly used by banks to lend money to businesses.

In ABL, a borrower firm offers its current assets, which include its inventory, cash, and account receivables, as collateral for a secured loan. The bank values the current assets and thereby sets loan terms for the firm, which consist of an interest rate and an advance rate for each type of current asset. The advance rate specifies the bank's valuation of the asset as a percentage of its balance sheet value. For instance, a 60% advance rate on inventory means that the bank is willing to lend the firm an amount up to 60% of the procurement cost of its inventory. ABL is useful to banks and borrowers alike. For the bank, it mitigates the cost of information asymmetry by imposing a credit limit and alleviates a problem of incomplete contracting by giving the bank a senior right to foreclose on the firm's assets and liquidate them in a default state (Hart and Moore 1998). Consequently, asset-based loans typically require less monitoring and simpler financial covenants (OCC 2014) and may carry lower interest rates than unsecured loans (Caouette et al. 2011). These features are useful to companies with large current assets, such as retailers. They also make ABL accessible to small businesses, which typically do not have access to cash flow financing availed by large companies with revenues in excess of $25 million and stable profits (Burroughs 2008).

ABL is a large industry. The total amount of outstanding asset-based loans in the United States ranged from $314 to $590 billion during 2000 to 2009 (CFA 2009), which constituted about 25% of the total amount of loans and short-term papers issued to nonfinancial corporations.[1] Asset-based loans secured solely by inventory are common in practice, especially in the retailing industry (Foley et al. 2012; GE Capital 1999, p. 14), which is one of the top three asset-based borrowers (CFA 2009). We provide specific loan examples in Section 3.

Despite its practical usage and dependence on inventory stocking decisions, ABL has not been well studied in the operations literature. A lone exception is Buzacott and Zhang (2004), who introduce ABL to the operations literature by studying two models: a multiperiod deterministic production and inventory model of a cash-constrained firm that uses ABL and a single-period stochastic inventory model in which the firm endowed with a starting equity makes inventory stocking and borrowing decisions under ABL. Our paper builds on Buzacott and Zhang (2004) by introducing two features to fully analyze the implications of ABL. First, we endogenize the firm's equity decision by allowing it to jointly optimize its inventory, debt, and equity. Second, we model the game-theoretic interaction between the bank and the borrowing firm under information asymmetry. This setting enables us to study operational investment and capital structure decisions in the context of ABL.

We set up a single-period game of incomplete information between two players, a business owner and a bank. The bank moves first and offers a menu of loans, where each loan offer is characterized by an interest rate and an inventory advance rate. The business owner then decides the amount of equity to invest in the business owner's new business, chooses a loan offering (if any), and makes a stocking decision to maximize the business owner's expected profit. The business owner sets up the business as a limited liability newsvendor firm, interacts with the bank on its behalf, and manages its operations. The business can be of two types that differ in the distribution of demand and are identical in all other respects. The type of the firm is known to the owner but not to the bank.

Our main results are as follows. First, we find that the two components of the loan terms, interest rate and advance rate, play different roles. Interest rates primarily respond to changes in the owner's opportunity cost of equity and are relatively insensitive to newsvendor model parameters, that is, demand uncertainty and inventory salvage value. In contrast, advance rates are highly sensitive to a firm's operational characteristics. For example, with respect to the salvage value, the average interest rate varies in the range of 10% to 11.2% whereas the average advance rate varies in the range of 45% to 95% in an extensive numerical study. Thus, ABL enables the bank to screen firms and thereby control each firm type's order quantity and leverage. Compared with an alternative lending model in which the bank optimizes the interest rate without imposing an asset-based credit limit, we find that ABL is most beneficial to the bank under more adverse lending conditions, such as a low salvage value or a high demand uncertainty and that ABL leads to a 23% higher expected profit for the bank, greater availability of lending, lower interest rates, and lower bankruptcy probabilities.

Second, the equilibrium order quantity under leverage is always greater than or equal to that under the pure equity solution. Overinvestment results exist in the finance literature as a result of debt holders' inability to prevent equity holders from making risky investment decisions (Myers 2001 and references therein). In contrast, the bank in our model has the ability to prevent overinvestment by offering relatively low inventory advance rates. We find that overinvestment occurs despite this ability because the firm's equity decision is endogenous to the model. The firm's participation constraint allows it to control the amount of equity investment and, in the extreme, to be constituted as a pure equity firm. This forces the bank to offer better loan terms. As a result, leveraged firms overinvest at equilibrium. Furthermore, information asymmetry exacerbates the bank's problem. The bank has to offer more generous loan terms to lower quality (higher demand variance) firms than under full information. As a result, lower quality firms use more leverage and overstock more compared with higher quality firms, leading to a positive association between leverage and overinvestment.

Finally, we demonstrate the effects of demand uncertainty and inventory salvage value on overinvestment, order quantity, leverage, and loan terms. These effects are difficult to predict a priori because they occur through two different mechanisms: the operational decision and the capital structure decision. For example, when the firm's demand uncertainty increases, the bank may offer less attractive loan terms, but the owner may also seek to invest less equity in the firm. Thus, the leverage of the firm may increase or decrease with demand uncertainty. Similar puzzles arise for other metrics of interest, such as the probability of bankruptcy or the loan terms at equilibrium. We resolve these questions and show how the equilibrium values of order quantity, financial leverage, and probability of bankruptcy vary *across* the two firm types as well as *within* a firm type as the operational characteristics of the firm change. These results emphasize the effects of operational characteristics on capital structure and financial distress in the context of ABL and lead to new cross-sectional and longitudinal hypotheses on the operations–finance interface that may be examined in future research.

It is important to note that we analyze a stylized model with specific assumptions. In particular, we assume a single-period interaction whereas, in practice, ABL may involve a multi-period relationship between a firm and a bank. We also assume that the bank moves first and determines loan terms by inferring the firm's best response from its demand type. However, banks in practice typically determine loan terms based on the liquidity and quality of existing inventory collateral. Thus, future researchers may change the sequence of moves or model the multi-period relationship between the counterparts to study ABL from perspectives not captured in our model.

2. Literature Review

Models of capital structure in corporate finance have focused on the implications of market frictions, such as interest rate spread, taxation, costly bankruptcy, and liquidity constraints, on the existence of an optimal capital structure (e.g., Modigliani and Miller 1963, Kraus and Litzenberger 1973, Gordon 1989) and the occurrence of a financing hierarchy under incomplete information (Jensen and Meckling 1976, Myers 1984, Myers and Majluf 1984, Childs et al. 2005). The recent literature in corporate finance has made further advancements quantifying the impact of operational characteristics of firms on their capital structure through empirical evidence (for example, see Banerjee et al. 2008 and Rauh and Sufi 2012; extensive reviews of the literature on capital structure are conducted by Harris and Raviv 1991 and Graham and Leary 2011).

While capital structure is affected by operational characteristics, the opposite link also exists as capital structure choice may affect a firm's operational investment decisions. Stiglitz and Weiss (1981) show that bank credit may be rationed at equilibrium because of asymmetric information and that higher interest rates induce firms to undertake riskier projects. Hart and Moore (1998) show the optimality of debt financing in situations of incomplete contractibility. The analytical models in corporate finance generate mixed predictions regarding the relationship between debt financing and investment. Among early studies, Hite (1977) analyzes a setting in which debt is proportional to investment and finds a positive relationship between leverage and investment. Hite's finding is driven by the absence of default risk in his model. Dotan and Ravid (1985) show that introducing bankruptcy risk and treating debt as an additional decision variable reverse Hite's findings. In their model, an increase in debt increases the cost of capital resulting from bankruptcy risk. As a result, investment decreases in leverage.

More generally, two opposing forces influence the relationship between investment and leverage. On the one hand, firms with high leverage may forgo profitable investment opportunities because of equity holders' unwillingness to share the benefits of an investment with debt holders. On the other hand, limited liability enables equity holders to shift the downside risk of an investment to debt holders and thereby incentivizes equity holders to invest in riskier projects. Thus, debt financing may lead to underinvestment resulting from the debt overhang problem (Myers 1977) or overinvestment because of risk shifting (Jensen and Meckling 1976). See Myers (2001), Childs et al. (2005) and references therein for the finance literature on the relationship between investment and leverage.

The operations management literature has begun to address the implications of financial considerations and market imperfections on operational decisions. This is a relatively new but growing area of research. Xu and Birge (2004) investigate the trade-off between bankruptcy costs and the tax benefits of debt for a cash-constrained newsvendor endowed with exogenous equity. Their analysis shows that integrating operational and financial decisions can improve firm value. Buzacott and Zhang (2004) develop a framework to study the optimal stocking decisions of a firm when it has access to an asset-based loan. The single-period model in their paper is relevant to our work. It analyzes the order quantity and borrowing amount for a profit-maximizing newsvendor under ABL and bankruptcy risk; equity is assumed to be exogenous, the interest rate is fixed, and there is no information asymmetry between the bank and the firm. Dada and Hu (2008) examine the game-theoretic interaction between a bank and a firm using a similar framework with the difference that the bank chooses an optimal interest rate instead of imposing a credit limit.

Besides single-period models, there has been research on multi-period models to derive optimal inventory policies under financial considerations. Hu and Sobel (2005) study a firm that can use short-term borrowing at a fixed interest rate in the presence of corporate taxes and costly reorganization bankruptcy. They find that the firm's capital structure is either pure debt or pure equity, depending on model parameters. Similarly, Chao et al. (2008) analyze a self-financing (pure equity) firm that faces cash flow constraints. Finally, Li et al. (2013) show that the joint optimization of inventory and financing decisions leads to a financing hierarchy in which the firm uses internal funds before raising external funds. Whereas the firm is typically endowed with a fixed equity in single-period models, the issuance of dividends and equity have been included as endogenous decisions in most multi-period inventory models.

Research on the impact of financial considerations on operational decisions is not limited to inventory models. Financial constraints and the risk of bankruptcy also affect the firm's survival strategy (Archibald et al. 2002), relations with its supply chain partners (e.g., Babich 2010, Yang and Birge 2011, Kouvelis and Zhao 2012), the choice of production technologies (e.g., Boyabatli and Toktay 2011, Chod and Zhou 2014), the optimal time to shut down a firm (Xu and Birge 2006), and the optimal time to offer an IPO (Babich and Sobel 2004). Our paper is also methodologically related to recent research in supply chain management that has dealt with mechanism design models aiming to mitigate the cost of information asymmetry for the less informed party. See, for instance, Ha (2001), Yang et al. (2009), and Babich et al. (2012).

