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RESEARCH ARTICLE

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Inventory financing under Risk-Adjusted-Return-On-Capital criterion

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Abstract

Risk-Adjusted-Return-On-Capital (RAROC) is a loan-pricing criterion under which a bank sets the loan term such that a certain rate of return is achieved on the regulatory capital required by the Basel regulation. Some banks calculate the amount of regulatory capital for each loan under the standardized approach ("standardized banks," the regulatory capital is proportional to the loan amount), and others under the internal rating-based (IRB) approach ("IRB banks," the regulatory capital is related to the Value-at-Risk of the loan). This article examines the impact of the RAROC criterion on the bank's loan-pricing decision and the retailer's inventory decision. We find that among the loan terms that satisfy the bank's RAROC criterion, the one that benefits the retailer the most requires the bank to specify an inventory advance rate in addition to the interest rate. Under this loan term, the retailer's inventory level is more sensitive to his asset level when facing an IRB bank compared to a standardized bank. An IRB (standardized) loan leads to higher profit and inventory level for retailers with high (low) asset. For retailers with medium asset, an IRB loan results in a higher retailer profit but a lower consumer welfare. Calibrated numerical study reveals that the benefit of choosing standardized banks (relative to IRB banks) can be as high as 30% for industries with severe capital constraints, volatile demands, and low profit margins, highlighting the importance for retailers to carefully choose the type of banks to borrow from. When the interest rate is capped by regulation, retailers borrowing from a standardized bank are more likely to be influenced by the interest rate cap than those borrowing from an IRB bank. Under strong empire-building incentives (the bank will offer loan terms to maximize the size of the loan), retailers with medium initial asset level shift their preference from IRB banks to standardized banks.

KEYWORDS

Basel regulation, inventory financing, inventory management, operations–finance interface, RAROC

1 | INTRODUCTION

Inventory financing, a common type of asset-based financing, is widely used in practice (Foley et al., 2012). In 2018, the total amount of outstanding asset-based loans in the United States is $106.6 billion, accounting for 43% of lenders' total credit commitments. Industries featuring heavy inventory investment especially rely on this form of financing. In particular, retailers, which constitute 10% of the overall population of asset-based borrowers, consistently rank first among all sectors in the usage of asset-based loans (Commercial Finance Association, 2018).

Given the strategic importance of inventory financing to retailers, the way that inventory financing terms are determined has significant implications on the retailer's inventory decisions. In practice, inventory financing terms commonly consist of an interest rate and an inventory advance rate, which is the maximum percentage of the value of inventory that a lender is willing to extend for a loan (OCC, 2014). In the past, when pricing inventory-based loans, banks adopted the expected profit criterion, under which a bank loan is priced so that its expected profit (interest revenue minus expected loss) equals zero when the lending market is competitive.[1] Recently, this criterion has been increasingly criticized for its failure to fully account for the distribution of the loan loss, to which banks pay close attention for a variety of reasons (The Economist, 2009, 2011, 2012). Therefore, starting in the 1990s, more and more banks began to adopt the Risk-Adjusted-Return-On-Capital (RAROC) criterion in loan pricing. According to a survey conducted by the Federal Reserve (Jones, 1998), the majority of US financial institutions switched to RAROC criterion in 1990s. A 2011 McKinsey report further confirms the prevalence of RAROC criterion based on a survey of worldwide banks (Baer et al., 2011).

Originally developed by the Bankers Trust in the 1970s, RAROC is defined as the ratio of the expected profit of the loan (also known as risk-adjusted returns) over the amount of economic capital that ensures the bank's survival if the loan defaults (Matten, 1996). Under the RAROC criterion, the bank prices the loan such that the RAROC calculated based on this loan is no less than the bank's cost of (core) capital. As this approach takes into account the cost that banks need to bear associated with holding the economic capital, the RAROC criterion is recognized to be more appropriate in loan pricing than the expected profit criterion. While the original RAROC definition leaves banks with some freedom in determining the amount of economic capital for each loan, recently, the economic capital under the RAROC approach is commonly calculated based on the capital adequacy guideline outlined in the Basel Accord, the global regulatory framework on banking (Basel Committee, 2006). Specifically, there are two commonly adopted approaches that banks use to calculate the economic capital as governed by the Basel regulation (*regulatory capital*): the *standardized* approach, and the *internal rating-based* (IRB) approach. When banks adopt the standardized approach ("standardized bank"), regulatory capital for a loan equals a fixed proportion of the face value of the loan. For banks following the IRB approach ("IRB bank"), regulatory capital is calculated based on the Value-at-Risk (VaR) of the loan. The capital regulation approach is a bank level decision, once the bank has decided on its capital regulation approach, this approach applies to all loans the bank issues. Compared to the standardized approach, the IRB approach is more sensitive to the riskiness of loans. However, adopting the IRB approach requires higher fixed costs (e.g., for the installation of a sophisticated risk management system), which may deter small banks from using this approach. As such, in the United States, the IRB approach is mandatory for large banks but not for small ones (Hakenes & Schnabel, 2011). In practice, the two approaches also co-exist. For example, Cummings and Durrani (2016) report that in an investigation into 23 Australian banks, five of them adopt the IRB approach, whereas the 18 relatively small banks follow the standardized approach.

Motivated by the wide adoption of the regulatory capital-based RAROC criterion in the banking industry, this article focuses on the implication of RAROC criterion, as well as the different approaches that banks adopt in calculating regulatory capital, on banks' inventory-based loan pricing terms, and on retailers' inventory decisions and performances. To do so, we model the interaction between a bank and a newsvendor-type retailer, who has a limited amount of initial asset and thus may need to obtain bank financing to invest in inventory. As the Stackelberg leader, the bank sets the loan term based on its specific regulation approach, which includes an interest rate and an inventory advance rate, under the RAROC criterion. That is, the loan's RAROC under the retailer's best response equals to the bank's cost of capital. The retailer follows by deciding the order quantity and the amount to borrow subject to the constraint imposed by the inventory advance rate.

Under this model, we find that with RAROC as the only performance criterion, a bank, either a standardized or an IRB one, is indifferent along a continuum of (λ, r) pairs, which we refer to as the indifference curve of loan terms, for a given cost of capital. Along the indifference curves, when the inventory advance rate (λ) is low, in anticipation that the retailer will use up all the credit offered and therefore increase the borrowing amount as λ increases, the bank needs to raise interest rate to sustain the required RAROC level (the binding credit limit region). For sufficiently large λ, the credit limit is no longer binding, and thus the interest rate is independent of λ (the non-binding credit limit region).

Among the loan terms that satisfy the bank's RAROC criterion, the one that maximizes the retailer's payoff (the Pareto dominant loan term) falls in the interior of the binding credit limit region. That is, both the interest rate and inventory advance rate are necessary levers to induce the retailer's optimal decision. This is different from the model where the retailer first determines the order quantity and the bank responds with a competitive interest rate (e.g., Xu & Birge, 2004), in which the interest rate is the only lever needed to properly incentivize the retailer. Under this Pareto dominant loan term, the inventory quantity decreases with the bank's cost of capital and regulatory capital adequacy ratio. Further, this inventory level depends crucially on the approach under which the regulatory capital is calculated. In general, low-risk retailers (characterized by large initial assets) are able to order more under IRB banks than under standardized banks while high-risk retailers stock more under

[1] We note that in the OM-Finance Interface literature, this expected profit is also commonly referred as expected value (Tanrisever et al., 2015).

standardized banks. This is because the regulatory capital under the IRB approach is more sensitive to the retailer's default risk, and thus the IRB bank charges a lower interest rate for low-risk retailers, while charging a higher interest rate for high-risk retailers compared to the standardized bank. For the same reason, with the option to choose between standardized banks and IRB ones, low-risk retailers prefer to borrow from IRB banks, while high-risk retailers favor standardized banks. However, for retailers with intermediate initial assets, IRB loans result in a higher retailer payoff, yet a lower inventory level, thus hurting consumers. This discrepancy is driven by the fact that the retailer's profit is a reflection of the cumulative financial cost, while the order quantity is determined by the marginal cost, which is more sensitive to the retailer's asset level. Based on a calibrated numerical study, we find that firms' preference between standardized and IRB banks is relatively robust across industries with different demand variabilities and profit margins. However, the potential benefit of choosing standardized banks versus IRB banks can be as high as 30% for industries with severe capital constraints, volatile demands, and low profit margins. Thus, severely capital-constrained firms would still prefer standardized banks even when IRB banks enjoy a lower cost of capital than standardized ones. For less financially constrained firms, a moderate increase in the standardized banks' cost of capital only nudge a small fraction of the firms to switch to IRB banks.

While the Pareto dominant loan term leads to the highest profit to the retailer, in practice, banks may face other considerations that influence their loan term decisions, which in turn affect the retailer's preference between standardized and IRB banks. For example, banks may face a cap on the interest rate that the loan bears, a regulatory restriction commonly adopted by governments, especially in the developing world (Maimbo & Gallegos, 2014). In this case, interest rate caps affect less retailers under the IRB approach than under the standardized one. In addition to external restrictions such as interest rate caps, banks' decisions are inevitably bound to their agents' behavior. For example, as managers' compensation is often linked to the amount of loan they generated (Berg et al., 2013), they may exhibit *empire building* behaviors, that is, offering loan terms that maximize the size of the loan subject to the RAROC criterion. Under such behavior, we find that while low-risk (high-risk) retailers still prefer IRB banks (standardized banks), retailers with medium initial asset shift their preference from IRB banks to standardized banks. In summary, by introducing the RAROC criterion and two different approaches in calculating regulatory capital to the context of inventory financing, we show that the specific approach that the bank adopts in loan pricing has significant impact on operational decisions. Given the prevalence of the RAROC criterion and the regulatory capital requirement, our findings suggest that operational managers and financial professionals take into account their impact on loan terms when making relevant business decisions.

This article is organized as follows. Section 2 reviews the related literature. The model is presented in Section 3. We analyze the bank's loan term decision under the RAROC criterion in Section 4, and the retailer's inventory choice and banking preference in Section 5. Section 6 extends the model by incorporating other practical considerations the bank may face. We conclude the article in Section 7. All proofs are in the Online appendix.

2 | LITERATURE REVIEW

Our work is closely related to two streams of research: (1) the interface of operations and finance literature; (2) the finance literature on the financial implication of the RAROC criterion and capital regulations.

