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Supply Chain Competition with Integrated Financial Policy, Capacity Strategy and Operations Planning under Demand and Credit-Market Risk

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ABSTRACT

Financial policy directly affects the availability and cost of a firm's working capital which has significant impacts on the firm's operations, profitability and risk. The capacity strategy also relies on the financing resources and is an integral part of the operations planning. This paper is the first research that examines the financial policy, capacity strategy, and operations planning in a holistic manner. We first develop an optimization model that integrates these three levels of decisions with the consideration of demand uncertainty and credit market risk. We also study the competition among firms who may use different financial policies and capacity strategies. In particular, we use the theory of variational inequality to model the equilibria of multiple competing firms under uncertain demand and credit conditions. We also provide numerical case studies which generate important managerial insights.

Keywords: *Supply Chain, Financial Policy, Capacity Strategy*

1. INTRODUCTION

Financial policy concerns about raising working capital to support and ensure the continuous operations of firm. There are two typical financing policies. Restrictive financial policy mainly uses short-term debt to finance working capital while the flexible financial policy finances the working capital using long-term debt. Since the working capital is crucial for daily operations of supply chain firms, financial policy can have deep impacts on all activities of supply chains. A flexible financial policy borrows long-term debt which means that the amount of available working capital is relatively stable over time and does not vary significantly in different situations. The restrictive financial policy, on the other hand, borrows short-term debt, and the amount of working capital may vary depending on the financing need and cost as well as the availability of financing resources. The long-term financing cost is usually higher than the short-term financing cost in normal economic conditions. Nevertheless, the short-term financing cost can become higher than the long-term cost in situations such as the high inflation period during 2022-2023.

Another decision that affects both financing decisions and operations decisions is the capacity strategy. Firms can build long-term capacities or use short-term capacities, such as, overtime, sub-contract, or short-term leasing to meet the demand. While the long-term capacity option typically costs less, the short-term capacity option can be more flexible to cope with demand variations. Typically, firms finance the long-term capacity using long-term debt with matching maturity. The financing of the short-term capacity can be either from the short-term debt or capital funded by the long-term debt. Therefore, the financing decisions, capacity strategy and operations planning are highly intertwined with one another and should be studied in an integrated manner. Nevertheless, there is no research in the current literature that focused on the integrated decision- making in these three tightly related areas.

Research at the intersection of finance and supply chain management ranges from studies that connect production planning with financial constraints to broader models of integrated operational and financial decision-making. Review papers have shown that supply chain finance has developed into a distinct research stream encompassing trade credit, reverse factoring, inventory and replenishment decisions, financing services, working capital management, and risk-related issues (Gelsomino *et al.,* 2016; Xu *et al.,* 2018; Huang *et al.,* 2022). Despite these important developments, the existing literature has focused mainly on operational financial instruments and working capital decisions, with less attention given to the higher-level strategic integration of financial policy, capacity strategy, and operational planning under competition and uncertainty.

This paper helps fill that gap by providing a novel approach to integrating financial policy and operational strategy. In particular, financial policy can be regarded as a higher-level strategic decision because it concerns long-term financing choices, which shape firms' capacity, operational flexibility, profitability, and risk exposure. Our case studies show that financial policy can significantly affect operational decisions, profits, and risk under different economic conditions, suggesting that managers should adopt a holistic and integrated approach when making decisions about financing and operations. Our research provides a tool to support such integrated decision-making.

This article is organized as follows. We first review and discuss the literature in Section 2. Section 3 develops the optimization model for individual firms. Section 4 uses the theory of variational inequality to study the competition of multiple supply chains firms. Section 5 uses numerical case studies to demonstrate how the model can be applied to investigate the impacts of demand and credit-market uncertainty on the firms. In the last section we present conclusions with managerial insights and future research directions.

2. LITERATURE REVIEW

This research falls on the intersection between supply chain management and finance. Gelsomino *et al.,* (2016) presented an extensive literature review regarding supply chain finance. The paper summarized that there were two perspectives of supply chain finance. The "finance-oriented perspective" primarily focuses on short-term financial solutions for supply chains while the "supply chain-oriented" perspective also considers working capital optimization including inventories. Xu *et al.,* (2018) also provided a thorough literature review where the authors grouped the papers into four clusters. Clusters one and two concerned about inventory decisions and trade credits. Cluster three and four considered replenishment decisions and roles of financing services, respectively. Huang *et al.,* (2022) presented the most recent literature review on supply chain finance where the authors classified the articles into nine dimensions, such as, financial service providers, supply chain financing instruments, supply chain financing adoption, risk management, credit rating, etc. For additional research on supply chain finance, see Pfohl and Gomm (2009), Gomm (2010), X. Liu and Zhou (2016), Hang and Tung (2019), Nagpal *et al.,* (2022), Ioannou and Demirel (2022).