The operations–finance interface literature also generates predictions regarding the impact of debt financing on operational investment. When a newsvendor firm's starting equity is fixed, borrowing from a profit-maximizing bank leads to an order quantity that is less than the classical newsvendor solution (Buzacott and Zhang 2004, Dada and Hu 2008). An alternative form of debt financing, trade credit, can be more attractive than bank loans because trade credit can improve supply chain coordination by creating a risk-sharing mechanism between a supplier and a buyer. As a result, increasing leverage via trade credit can lead to higher stocking quantities (Yang and Birge 2011, Kouvelis and Zhao 2012). More recently, Chod (2017) shows that bank financing distorts a firm's inventory mix because of risk shifting, and trade credit mitigates this distortion.

Despite enhancing our understanding of capital structure, the corporate finance literature typically does not include the details of operational characteristics, decisions, and their implications for financing. As a result, it is difficult to gain operational insights from the corporate finance literature. In contrast, the operations–finance interface literature provides insights into the impact of financial constraints on operational decisions, but limited work has been done on the practice of ABL. Moreover, the single-period models in this literature typically assume exogenous equity and full information whereas the multi-period models do not consider a firm's game-theoretic interactions with lenders. Our model contributes to the operations management literature by studying these factors and demonstrating the benefits of ABL.

3. Model

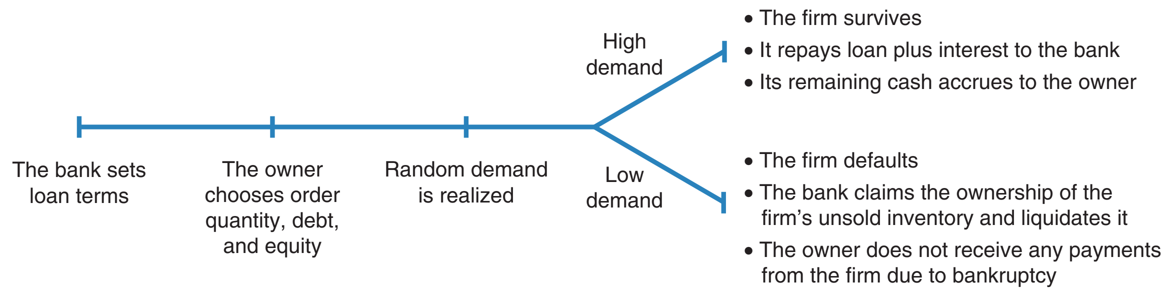
We analyze a single-period screening game with two players, a business owner and a commercial bank. The business is modeled as a newsvendor firm, which is a price taker in its product market and stocks inventory to serve random demand. Let c denote its per unit procurement cost, s the salvage value, p the selling price, q the quantity of inventory procured, and ξ the random demand. The owner maximizes the owner's expected profit by making three related decisions: how much equity and debt to have in the firm and what stocking quantity to purchase. The first two constitute the capital structure of the firm and the third its operational investment.

The owner establishes the newsvendor firm with limited liability, which means that the owner and the firm are separate legal personalities as per corporate law, and the owner's loss is limited to the amount of equity if the firm defaults on the loan. However, since the owner makes the stocking and borrowing decisions for the firm, their objectives are aligned. We use the terms newsvendor and firm interchangeably.

The firm can be of two types denoted $i = 1, 2$ that differ in the distribution of demand and are identical in all other respects. Let $\lambda \in [0, 1]$ and $1 - \lambda$ denote the probability that the firm is of types 1 and 2, respectively. We focus on a relatively common asymmetric information framework in which firm type is known to the owner but not to the bank. All other model parameters are common knowledge because they can be credibly communicated to the bank whereas the demand forecast cannot be. For instance, the bank can learn the firm's cost parameters and order quantity by auditing the firm's financial statements and operations. The demand for each firm type is nonnegative and follows a continuous probability distribution with increasing failure rate (IFR). The pdf, cdf, complementary cdf (ccdf), and inverse ccdf of the demand distribution for firm type i are denoted as f_i, F_i, $\bar{F}_i$, and $\bar{F}_i^{-1}$, respectively, where f_i is positive on an interval and zero elsewhere.

Figure 1 shows the sequence of events. The bank moves first and offers a menu of loans $\{(\alpha_i, \gamma_i)\}_{i=1,2}$ to the firm. Each loan offer in the menu is specified by an interest rate α and a credit limit $\gamma c q$, where $\gamma \in [0, 1]$ is called the inventory advance rate, and cq is the firm's cost of procuring inventory q. Then the owner selects a loan offer (or chooses not to borrow) and determines the equity, the debt, and the order quantity of the firm. Then random demand is realized. If the firm's realized

Figure 1. (Color online) Sequence of Events for the Screening Game Played Between a Newsvendor Business Owner and an Asset-Based Lender



demand is sufficiently high for it to avoid bankruptcy, then it salvages the excess inventory (if any), repays the loan plus interest to the bank, and the remaining (ending) cash accrues to the owner. Otherwise, the bank initiates bankruptcy proceedings against the firm and gains possession of its cash and unsold inventory. The bank liquidates the firm's unsold inventory to compensate for its losses. The owner does not receive any payments from the firm because of bankruptcy.

Some assumptions in our model require justification. First, *we set up a single-period model* whereas ABL in practice may involve multi-period interactions between the counterparts. A single-period model enables us to study the game-theoretic interactions between operational and capital structure decisions while avoiding additional considerations required in a multi-period model, such as dividends, a revolving line of credit, and bankruptcy reorganization. Second, similar to Buzacott and Zhang (2004), *we assume that the bank is a monopoly*. The financial economics literature shows that the bank's market power, ranging from monopoly (typically faced by young and small firms) to perfect competition (typically faced by large firms), may affect firms' access to debt financing (see Petersen and Rajan 1995 for a seminal study and Guzman 2000 for an overview of this literature). Treating the bank as a monopoly implies that our model is more applicable to small firms that typically do not have access to competitive lending. The operations–finance interface literature has both monopoly (e.g., Dada and Hu 2008) and competitive (e.g., Xu and Birge 2004) lending models. Accordingly, we show the robustness of our findings with respect to lending market competition by studying an alternative lending model in Section B in the online appendix.

Third, *we assume that the bank moves first*. Borrower–lender interactions under information asymmetry can be modeled with either the bank or the firm moving first. We model a screening game to examine how the bank can use ABL to mitigate information asymmetry by designing a menu of loan offers based on demand types. If, instead, the firm were to move first, then we would have a signaling game wherein the firm would use its inventory and equity decisions as signals of its true type to the bank, and the bank would set the interest rate and advance rate based on those signals. Such a lending model can be studied in future research to examine pooling and separating equilibria under ABL.

Finally, *we assume that each loan offer consists of two terms, α and γ, and is collateralized by inventory*. In practice, banks may include more loan conditions, such as an absolute cap on the total amount of loan given. Nevertheless, interest rate and inventory advance rate (or an inventory-based credit limit) are the most interesting and prevalent features of inventory-based loan contracts in practice. For example, in 2011, Dick's Sporting Goods had a $440 million credit line at the prime interest rate secured solely by inventory with an advance rate of "the lesser of 70% of eligible inventory [at cost] or 85% of liquidation value of inventory." Dillard's had a $1 billion credit line, J.C. Penney $1.25 billion, Neiman Marcus $700 million, and Saks $500 million (Foley et al. 2012). See Buzacott and Zhang (2004), Foley et al. (2012), and OCC (2014) for more contract examples. Because increasing the number of model parameters would complicate our model without changing the essence of borrower–lender interactions, we focus on a set of contracts specified as (α, γ) pairs.

Collateralizing the loan gives the bank the legal right to possess and salvage the firm's inventory in a default event. A good illustration of the usefulness of salvaging inventory in ABL is provided by the bankruptcy filing and the subsequent inventory liquidation of the Borders Group, Inc. Borders obtained an asset-based loan of $700 million in April 2010 from a consortium of lenders (*Business Wire* 2010). After its Chapter 11 bankruptcy protection in February 2011 and Chapter 7 liquidation in July 2011, Gordon Brothers Group and Hilco Merchant Resources sold Borders' inventories at 40% to 60% discounts (Krug 2011). Our model mimics this possibility because offering an asset-based loan allows the bank to claim the ownership of the firm's unsold inventory and liquidate it in case the firm defaults. Foley et al. (2012) describe many such examples of ABL. The lender bank in ABL has the senior-most claim over the secured assets of the firm, and the claims of other lenders (e.g., unsecured lenders or suppliers) are junior to it.

Since the game is sequential, we solve it by backward induction. In Section 3.1, we suppress the firm subscript i for ease of notation and characterize the firm owner's best response to a generic loan offer, (α, γ). In Section 3.2, we study the bank's problem.

3.1. The Business Owner's Problem

Let x and w denote the amount of equity and debt of the newsvendor, respectively. To formulate the business owner's problem, we write the ending cash position of the newsvendor as

$$\pi(q, x, w, \xi) = \big(x + w - cq + p\min\{q, \xi\} + s(q-\xi)^+ - (1+\alpha)w\big)^+, \qquad (1)$$

where $(\cdot)^+ \equiv \max\{\cdot, 0\}$. Here, α denotes the interest rate charged by the bank on the loan. If the demand ξ is sufficiently large, the firm repays the loan plus interest, $(1+\alpha)w$, to the bank and its *ending cash position* accrues to the owner. Otherwise, it files for bankruptcy liquidation, and its cash and inventory are possessed by the bank. Note that the firm's ending cash position $\pi(q, w, x, \xi)$ is always nonnegative because of limited liability.

The owner decides how to allocate the owner's available wealth between the newsvendor firm and other potential investments. Thus, the owner has an opportunity cost for the owner's equity investment in the newsvendor firm because investing x in the firm implies giving up the expected return of x from alternative investment opportunities available in the market. Accordingly, we treat the opportunity cost as an exogenous constant and call it as the hurdle rate. With this, we solve the following owner's problem as a function of loan terms α and γ:

$$\Pi^*(\alpha, \gamma) \equiv \max_{(q,x,w)\in\mathbb{C}'} \big\{E_F[\pi(q, x, w, \xi)] - (1+\bar{\alpha}_m)x\big\}, \qquad (2)$$

$$\text{where} \quad \mathbb{C}' \equiv \big\{(q, x, w)\colon cq \le x + w, w \le \gamma cq, q \ge 0, x \ge 0, w \ge 0\big\}. \qquad (3)$$

Here, E_F denotes expectation with respect to the demand distribution, and $\bar{\alpha}_m \ge 0$ denotes the hurdle rate.