Focusing on the impact of RAROC in inventory decisions, our article belongs to the literature on the interface of operations and finance. We complement the extant literature in that, unlike most papers in this literature, which consider the expected profit as the bank's decision criterion (e.g., Xu & Birge, 2004), we focus on the case where banks operate under the RAROC criterion. To the best of our knowledge, this article is the first to consider the RAROC criterion in the context of inventory financing. This framework allows us not only to connect RAROC and regulatory capital to other sources of financial frictions when the bank offers the Pareto dominant loan terms, but also examine the implication of RAROC and regulatory capital on operational decisions when such Pareto dominant loan terms are prohibited due to internal incentive conflict (e.g., empire building) or external restrictions (e.g., interest rate cap). Under the Pareto dominant loan terms, we establish the RAROC criterion and regulatory capital requirement as a form of financial friction that links the firm's financial situation and operational decisions under the classic Modigiliani–Miller framework. In this aspect, our article is related to those that examine firms' optimal operational decisions in the presence of various forms of financial market frictions, such as cost of financial distress (Boyabatlı & Toktay, 2011; Kouvelis & Zhao, 2011; Yang & Birge, 2018), tax (Chod & Zhou, 2013; Hsu et al., 2019; Xiao et al., 2015; Xu et al., 2018), information asymmetry (Alan & Gaur, 2018; Cai et al., 2014; Lai & Xiao, 2018; Ning & Babich, 2018; Tang et al., 2018; Zhao et al., 2019), bank's market power (Buzacott & Zhang, 2004; Dada & Hu, 2008), and transaction cost (Hu et al., 2018; Tanrisever et al., 2018; Tanrısever et al., 2012; Yang et al., 2015). Our article complements the above ones by introducing RAROC and regulatory capital as a source of financial friction, and quantifying its impact on firms' inventory decisions in a unique fashion. For example, the co-existence of the standardized approach and IRB approach allows the specific form of the financial friction to be an endogenous choice based on the retailer's risk profile. In addition, as the IRB approach is related to VaR, our work is also connected to the papers focusing on risk-averse players (Chen et al., 2007; Gaur &

Seshadri, 2005), and in particular those related to VaR and CVaR (Kouvelis & Li, 2019; Park et al., 2017; Tomlin & Wang, 2005). In our article, even though both players are risk-neutral, the regulatory capital requirement under the IRB approach induces certain risk-aversion-like behavior. Finally, see Osadchiy et al. (2015), Peura et al. (2017), Yi et al. (2017), Wu et al. (2019) and reference within for other related works in the interface area of operations and finance. In general, this article contributes to the OM-Finance interface literature by introducing the RAROC criterion to the OM-Finance interface literature, and quantifying the impact of bank capital regulation, which is a type of under-studied financial market friction, on retailers' inventory decisions and financial performances. Comparing with other forms of financial frictions, its unique impacts merit our attention.

In the finance literature, the RAROC criterion in banking has been examined in the context of risk pricing (Jones, 1998; Karandikar et al., 2007; Prokopczuk et al., 2007), portfolio management (Rossi, 2011), and performance evaluation (James, 1996). Differently, our article studies the impact of the RAROC criterion in a classic operations management context by taking into consideration the interaction between the bank and the borrower (the retailer) under endogenous operational decisions. In addition, given its importance, bank capital regulation has also been examined theoretically and empirically in the banking literature. On the empirical side, Wallen (2017) quantifies the impact of bank capital regulation on loan pricing. Schwert (2018) finds that bank-dependent firms tend to borrow from well-capitalized banks, while firms with access to the public bond market borrow from banks with less capital. Our results complement these papers by showing that bank capital regulation significantly influences firms' lending rates and choice of banks in practice. On the modeling side, our article is closely related to Ruthenberg and Landskroner (2008), who compare loan pricing between the standardized approach and the IRB approach. Similar to their paper, we also show that categorically, low-risk borrowers will be attracted to IRB banks, while high-risk ones prefer standardized banks. Differently, by endogenizing firms' operational decision, our article reveals on how firms' operational parameters affect banks' loan pricing and how banking parameters, such as capital adequacy ratio and cost of capital, influence firms' operational decisions. For example, we show that while the IRB approach may generate higher profit for the retailer of medium risk level compared to the standardized approach, it leads a lower inventory level, thus hurting consumers. Thus, at a high level, our article contributes to the finance and banking literature by deepening the understanding of bank capital regulation on the real economy.

3 | THE MODEL

Consider a single-period model consisting of a capital-constrained retailer ("he") who faces newsvendor-type uncertain demands, and a bank ("she") who operates in a fully competitive banking sector where loan terms are determined such that the bank's RAROC criterion is satisfied. According to Matten (1996), the bank's RAROC is defined as:

$$\begin{aligned}\text{RAROC} &= \frac{\text{Risk} - \text{Adjusted Return}}{\text{(Regulatory) Capital}}\\ &= \frac{\text{Interest Income} - \text{Expected Loss}}{\text{(Regulatory) Capital}}. \qquad (1)\end{aligned}$$

Under the RAROC criterion, the bank sets the loan term, which includes an interest rate (r) and an inventory advance rate (λ) so that the loan's RAROC equals the bank's cost of capital $\delta > 0$,[2] as market competition prohibits the bank from earning a RAROC strictly higher than her cost of capital.

By the above definition, we note that the RAROC criterion can be seen as a generalization of the expected profit criterion, which prices a loan so that the interest income equals to the expected loss (Xu & Birge, 2004). Indeed, when either the bank's regulatory capital is zero or her cost of capital equals to the risk-free rate, which we normalize to zero, the RAROC criterion degenerates to the expected profit one. However, in practice, the bank's cost of capital is strictly higher than the risk-free rate. For example, between 1998 and 2018, the average cost of capital among US banks is 5% above the 3-month treasury bill rate, a commonly used proxy for the risk-free rate.[3] In addition, banks are required to hold a certain amount of regulatory capital for each loan under the Basel Accord. Thus, practically, the RAROC criterion significantly deviates from the expected profit one, and the deviation depends critically on the calculation of the regulatory capital. Specifically, according to the Basel regulation, regulatory capital is calculated by either the standardized approach (the amount of regulatory capital equals to a proportion of the loan amount), and the IRB approach (the amount of regulatory capital is related to the Value-at-Risk of the loan). The technical details of these two approaches are described in Sections 4.2 and 4.3, respectively.

On the retailer side, the newsvendor-type retailer faces an uncertain demand, which is characterized by the random variable $\tilde{u}$, with the probability density function (PDF) $f(\cdot)$, the cumulative distribution function (CDF) is $F(\cdot)$, and the failure rate is $z(\cdot) = f(\cdot)/\overline{F}(\cdot)$, which is assumed to be non-decreasing. Endowed with an initial asset $A \geq 0$, the retailer needs to decide the order quantity q at unit wholesale price c. He seeks for bank financing when A is insufficient for his inventory investment cq. The retail price of each unit of inventory is p. Unsold inventory are salvaged at unit price s. To avoid trivial cases, we assume $s < c \leq c(1+r) \leq p$. The retailer is risk-neutral with the objective to maximize his expected profit at the end of the sales season.

[2] δ can also be interpreted as the return the bank demanded on the regulatory capital (i.e., core equity capital). This parameter is only relevant when the bank is required to hold positive amount of capital.

[3] The 3-month treasury bill rates are gathered from the website of U.S. Department of the Treasury. Banks' cost of capital is estimated by Aswath Damodaran (2018).

The sequence of events for our model is as follows. At the beginning of the sales season, the bank, either a standardized one or an IRB one,[4] sets the loan term (r, λ). Under the loan term, the retailer decides the order quantity q, loan amount L, which is no more than the bank's credit limit $\overline{L} = \lambda cq$. After pledging inventory to the bank, the retailer receives loan and pays cq to procure the inventory. At the end of the sales season, demand is realized. We denote the realization of $\widetilde{u}$ as u. The retailer earns revenue by both realizing market sales $p\min(u, q)$ and liquidating leftover inventory $s\max(q-u, 0)$. The retailer is of limited liability and repays his loan obligation to the extent possible. As such, the retailer will not default if his revenue $p\min(u, q) + s\max(q-u, 0)$ is no less than the loan obligation $L(1+r)$. Otherwise, the retailer defaults and transfers all his remaining assets to the bank.

Before closing, we note that the sequence of events in our model is consistent with other papers focusing on inventory financing (Alan & Gaur, 2018; Buzacott & Zhang, 2004). This sequence differs from some other papers in the OM-Finance Interface literature, which assume that the retailer acts as the Stackelberg leader that proposes the borrowing amount and the bank responds with an equilibrium interest rate (Kouvelis & Zhao, 2011; Tang et al., 2018; Xu & Birge, 2004). However, as shown later, this bank-leading formulation of the game not only leads to the same inventory decision as under the retailer-lead formulation under a specific case, but also better enables us to extend the model along different dimensions in Section 6.

4 | LOAN PRICING UNDER RAROC

We conduct the analysis by backward induction, starting with the retailer's inventory decision under exogenous loan terms (r, λ), and then the bank's choice of loan terms to satisfy the RAROC criterion in anticipation of the retailer's inventory decision.

4.1 | Retailer's order quantity under exogenous loan terms

According to the model, the retailer's profit at the end of the sales season under inventory quantity q and borrowing amount L is

$$\Pi(q, L) = (\underbrace{p\min(u,q)}_{\text{Sales revenue}} + \underbrace{s\max(q-u,0)}_{\text{Salvage value}} + \underbrace{A + L - cq}_{\text{Leftover cash}} - \underbrace{L(1+r)}_{\text{Loan obligation}})^{+} - A. \quad (2)$$

Since the retailer is of limited liability, his cash position after repaying the bank's loan, which is $\Pi(q, L) + A$, will always be non-negative. As the interest rate of the bank loan is no less than the risk-free rate, the retailer only borrows the shortage amount to pay his procurement cost in full, that is, $L = (cq - A)^{+}$. When the retailer borrows, if the combined value of the sales revenue and salvage value $p\min(u, q) + s\max(q-u, 0)$ is smaller than the loan principal and interest $L(1+r)$, or equivalently, if the realized demand u is smaller than the default threshold $k(q) := \max\left(0, \frac{L(1+r)-sq}{p-s}\right)$, the loan defaults. Note that when $r < \frac{s}{\lambda c} - 1$, that is, $\overline{L}(1+r) < sq$, the salvage value of the inventory alone is sufficient for repaying the loan, and hence the retailer never defaults regardless of the order quantity. Thus, the following analysis focuses on the non-trivial case with $r \geq \frac{s}{\lambda c} - 1$. Maximizing his expected profit $\mathbb{E}[\Pi(q, L)]$ under the bank's credit limit $L \leq \overline{L} = \lambda cq$, the retailer obtains his optimal order quantity as follows.

Lemma 1 *Given the bank's loan price r and λ, $\exists$ thresholds r_n and r_{bf} and threshold function $r_{bc}(\lambda)$ such that the retailer's financing strategy and the optimal order quantity $q(r, \lambda)$ are as follows.*

1. *When $r \geq r_n$, the retailer does not borrow, and $q(r, \lambda) = \min\left(q_n, \frac{A}{c}\right)$ where $q_n := \overline{F}^{-1}\left(\frac{c-s}{p-s}\right)$.*
2. *When $r \in [r_{bf}, r_n)$, the retailer borrows a risk-free loan, and $q(r, \lambda) = q_{bf}(r) := \overline{F}^{-1}\left(\frac{c(1+r)-s}{p-s}\right)$.*
3. *When $r \in [r_{bc}(\lambda), r_{bf})$, the retailer borrows a risky loan, and $q(r, \lambda) = q_{bn}(r)$, which follows:*

$$\overline{F}(q_{bn}(r)) = \frac{c(1+r)-s}{p-s}\overline{F}(k(q_{bn}(r))). \quad (3)$$

The loan amount satisfies $L < \overline{L} = \lambda cq(r, \lambda)$, that is, the credit limit is not binding.

4. *When $r < r_{bc}(\lambda)$, the retailer borrows a risky loan, the order quantity $q(r, \lambda) = q_{bc}(\lambda) := \frac{A}{c(1-\lambda)}$. The loan amount $L = \overline{L} = \lambda cq(r, \lambda)$, that is, the credit limit is binding.*

For expositional brevity, the expressions of thresholds r_n and r_{bf} and function $r_{bc}(\lambda)$ are given in the proof of Lemma 1 in Appendix C online. These thresholds divide the retailer's optimal order quantity into four regions, as illustrated in Figure 1. When the interest rate is sufficiently high $(r \geq r_n)$, the retailer does not borrow. In this region, if the retailer has abundant initial asset $(A \geq cq_n)$, he orders up to the classical newsvendor quantity q_n; otherwise, the retailer uses up all his initial asset and orders A/c. As the bank lowers the interest rate, the retailer begins to borrow. Specifically, when the interest rate is between r_{bf} and r_n, the retailer borrows a small amount. In this case, as the inventory's liquidation value is

[4]Following practice (Cummings & Durrani, 2016), we assume that the bank's type (its regulatory capital approach) is exogenous to our model.