It is worth noting that several studies in the literature have focused on an integrated approach to study financial and supply chain decisions. For example, Guillen *et al.,* (2007) represents one of the first attempts to develop a holistic framework that integrated financial planning and production decisions. The authors derived an optimization model that combined process operations and budgetary constraints. However, the model does not consider financial policies as part of the decision-making framework, nor does it account for competition. Silvestro and Lustrato (2014) presented a conceptual and qualitative study on the integration of financial and physical supply chains with the focus on the role of banks. In particular, the paper examines how banks can support the key enablers of supply chain integration and thereby help buyers and suppliers achieve better alignment between physical and financial supply chains. It also presents case studies illustrating how banks can assist their clients in improving such integration through investments in technology and the development of appropriate strategies.

Gupta and Dutta (2011) developed a financial supply chain model that focused on the on-time payments between supply chain partners. The authors discussed the different characteristics of downstream flow of goods and upstream flow of money and developed an optimization model for a wholesaler who purchases finished goods from multiple manufacturers and sells the products to multiple retailers. The paper showed that the static model was NP-complete, and developed heuristics to solve the static and dynamic problems.

Note that the existing literature has focused predominantly on operational financial decisions, such as trade credit, reverse factoring, and inventory management, while paying much less attention to the higher-level strategic integration of financial policy, capacity strategy, and operational planning under competition and uncertainty. In contrast, our paper focuses on the impact of higher-level financial policy decisions on supply chain firms operating in competitive environments. To the best of our knowledge, this study is the first to develop an integrated approach that jointly incorporates financial policy, capacity strategy, and operational decisions.

Our approach is based on the theory of variational inequalities, which has been widely used in studying economic, social, and engineering problems. Nagurney (2013) presented a complete and thorough introduction of the theory, computational methods, and applications of variational inequalities. Nagurney *et al.,* (2002) applied the theory of variational inequalities to develop the first model of network equilibrium that studied transaction flows of multi-tiered supply chains. Since then the theory has been used to investigate a wide range of supply chain problems, such as, sustainable supply chains, finance and supply chains, humanitarian supply chains, and agricultural supply chains (e.g., Besik *et al.,* 2023; Z. Liu and Wang, 2019; Dong *et al.,* 2005; Cruz, 2008; Cruz *et al.,* 2006; Allevi *et al.,* 2018; Toyasaki *et al.,* 2014). Although our research uses the similar mathematical method we focus on a novel problem, which is the integrated decision-making of financial policy, capacity strategy, and operations planning for supply chain firms under competition and uncertainty.

3. THE OPTIMIZATION PROBLEM OF AN INDIVIDUAL FIRM

In this section, we develop the optimization model with financial policy and capacity strategy under demand and interest-rate risk. Tables 1 and 2 show the notation used in the paper. We assume that there are T periods and denote each period by t.

We assume that there are J manufacturers who produce substitutable products, and are engaged in Cournot competition under the uncertainty of demand quantity and credit market. Each manufacturer is faced with three types of decisions. First, they need to decide how to finance their capacities and operations. The manufacturers can use long-term financing where they can issue bonds in the financial market or borrow long-term loans. Alternatively, they can also use short-term financing, such as, short-term loans. Typically, long-term borrowing rates are higher than short-term rates. However, short-term rates frequently fluctuate, and may exceed long-term rate sometimes. In addition, during economic downturns or banking crisis the availability of financing sources may become limited, and the cost may increase significantly.

Second, they must decide the capacity strategy. They can choose to build long-term fixed capacities or use short-term temporary capacities, such as, subcontracting or short-

Table 1 Decision Variables for the Optimization Model

Notation	Definition
w_j^0	Manufacturer j's long-term fixed capacity. We group the w_j^0s into the vector W^0.
$w_{jt\phi_t}$	Manufacturer j's short-term capacity used in period t and in scenario ϕ_t. We group the $w_{jt\phi_t}$s into the vector *W*.
u_j^0	The amount of Manufacturer j's working capital provided by long-term financing. We group the u_j^0s into the vector U^0.
$u_{jt\phi_t}$	The amount of Manufacturer j's working capital provided by short-term financing in period t and in scenario ϕ_t. We group the $u_{jt\phi_t}$s into the vector *U*.
$x_{jt\phi_t}$	The amount of the goods bought by Manufacturer *j* in period t and in scenario ϕ_t. We group all $x_{jt\phi_t}$s into the vector *X*.
$z^0_{jt\phi t}$	The production quantity using long-term capacity by Manufacturer *j* in period t and in scenario ϕ_t. We group all $z^0_{jt\phi_t}$s into the vector Z^0.
$z_{jt\phi_t}$	The production quantity using short-term capacity by Manufacturer *j* in period t and in scenario ϕ_t. We group all $z_{jt\phi_t}$s into the vector *Z*.
$y_{jt\phi_t}$	The amount of the product Manufacturer *j* sells in period t and in scenario ϕ_t. We group the $y_{jt\phi_t}$s in period t and scenario ϕ_t into the vector $Y_{t\phi_t}$. We group all $y_{jt\phi_t}$s into the vector *Y*.