The owner can, in general, make the owner's decision using a hurdle rate, a net present value (NPV) computed with respect to the capital asset pricing model (CAPM), an internal rate of return (IRR), payback period, or accounting rates of return. Graham and Harvey (2001) conduct a survey of chief financial officers of firms and find that hurdle rate, NPV, and IRR are the three most frequently used evaluation methods in practice with NPV being favored by large firms and hurdle rate by small firms. Our exogenous hurdle rate assumption is similar to Chod and Zhou's (2014) exogenous cost of equity assumption in a setting where the firm makes capacity choice (dedicated versus flexible) and capital structure decisions. Alternatively, modeling the owner's cost of equity via CAPM makes $\bar{\alpha}_m$ a function of the covariance between the firm's cash flows and the market portfolio return, which in turn is a function of the firm's actions (Birge 2015). This endogenizes the cost of equity and makes the model intractable. We leave the analysis of this more complex consideration for future research.

For the newsvendor problem to be nontrivial, we assume that $p > (1+\bar{\alpha}_m)c$, $p > (1+\alpha)c$, and $c > s$. $\mathbb{C}'$ in (3) defines the feasible region for this problem, in which the first constraint specifies that the cost of procurement must be less than the starting cash available (i.e., debt plus equity) to the firm, the second constraint limits the borrowing amount w to the asset-based credit limit γcq set by the bank, and the remaining constraints ensure that the firm starts its operations with nonnegative inventory, equity, and debt.

The problem (2) and (3) is a constrained nonlinear optimization problem. It is not concave because of the imposition of limited liability. In Proposition 1, we solve this problem using the KKT conditions and show that it admits up to two local maxima. For this, we first note that the firm will never borrow and hold cash because of the interest levied on the loan. Moreover, the firm will not hold unused equity as cash because of the nonnegative hurdle rate, $\bar{\alpha}_m$. Therefore, the constraint $cq \le x + w$ will be binding in the firm's optimal solution. Substituting $x = cq - w$ into the problem formulation, we obtain an optimization problem in two dimensions, q and w, as follows:

$$\Pi^*(\alpha, \gamma) = \max_{(q,w)\in\mathbb{C}} \big\{E_F[\pi(q, cq - w, w, \xi)] - (1+\bar{\alpha}_m)(cq - w)\big\}, \qquad (4)$$

$$\text{where} \quad \mathbb{C} \equiv \big\{(q, w)\colon 0 \le w \le \gamma cq\big\}. \qquad (5)$$

We simplify the objective function of this problem under various conditions. There can be two possible capital structure outcomes based on the inventory procurement cost, cq, and the borrowing amount, w. In the pure equity (PE) scenario, the newsvendor does not borrow any money from the bank and finances its inventory investment with equity. In the debt-equity mix (DE) scenario, the newsvendor uses a mix of debt and equity to finance its inventory investment. We characterize the newsvendor's expected ending cash position in each scenario.

3.1.1. Pure Equity. This scenario occurs when the constraint $w \ge 0$ is binding. Setting $w = 0$ in (4) and (5) reveals that the owner's problem reduces to a traditional newsvendor problem in which the procurement cost per unit is $(1+\bar{\alpha}_m)c$. Let $\mathbb{C}^{\mathrm{PE}} \equiv \{(q, w)\colon w = 0, q \ge 0\}$. The owner solves

$$\Pi^{\mathrm{PE}} \equiv \max_{q\in\mathbb{C}^{\mathrm{PE}}} (p - s)\int_0^q \bar{F}(\xi)\,d\xi - [(1+\bar{\alpha}_m)c - s]q. \qquad (6)$$

3.1.2. Debt–Equity Mix. This scenario occurs when $w \geq 0$ is nonbinding so that the newsvendor finances its inventory investment with a mix of debt and equity. The owner's objective function under DE can be written as

$$\pi^{\mathrm{DE}}(q, cq-w, w, \xi) = \left(p\min\{q,\xi\} + s(q-\xi)^+ - (1+\alpha)w\right)^+. \quad (7)$$

In this scenario, for each (q, w), there is a threshold value of demand below which the firm is unable to repay the loan and interest in full. Let d_B denote this threshold. Setting $\pi^{\mathrm{DE}}(q, cq-w, w, d_B)$ equal to zero in (7) and rearranging terms give

$$d_B(q,w) = \frac{[(1+\alpha)w - sq]^+}{p-s}. \quad (8)$$

This threshold implies that the firm survives with probability one if it does not borrow or if the borrowing amount is smaller than $(s/(1+\alpha))q$. Otherwise, that is, when $w > (s/(1+\alpha))q$, the firm has nonzero probability of bankruptcy. If $w \leq (s/(1+\alpha))q$, then the firm's ending cash position is

$$\pi^{\mathrm{DE}}\left(q, cq-w, w, \xi \,\middle|\, 0 < w \leq \frac{s}{1+\alpha}q\right) = (p-s)\min\{q,\xi\} + sq - (1+\alpha)w. \quad (9)$$

If $w > (s/(1+\alpha))q$, then there are two scenarios. If the realized demand is less than d_B, then the firm declares bankruptcy. If the realized demand exceeds d_B, then the firm survives and repays the loan plus interest to the bank. Thus, for $w > (s/(1+\alpha))q$, we have

$$\begin{aligned}\pi^{\mathrm{DE}}\left(q, cq-w, w, \xi \,\middle|\, w > \frac{s}{1+\alpha}q\right) &= ((p-s)\min\{q,\xi\} + sq - (1+\alpha)w)^+ \quad (10)\\ &= (p-s)(\min\{q,\xi\} - \min\{d_B(q,w),\xi\}), \quad (11)\end{aligned}$$

which equals zero when $\xi \leq d_B$ and (9) otherwise. Taking expectation of (9) and (11) gives

$$E_F[\pi^{\mathrm{DE}}(q, cq-w, w, \xi)] = \begin{cases} (p-s)\displaystyle\int_0^q \bar{F}(\xi)\,d\xi + sq - (1+\alpha)w, & \text{if } 0 < w \leq \dfrac{s}{1+\alpha}q, \\ (p-s)\displaystyle\int_{d_B(q,w)}^q \bar{F}(\xi)\,d\xi, & \text{if } w > \dfrac{s}{1+\alpha}q. \end{cases} \quad (12)$$

The same expectation can be concisely written as

$$E_F[\pi^{\mathrm{DE}}(q, cq-w, w, \xi)] = (p-s)\int_{d_B(q,w)}^q \bar{F}(\xi)\,d\xi + [sq - (1+\alpha)w]^+. \quad (13)$$

Let $\mathbb{C}^{\mathrm{DE}} \equiv \{(q,w)\colon 0 < w \leq \gamma cq\}$ denote the constraint set that ensures a debt–equity mix. Then, the owner's problem under DE can be written as

$$\Pi^{\mathrm{DE}}(\alpha,\gamma) \equiv \max_{(q,w)\in\mathbb{C}^{\mathrm{DE}}} \left\{(p-s)\int_{d_B(q,w)}^q \bar{F}(\xi)\,d\xi + [sq-(1+\alpha)w]^+ - (1+\bar{\alpha}_m)(cq-w)\right\}. \quad (14)$$

3.1.3. Reformulation and Solution of the Owner's Problem. The constraint sets of the PE and DE scenarios are mutually exclusive and exhaustive subsets of the firm's constrained set $\mathbb{C}$. Further, the objective function of the DE scenario is a generalization of the objective function of the PE scenario. These properties allow us to write the owner's problem as follows:

$$\Pi^*(\alpha,\gamma) = \max_{(q,w)\in\mathbb{C}} \left\{(p-s)\int_{d_B(q,w)}^q \bar{F}(\xi)\,d\xi + [sq-(1+\alpha)w]^+ - (1+\bar{\alpha}_m)(cq-w)\right\}. \quad (15)$$

To see how the PE scenario is subsumed in (15), note that setting $w = 0$ in (15) leads to $d_B(q, 0) = 0$, which in turn leads to the objective function of a pure equity firm specified in (6). Thus, solving (15) is sufficient to find the owner's best response to a loan offer. Having determined the objective function under different binding constraints, we can now show in Proposition 1 that the owner's objective function has at most two local maxima. All proofs are presented in the online appendix.

Proposition 1. *Let q^{PE}, and q^{DE} be the order quantities defined by*

$$q^{\mathrm{PE}} = \bar{F}^{-1}\left(\frac{(1+\bar{\alpha}_m)c - s}{p-s}\right), \quad (16)$$

$$q^{\mathrm{DE}} = \begin{cases} \bar{F}^{-1}\left(\dfrac{[1+\gamma\alpha+(1-\gamma)\bar{\alpha}_m]c - s}{p-s}\right), & \text{if } 0 \leq \gamma \leq \dfrac{s}{(1+\alpha)c}, \\ \bar{F}^{-1}\left(\dfrac{(1+\alpha)\gamma c - s}{p-s}\bar{F}\left(\dfrac{(1+\alpha)\gamma c - s}{p-s}q^{\mathrm{DE}}\right) + \dfrac{(1+\bar{\alpha}_m)(1-\gamma)c}{p-s}\right), & \text{if } \dfrac{s}{(1+\alpha)c} < \gamma \leq 1. \end{cases} \quad (17)$$

The owner's objective function defined in (15) attains up to two local maxima. First, $(q,w) = (q^{\mathrm{PE}}, 0)$ is a local maximum if and only if $\alpha \geq \bar{\alpha}_m$. Second, $(q,w) = (q^{\mathrm{DE}}, \gamma cq^{\mathrm{DE}})$ is a local maximum if and only if $(1+\bar{\alpha}_m)/(1+\alpha) \geq \bar{F}((([(1+\alpha)\gamma c - s]^+)/(p-s))q^{\mathrm{DE}})$, which holds trivially for $\alpha \leq \bar{\alpha}_m$.