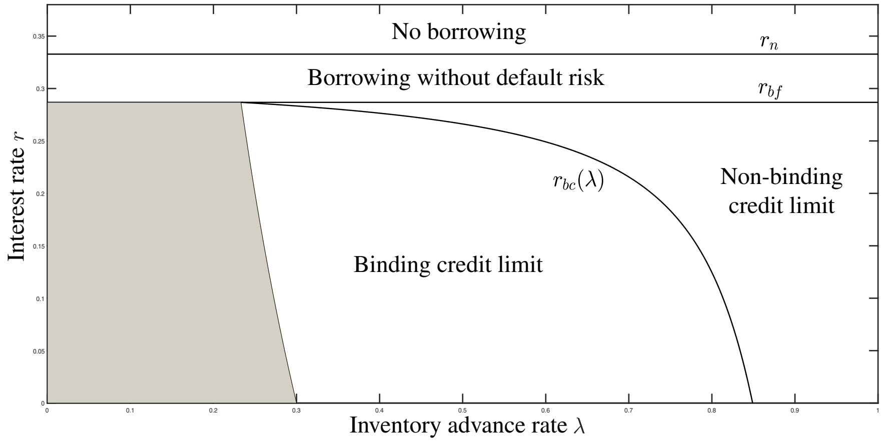

FIGURE 1 Interest rate boundaries. Parameter values for the above figure: $p = 1.5$, $c = 1$, $s = 0.3$, $A = 1.5$, demand follows an exponential distribution with mean 10. Shaded region corresponds to the case with $r < \frac{s}{\lambda c} - 1$, which is not of primary interest in our article as the value of salvage inventory alone is sufficient for replaying the loan, and hence the retailer never defaults regardless of the order quantity [Colour figure can be viewed at wileyonlinelibrary.com]

enough to repay the bank's loan obligation, the loan is not subject to any default risk. As the interest rate decreases, the retailer borrows more and the loan is subject to default risk. In this region, the retailer's inventory decision depends crucially on the inventory advance rate (λ). When λ is sufficiently high, which corresponds to the non-binding credit limit region in Figure 1, the bank's credit limit exceeds the retailer's actual financing need, thus inventory advance rate has no impact on the retailer's ordering decision. This is reflected in the fact that the retailer's order quantity in this region, $q_{bn}(r)$, does not depend on λ. However, for a lower λ, the retailer's order quantity is limited by the inventory advance rate. As such, $q_{bc}(\lambda)$ increases in λ.

Corollary 1 *r_n and r_{bf} decrease in the retailer's asset (A). $r_{bc}(\lambda)$ decreases in A and λ.*

The decreasing relationship between interest rate boundaries (r_n, r_{bf}, and $r_{bc}(\lambda)$) and the retailer's initial asset confirms that low-risk retailers (with high initial assets) are less willing to borrow if the bank charges a high interest rate. On the other hand, low-risk retailers are also less likely to encounter a binding credit limit.

4.2 | Loan terms under the standardized approach

With the retailer's best response under exogenous loan terms, we move to examine the bank's decision of loan terms under the RAROC criterion. We first consider the case when the amount of regulatory capital under RAROC is calculated under the standardized approach. The standardized approach is established in the Basel I Accord (Basel Committee, 1988) as the basic method for banks to calculate their regulatory capital. Under this approach, the regulatory capital in Equation (1) is calculated as a fixed percentage of the face value of the loan, regardless of the loan's underlying risk. That is,

$$C^S = \beta^S L, \tag{4}$$

where β^S is the capital adequacy ratio under the standardized approach.[5] The Basel I Accord (Basel Committee, 1988) specifies β^S to be at least 8%. In practice, β^S vary in different countries according to their own regulations. For example, after the 2008 Global Financial Crisis, US strengthened its capital requirement by increasing β^S to 10.5% (Walter, 2019). In addition, as it is unreasonable for banks to hold more regulatory capital than the maximum loss of the loan, we assume $\beta^S < 1 - s/c$. The calculation of C^S implies as long as two firms borrow the same amount, a standardized bank reserves the same amount of capital for the two firms, irrespective of the possible differences of the riskiness of the loans. For this reason, the standardized approach is generally recognized as risk-insensitive.

To calculate the loan's expected loss, we note that if realized demand u is less than the retailer's default threshold $k(q) = \max\left(0, \frac{L(1+r)-sq}{p-s}\right)$, the retailer defaults and transfers the remaining asset $sq(r,\lambda) + (p-s)u$ to the bank. Therefore, the bank's expected loss (EL) in Equation (1) is

$$EL = (p-s)\left(k(q(r,\lambda)) - \int_0^{k(q(r,\lambda))} \overline{F}(u)\,\mathrm{d}u\right). \tag{5}$$

As the bank collects an interest income of rL when the loan does not default, following Equation (1), the RAROC criterion under the standardized approach and loan term (r, λ) can be expressed as[6]

$$R^S(r,\lambda) = \frac{rL - (p-s)\left[k(q(r,\lambda)) - \int_0^{k(q(r,\lambda))} \overline{F}(u)\,\mathrm{d}u\right]}{\beta^S L}. \tag{6}$$

Let $r^S(\lambda;\delta)$ be the interest rate such that under this rate, the inventory advance rate λ, and the retailer's equilibrium order quantity $q(r^S(\lambda;\delta),\lambda)$ from Lemma 1, the bank's RAROC

[5]We use superscript S and I to represent the standardized approach and the IRB approach, respectively.
[6]When $\beta^S = 0$, the RAROC criterion in fraction format becomes irrelevant and the bank prices according to the traditional expected profit criterion.

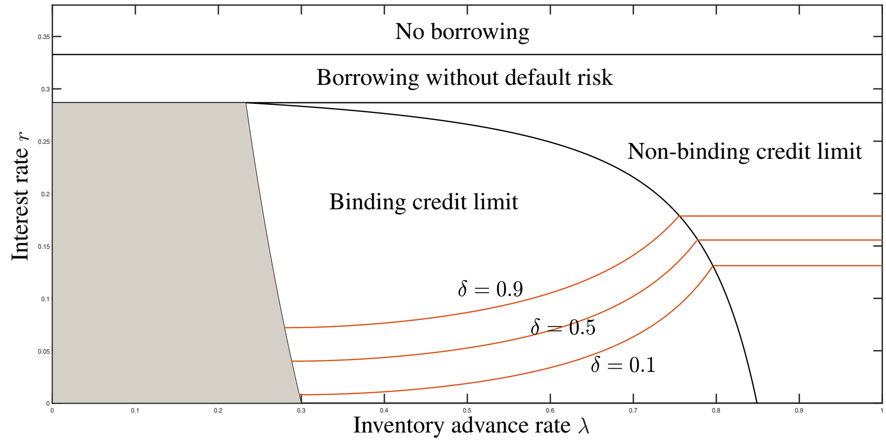

FIGURE 2 Banks's RAROC indifference map under the standardized approach. Parameter values: $p = 1.5$, $c = 1$, $s = 0.3$, $A = 1.5$, $\beta^S = 8\%$, demand follows an exponential distribution with mean 10 [Colour figure can be viewed at wileyonlinelibrary.com]

equals to δ, that is, $R^S(r^S(\lambda;\delta),\lambda) = \delta$.[7] Put differently, using RAROC as the sole criterion, the bank is indifferent along the curve $(\lambda, r^S(\lambda;\delta))$. The properties of these RAROC indifference curves are summarized in the following proposition and further illustrated in Figure 2.

Proposition 1 *When the bank calculates her regulatory capital under the standardized approach, her RAROC indifference curve $(\lambda, r^S(\lambda;\delta))$ satisfy:*

1. *When $r^S(\lambda;\delta) \in (r_{bc}(\lambda), r_{bf})$ (the non-binding credit limit region), $r^S(\lambda;\delta)$ increases in δ.*
2. *When $r^S(\lambda;\delta) \le r_{bc}(\lambda)$ (the binding credit limit region), $r^S(\lambda;\delta)$ increases in δ and λ. For $\lambda > 0.5$, $r^S(\lambda;\delta)$ is convex on λ.*

According to Proposition 1, when the bank's RAROC indifference curve $(\lambda, r^S(\lambda;\delta))$ falls in the non-binding credit limit region, $r^S(\lambda,\delta)$ is independent of λ as the retailer orders a fixed quantity independent of λ. On the other hand, as the per unit cost of capital (δ) increases, the bank demands for a higher RAROC, and hence raises the interest rate to increase her interest income.

Similarly, when the indifference curve falls in the binding credit limit region, the increase in δ also leads to a higher interest rate when λ is kept constant. In addition, instead of raising r, the bank may lower the inventory advance rate (λ) to reduce the regulatory capital requirement, which also results in a higher RAROC. This is illustrated in Figure 2, which shows that the indifference curve $(\lambda, r^S(\lambda;\delta))$ shifts up and left as δ increases. This upward shape of the indifference curve also reveals that, when holding δ constant, the bank charges a higher interest rate if the retailer is allowed to increase his leverage (a greater λ). Finally, the convexity of $r^S(\lambda;\delta)$ indicates that when the retailer has already borrowed a large amount, the required interest rate increase for an additional unit of borrowing is higher than if the retailer has borrowed a small amount.

4.3 | Loan terms under the IRB approach

Unlike the standardized approach, the internal-rating based (IRB) approach improves the risk-sensitivity of the RAROC criterion by calculating the regulatory capital as the difference between Value-at-Risk (VaR) and expected loss (Basel Committee, 2006; Cummings & Durrani, 2016; Krüger et al., 2018; Ruthenberg & Landskroner, 2008), where VaR is the quantile of the loan's loss distribution corresponding to a certain confidence level α. That is, $\text{Prob}\,(\,(p-s)(k(q(r,\lambda)) - u) \le VaR\,) = \alpha$, or equivalently,

$$VaR = (p-s)[k(q(r,\lambda)) - F^{-1}(1-\alpha)]. \tag{7}$$

The confidence level α used in calculating VaR is often related to the bank's desired rating and is required to be no less than 99.9% according to the Basel II Accord (Basel Committee, 2006, paragraph 346). For example, to maintain a credit rating of AA, Bank of America capitalizes each of its business units according to a 99.97% confidence level (Zaik et al., 1996). Under such high confidence levels, the associated VaR is often significantly greater than the loan's expected loss. However, when the retailer has a very low risk level, the bank may still estimate the loan as having very low risk (VaR is close to zero). In this case, Basel II also requires a minimum capital amount of $\beta^{IS}L$ to be reserved for contingencies, where β^{IS} is the minimum required capital adequacy ratio under the IRB approach (Basel Committee, 2006, paragraphs 285 and 295). This minimum capital adequacy ratio is often significantly less than that required by the standardized approach (β^S). Combining the above two scenarios, the regulatory capital under the IRB approach C^I is:

$$C^I = \max\,(VaR - EL, \beta^{IS}L). \tag{8}$$

[7] We show that real solutions exist for $R^S(r^S(\lambda;\delta),\lambda) = \delta$ in Technical Lemma 3 in Appendix C online.