In Proposition 1, q^{PE} and q^{DE} are the optimal order quantities in the pure equity and debt–equity mix scenarios, respectively. The owner's inventory stocking decision deviates from the classical newsvendor solution because of adjustments to the overage and underage costs. For instance, when a firm borrows with risk, that is, $\gamma > s/((1+\alpha)c)$, it finances $100\gamma\%$ of its purchase via debt and the rest via equity. Then the underage cost equals $p - [\gamma(1+\alpha) + (1-\gamma)(1+\bar{\alpha}_m)]c$, which captures the effect of the firm's capital structure choice on its procurement cost. The overage cost depends on survival. If the firm survives, buying an extra unit that is eventually salvaged costs $[\gamma(1+\alpha) + (1-\gamma)(1+\bar{\alpha}_m)]c - s$. If it defaults, then buying an extra unit that is eventually liquidated by the bank costs $(1-\gamma)(1+\bar{\alpha}_m)c$ because the firm is not obligated to repay $\gamma(1+\alpha)c$ to the bank because of bankruptcy, but it also forgoes the opportunity to salvage that unit. Thus, the firm's optimal order quantity solves

$$\begin{aligned}&\{p - [\gamma(1+\alpha) + (1-\gamma)(1+\bar{\alpha}_m)]c\}\bar{F}(q)\\ &\quad - (1-\gamma)(1+\bar{\alpha}_m)cF(d_B(q,\gamma c q))\\ &\quad - \{[\gamma(1+\alpha) + (1-\gamma)(1+\bar{\alpha}_m)]c - s\}\\ &\quad \cdot [\bar{F}(d_B(q,\gamma c q)) - \bar{F}(q)] = 0. \end{aligned} \tag{18}$$

Rearranging terms leads to q^{DE} formulated in (17). In fact, (18) can be intuitively written as

$$\begin{aligned}\bar{F}(q) = &\frac{[1+\gamma\alpha + (1-\gamma)\bar{\alpha}_m]c - s}{p-s} - \frac{(1+\alpha)\gamma c - s}{p-s}\\ &\times \Pr(\text{Bankruptcy}),\end{aligned} \tag{19}$$

where the probability of bankruptcy Pr(Bankruptcy) is a function of q. The same intuition also applies to (16) as setting $\gamma = 0$ (i.e., no borrowing) in (19) leads to the pure equity order quantity.

One of the local maxima identified in Proposition 1 must be the optimal solution for the owner. We find that the pure equity solution, $(q^{\mathrm{PE}}, 0)$, cannot be optimal when $\alpha < \bar{\alpha}_m$ because the firm's profit is increasing in w when $\alpha < \bar{\alpha}_m$. Intuitively, this result arises because a low interest rate allows the firm to lower its cost of capital, which makes it optimal for the firm to borrow. Thus, there is a single local maximum when $\alpha < \bar{\alpha}_m$, and the firm finances its inventory investment with a mix of debt and equity. The optimal solution is more complicated when $\alpha \geq \bar{\alpha}_m$ because there can be two local maxima. Whether the firm borrows or relies on pure equity depends on the costs and benefits of borrowing. On one hand, borrowing increases the firm's cost of capital, but on the other hand, it allows the owner to share the owner's risk with the bank. In Lemmas 1 and 2, we exploit the monotonicity properties of the owner's objective function to characterize the firm's best response to a loan offer when $\alpha \geq \bar{\alpha}_m$. Lemma 1 provides a threshold value of α above which the firm always chooses the pure equity solution because the interest rate is prohibitively high.

Lemma 1. (i) *There exists a unique interest rate threshold $\bar{\alpha}$ that solves the equation $\Pi^{\mathrm{DE}}(\bar{\alpha},1) = \Pi^{\mathrm{PE}}$, where Π^{PE} and $\Pi^{\mathrm{DE}}(\bar{\alpha},1)$ are defined in* (6) *and* (14), *respectively.* (ii) *The threshold value $\bar{\alpha}$ is greater than or equal to $\bar{\alpha}_m$.* (iii) *If the bank sets the interest rate higher than $\bar{\alpha}$, then the pure equity solution, $(q,w) = (q^{\mathrm{PE}},0)$, is optimal for the firm regardless of the inventory advance rate, γ.*

To interpret Lemma 1, we first note that, for a given interest rate, the owner's optimal expected profit is nondecreasing in γ because increasing γ expands the feasible region of the owner's problem. Thus, for a given α, the owner desires to have $\gamma = 1$. On the contrary, the owner's optimal expected profit decreases in α for a given γ, so the owner desires a low interest rate. In Lemma 1, $\bar{\alpha}$ represents the interest rate at which the firm owner is indifferent between creating a pure equity firm and a pure debt firm when $\gamma = 1$. Consequently, any interest rate that is above $\bar{\alpha}$ is prohibitively high, which forces the owner to create a pure equity firm.

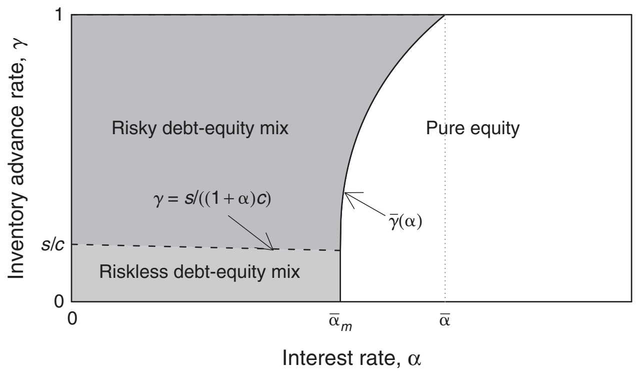
So far, we have shown that the firm owner chooses to borrow when the interest rate is low (i.e., when $\alpha \leq \bar{\alpha}_m$) and avoids borrowing when the interest rate is high (i.e., when $\alpha > \bar{\alpha}$). What happens when $\alpha \in [\bar{\alpha}_m, \bar{\alpha}]$? The owner's capital structure choice depends on the advance rate γ. In particular, for any $\alpha \in [\bar{\alpha}_m, \bar{\alpha}]$, there exists a threshold $\bar{\gamma}(\alpha)$ value above (below) which the firm uses (avoids) leverage. This result is formalized in the following lemma.

Lemma 2. (i) *For $\alpha \in [\bar{\alpha}_m, \bar{\alpha}]$, there exists a unique advance rate $\bar{\gamma}(\alpha)$ that solves the equation $\Pi^{DE}(\alpha,\gamma) = \Pi^{PE}$, where Π^{PE} and Π^{DE} are defined in* (6) *and* (14), *respectively.* (ii) *$\bar{\gamma}(\alpha)$ increases in $\alpha \in [\bar{\alpha}_m, \bar{\alpha}]$ with $\bar{\gamma}(\bar{\alpha}_m) = s/((1+\bar{\alpha}_m)c)$ and $\bar{\gamma}(\bar{\alpha}) = 1$.* (iii) *For $\alpha \in [\bar{\alpha}_m, \bar{\alpha}]$, the owner borrows when $\gamma \geq \bar{\gamma}(\alpha)$ and creates a pure equity firm when $\gamma < \bar{\gamma}(\alpha)$.*

In words, Lemma 2 shows that for intermediate values of α (i.e., when $\alpha \in [\bar{\alpha}_m, \bar{\alpha}]$), the advance rate of inventory should be sufficiently large to entice the firm to borrow. In fact, the threshold advance rate of inventory above which the firm borrows increases in the interest rate. This is so because if the interest rate increases without a compensating increase in the credit limit, the firm eventually switches to the pure equity solution.

Integrating Lemmas 1 and 2, Figure 2 depicts the owner's optimal capital structure as a function of the interest rate, α, and the inventory advance rate, γ. Note that the capital structure can be of different forms: pure debt, which can take place only when $\gamma = 1$; debt–equity mix; or pure equity. Moreover, borrowing may or may not entail bankruptcy risk depending on the

Figure 2. The Owner's Capital Structure Choice as a Function of α and γ



Notes. We generate this figure using the following model parameters: $p = 2.5$, $c = 1$, $s = 0.2$, $\bar{\alpha}_m = 0.12$. Demand is Weibull with $\bar{F}(q) = \exp(-(q/\eta)^k)$. We set the expected demand equal to 100 and the demand standard deviation equal to 50 by setting $\eta = 112.91$ and $k = 2.10$. $\bar{\alpha} = 0.17$.

value of γ. The bank has to offer a low interest rate and/or a high advance rate to facilitate lending. Proposition 2 formalizes Figure 2 and provides a full characterization of the owner's best response to a loan offer.

Proposition 2. *If $\alpha \le \bar{\alpha}_m$, the owner's best response is $(q^*, w^*) = (q^{\mathrm{DE}}, \gamma c q^{\mathrm{DE}})$. If $\alpha \in (\bar{\alpha}_m, \bar{\alpha}]$, the owner's best response is*

$$(q^*, w^*) = \begin{cases} (q^{\mathrm{PE}}, 0), & \text{if } \gamma < \bar{\gamma}(\alpha), \\ (q^{\mathrm{DE}}, \gamma c q^{\mathrm{DE}}), & \text{if } \bar{\gamma}(\alpha) \le \gamma \le 1, \end{cases} \tag{20}$$

where $\bar{\alpha}$ and $\bar{\gamma}(\alpha)$ are defined in Lemmas 1 and 2, respectively. Finally, if $\alpha > \bar{\alpha}$, $(q^*, w^*) = (q^{\mathrm{PE}}, 0)$ for all $\gamma \in [0, 1]$.

Intuitively, Proposition 2 implies that $\alpha < \bar{\alpha}_m$ is sufficient for the owner to borrow. When $\alpha \in [\bar{\alpha}_m, \alpha]$, the owner chooses borrowing only when the credit limit is sufficiently high. Otherwise, creating a pure equity firm is a better option. Finally, when the interest rate exceeds $\bar{\alpha}$, the owner chooses pure equity no matter how large the credit limit is.

3.1.4. Remarks. The owner's best response remains qualitatively similar when the borrowing constraint is specified as an affine function of inventory (e.g., $w \le aq + b$, where $a, b > 0$). Our analysis applies for such a formulation as well with minor modifications to the threshold values (e.g., $\bar{\gamma}(\alpha)$). We set $w \le \gamma c q$ because using a single parameter γ to define the credit limit is more consistent with practice. The owner's best response also remains qualitatively similar when there is corporate taxation. Imposing taxes makes the firm more likely to borrow because interest expense is tax deductible. As a result, the boundaries of the regimes depicted in Figure 2 change such that the pure equity solution region shrinks. Since corporate taxation does not lead to significantly different insights but makes the analysis more cumbersome, we omit taxes for simplicity.

3.2. The Bank's Problem

In this section, we first derive the bank's profit function given the firm owner's best response to a generic loan offer. We suppress the firm subscript i in this derivation for clarity of exposition. Then we introduce firm subscripts to formulate the bank's problem in the screening game.

Let $\kappa(q, w, \xi)$ denote the bank's profit as a function of the firm's decision variables (q, w) and demand occurrence ξ. For a given (q, w) pair, (8) defines a demand threshold $d_B = ([(1+\alpha)w - sq]^+)/(p - s)$ above (below) which the firm survives (defaults). When $\xi \ge d_B$, the firm repays the loan plus interest, $(1+\alpha)w$, to the bank. In contrast, if the realized demand is less than d_B, the firm defaults on the loan. Consequently, the bank initiates bankruptcy proceedings to receive a cash amount of $p\xi$ and possess the ownership of the firm's unsold inventory $q - \xi$. The bank liquidates this inventory, incurring a bankruptcy cost because of forced liquidation.