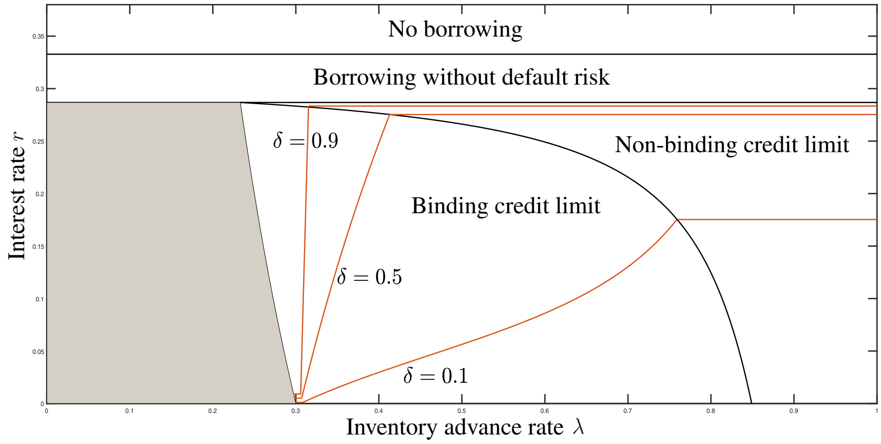

FIGURE 3 RAROC indifference map under the IRB approach. Parameter values: $p = 1.5$, $c = 1$, $s = 0.3$, $A = 1.5$, $\beta^{IS} = 1\%$, $\alpha = 99.9\%$, demand follows an exponential distribution with mean 10 [Colour figure can be viewed at wileyonlinelibrary.com]

Therefore, the RAROC under the IRB approach and loan term (r, λ) can be expressed as:

$$R^I(r,\lambda) = \frac{rL - (p-s)\left[k(q(r,\lambda)) - \int_0^{k(q(r,\lambda))} \overline{F}(u)\,\mathrm{d}u\right]}{\max\left(VaR - EL, \beta^{IS}L\right)}, \quad (9)$$

where EL and VaR follows Equations (5) and (7), respectively. Similar to the case under the standardized approach, we define $r^I(\lambda;\delta)$ as $R^I(r^I(\lambda;\delta),\lambda) = \delta$. That is, the bank is indifferent along the curve $(\lambda, r^I(\lambda;\delta))$ in terms of RAROC. As illustrated in Figure 3, these indifference curves exhibit the same monotonic properties as summarized in Proposition 1 (see the proof in Appendix xxxx for the formal statement). However, we note that within the binding credit limit region, $r^I(\lambda;\delta)$ increases slowly in λ when λ is sufficiently small, and then increases sharply in λ. This two-phase structure is due to the way that the regulatory capital is calculated under the IRB approach: when λ is small, the retailer is only able to borrow a small amount, exposing the bank to a minimal level of risk. Thus, her regulatory capital is governed by $C^I = \beta^{IS}L$. However, as λ increases, the retailer borrows more and the loan becomes riskier. Thus, the amount of regulatory capital held by the bank becomes $VaR - EL$, which is more sensitive to the retailer's borrowing amount than $\beta^{IS}L$. Thus, when extending the bank's credit limit (λ increases), the bank needs to increase the interest rate at a faster pace to maintain a constant RAROC.

Corollary 2 *Given the cost of capital δ, when $r^S(\lambda;\delta)$, $r^I(\lambda;\delta) < r_{bc}(\lambda)$, $\frac{\partial r^I(\lambda;\delta)}{\partial\lambda} > \frac{\partial r^S(\lambda;\delta)}{\partial\lambda}$ for sufficiently large λ.*

The slope of a RAROC indifference curve captures the necessary amount of interest rate increase as the bank extends the retailer's credit limit, in order to ensure the required RAROC (δ). In the binding region, for sufficiently large λ, C^I is calculated as $VaR - EL$, which is more sensitive to the loan's underlying risk than C^S. Therefore, for an additional unit of borrowing, the IRB bank needs to reserve more regulatory capital than the standardized bank. To compensate for this bigger capital regulation cost, the IRB bank charges a higher interest rate for the additional unit of borrowing, leading to steeper RAROC indifference curves in Figure 3 than those in Figure 2.

5 | INVENTORY DECISION UNDER THE PARETO DOMINANT LOAN TERM

According to the previous result, with RAROC as the sole criterion, a standardized bank is indifferent among all loan terms along the curve $(\lambda, r^S(\lambda;\delta))$. Similarly, an IRB bank is indifferent among all loan terms along the curve $(\lambda, r^I(\lambda;\delta))$. However, the retailer's inventory decision and profitability clearly vary across different (λ, r) pairs along the curve. As illustrated in Figure 4, along a standardized bank's indifference curve $(\lambda, r^S(\lambda;\delta))$ with $\delta = 0.1$, as λ increases, while the retailer's order quantity always increases, his expected profit first increases and then decreases, reaching the maximum when $(\lambda, r^S(\lambda;\delta))$ falls within the binding credit limit region. By the definition of $r^S(\lambda;\delta)$, among all $(\lambda, r^S(\lambda;\delta))$, the pair that maximizes the retailer's expected profit is the *Pareto dominant* one when the bank's sole criterion is to meet her RAROC requirement. This Pareto dominant loan term is also likely to be the equilibrium one when the bank is driven by market competition or has an incentive to build long-term relationships with the borrowing firm. Thus, in this section, we focus on this Pareto dominant loan term.[8]

5.1 | Inventory decision under the standardized approach

When a standardized bank offers the Pareto dominant loan term to the retailer, the retailer's financing strategy and

[8]In practice, due to other considerations, the bank may not offer this loan term. See Section 6 for how banks' other considerations influence the loan term and the retailer's inventory decision.

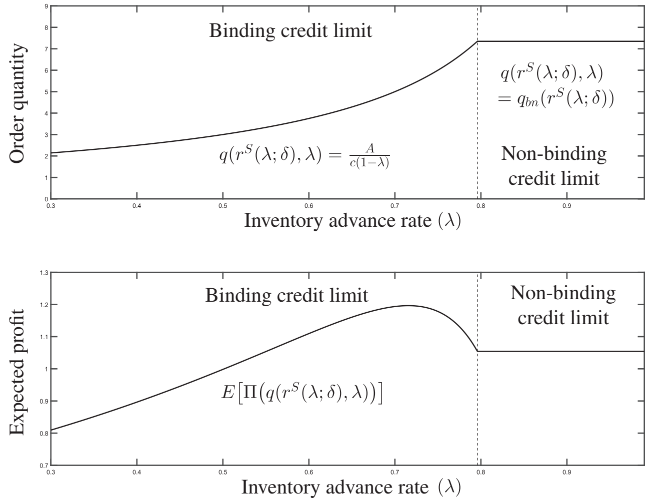

FIGURE 4 Retailer's order quantity and expected profit on the RAROC indifference curve. Parameter values: $p = 1.5$, $c = 1$, $s = 0.3$, $A = 1.5$, $\beta^S = 8\%$, $\delta = 0.1$, demand follows an exponential distribution with mean 10

equilibrium order quantity q^{S*} are summarized in the following proposition.

Proposition 2 *When the standardized bank offers the Pareto dominant loan term, the loan term* (λ^{S*}, r^{S*}) *and the retailer's order quantity* q^{S*} *follow*:

1. *If* $A \geq cq^S$, *where* $q^S := \overline{F}^{-1}\left(\frac{c(1+\beta^S\delta)-s}{p-s}\right)$, *the retailer does not borrow, and* $q^{S*} = \min\left(q_n, \frac{A}{c}\right)$.
2. *If* $A < cq^S$, *the bank sets* $\lambda^{S*} = 1 - \frac{A}{cq^S}$ *and* $r^{S*} = r^S(\lambda^{S*};\delta)$, *where* $r^{S*} < r_{bc}(\lambda^{S*})$ *for* $A > 0$. *The retailer borrows a risky loan, and* $q^{S*} = q^S$.

Proposition 2 shows how the retailer's inventory level depends on his initial asset when facing a standardized bank. When the retailer has an abundant initial asset ($A \geq cq_n$), he can afford the traditional newsvendor quantity q_n without external financing. When the initial asset is in the intermediate range ($A \in [cq^S,\ cq_n)$), the retailer uses up all the initial asset to purchase inventory A/c, but does not borrow given the strictly positive interest cost. Finally, as the retailer's initial asset further decreases, the retailer borrows and orders less than the traditional newsvendor amount. This is because for every additional unit ordered, the retailer needs to borrow c from the bank. Under the standardized approach, the bank is required to hold $\beta^S c$ amount of capital, incurring a cost of $\delta\beta^S c$, which is eventually passed to the retailer. Therefore, the retailer's overage cost is the sum of unit purchasing cost c and the bank's unit cost of regulatory capital $c\beta^S\delta$, leading to the order quantity q^S, which is lower than the traditional newsvendor, and is constant for any A that is sufficiently small ($A < cq^S$). The expression of q^S further reveals that the retailer's order quantity decreases with the bank's cost of capital (δ) and the regulatory capital adequacy ratio (β^S). Finally, we note that in order to induce this order quantity, the Pareto dominant loan term (λ^{S*}, r^{S*}) lays in the binding credit limit region in Figure 2. This confirms that the observation we made in Figure 4 is a general phenomenon. Thus, inventory advance rate is a necessary lever the bank needs to apply in order to deter the retailer from over-borrowing.

5.2 | Inventory decision under the IRB approach

Similarly, the retailer's financing strategy and order quantity when facing an IRB bank offering the Pareto dominant loan term under the IRB approach is summarized in the following proposition.

Proposition 3 *When facing an IRB bank offering the Pareto dominant loan term* (λ^{I*}, r^{I*}), *there exist asset thresholds* A^{IB} *and* A^{IV} *with* $A^{IB} > A^{IV}$ *such that*:

1. *if* $A \geq cq^{IS}$, *where* $q^{IS} := \overline{F}^{-1}\left(\frac{c(1+\beta^{IS}\delta)-s}{p-s}\right)$, *the retailer does not borrow, and* $q^{I*} = \min\left(q_n, \frac{A}{c}\right)$;
2. *if* $A < cq^{IS}$, *the retailer borrows, his order quantity* q^{I*} *and the regulatory capital* C^I *that the bank is required to hold for the loan are*:
   a. *if* $A \in [A^{IB},\ cq^{IS})$, $q^{I*} = q^{IS} := \overline{F}^{-1}\left(\frac{c(1+\beta^{IS}\delta)-s}{p-s}\right)$. $C^I = \beta^{IS}L$;
   b. *if* $A \in [A^{IV},\ A^{IB})$, $q^{I*} = q^{IB}(A) := \frac{(p-s)F^{-1}(1-\alpha)+(1-(1-\delta)\beta^{IS})A}{(1-(1-\delta)\beta^{IS})c-s}$. $C^I = \beta^{IS}L = VaR - EL$;
   c. *if* $A < A^{IV}$, $q^{I*} = q^{IV} := \overline{F}^{-1}\left(\frac{c-s}{(p-s)(1-\delta)}\right)$. $C^I = VaR - EL$. (λ^{I*}, r^{I*}) *satisfies*: $\lambda^{I*} = 1 - \frac{A}{cq^{I*}}$ *and* $r^{I*} = r^I(\lambda^{I*};\delta)$, *where* $r^{I*} < r_{bc}(\lambda^{I*})$ *for* $A > 0$.

At a high level, the retailer's financing strategy when facing an IRB bank is similar to that when facing a standardized bank. That is, the retailer only borrows from the IRB bank when A is not sufficiently high. However, in the borrowing region ($A < cq^{IS}$), the retailer's order quantity under the IRB approach, as shown in Figure 5, is more sensitive to the retailer's initial asset compared to that under the standardized approach. This is due to how the regulatory capital is calculated under the IRB approach. Specifically, when the retailer's initial asset is reasonably high ($A \geq A^{IB}$), the VaR of the loan is very low. Thus, the regulatory capital C^I is determined by $\beta^{IS}L$, which is structurally similar to the capital required by the standardized bank ($C^S = \beta^S L$). However, as $\beta^{IS} < \beta^S$, compared to the standardized approach, the IRB

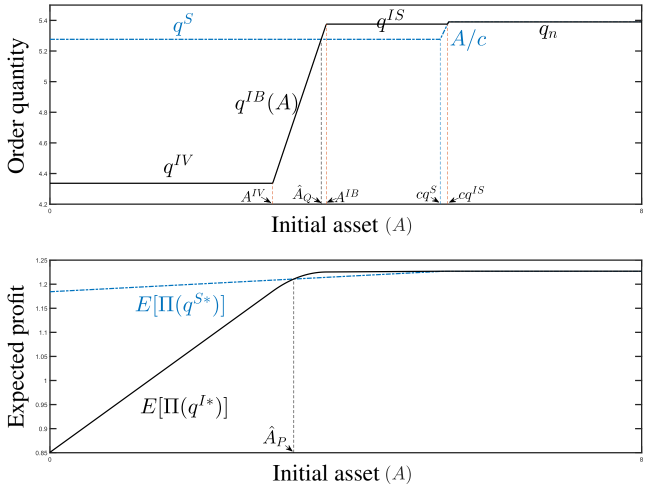

FIGURE 5 Retailer's equilibrium order quantity and expected profit under Pareto dominant loan terms. Blue dashed lines correspond to the results under the standardized approach, and black solid lines to those under the IRB approach. Parameter values for the above figure: $p = 1.5$, $c = 1$, $s = 0.3$, $\beta^{IS} = 1\%$, $\beta^{S} = 8\%$, $\alpha = 99.9\%$, demand follows an exponential distribution with mean 10 [Colour figure can be viewed at wileyonlinelibrary.com]

approach leads to a lower interest rate, and consequently a higher order quantity, that is, $q^{IS} > q^{S}$. As a result, the IRB loan also induces the retailer to borrow under a larger region of initial asset ($A < cq^{IS}$). At the other extreme, when the initial asset is extremely low ($A < A^{IV}$), the loan becomes significantly riskier, and hence the regulatory capital C^{I} for each loan equals $VaR - EL$, which is more sensitive to the order quantity q than not only $\beta^{IS}L$, but also $\beta^{S}L$. Thus, the retailer's inventory in this region, q^{IV}, is even smaller than q^{S} under the standardized approach. In between ($A \in (A^{IV}, A^{IB})$), the amount of regulatory capital calculated by $VaR - EL$ is equal to that calculated by $\beta^{IS}L$, and the retailer's order quantity $q^{IB}(A)$ depends directly on the asset level A, laying between q^{IV} and q^{IS}. Finally, we note that similar to the loan terms under the standardized approach, under the IRB approach, (λ^{I*}, r^{I*}) also falls in the interior of the binding credit limit region, confirming that under the IRB approach, the inventory advance rate is also necessary to lead the retailer to choose the order quantity that maximizes his expected profit.

5.3 | Retailer's preference between standardized and IRB banks

Based on the retailer's inventory decision when borrowing from either a standardized or an IRB bank, the following result presents the retailer's preference between the two types of banks by comparing the retailer's expected profit under the two types of banks when the retailer has access to both types of banks.

Proposition 4 *With access to both a standardized bank and an IRB bank with the same cost of capital* δ, $\exists \hat{A}_P, \ \hat{A}_Q$ *where* $\hat{A}_P \le \hat{A}_Q \le A^{IB}$, *such that:*

1. *The retailer prefers to borrow from the IRB bank if and only if* $A \in (\hat{A}_P, \ cq^{IS})$.
2. *The retailer's order quantity when borrowing from the IRB bank is greater than that when borrowing from the standardized bank if and only if* $A \in (\hat{A}_Q, \ cq^{IS})$.

$\hat{A}_P$ *increases in the IRB bank's confidence level* (α) *and minimum capital adequacy ratio* (β^{IS}), *and decreases in the standardized bank's capital adequacy ratio* (β^{S}).

As illustrated in the bottom panel of Figure 5, Proposition 4 reveals that when the retailer's asset level is sufficiently low ($A < \hat{A}_P$), he prefers to borrow from standardized banks, and this also results in a higher order quantity. On the other hand, IRB banks are preferred by retailers with relatively high asset levels ($A \in (\hat{A}_P, \ cq^{IS})$). However, in this situation, borrowing from IRB banks does not necessarily lead to a higher amount of inventory, which proxies consumer welfare. Specifically, when $A \in [\hat{A}_Q, \ cq^{IS})$, the retailer's banking preference coincidences with inventory efficiency. Thus, the retailer's preference and consumer welfare are consistent. However, for $A \in (\hat{A}_P, \ \hat{A}_Q)$, while the retailer still prefers the IRB bank, consumers benefit more if the retailer actually borrows from the standardized bank. This discrepancy originates from the underlying drivers of the retailer's profit and order decision. While both are influenced by financing costs, the retailer's profit is a reflection of the cumulative financing cost, while order quantity is driven by the marginal one. For low-risk retailers, the regulatory capital requirement is lower under the IRB approach ($\beta^{IS}L$), resulting in a higher net margin (operational margin net financing cost), and hence a higher order quantity. As a result, in this region, the IRB loan becomes increasingly more advantageous in terms of the retailer's profit as the retailer's asset level decreases. However, as the retailer becomes riskier, the regulatory capital under the IRB approach ($VaR - EL$) becomes more sensitive to the underlying risk, quickly lowering the retailer's net margin and the order quantity. As the retailer's payoff is less sensitive to this marginal effect, the IRB loan manages to maintain its advantage in the retailer's profit for $A \in (\hat{A}_P, \ \hat{A}_Q)$, but this advantage eventually disappears as the retailer's risk increases.

Besides the retailer's own risk profile (i.e., initial asset level), parameters related to banking regulation also influence the retailer's preference toward the two types of banks. For example, a tightening requirement under the standardized approach (greater β^{S}) or a loosening requirement under the IRB approach (smaller α or β^{IS}) will make the IRB bank more attractive by enlarging the region wherein the IRB bank is preferred.

To quantify the economic impact of the retailer's choice between standardized and IRB banks, we conduct a calibrated numerical study. When choosing banking regulatory parameters, we set $\beta^{S} = 8\%$, $\beta^{IS} = 0.1\%$, and $\alpha = 99.9\%$

TABLE 1 Calibrated parameters

Scenarios	Profit margins 25th	50th	75th
Low variability ($cv = 1.16$)	0.28	0.46	0.67
Medium variability ($cv = 1.38$)	0.19	0.29	0.44
High variability ($cv = 1.62$)	0.17	0.23	0.33

according to Basel Committee (2006). The banks' cost of capital is set to be 5% according to Damodaran (2018).

On the operations side, calibrating a newsvendor model requires both demand distribution and profit margin. For demand distribution, we follow Jain et al. (2021), who use the A. C. Nielsen Homescan panel data set over 2004–2009 to estimate the monthly coefficient of variation (cv) for log-normal distribution across various industries. As in Jain et al. (2021), we classify industries into three groups characterized by low, medium, and high levels of cv. According to the estimate in Jain et al. (2021), we use the 25th, 50th, and 75th percentile of the monthly cv across all industries as the representative cv for low ($cv = 2.01$), medium ($cv = 2.39$), and high ($cv = 2.80$) scenarios. Next, we transform monthly cv into quarterly cv by assuming independence of demand across months. For example, in the low scenario, monthly cv of 2.01 corresponds to quarterly cv of $\frac{2.01}{\sqrt{3}} = 1.16$. Similarly, in the medium scenario, quarterly $cv = \frac{2.39}{\sqrt{3}} = 1.38$, and in the high scenario, quarterly $cv = \frac{2.8}{\sqrt{3}} = 1.62$.

For profit margin, we use the Worldscope 2004–2009 data set, which contains quarterly financial information for 30 622 public firms across 899 industries. We focus on the 105 industries considered in Jain et al. (2021), with 3271 firms and 46 296 observations on firm-quarter financials. We estimate quarterly profit margin for the three industry groups characterized by low, medium, and high levels of cv as detailed above. For firms within each cv group, we use "revenues (R)" and "costs of goods sold (COGS)" to construct quarterly profit margin $= (R - COGS)/R$ for each firm that belong to the industries in the low group. Next, a firm-level representative profit margin is obtained by taking the median of profit margin across various quarters. Finally, we use the 25th, 50th, and 75th percentile of profit margin across firms within this cv group as the representative profit margins for this group. Table 1 presents the calibrated operational parameters. As profit margin $= (p - c)/(p - s)$, we can roughly infer sales price p from profit margin.[9]

Figure 6 presents the relative profit difference between standardized and IRB banks across low, medium, and high cv industry groups based on the above parameters. Relative profit difference (y-axis) is defined as the firm's profit difference between standardized and IRB banks as a percentage of the firm's profit under standardized banks, that is, $(\Pi^S - \Pi^I)/\Pi^S$. Therefore, this value is positive (negative) when the firm's optimal banking choice is standardized (IRB) banks. We use this measure to quantify the economic impact of choosing standardized and IRB banks. On the x-axis, we normalize the firm's initial asset A by the amount of capital the firm would need to finance the unconstrained level of inventory, that is, cq^{IS}. As shown, across different demand variabilities and profit margins, it is robust that firms with asset (A) approximately less than 80% of the financially unconstrained procurement cost (cq^{IS}) would prefer standardized banks over IRB banks. In general, the potential benefit of using a standardized loan (up to 30%) is much more economically significant than the potential benefit of using an IRB loan (1%). This asymmetry suggests that it is more crucial for the more financially constrained firms (low A) to borrow from a standardized bank than the less financially constrained firms borrowing from an IRB one.

Further, we note that the relative benefit of using a standardized bank varies significantly across different scenarios. In general, choosing standardized banks is most beneficial for industries with severe capital constraints, volatile demands, and low profit margins. For example, for a firm in the low cv group, the maximum relative advantage of using a standardized banks (when $A = 0$) is below 5% when the firm's profit margin is high (0.67), but jumps to more than 15% for firms with low profit margins. This is because when profit margin increases, the loan's risk decreases. As the IRB approach is more risk-sensitive than the standardized approach, the financing cost of IRB banks drops more significantly than standardized banks when profit margin increases, thus narrowing their performance gap. Similarly, a decrease in cv also reduces the risk of the loan. According to the calibrated parameters shown in Table 1, industries with lower cv also tend to have higher profit margin. Therefore, industries in the high cv group, such as cereal breakfast foods, chicken eggs, creamery butter, pet food, and paper products, are of high risk. The relative advantage of standardized banks over IRB banks in this group can be as high as 30%. However, industries in the low cv group, such as manufactured ice, lamp bulbs, electronics, perfumes, and cosmetics, are of low risk. The relative advantage of standardized banks over IRB banks in the low cv group reduces to less than 16%.

Finally, note that in Figure 6, we assume that the cost of capital (δ) is the same between standardized banks and IRB ones. In practice, due to the size advantage and superior risk management capability, IRB banks may enjoy a lower cost of capital than standardized banks. To evaluate how this difference could influence the firm's preference between standardized and IRB banks, we calculate the standardized banks' cost of capital (δ^S) under which the firm is indifferent between borrowing from standardized and from IRB banks with $\delta^I = 5\%$. As shown in Figure 7, the most financially constrained firms (A close to zero), regardless of the firm's demand volatility and profit margin, would prefer borrowing from standardized banks as long as δ^S is less than 50%, which far exceeds any realistic estimate of banks' cost of capital.