Foley et al. (2012) describe the bankruptcy liquidation process under ABL. Forced inventory liquidation is typically conducted on-site, that is, in the firm's stores, by a third-party company that specializes in store foreclosures. Forced liquidation is constrained to a short time frame (e.g., 30 or 60 days) compared with the time it takes for a going concern to salvage its unsold units. We assume for simplicity that the liquidation of inventory happens at the salvage value s because the bank or the liquidator can access the same marketplace as the firm. Nonetheless, foreclosure, legal fees, and transfer of inventory to a liquidator create extra costs for the bank. We model these bankruptcy-related costs with an additional bankruptcy cost proportional to the size of bankruptcy of the firm.

Our model can be generalized by allowing the forced liquidation value of inventory to differ from the firm's salvage value s with some increase in notational complexity. This generalization does not add significant new insights because the qualitative effect of a different salvage value is similar to the impact of bankruptcy cost. Thus, for simplicity, we use a single parameter for salvage value as well as forced liquidation value of inventory.

Mathematically, if a firm defaults, the bank's profit after forced liquidation can be written as

$$\kappa\left(q, w, \xi \,\middle|\, w > \frac{s}{1+\alpha} q, \xi < d_B\right) = p\xi + s(q - \xi) - b(d_B - \xi) - w. \tag{21}$$

Here, $b \ge 0$ is the bankruptcy cost per unit, and the size of the bankruptcy is given by the difference between the bankruptcy threshold demand d_B and the realized demand ξ. We rewrite (21) more intuitively as consisting of two terms, the bank's profit in case of no default and the cost incurred by the bank because of bankruptcy:

$$\kappa\left(q, w, \xi \,\middle|\, w > \frac{s}{1+\alpha} q, \xi < d_B\right) = \alpha w - \left[(p-s)\left(\frac{(1+\alpha)w - sq}{p-s} - \xi\right) + b(d_B - \xi)\right] \quad (22)$$

$$= \alpha w - (p - s + b)(d_B - \xi). \quad (23)$$

Unconditional on the loan amount and the demand realization, we get

$$\kappa(q, w, \xi) = \alpha w - (p - s + b)[d_B - \xi]^+. \quad (24)$$

This expression is equal to zero if the firm does not borrow, equal to αw if the firm borrows and survives, and equal to (21) if the firm borrows and defaults.

In the remainder of the paper, we use the subscript i to denote the expressions specific to firm type i. For example, q_i^{PE} represents the order quantity of a pure equity firm under F_i. For $i = 1, 2$, let $(q_i^*(\alpha,\gamma), w_i^*(\alpha,\gamma))$ denote firm type i's best response to a loan offer. This response can be characterized by replacing F with F_i in Proposition 2. Accordingly, the bank's expected profit for firm type $i = 1, 2$ can be written by taking expectation of (24) as

$$\Gamma_i(\alpha,\gamma) = \alpha w_i^*(\alpha,\gamma) - (p - s + b) \cdot \int_0^{([(1+\alpha)w_i^*(\alpha,\gamma) - s q_i^*(\alpha,\gamma)]^+)/(p-s)} F_i(\xi)\, d\xi. \quad (25)$$

The next lemma characterizes the bank's expected profit from firm type i for a generic loan offer (α,γ) and shows that it is not a well-behaved function of (α,γ).

Lemma 3. *Let* $\mathbb{B}_i \equiv \{(\alpha,\gamma)\colon 0 \le \alpha \le \bar{\alpha}_m, 0 \le \gamma \le 1\} \cup \{(\alpha,\gamma)\colon \bar{\alpha}_m \le \alpha \le \bar{\alpha}_i, \bar{\gamma}_i(\alpha) \le \gamma \le 1\}$.

(i) *The bank's expected profit from firm type i equals*

$$\Gamma_i(\alpha,\gamma) = \begin{cases} \alpha\gamma c q_i^{DE}(\alpha,\gamma) - (p-s+b) \cdot \int_0^{([(1+\alpha)\gamma c - s]^+/(p-s)) q_i^{DE}(\alpha,\gamma)} F_i(\xi)\, d\xi, & \text{if } (\alpha,\gamma) \in \mathbb{B}_i, \\ 0, & \text{otherwise.} \end{cases} \quad (26)$$

(ii) $\Gamma_i(\alpha,\gamma)$ *is not quasi-concave in* (α,γ).

(iii) *Firm type i's probability of bankruptcy* (*i.e., the default probability of the loan*) *equals*

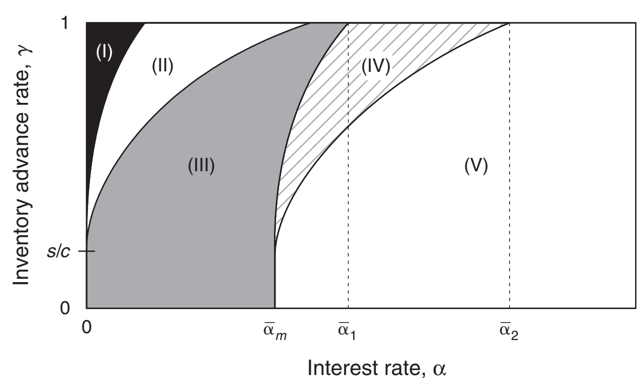
$$\rho_i(\alpha,\gamma) = \begin{cases} F_i\left(\dfrac{[(1+\alpha)\gamma c - s]^+}{p-s} q_i^{\mathrm{DE}}(\alpha,\gamma)\right), & \text{if } (\alpha,\gamma) \in \mathbb{B}_i, \\ 0, & \text{otherwise.} \end{cases} \quad (27)$$

Lemma 3 reveals that the bank may lose the firm's business by setting the interest rate too high and/or setting the advance rate of inventory too low. Furthermore, it illustrates that the bank's expected profit from firm type i is not a well-behaved function of the loan terms. This result arises in part because of the owner's best response. For instance, it may be optimal for the owner to borrow when the bank offers $(\alpha^{[1]}, \gamma^{[1]})$ or $(\alpha^{[2]}, \gamma^{[2]})$, but this does not necessarily mean that the owner will also borrow under a third loan contract that is a linear combination of the first two contracts (e.g., $(\alpha^{[3]}, \gamma^{[3]}) = 0.5(\alpha^{[1]}, \gamma^{[1]}) + 0.5(\alpha^{[2]}, \gamma^{[2]})$) because $\mathbb{B}_i$, the set of (α,γ) values in which firm type i borrows, is not a convex set as depicted in Figure 2. Lemma 3 also shows the firm's probability of bankruptcy as a function of the loan terms and the newsvendor model parameters.

Figure 3 depicts the borrowing regions for two different firm types. For firm type 1 (low risk firm), the curve that separates regions (I) and (II) is the bank's indifference curve (i.e., the set of (α,γ) pairs such that $\Gamma_1(\alpha,\gamma) = 0$) whereas the curve that separates regions (III) and (IV) is the owner's indifference curve (i.e., the set of (α,γ) pairs such that $\Pi_1(\alpha,\gamma) = \Pi_1^{\mathrm{PE}}$). That is, regions (II) and (III) represent the set of contracts that make both the bank and the owner of a type 1 firm better off compared with the pure equity scenario; the bank loses money in (I), and the owner chooses not to borrow in (IV) and (V). Similarly, for firm type 2 (high risk firm), the curve that separates regions (II) and (III) is the bank's indifference curve whereas the curve that separates regions (IV) and (V) is the owner's indifference curve.

Under full information, the bank would solve a separate optimization problem for each firm type. Maximizing $\Gamma_i(\alpha,\gamma)$ would require the bank to pick the best (α,γ) pair from the set $\mathbb{B}_i$. For instance, for firm type 1

Figure 3. Borrowing Regions for Two Firm Types as a Function of α and γ



Notes. We generate this figure using the following model parameters: $p = 2.5$, $c = 1$, $s = 0.2$, $\bar{\alpha}_m = 0.12$. Demand for firm type 1 is Weibull with mean 100 and standard deviation 50. Demand for firm type 2 is also Weibull with mean 100 and standard deviation 75. $\bar{\alpha}_1 = 0.17$ and $\bar{\alpha}_2 = 0.27$.

depicted in Figure 3, the bank would pick the best contract from regions (I), (II), and (III). However, incomplete information regarding firm types complicates the bank's problem because the firm type with *poor* demand prospects might choose the contract designed for the firm type with *good* demand prospects. The bank can address this shortcoming by designing a menu of contracts. Following the revelation principle (Myerson 1979), we formulate the bank's problem by focusing on direct revelation mechanisms that induce the owner to reveal the owner's firm's type by picking a contract from the menu. Accordingly, the bank offers a menu of contracts, $\{(\alpha_1, \gamma_1), (\alpha_2, \gamma_2)\}$, with the objective of maximizing its expected profit by lending to firm type 1 through (α_1, γ_1) and firm type 2 through (α_2, γ_2). Thus, the bank solves the following problem:

$$\max_{\{(\alpha_1,\gamma_1),(\alpha_2,\gamma_2)\}} \{\lambda\Gamma_1(\alpha_1,\gamma_1) + (1-\lambda)\Gamma_2(\alpha_2,\gamma_2)\} \quad (28)$$

$$\text{s.t.}\ \Pi_1^*(\alpha_1,\gamma_1) \geq \Pi_1^*(\alpha_2,\gamma_2), \quad (29)$$

$$\Pi_2^*(\alpha_2,\gamma_2) \geq \Pi_2^*(\alpha_1,\gamma_1). \quad (30)$$

Here, incentive compatibility constraints (29) and (30) ensure that firm type 1 chooses (α_1, γ_1) and firm type 2 chooses (α_2, γ_2). Participation constraints are embedded in (29) and (30) because $\Pi_i^*(\alpha_i, \gamma_i) = \Pi_i^{\mathrm{PE}}$ and $\Gamma_i(\alpha_i, \gamma_i) = 0$ if firm i chooses not to borrow. Furthermore, this formulation subsumes an alternative lending model in which the bank offers the same loan terms to both firm types because $(\alpha_1, \gamma_1) = (\alpha_2, \gamma_2)$ is a feasible solution to (28)–(30). The next proposition formalizes the structure of the optimal loan contracts.

Proposition 3. *There exist $(\alpha_1, \gamma_1) \neq (\alpha_2, \gamma_2)$ such that both firms borrow, where firm 1 picks (α_1, γ_1) and firm 2 picks (α_2, γ_2). Furthermore, the menu of loans that maximizes the bank's expected profit under information asymmetry, $\{(\alpha_i^*, \gamma_i^*)\}_{i=1,2}$, is such that γ_i^* increases in α_i^*.*

Proposition 3 shows that sorting through a menu of loans is feasible under ABL. In addition, if it is optimal for the bank to sort firm types by offering two distinct contracts, then a high (low) interest rate must be paired with a high (low) credit limit. Its proof is straightforward because otherwise both firm types would choose the loan contract with the lower interest rate and the higher advance rate. This observation is well aligned with practice because, all else being equal, a higher credit line typically requires a higher interest rate.

Does the firm stock a higher order quantity at equilibrium when it is leveraged? On the one hand, leverage allows the owner to share excess inventory risk with the bank. This outcome can be seen in (19), where the presence of bankruptcy risk lowers the firm's critical fractile. The existing literature suggests that this risk-shifting effect should lead to overinvestment. On the other hand, the bank may be able to prevent overinvestment by setting a low inventory advance rate and/or a high interest rate. For instance, Figures 2 and 3 show that the interest rate offered by the bank may exceed $\bar{\alpha}_m$ and the firm may still borrow. Thus, the answer is unclear a priori. We answer this question in the next proposition.

Proposition 4. *The equilibrium order quantity, $q_i^*(\alpha_i^*, \gamma_i^*)$ is greater than or equal to the order quantity of a pure equity firm, $q_i^{\mathrm{PE}} = \bar{F}_i(((1+\bar{\alpha}_m)c - s)/(p-s))$, for $i = 1, 2$.*

The proof of the proposition shows that overinvestment occurs because of a combination of limited liability and equity optimization. Limited liability creates the well-known risk-shifting effect. Additionally, the owner's ability to adjust equity allows the owner to reject any loan offers that lead to an order quantity that is less than the pure equity order quantity. If the owner did not have this ability, the bank would have been able to dictate stricter loan terms (e.g., higher interest rates) to an equity-constrained firm, which could force such a firm to stock less than a firm with higher starting equity even under limited liability. The proof also reveals that overinvestment arises regardless of information asymmetry and asset-based lending. Nevertheless, those factors affect the magnitude of overinvestment as we show in Section 4.2.

In the next section, we examine the effects of model parameters on the equilibrium outcomes, including loan terms, leverage, order quantity, and bankruptcy occurrence. We do so numerically because of the nonconvexity of our problem. It is well-documented in the literature (e.g., Rasmusen 2007, pp. 194–195) that participation and incentive compatibility constraints in principal–agent frameworks make the principal's constraint set nonconvex, which in turn makes the principal's problem (the bank's problem in our setting) difficult to analyze. When the principal's objective function is well behaved, the optimal solution can be characterized either in closed form or using the first order conditions of the objective function. In our context, a linear combination of two non-quasi-concave functions $\Gamma_i(\alpha, \gamma)$, $i = 1, 2$ makes such a characterization of the optimal solution difficult if not impossible. Thus, having derived the bank's profit function and shown the feasibility of a screening solution, we now numerically examine the operational and financial implications of ABL.

4. Managerial Insights

In this section, we examine the operational and financial implications of ABL: Section 4.1 deals with the effects of model parameters on the loan terms at equilibrium, Section 4.2 discusses the relationship between the firm's financial leverage and inventory investment, Section 4.3 examines the impact of operational characteristics on financial distress, Section 4.4 compares ABL with pure interest rate optimization and identifies conditions under which ABL is most beneficial to the bank, and Section 4.5 discusses the robustness of our findings with respect to alternative assumptions. We conclude each subsection with empirically testable hypotheses emerging from our findings.

The results of this section are based on a numerical study for a wide range of parameter values. The parameter combinations are as follows: salvage value s ranges from 0 to 0.45 in increments of 0.05; the probability of occurrence of firm type 1, λ, ranges from 0.1 to 0.9 in increments of 0.1; and the hurdle rate, $\bar{\alpha}_m$, ranges from 0.02 to 0.18 in increments of 0.02. Demand is modeled with a Weibull distribution with mean and standard deviation (μ_i, σ_i). Also let ϕ_i denote the coefficient of variation (cv) of demand for firm type i. We set $\mu_1 = \mu_2 = 100$, $\sigma_1 = \phi_1\mu_1$, and $\sigma_2 = 2\phi_1\mu_2$; that is, firm type 2 has equal mean and twice the standard deviation of demand as firm type 1. We vary ϕ_1 between 0.35 and 0.5 in increments of 0.025; correspondingly, the cv of demand for firm type 2, ϕ_2, varies from 0.7 to 1.0. All other parameters are kept constant: $p = 1$, $c = 0.5$, and $b = 0.1$. In total, there are 5,670 unique scenarios generated from 10 values of s, nine values of λ, nine values of $\bar{\alpha}_m$, and seven values of ϕ_1. We set the range and increment for each parameter such that the standardized values vary between −1.5 and 1.5 across all 5,670 scenarios. The standardized values allow us to compare the relative sensitivity of loan terms with different parameters. For each scenario, we compute the pure equity solution and the ABL equilibrium solution under full and partial information.

4.1. Sensitivity of Loan Terms to Model Parameters

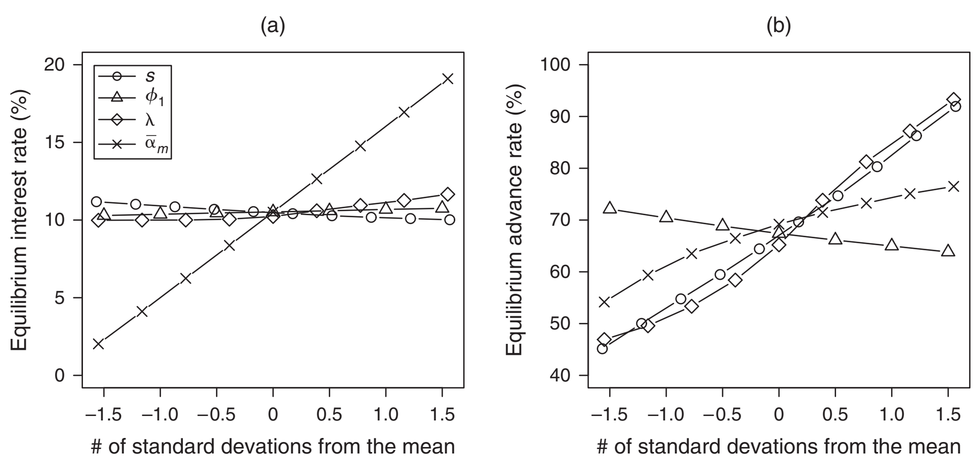
A priori, the directional effects of changes in model parameters on loan terms are difficult to predict because the loan terms consist of two components. For example, an increase in salvage value may lead to an increase or a decrease in interest rate depending on how the advance rate changes. The other parameters, such as demand uncertainty, also lead to similar situations.

We find that the average interest rates offered to firm types 1 and 2 under partial information equal 10.53% and 15.27%, respectively, and the average advance rates equal 67.67% and 87.65%, respectively, across all 5,670 scenarios. Thus, the firm with the lower demand uncertainty has a lower cost of borrowing and a lower leverage. Figures 4(a) and (b) show the sensitivity of firm type 1's interest rate and advance rate, respectively, to different model parameters. The interest rate for firm type 1 decreases in the salvage value (s), increases in the demand coefficient of variation (ϕ_1), increases in the probability that the firm is type 1 (λ), and increases in the hurdle rate ($\bar{\alpha}_m$). The advance rate for firm type 1 increases in s, λ, and $\bar{\alpha}_m$, and decreases in ϕ_1.

The impacts of s and ϕ_i on loan terms are intuitive because an increase in s or a decrease in ϕ_i makes lending less risky for the bank. The impact of $\bar{\alpha}_m$ is also anticipated because an increase in $\bar{\alpha}_m$ raises the owner's opportunity cost, which enables the bank to lend more at higher interest rates. However, the impact of the probability that the firm is type 1 (λ) is not intuitive. One might expect to see a negative relationship between interest rates and λ because an increase in λ improves the quality of the borrowing pool. However, rather than decreasing the interest rate in response to a higher λ, the bank offers a more generous advance rate at a higher interest rate.

An important takeaway from Figure 4(a) is that the equilibrium interest rate is most sensitive to the hurdle

Figure 4. The Average Equilibrium Interest Rate (a) and Inventory Advance Rate (b) for Firm Type 1 as a Function of the Standardized Values of the Salvage Value (s), the Demand Coefficient of Variation (ϕ_1), the Probability that Firm is Type 1 (λ), and the Hurdle Rate ($\bar{\alpha}_m$)



Notes. We standardize a model parameter by subtracting its mean and dividing by its standard deviation computed across all 5,670 data points. Each data point represents the average value of the response variable for a particular standardized value of a model parameter. For instance, in (a), the data point at which the standardized $\bar{\alpha}_m$ equals zero represents the average equilibrium interest rate over 5,670/9 = 630 scenarios with $\bar{\alpha}_m$ 10%, which is the average $\bar{\alpha}_m$ in the data set.

rate, $\bar{\alpha}_m$. To see this, observe that a one standard deviation increase in $\bar{\alpha}_m$ raises the average interest rate by more than 5%, from 10.51% to 15.86%, whereas a one standard deviation change in the salvage value or demand coefficient variation changes the average interest rate by less than 1%. Put differently, a firm's operational characteristics (i.e., s and ϕ_i) play less significant roles than $\bar{\alpha}_m$ in determining the cost of borrowing. Unlike the interest rate, the advance rate is highly sensitive to a firm's operational characteristics. This leads to a hypothesis that may be tested in future empirical research: interest rates under ABL are more sensitive to hurdle rate than to operational characteristics of firms whereas advance rates are more sensitive to operational characteristics of firms.

Analyzing the sensitivity of the loan terms to model parameters for firm type 2 leads to similar insights and is omitted for brevity.