[9]We assume $s = 0$ as most of the industries we consider belong to the perishable food and beverage category.

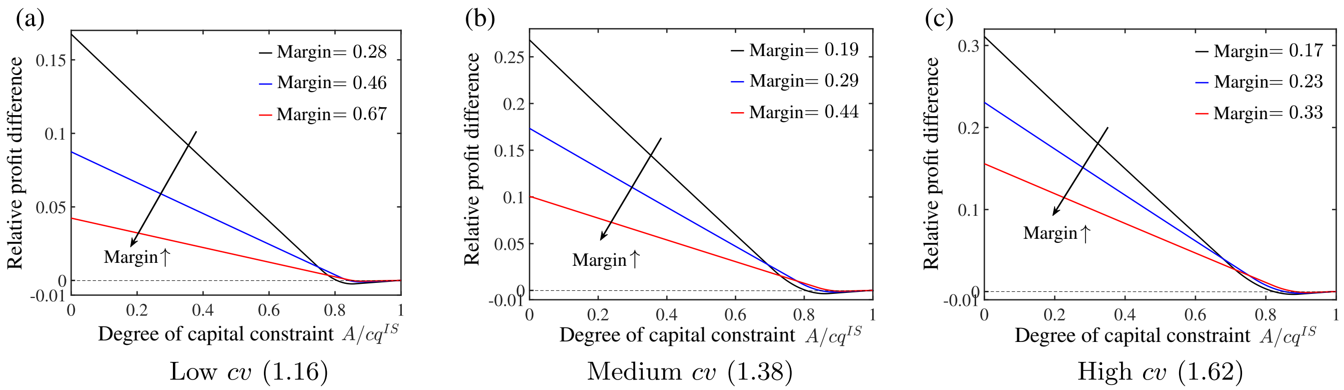

FIGURE 6 Relative profit difference between standardized and IRB banks under lognormal distribution. Relative profit difference defined as $(\Pi^S - \Pi^I)/\Pi^S$, where Π^S (Π^I) is the firm's profit when borrowing from a standardized bank (an IRB bank). cq^{IS} is the asset level above which the firm does not borrow. (A) Low cv (1.16). (B) Low cv (1.38). (C) Low cv (1.62) [Colour figure can be viewed at wileyonlinelibrary.com]

Thus, for those firms, standardized banks would remain as the preferred funding source even when their cost of capital is marginally higher than that of the IRB bank. However, for less financially constrained firms, a reasonably high δ^S could nudge them to choose borrowing from IRB banks. For example, when δ^S increases to 0.25, the proportion of firms favor standardized banks drops by 10%, and the rate of such drop increases as δ^S increases. This suggests that small standardized banks with deteriorating performances, which face increasing cost of capital δ^S, are more likely to lose loan customers to large IRB banks.

5.4 | Regulatory capital as a source of financial friction

Before closing this section, we note a connection between the above equilibrium quantities and those under an alternative game where the retailer first decides the order quantity and corresponding loan amount, and the bank then follows by competitively charging an interest rate (Xu & Birge, 2004). By removing corporate tax and replacing the bankruptcy cost in Xu and Birge (2004) by the bank's RAROC and regulatory capital consideration, we can calculate that under the alternative game, the retailer's payoff under order quantity q is: $(p-s)\int_0^q \overline{F}(u)\,\mathrm{d}u - (c-s)q - \delta C^j$ for $j = S, I$, where C^S (or C^I) is the regulatory capital that the bank is required to hold for the loan under the standardized (or IRB) approach.[10]

Corollary 3 *The retailer's order quantity under the Pareto dominant loan term* (λ^{j*}, r^{j*}) *for* $j = S, I$ *satisfies*

$$q^{j*} = \arg\max_q \; (p-s)\int_0^q \overline{F}(u)\,\mathrm{d}u - (c-s)q - \delta C^j, \quad (10)$$

where $C^S = \beta^S (A - cq)^+$ *and* $C^I = \max(\beta^{IS}(A - cq)^+,\ VaR - EL)$.

As Corollary 3 reveals, the retailer's order quantity under the Pareto dominant loan term is also optimal under the alternative game where the bank responds to the retailer's order quantity by setting the interest rate competitively. In fact, we can also show that the equilibrium interest rates under these two games are also the same. Nevertheless, the loan terms that lead to this decision under these two formulations depend crucially on the sequence of the events. Specifically, when the bank has the flexibility to react to the retailer's order quantity, interest rate is the only lever needed to prevent the retailer from over-borrowing. However, when the bank needs to set the loan terms before the retailer's ordering decision, the bank needs to use inventory advance rate together with interest rate to induce the same inventory decision from the retailer. This is reflected by the fact that the Pareto dominant loan terms lay within the interior of the binding credit limit region. This result complements the extant literature on the role of inventory advance rate (e.g., Alan & Gaur, 2018) by proposing an alternative explanation on the widespread usage of a quantity lever (inventory advance rate) in addition to the price one (interest rate) for asset-based loans.

In addition, through the retailer's payoff under the alternative game formulation, we can clearly observe that when the banks offer the Pareto dominant loan terms, the fundamental market imperfection that prevents the retailer from achieving the financial unconstrained inventory level (q_n) is the requirement of regulatory capital (C^S or C^I) and the cost associated to it (δ). This corresponds to our observation that the retailer's payoff function under the alternative formulation is identical to the classic newsvendor one when $\delta C^j = 0$. The fact that the regulatory capital serves as a form of financial friction has two implications. First, despite the fact that the intention of imposing regulatory capital is to improve the stability of the global banking system, it also has the unintended consequence of aggravating the already heavy financial burden faced by small businesses and distorting their operational decisions.

Second, regulatory capital as a financial friction affects the retailer's order quantity differently from other well-studied market frictions, such as bankruptcy cost. As shown by Xu and Birge (2004), when borrowing a risky loan, the retailer's inventory quantity in the presence of bankruptcy cost continues to drop as the retailer's asset level decreases. However, with regulatory capital as the sole form of financial

[10] We refer the readers to Appendix B for details.

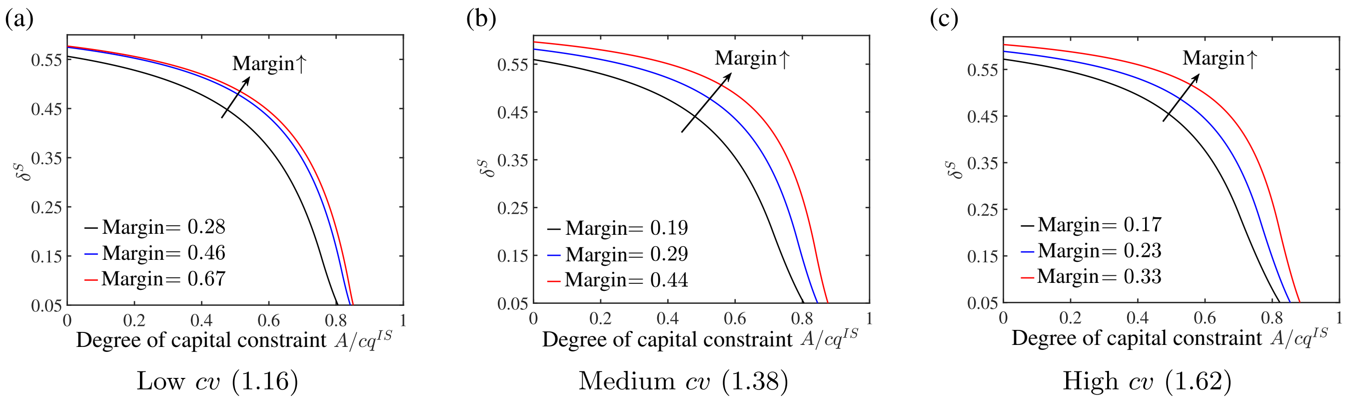

FIGURE 7 Standardized Bank's cost of capital (δ^S) under which the retailer is indifferent between standardized and IRB banks with $\delta^I = 5\%$. (A) Low cv (1.16). (B) Low cv (1.38). (C) Low cv (1.62) [Colour figure can be viewed at wileyonlinelibrary.com]

friction, due to its specific form, the retailer's inventory decision is independent of his asset level when A is sufficiently small, specifically, when $A < cq^S$ with standardized banks, and $A < A^{IV}$ with IRB banks. This suggests that while the retailer's profit is still sensitive to his asset level in this region, consumers can enjoy a relatively reliable service level when regulatory capital is the main source of financial friction.

6 | EXTENSIONS

In the above section, given that the bank's RAROC criterion is satisfied, we assume that the bank acts in the interest of the retailer when offering the loan terms. However, in practice, the bank's choice of loan terms may be subject to other considerations. In this section, we consider two of such considerations: when the bank is subject to a cap on interest rate, and when the bank's incentive is to maximize her loan size (empire building).

6.1 | Impact of interest rate cap

In practice, bank are often subject to interest rate regulations and cannot freely charge interest rates. Indeed, a 2014 World Bank review found that at least 76 countries, including both developing and developed ones, impose limits on interest rates (Maimbo & Gallegos, 2014). Motivated by this phenomenon, this section examines the impact of an interest rate cap on the retailer's inventory decision and preference between standardized and IRB banks. Specifically, we assume that while the bank still acts in the interest of the retailer, the interest rate that the bank charges cannot exceed an exogenous interest rate cap $\bar{r}$.

Proposition 5 *For a standardized bank, there exists $\bar{r}_c^S > \beta^S\delta$ and $\bar{A}_c^S < cq^S$ such that*

1. *For $\bar{r} \geq \bar{r}_c^S$, the interest rate cap has no impact on the loan term and the inventory level.*
2. *For $\bar{r} \in [\beta^S\delta,\ \bar{r}_c^S)$,*
   a. *If $A \geq \bar{A}_c^S$, the interest rate cap has no impact on the loan term and the inventory level.*
   b. *If $A < \bar{A}_c^S$, the bank offers interest rate $\bar{r}$ and inventory advance rate $\bar{\lambda}^{S*}$, which satisfy $r^S(\bar{\lambda}^{S*};\delta) = \bar{r}$. In this region, the retailer's order quantity $\bar{q}^{S*}$ increases in $\bar{r}$ and A.*
3. *For $\bar{r} < \beta^S\delta$, the bank does not lend to any retailer.*

Proposition 5 shows that, intuitively, the impact of an interest rate cap becomes more severe as the interest rate regulation is tightened (smaller $\bar{r}$). In particular, when $\bar{r}$ is sufficiently large, the interest rate cap has no impact on the loan terms that the retailer faces, as well as his own inventory decision and profit. As $\bar{r}$ drops below the unconstrained equilibrium rate r^{S*}, to maintain her own RAROC level, the bank tightens the amount that she is willing to lend by decreasing the inventory advance rate. Correspondingly, the retailer's inventory increases in the interest rate cap. Furthermore, recall from Proposition 2 that without the interest rate cap, the retailer's inventory quantity $q^{S*} = q^S$, which is independent of A. This is because as A decreases, the bank simultaneously increases the interest rate and inventory advance rate to maintain her own RAROC as well as the retailer's margin. However, in the presence of $\bar{r}$, without the interest rate as an effective lever to control RAROC, the bank needs to lower λ in response to smaller A, leading to a smaller inventory level. Finally, when the interest rate cap further decreases to be smaller than $\beta^S\delta$, all retailers are rejected by the lending market.