4.2. Financial Leverage and Order Quantity

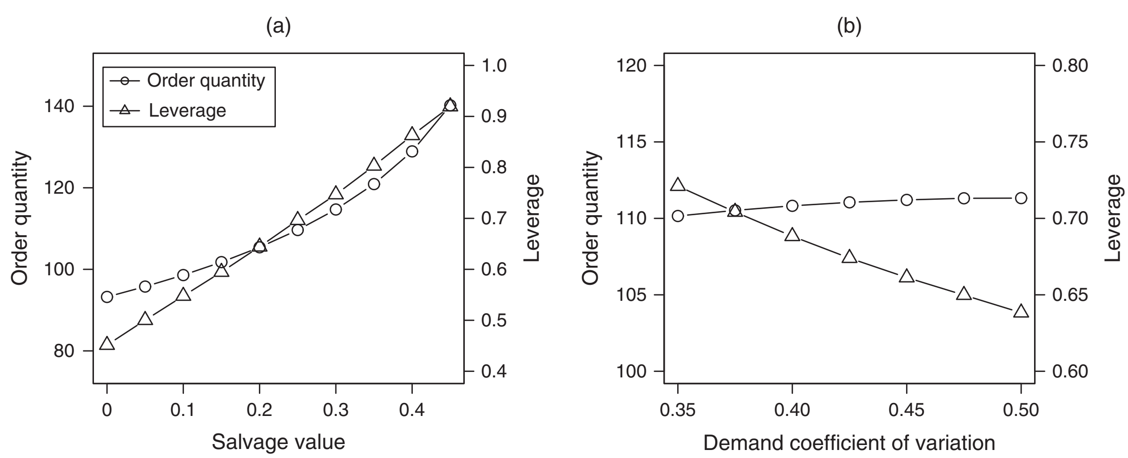
We showed in Proposition 4 that a firm stocks more inventory at equilibrium when it is leveraged than when it chooses a pure equity solution. That proposition was driven by a combination of limited liability and the owner's ability to optimize equity. We examine two further aspects of financial leverage and order quantity in this section: the effect of model parameters and the effect of screening through a menu of asset-based loans. By varying the model parameters, we observe how the financial leverage and order quantity for a given firm type can change as a function of the firm's operational characteristics. By comparing across the two firm types, we observe how the financial leverage and order quantity vary across a cross-section of firms.

Figure 5 shows financial leverage and order quantity as functions of salvage value and demand uncertainty for firm type 1 under information asymmetry. In Figure 5(a), we see that leverage and order quantity both increase when s increases. This result arises because an increase in s leads to a higher stocking quantity as well as more lenient loan terms from the bank, which enable the firm to increase both order quantity and leverage. On the contrary, Figure 5(b) shows that changes in ϕ_1 lead to a negative relationship between leverage and order quantity. This result arises because the firm's stocking quantity increases in ϕ_1 but the bank offers less attractive loan terms to the firm.

The extent of overinvestment by the firm, compared with the pure equity solution, is also influenced by the salvage value and demand uncertainty. We find that a higher salvage value leads to declining overinvestment as both order quantity and leverage increase but the risk-sharing benefit of limited liability becomes less valuable to the firm. Specifically, a one standard deviation increase in s decreases the average overinvestment level (i.e., percentage deviation from the pure equity order quantity) from 21.35% to 17.13% for firm type 2 under information asymmetry. On the other hand, a higher demand uncertainty leads to increasing overinvestment as limited liability becomes more valuable to the firm; a one standard increase in ϕ_2 increases the average overinvestment from 20.11% to 22.60% for firm type 2 under information asymmetry. Thus, to summarize, the equilibrium order quantity and the extent of overinvestment may increase or decrease with leverage for a firm depending on which underlying operational parameter varies: salvage value or demand uncertainty.

Another way to examine the leverage–order quantity relationship is through the effect of screening under information asymmetry. Table 1 reports the average leverage ratios, order quantities, and extent of overinvestment by firms across the 5,670 scenarios in our

Figure 5. Order Quantity and Leverage as a Function of Salvage Value (a) and Demand Coefficient of Variation (b) for Firm Type 1 Under Information Asymmetry



Notes. Each data point in (a) represents an average of 5,670/10 = 567 scenarios with the same s value. Similarly, each data point in (b) represents an average of 5,670/7 = 810 scenarios with the same ϕ_2 value.

Table 1. The Relationship Between Leverage and Overinvestment Across the Cross-Section of Firms with Varying Demand Uncertainty

	Full information			Partial information		
Firm	Leverage (%)	Order qty.	Overinvestment (%)	Leverage (%)	Order qty.	Overinvestment (%)
1	99.53	114.18	4.20	67.67	110.91	0.93
2	87.01	117.54	15.67	87.65	121.08	19.80

Notes. The leverage columns report the average debt-to-assets ratios computed across all 5,670 data points. The overinvestment columns report the average percentage deviation from the pure equity solution across all 5,670 data points.

analysis. (Here, we compare the amounts of overinvestment because the two firm types have different optimal order quantities in pure equity solutions so that their order quantities cannot be compared directly.) Under full information, firm type 1 has higher leverage than firm type 2 (99.5% versus 87.0%) because firm type 1 has lesser demand uncertainty and the bank offers more attractive loan terms to firm type 1, consisting of a lower interest rate and a higher advance rate. Under information asymmetry, the bank is forced to sort the firms on interest rate and advance rate. As a result, firm type 1 has lower leverage (67.7% versus 87.7%) and also overinvests by less than firm type 2. Thus, screening leads to a positive relationship between leverage and overinvestment across the cross-section of firms.

While the lender's inability to control the borrower firm's actions and risk-shifting incentives are known in the literature to cause overinvestment, it is interesting to note that the bank in our model has the ability to minimize or even prevent overinvestment by offering relatively low advance rates. For instance, when $s > 0$, setting $(\alpha_i, \gamma_i) = (\bar{\alpha}_m, s/((1+\bar{\alpha}_m)c))$ would force both firm types to stock their pure equity order quantities while allowing the bank to make money. However, the pure equity order quantities are too small to maximize the bank's expected profit. Screening through ABL enables the bank to maximize its expected profit but at the cost of encouraging overinvestment by firm type 2.

In summary, we find that the relationship of financial leverage with order quantity and overinvestment is driven by limited liability, screening through a menu of asset-based loans, and variation in underlying model parameters. We find that (i) a firm orders more inventory under leverage than under pure equity. (ii) Order quantity and financial leverage increase and overinvestment decreases with an increase in salvage value for a firm. (iii) Order quantity increases, leverage decreases, and overinvestment increases with an increase in demand uncertainty for a firm. (iv) Under information asymmetry, screening through ABL leads to a positive correlation between leverage and overinvestment across the cross-section of firms with varying demand uncertainty.

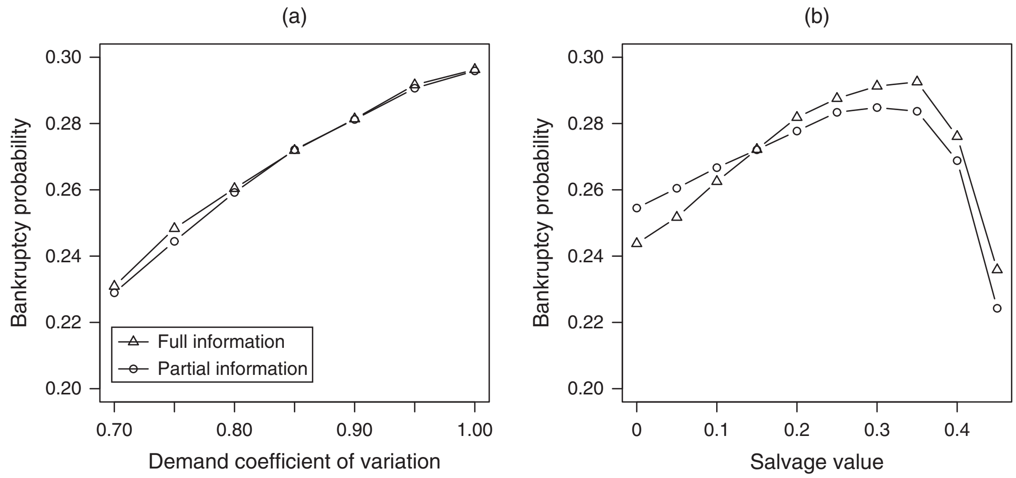
4.3. Operational Parameters and the Probability of Bankruptcy

The average probability of bankruptcy of firm type 1 across all scenarios is 2.71% and of firm type 2 is 26.75% under partial information. Under full information, the corresponding values are 10.28% and 26.87%, respectively. Moreover, our model enables us to examine the effects of operational characteristics (i.e., demand uncertainty and inventory salvage value) on a firm's bankruptcy risk.

The classical inventory models imply that an increase in demand uncertainty makes it more challenging to match supply with demand, which in turn might make bankruptcy risk more prevalent because of more volatile cash flows. Thus, one might infer a positive relationship between demand uncertainty and financial distress. However, a firm's capital structure may also change with demand uncertainty. As discussed in Section 4.1, the equilibrium advance rate decreases in demand uncertainty. Consequently, the firm is forced to use less leverage, which might lead to a negative relationship between demand uncertainty and financial distress. Figure 6(a) examines these counterclaims for firm type 2 and shows that the probability of bankruptcy increases in the demand coefficient of variation under both full and partial information. A case-by-case analysis of the 5,670 scenarios reveals that the demand threshold below which the firm is bankrupt decreases in demand uncertainty because of a decline in the advance rate. However, this decrease is insufficient to offset the increase in the probability of experiencing relatively low demand realizations. Thus, we find that a higher demand uncertainty leads to a higher bankruptcy risk under ABL.

Similarly, salvage value, s, may also lead to countervailing arguments. All else being equal, an increase in s should lead to a lower probability of bankruptcy because such an increase enables the firm to recover from a low demand realization by selling its unsold inventory at a relatively small discount. However, the classical newsvendor model suggests that a firm should stock more when s is high. Furthermore, the equilibrium inventory advance rate increases s as documented in Section 4.1. Consequently, an increase in s enables the firm to use more leverage and stock more,

Figure 6. The Average Equilibrium Probability of Bankruptcy of the High-Risk Firm (Firm Type 2) as a Function of Its Demand Coefficient of Variation (a) and the Salvage Value (b)



which may lead to a higher bankruptcy risk. Figure 6(b) shows that the relationship between salvage value and bankruptcy risk is nonmonotone because of these opposing forces. Thus, we find that a high salvage value does not necessarily lead to a lower bankruptcy risk under ABL.

In summary, the probability of bankruptcy increases in demand uncertainty. It is nonmonotone in salvage value, being first increasing and then decreasing when salvage value is large enough.

4.4. When Is ABL Most Beneficial to the Bank?

We compare the effectiveness of ABL with respect to pure interest rate optimization (PIRO), which has been commonly used as a lending model in the literature for settings with complete information and exogenous equity (e.g., Xu and Birge 2004, Dada and Hu 2008, Boyabatli and Toktay 2011).

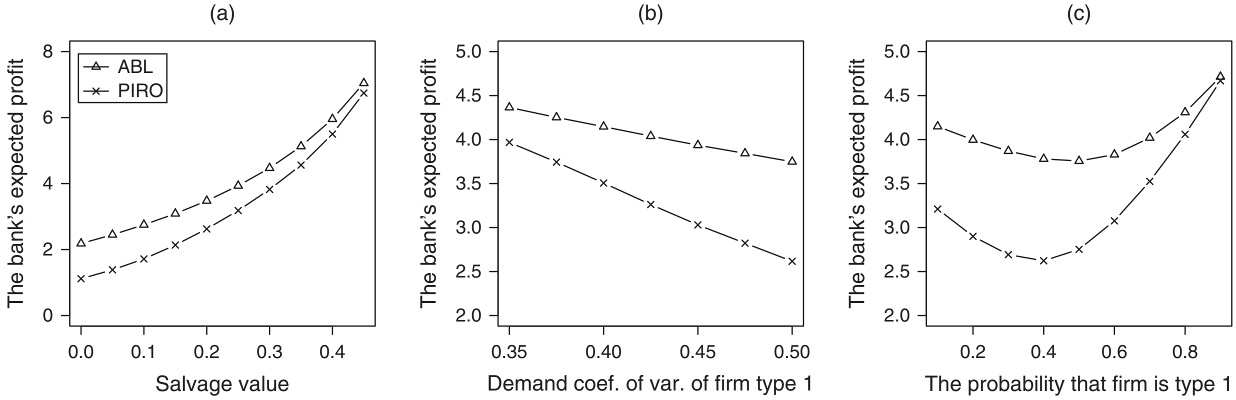
PIRO is a special case of our model obtained by setting the advance rate $\gamma = 1$. From Figure 2, it follows that the firm's best response will be either pure debt or pure equity. This result arises because the owner makes both equity and debt decisions in our model. Moreover, low interest rate contracts are strictly better than high interest rate contracts for both firm types, so the bank cannot benefit by offering a menu of interest rates. Instead, it optimizes on a single interest rate under information asymmetry. This simplifies the problem considerably.

Let α^{PIRO} denote the bank's optimal interest rate under PIRO. From Proposition 2, $\bar{\alpha}_i$ is the maximum interest rate at which firm i borrows. The bank's objective function has jump discontinuities at $\alpha = \bar{\alpha}_i$, $i = 1, 2$, where firm type i switches from pure debt to pure equity. If $\alpha^{\text{PIRO}} \le \min\{\bar{\alpha}_1, \bar{\alpha}_2\}$, then we have a pooling equilibrium in which both firm types choose pure debt. If α^{PIRO} lies between $\bar{\alpha}_1$ and $\bar{\alpha}_2$, then we have a separating equilibrium in which one firm type chooses pure debt and the other chooses pure equity. Finally, if $\alpha^{\text{PIRO}} > \max\{\bar{\alpha}_1, \bar{\alpha}_2\}$, then we have a pooling equilibrium in which both firm types choose pure equity. The last outcome arises when the bank's expected profit is negative for all interest rates at which the firms borrow. In such scenarios, the bank sets the interest rate above $\max\{\bar{\alpha}_1, \bar{\alpha}_2\}$ to make borrowing unattractive to both firm types. One sufficient condition for the existence of this outcome is a high bankruptcy cost b, which does not affect the owner's best response for a given α, but increases the bank's loss in case of firm default.

Under ABL, the bank lends to both firm types in all 5,670 scenarios. Under PIRO, it lends to both firm types in 2,907 scenarios, only to firm type 2 in 1,701 scenarios, and to neither firm (i.e., the lending market collapses) in the remaining 1,062 scenarios. The average ABL equilibrium interest rates offered to firm types 1 and 2 under partial information equal 10.53% and 15.27%, respectively. In contrast, the equilibrium interest rate offered by the bank under PIRO is 19.25% on average but can be as high as 53.81%. The loan sizes are smaller under ABL. By focusing on the scenarios in which borrowing takes place, the average loan sizes of firm types 1 and 2 under PIRO equal 58.61 and 70.89, respectively. Under ABL, the corresponding amounts are 50.34 and 60.13, respectively.

The bank's average expected profit is 3.28 under PIRO and 4.05 under ABL, which is an increase of 23%. Firm type 1's profit is equal to its reservation payoff, that is, the pure equity expected profit, in all scenarios for both ABL and PIRO. Firm type 2's profit is 6.71% higher on average than its pure equity profit under ABL and 10.85% higher under PIRO. Thus, firm type 2 enjoys an information rent because of information asymmetry. ABL reduces the amount of information rent. Comparing the scenarios where both firm

Figure 7. The Comparison of the Bank's Expected Profit Under ABL and PIRO as a Function of the Salvage Value (a), Firm Type 1's Demand Coefficient of Variation (b), and the Probability that Firm Is Type 1 (c) Under Information Asymmetry



Note. We use the entire data set to compute the bank's average equilibrium expected profit under ABL and PIRO for each value of s, ϕ_1, and λ.

types borrow, the order quantity under ABL is 0.93% higher than the pure equity solution for firm type 1 and 19.80% higher for firm type 2; under PIRO, the corresponding amounts are 1.82% and 30.11%, respectively. The average bankruptcy probabilities for firm types 1 and 2 are 2.71% and 26.75% under ABL and 4.64% and 29.57% under PIRO.

The superiority of ABL for the bank is not surprising because the bank's optimal contract under PIRO is a feasible solution to its problem under ABL. Nonetheless, it is not clear a priori when ABL would be more beneficial to the bank. Figure 7 examines the bank's expected profit under ABL and PIRO for various parameter values. Figure 7(a) shows that ABL is more beneficial when the salvage value is low. A priori, we might expect the opposite because a high salvage value enables the bank to recover its losses in case of default. However, in this situation, both PIRO and ABL perform well. Figure 7(b) demonstrates the impact of the demand coefficient of variation of firm type 1, ϕ_1, on the performance gap. We find that ABL is more beneficial when demand volatility is high. Finally, Figure 7(c) demonstrates that the benefits of ABL are more pronounced when the probability of occurrence of firm type 1, λ, is relatively low. Thus, ABL is more advantageous when the bank is less likely to face firm type 1 because adverse selection is more severe and lending is more risky.

In summary, ABL is superior to PIRO in many respects. The undesirable consequences of PIRO, such as excessive borrowing, clustering of firms to two extreme capital structure outcomes (i.e., pure debt and pure equity), prohibitively high interest rates, and a potential market collapse, vanish under ABL. Moreover, the bank lends to both firm types, which mitigates adverse selection and increases the bank's expected profit. Both firm types borrow at lower interest rates and make stocking decisions that are closer to the pure equity order quantity. Interestingly, the bank lends a smaller average amount at a lower interest rate but makes a higher average profit under ABL than under PIRO. Our numerical analyses lead to the following hypotheses: (i) Asset-based loans have lower interest rates compared with pure interest rate loans. (ii) Asset-based loan arrangements are more likely to emerge under more adverse lending circumstances (e.g., high demand uncertainty, low salvage value) as compared with pure interest loans.

4.5. Robustness Checks

We checked the robustness of our numerical results with respect to lending market competition and information asymmetry based on mean demand. Analyzing ABL in a competitive lending market setting revealed that competition does not change our main insights. Furthermore, a comparison of outcomes under competitive and monopoly lending yields the following hypotheses: (i) Lending market competition leads to more overinvestment by borrower firms than lending from a monopoly bank. (ii) Lending market competition leads to significantly lower interest rates but has only a small effect on advance rates compared with monopoly lending. We report our competitive lending market analysis in Section B in the online appendix.

In addition, we replicated our numerical study for an alternative setting in which the two firm types have the same standard deviation of demand but differ in mean demand. Although these two settings do not allow apples-to-apples comparison, our qualitative insights remained unchanged with one exception. Namely, the third hypothesis in Section 4.2 is changed. Whereas that hypothesis states that the order quantity increases with demand uncertainty, we observe that the order quantity increases with average demand when we keep the demand standard deviation constant and vary the average demand across the two firm types. Thus, the order quantity increases in the demand cv in our original numerical study whereas it decreases in the demand cv in the new study. All other hypotheses are supported in the new study. Our analysis, which we do not report in the paper because of space limitations, is available upon request.

5. Conclusions

Our paper puts the classical newsvendor model in a broader context in a novel setting of ABL. It provides insights regarding the different roles played by interest rate and advance rate in a loan offer, the benefits of ABL, the relationship between leverage and overinvestment, and the effect of operational characteristics on the equilibrium through inventory and capital structure decisions.

Comparing our results with those in the literature, we find that they differ mainly because of the effect of endogenous equity decisions. Dada and Hu (2008) show that, in an interaction between a capital-constrained newsvendor and an interest rate–optimizing bank, there is a threshold starting equity value below which the firm is financed via a mix of debt and equity, and the equilibrium order quantity is less than the classical newsvendor quantity. Their model is a special case of our model with a fixed starting equity x, full information, and $s = 0$, $b = 0$, $\bar{\alpha}_m = 0$, and $\gamma = 1$. Our analysis implies that endogenizing the equity decision in the same context leads to an extreme capital structure outcome (pure debt or pure equity) and that the equilibrium order quantity is greater than the pure equity order quantity because of the firm's ability to optimize its equity. Similarly, Buzacott and Zhang (2004, p. 1285) state,

> From our analysis above, it is not difficult to see that if the bank has the freedom of choosing the appropriate interest rate for each retailer it serves, it can find an optimal interest rate for each individual retailer based on the retailer's wealth level and maybe other parameters associated with each retailer (demand distribution, cost structure, etc.). Hence, interest rate alone is sufficient to guarantee optimal bank returns.

In contrast, we show that interest rate optimization can be insufficient to maximize the bank's expected profit when equity is an endogenous decision for the owner and the use of ABL is beneficial even in settings where the bank has the freedom of optimizing the interest rate under full information. Thus, endogenizing the owner's equity decision significantly affects model predictions in settings where a firm makes joint ordering and capital structure decisions.

Our paper falls in a rich area of research. It captures some practical aspects of ABL, such as the inventory advance rate, the possession and liquidation of inventory collateral by the bank, and information asymmetry. However, it also leaves out other practical aspects of ABL such as multi-period interactions and loan terms that are based on existing collateral. Thus, future research can study ABL under alternative decision frameworks. For instance, the interaction between the firm and the bank can be modeled as a signaling game instead of a screening game to allow the bank to move after observing the firm's decisions and collateral. Similarly, studying ABL in a multi-period setting maybe useful to illustrate how the firm's inventory position and revolving line of credit change over time. In addition, the owner's interactions with financial markets can be enriched by allowing trading between the bank and the owner or enabling the owner to solve a CAPM-based portfolio optimization problem with multiple investment opportunities. Finally, it will be fruitful to examine our model's predictions regarding the operational and financial implications of ABL using data.

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Endnote

[1] Commercial Finance Association, the trade association for asset-based lenders, publishes annual and quarterly ABL surveys, which are available at http://www.cfa.com. See Federal Reserve (2010, p. 66, line 39) and earlier reports for the total amount of loans and short-term papers issued to nonfinancial corporations.

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