Proposition 6 *For an IRB bank, there exists $\bar{r}_c^I$ and $\bar{A}_c^I < \bar{A}_c^S$ such that the bank sets the interest rate equals $\bar{r}$ if and only if $\bar{r} \in (\beta^{IS}\delta,\ \bar{r}_c^I)$ and $A \leq \bar{A}_c^I$.*

Proposition 6 shows that the impact of an interest rate cap on an IRB bank follows a similar structure as on a standardized bank. That is, the bank's interest rate is constrained at the cap $\bar{r}$ when the retailer's initial asset is smaller than a threshold. However, this threshold under the IRB loan, $\overline{A}_c^I$, is smaller than that under the standardized one ($\overline{A}_c^S$). This highlights that everything else being equal, fewer retailers will be adversely affected under IRB banks than standardized banks. This is because the more risk-sensitive IRB approach results in a lower interest rate for low-risk retailers, making them less likely to be affected by a stringent interest rate cap.

The above results alert regulators that while the purpose of imposing interest rate caps is often to improve access to financing for small firms (Maimbo & Gallegos, 2014), the actual effect of interest rate caps might be the opposite. The negative impact is particularly notable when the banks that they regulate mainly adopt the more basic standardized approach in loan pricing.

6.2 | Impact of bank's empire building incentive

In the above analysis, when satisfying the banks' RAROC criterion, we mainly focus on the case in which the bank offers the loan term that is most beneficial for the retailer. However, in practice, banks may have other self-serving incentives. For example, it is well documented that loan officers, who are responsible for loan origination, often receive compensation packages that are positively correlated with the loan amount they have generated, therefore, fostering the pursuit of loan size (Berg et al., 2013). In our model, such empire building incentives mean the bank will offer the specific loan term that induces the maximum loan size along the RAROC indifference curve. Clearly, this specific loan term corresponds to the intersection of $r_{bc}(\lambda)$, which is the boundary that separates the binding credit limit region and the non-binding credit limit region, and the RAROC indifference curve ($r^S(\lambda;\delta)$ for the standardized bank and $r^I(\lambda;\delta)$ for the IRB bank). Corollary 1 and Proposition 1 guarantee the existence and uniqueness of this intersection.[11] Thus, it is clear that under the same approach (standardized or IRB), compared with the case where banks offer the loan term that maximizes the retailer's payoff, the empire building incentive results in a higher interest rate and a higher inventory advance rate. This will increase the retailer's loan amount and order quantity, but decrease the retailer's expected profit. However, it is less clear how such empire building behavior influences the retailer's preference between a standardized bank and an IRB one.

Proposition 7 *Under the bank's empire building incentive, $\exists \hat{A}_P^L > \hat{A}_P$ such that the retailer strictly prefers to borrow from an IRB bank if and only if his initial asset $A \in (\hat{A}_P^L,\ cq^{IS})$.*

Proposition 7 shows that directionally, the retailer's preference between the standardized bank and the IRB one is not influenced by banks' empire building incentive, that is, a low-risk retailer prefers the IRB bank and a high-risk one favors the standardized bank. However, compared with the case in which banks act in the interest of the retailer, a retailer with $A \in (\hat{A}_P, \hat{A}_P^L]$ changes his banking preference from an IRB bank to a standardized bank under banks' empire building behaviors. This is because the banks' empire building incentive increases the riskiness of the loan. As such, the marginal regulatory capital that the bank is required to hold under the more risk-sensitive IRB approach is greater than that under the standardized approach for a retailer with an intermediate initial asset level ($A \in (\hat{A}_P, \hat{A}_P^L]$), thus shifting the retailer's preference to the standardized bank. Based on this result, we hypothesize that in cases where banks are more likely to have an empire building incentive, small standardized banks might take up a larger share in the overall lending market.

7 | CONCLUSION

Despite its prevalence in practice, inventory financing under the RAROC criterion is under-studied in the OM-Finance interface literature. In this article, by explicitly modeling the bank's loan term and the retailer's inventory decision, we capture the operational implications of the RAROC criterion and the specific approaches whereby RAROC is calculated. In particular, we find that as a form of financial friction, RAROC and regulatory capital affect inventory decisions in a fashion different from other financial frictions, such as cost of financial distress. Thus, it is important that managers take them into consideration when making operational decisions. In addition, the exact capital regulation approach (standardized vs. IRB) determines retailers' banking choice. Our results reveal that high-risk retailers prefer to borrow from standardized banks, where they enjoy lower financing costs and are able to stock more inventory for future demand. On the other hand, low-risk retailers should finance from IRB banks. Our calibrated numerical study suggests that the economic impact of choosing the wrong type of bank can be significant. Finally, we show that various other considerations will also impact retailers' banking preference. Our results indicate that in cases where banks face stringent interest rate caps and are not aggressive in empire building, IRB banks will become more favorable. Combining analytical results and numerical studies, this article offers practical guidance on how to choose between standardized and IRB banks, along with the corresponding economic impacts for various industries under different banking conditions.

As the first article to incorporate RAROC and regulatory capital in the context of operations, this research can be extended along different dimensions. For example, the implications of RAROC and regulatory capital may spill over to upstream manufacturers/suppliers in the supply chain, affecting these parties' contracting decisions (e.g., the manufacturer

[11] Under this interest rate, a higher inventory advance rate does not generate a larger loan amount as the loan term will fall in the non-binding credit limit region.

may offer different wholesale prices to low-risk retailers borrowing from IRB banks and high-risk retailers borrowing from standardized banks), affecting their performances and the efficiency of the entire supply chain. In addition, empirical studies on retailers' banking choices under different operational and financial conditions can also be a promising topic. Finally, for tractability, we focus on a single-period model. While we anticipate the managerial insights remain unchanged, extending the model to a multi-period setting could potentially lead to richer results.

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DATA AVAILABILITY STATEMENT

In the article, we used the WorldScope dataset (https://www.refinitiv.com/content/dam/marketing/en_us/documents/fact-sheets/fundamentals-worldscope-fact-sheet.pdf/) to calibrate our numerical study. The data is subject to third party restrictions (subscription is needed).

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REFERENCES

Alan, Y., & Gaur, V. (2018). Operational investment and capital structure under asset-based lending. *Manufacturing & Service Operations Management*, *20*(4), 637–654.

Baer, T., Mehta, A., & Samandari, H. (2011). *The use of economic capital in performance management for banks: A perspective*. McKinsey Working Papers on Risk. McKinsey & Company.

Basel Committee. (1988). *International convergence of capital measurement and capital standards*. Technical report. Basel Committee on Banking Supervision (BCBS), Basel, Switzerland.

Basel Committee. (2006). *International convergence of capital measurement and capital standards: A revised framework*. Technical report. Basel Committee on Banking Supervision (BCBS), Basel, Switzerland.

Berg, T., Puri, M., & Rocholl, J. (2013) *Loan officer incentives and the limits of hard information*. NBER Working Paper No. 19051.

Boyabatlı, O., & Toktay, L. (2011). Stochastic capacity investment and flexible vs. dedicated technology choice in imperfect capital markets. *Management Science*, *57*(12), 2163–2179.

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

Cai, G. G., Chen, X., & Xiao, Z. (2014). The roles of bank and trade credits: Theoretical analysis and empirical evidence. *Production and Operations Management*, *23*(4), 583–598.

Chen, X., Sim, M., Simchi-Levi, D., & Sun, P. (2007). Risk aversion in inventory management. *Operations Research*, *55*(5), 828–842.

Chod, J., & Zhou, J. (2013). Resource flexibility and capital structure. *Management Science*, *60*(3), 708–729.

Commercial Finance Association. (2018). *Annual asset-based lending and factoring survey*. Technical report.

Cummings, J., & Durrani, K. (2016). Effect of the Basel Accord capital requirements on the loan-loss provisioning practices of Australian banks. *Journal of Banking & Finance*, *67*, 23–36.

Dada, M., & Hu, Q. (2008). Financing newsvendor inventory. *Operations Research Letters*, *36*(5), 569–573.

Damodaran, A. (2018). *Banks' cost of capital*. Accessed on October 12, 2020.

Foley, C. F., Raman, A., & Craig, N. C. (2012). *Inventory-based lending industry note*. Harvard Business School, Industry and Background Note, 612-057.

Gaur, V., & Seshadri, S. (2005). Hedging inventory risk through market instruments. *Manufacturing & Service Operations Management*, *7*(2), 103–120 ISSN 1526-5498.

Hakenes, H., & Schnabel, I. (2011). Bank size and risk-taking under Basel II. *Journal of Banking & Finance*, *35*(6), 1436–1449.

Hsu, V. N., Xiao, W., & Xu, J. (2019). The impact of tax and transfer pricing on a multinational firm's strategic decision of selling to a rival. *Production and Operations Management*, *28*(9), 2279–2290.

Hu, M., Qian, Q., & Yang, S. A. (2018). *Financial pooling in a supply chain*. Available at SSRN (2783833).

James, C. (1996). *RAROC based capital budgeting and performance evaluation: A case study of bank capital allocation*. Working Paper. Gainesville: University of Florida.

Jones, D. (1998). *Credit risk models at major us banking institutions: Current state of the art and implications for assessments of capital adequacy*. Technical Report. Board of Governors of the Federal Reserve System, Washington, DC.

Karandikar, R., Khaparde, S., & Kulkarni, S. (2007). Quantifying price risk of electricity retailer based on CAPM and RAROC methodology. *International Journal of Electrical Power and Energy Systems*, *29*(10), 803–809.

Kouvelis, P., & Li, R. (2019). Integrated risk management for newsvendors with value-at-risk constraints. *Manufacturing & Service Operations Management*, *21*(4), 816–832.

Kouvelis, P., & Zhao, W. (2011). The newsvendor problem and price-only contract when bankruptcy costs exist. *Production and Operations Management*, *20*(6), 921–936.

Krüger, S., Rösch, D., & Scheule, H. (2018). The impact of loan loss provisioning on bank capital requirements. *Journal of Financial Stability*, *36*, 114–129.

Lai, G., & Xiao, W. (2018). Inventory decisions and signals of demand uncertainty to investors. *Manufacturing & Service Operations Management*, *20*(1), 113–129.

Maimbo, S. M., & Gallegos, C. A. H. (2014) *Interest rate caps around the world: Still popular, but a blunt instrument*. Policy Research Working Paper. The World Bank.

Matten, C. (1996). Managing bank capital: Capital allocation and performance measurement. Wiley.

Ning, J., & Babich, V. (2018). R&d investments in the presence of knowledge spillover and debt financing: Can risk shifting cure free riding? *Manufacturing & Service Operations Management*, *20*(1), 97–112.

OCC. (2014). Comptroller's handbook–A–ABL. Technical report. Office of the Comptroller of the Currency.

Osadchiy, N., Gaur, V., & Seshadri, S. (2015). Systematic risk in supply chain networks. *Management Science*, *62*(6), 1755–1777.

Park, J. H., Kazaz, B., & Webster, S. (2017). Risk mitigation of production hedging. *Production and Operations Management*, *26*(7), 1299–1314.

Peura, H., Yang, S. A., & Lai, G. (2017). Trade credit in competition: A horizontal benefit. *Manufacturing & Service Operations Management*, *19*(2), 263–289.

Prokopczuk, M., Rachev, S., Schindlmayr, G., & Trück, S. (2007). Quantifying risk in the electricity business: A RAROC-based approach. *Energy Economics*, *29*(5), 1033–1049.

Rossi, C. (2011). Risk-adjusted performance: Lessons from the financial crisis. *Journal of Structured Finance*, *17*, 28–35.

Ruthenberg, D., & Landskroner, Y. (2008). Loan pricing under Basel II in an imperfectly competitive banking market. *Journal of Banking & Finance*, *32*(12), 2725–2733.

Schwert, M. (2018). Bank capital and lending relationships. *The Journal of Finance*, *73*(2), 787–830.

Tang, C. S., Yang, S. A., & Wu, J. (2018). Sourcing from suppliers with financial constraints and performance risk. *Manufacturing & Service Operations Management*, *20*(1), 70–84.

Tanrisever, F., Cetinay, H., Reindorp, M., & Fransoo, J. C. (2015). *Value of reverse factoring in multi-stage supply chains*. Available at SSRN (2183991).

Tanrısever, F., Erzurumlu, S. S., & Joglekar, N. (2012). Production, process investment, and the survival of debt-financed startup firms. *Production and Operations Management*, *21*(4), 637–652.

Tanrisever, F., Joglekar, N., Erzurumlu, S., & Levesque, M. (2018) *Managing capital market frictions via cost-reduction investments*. Available at SSRN (3095186).

The Economist. (2009). The revolution within. Author.

The Economist. (2011). Renaissance men. Author.

The Economist. (2012). The Bank of England busts myths on equity capital requirements. Author.

Tomlin, B., & Wang, Y. (2005). On the value of mix flexibility and dual sourcing in unreliable newsvendor networks. *Manufacturing & Service Operations Management*, *7*(1), 37–57.

Wallen, J. (2017). *The effect of bank capital requirements on bank loan rates*. Available at SSRN (2954346).

Walter, J. (2019). Us bank capital regulation: History and changes since the financial crisis. *Economic Quarterly*, *105*(1), 1–40.

Wu, Q., Muthuraman, K., & Seshadri, S. (2019). Effect of financing costs and constraints on real investments: The case of inventories. *Production and Operations Management*, *28*(10), 2573–2593.

Xiao, W., Hsu, V. N., & Hu, Q. (2015). Manufacturing capacity decisions with demand uncertainty and tax cross-crediting. *Manufacturing & Service Operations Management*, *17*(3), 384–398.

Xu, J., Hsu, V. N., & Niu, B. (2018). The impacts of markets and tax on a multinational firm's procurement strategy in China. *Production and Operations Management*, *27*(2), 251–264.

Xu, X., & Birge, J. (2004). *Joint production and financing decisions: Modeling and analysis*. Available at SSRN (652562).

Yang, S. A., Birge, J., & Parker, R. (2015). The supply chain effects of bankruptcy. *Management Science*, *61*(10), 2320–2338.

Yang, S. A., & Birge, J. R. (2018). Trade credit, risk sharing, and inventory financing portfolios. *Management Science*, *64*(8), 3667–3689.

Yi, Z., Wang, Y., & Chen, Y.-J. C (2017). *Sustainability building of an agricultural supply chain with a capital-constrained farmer in developing economies*. Available at SSRN (3074319).

Zaik, E., Walter, J., Retting, G., & James, C. (1996). RAROC at Bank of America: From theory to practice. *Journal of Applied Corporate Finance*, *9*(2), 83–93.

Zhao, X., Lai, G., & Xiao, W. (2019). *Strategic financing and information revelation amid market competition*. Available at SSRN (3452885).

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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APPENDIX A: SUMMARY OF NOTATION

Notation used in the article is summarized in Table A1. We use subscript n, bf, bn, and bc to represent cases when the retailer does not borrow, borrows a risk-free loan, borrows a risky loan and bank's credit limit is non-binding, and borrows a risky loan and bank's credit limit is binding. We further use superscript S and I to represent standardized approach and IRB approach, respectively.

APPENDIX B: RETAILER'S PROFIT FUNCTION UNDER THE ALTERNATIVE GAME

In this section, we show that under the alternative game studied by Xu and Birge (2004) where the retailer first decides the order quantity and corresponding loan amount, and the bank then follows by competitively charging an interest rate, the retailer's expected profit under RAROC and regulatory capital can be obtained by removing corporate tax and replacing bankruptcy cost in Xu and Birge (2004) to the cost of regulatory capital.

First, we would like to show that the retailer's expected profit given by Equation (5) in Xu and Birge (2004) can be written as the retailer's expected profit without capital constraint minus the bankruptcy cost. Removing corporate tax ($\tau = 0$) in Equation (5) in Xu and Birge (2004), we have[12]

$$\mathbb{E}[\Pi] = \int_q^\infty pqf(u)\,\mathrm{d}u + \int_{k(q)}^q [(p-s)u + sq]f(u)\,\mathrm{d}u + \gamma\int_0^{k(q)} [(p-s)u + sq]f(u)\,\mathrm{d}u - cq$$
$$= \int_q^\infty pqf(u)\,\mathrm{d}u + \int_0^q [(p-s)u + sq]f(u)\,\mathrm{d}u$$

[12]We also change the notation to ours and add in salvage value.

TABLE A1 Notation

Parameters	
p	Retail price
c	Inventory's procurement cost
s	Inventory's salvage value, $s < c < p$
A	Retailer's initial asset
$\tilde{u}$	Uncertain demand, which follows PDF $f(\cdot)$, CDF $F(\cdot)$, and failure rate $z(\cdot)$
δ	Bank's cost of capital
β^S	Capital adequacy ratio under standardized approach
β^{IS}	Minimum capital adequacy ratio under IRB approach
α	Bank's confidence level used in calculating VaR under IRB approach
$\bar{r}$	Interest rate cap
Decisions	
q	Retailer's order quantity
r	Bank's interest rate
λ	Bank's inventory advance rate
$\bar{L}$	Bank's credit limit: $\bar{L} = \lambda cq$
L	Retailer's loan amount: $L = \min((cq - A)^+, \bar{L})$
Derived	
$k(q)$	Retailer's default threshold: $k(q) = \max\left(0, \frac{L(1+r)-sq}{p-s}\right)$
r_n	Interest rate boundary above which retailer does not borrow (Lemma 1)
r_{bf}	Interest rate boundary such that when $r \in [r_{bf}, r_n)$, retailer borrows a risk-free loan (Lemma 1)
$r_{bc}(\lambda)$	Interest rate boundary such that when $r \in [r_{bc}(\lambda), r_{bf})$, retailer borrows a risky loan (Lemma 1)
A^{IV}	Asset threshold for retailer's inventory decision under IRB approach, when $A < A^{IV}$, $q^{I*} = q^{IV}$ (Proposition 3)
A^{IB}	Asset threshold for retailer's inventory decision under IRB approach, when $A \in [A^{IV}, A^{IB})$, $q^{I*} = q^{IB}(A)$ (Proposition 3)
$\hat{A}_Q$	Asset threshold above which retailer's order quantity under IRB approach is greater than that under standardized approach (Proposition 4)
$\hat{A}_P$	Asset threshold above which retailer prefers IRB bank (Proposition 4)
$\hat{A}_P^L$	Asset threshold above which retailer prefers IRB bank under bank's empire building incentive (Proposition 7)
$\bar{A}_c^j$	Asset threshold above which the interest rate cap $\bar{r}$ has no impact under regulatory approach $j \in \{S, I\}$ (Propositions 5 and 6)
Π	Retailer's profit
R^j	Bank's RAROC under regulatory approach $j \in \{S, I\}$
C	Bank's regulatory capital
EL	Bank's expected loss
VaR	Bank's Value-at-Risk at confidence level α

$$- cq - (1-\gamma)\int_0^{k(q)} [(p-s)u + sq] f(u)\,\mathrm{d}u$$
$$= pq\bar{F}(q) + (p-s)\left(\int_0^q \bar{F}(u)\,\mathrm{d}u - q\bar{F}(q)\right)$$
$$+ sqF(q) - cq - (1-\gamma)\int_0^{k(q)} [(p-s)u + sq] f(u)\,\mathrm{d}u$$
$$= \underbrace{(p-s)\int_0^q \bar{F}(u)\,\mathrm{d}u - (c-s)q}_{\text{Expected profit without capital constraint}}$$
$$\underbrace{-(1-\gamma)\int_0^{k(q)} [(p-s)u + sq] f(u)\,\mathrm{d}u}_{\text{Bankruptcy cost}}, \tag{A.1}$$

where $\gamma < 1$ is the asset recovery rate.

Next, we show that under the alternative game, with RAROC and regulatory capital replacing bankruptcy cost, the retailer's expected profit $\mathbb{E}[\Pi]$ can be written as expected profit without capital constraint minus cost of regulatory capital (δC^j for $j = S, I$). Based on Equation (2), the retailer's profit when borrowing under RAROC and regulatory capital is

$$\Pi = \begin{cases} -A & \text{for} \quad u < k(q) \\ (p-s)u + sq - L(1+r) - A & \text{for} \quad k(q) \le u \le q \\ pq - L(1+r) - A & \text{for} \quad u > q \end{cases}. \tag{A.2}$$

Taking expectation w.r.t. u, we have the retailer's expected profit

$$\mathbb{E}[\Pi] = \int_q^\infty [pq - L(1+r)] f(u)\,\mathrm{d}u$$
$$+ \int_{k(q)}^q [(p-s)u + sq - L(1+r)] f(u)\,\mathrm{d}u - A$$
$$= (p-s)q\bar{F}(q) - (p-s)k(q)\bar{F}(k(q))$$
$$+ (p-s)\int_{k(q)}^q uf(u)\,\mathrm{d}u - A$$
$$= (p-s)\int_0^q \bar{F}(u)\,\mathrm{d}u - (p-s)\int_0^{k(q)} \bar{F}(u)\,\mathrm{d}u - (cq - L). \tag{A.3}$$

Rearranging the bank's loan pricing equation under standardized approach $R^S(r,\lambda) = \delta$ based on Equation (6), we have

$$rL - (p-s)\left[k(q) - \int_0^{k(q)} \overline{F}(u)\,\mathrm{d}u\right] = \delta\beta^S L, \tag{A.4}$$

which is

$$(p-s)\int_0^{k(q)} \overline{F}(u)\,\mathrm{d}u = \delta\beta^S L - sq + L. \tag{A.5}$$

Taking Equation (A.5) into Equation (A.3), we have under standardized approach

$$\mathbb{E}[\Pi^S] = (p-s)\int_0^{q} \overline{F}(u)\,\mathrm{d}u - (c-s)q - \delta C^S, \tag{A.6}$$

where $C^S = \beta^S L$. Comparing with Equation (A.1), $\mathbb{E}[\Pi^S]$ can be interpreted as expected profit without capital constraint minus cost of regulatory capital (δC^S). Similarly, under IRB approach, the bank's loan pricing equation $R^I(r,\lambda) = \delta$ based on Equation (9) is

$$rL - (p-s)\left[k(q) - \int_0^{k(q)} \overline{F}(u)\,\mathrm{d}u\right] = \delta C^I, \tag{A.7}$$

where $C^I = \max(VaR - EL, \beta^{IS} L)$. Taking Equation (A.7) into Equation (A.3), we have under IRB approach

$$\mathbb{E}[\Pi^I] = (p-s)\int_0^{q} \overline{F}(u)\,\mathrm{d}u - (c-s)q - \delta C^I. \tag{A.8}$$

Therefore, under the alternative game, the retailer's expected profit under order quantity q is: $(p-s)\int_0^q \overline{F}(u)\,\mathrm{d}u - (c-s)q - \delta C^j$ for $j = S, I$, where C^S (or C^I) is the regulatory capital that the bank is required to hold for the loan under the standardized (or IRB) approach. This profit function can be obtained by removing corporate tax and change bankruptcy cost to the cost of regulatory capital following Equation (5) in Xu and Birge (2004).