Table 2 Parameters for the Optimization Model

Notation	Definition
$\phi \in \Phi$	The random states.
$f(\phi_t)$	The probability density function.
LU_j^0	The limit of the working capital provided by long-term financing of Manufacturer *j*.
$LU_{jt\phi_t}$	The limit of the working capital provided by short-term financing of Manufacturer in period t and in scenario ϕ_t.
LW_j^0	The limit of the long-term capacity of Manufacturer *j*.
LW_j	The limit of the short-term capacity of Manufacturer *j*.
$\rho_{jt\phi_t}(Y_{t\phi_t})$	The inverse demand function in period t and in scenario ϕ_t.
v	Unit cost of the material.
c_j	The unit operation/production cost using short-term capacity of Manufacturer *j*.
c_j^0	The unit operation/production cost using long-term capacity of Manufacturer *j*
g_j^0	The unit cost of the long-term capacity of Manufacturer *j*
h_j	The unit cost of the short-term capacity of Manufacturer *j*
r_j^0	The long-term financing rate of Manufacturer *j*
$r_{jt\phi_t}$	The short-term financing rate of Manufacturer *j* in time period t and in scenario ϕ_t.

term leasing. These capacity options, however, are constrained by the long-term and short-term financing resources resulted from the financing decisions. The long-term capacities are fixed after completion, and will always be available for productions and operations. However, in low demand scenarios, the long-term capacities may be underutilized while the firms still need to pay the same amount of financing and operation costs. Thus, in such situations the long-term capacity might become a burden and cause financial distress. The short-term capacities, on the other hand, are more flexible. The firms do not have to purchase them if the demands are low. However, the short-term capacities typically are more costly, and may not be always available when needed.

Finally, the manufacturers make production decisions under demand uncertainty, which are also subject to the available capacities and financing resources. The three types of decisions should not be made independently. Instead, the firms need to use a holistic approach to analyze and determine the financing strategy, the capacity strategy, and the operation decisions.

We now analyze the optimization problem faced by each individual manufacturer. In each period, an individual manufacturer is faced with the uncertain demand and credit conditions. The long-term financing decision, u_j^0, and the long-term capacity decision, w_j^0, are determined before knowing the actual demand and credit conditions. The short-term financing decision, $u_{jt\phi_t}$, the short-term capacity decision, $w_{jt\phi_t}$, and the operations decisions, $x_{jt\phi_t}$, $z^0_{jt\phi t}$, $z_{jt\phi_t}$, and $y_{jt\phi_t}$, are determined after the actual demand and credit conditions are revealed. Therefore, the long-term decisions will be the same for all random states while the short-term decisions can be different based on the actual demand and credit conditions in each random state. The objective is to maximize the expected profit of the entire planning horizon.

Firm j's optimization problem can be developed as follows:

$$\text{Maximize } \mathrm{E}(Profit_j) = -g_j^0 w_j^0 + \sum_{t=0}^{T} [\sum_{\phi_t \in \Phi_t} f(\phi_t) \rho_{jt\phi_t}(Y_{\phi_t}) y_{jt\phi_t} - \sum_{\phi_t \in \Phi_t} f(\phi_t)(v x_{jt\phi_t} + c_j^0 z_{jt\phi_t}^0 + c_j z_{jt\phi_t}) - r_j^0 u_j^0 - \sum_{\phi_t \in \Phi_t} f(\phi_t)(r_{jt\phi_t} u_{jt\phi_t} + h_j w_{jt\phi_t})] \quad (1)$$

Subject to

$$z_{jt\phi_t}^0 \le w_j^0, \quad \phi_t \in \Phi_t, t = 1, \ldots, T; \quad (2)$$

$$z_{jt\phi_t} \le w_{jt\phi_t}, \phi_t \in \Phi_t, t = 1, \ldots, T; \quad (3)$$

$$z_{jt\phi_t}^0 + z_{jt\phi_t} \le x_{jt\phi_t}, \phi_t \in \Phi_t, t = 1, \ldots, T; \quad (4)$$

$$y_{jt\phi_t} \le z_{jt\phi_t}^0 + z_{jt\phi_t}, \phi_t \in \Phi_t, t = 1, \ldots, T; \quad (5)$$

$$a_{j1} h_j w_{jt\phi_t} + a_{j2} c_j^0 z_{jt\phi_t}^0 + a_{j3} c_j z_{jt\phi_t} + a_{j4} v x_{jt\phi_t} \le u_j^0 + u_{jt\phi_t}, \phi_t \in \Phi_t, t = 1, \ldots, T; \quad (6)$$

$$u_j^0 \le LU_j^0; \quad (7)$$

$$u_{jt\phi_t} \le LU_{jt\phi_t}, \phi_t \in \Phi_t, t = 1, \ldots, T; \quad (8)$$

$$w_j^0 \le LW_j^0; \quad (9)$$

$$w_{jt\phi_t} \le LW_j, \phi_t \in \Phi_t, t = 1, \ldots, T; \quad (10)$$

$$x_{jt\phi_t} \ge 0, z_{jt\phi_t}^0 \ge 0, z_{jt\phi_t} \ge 0, \phi_t \in \Phi_t, t = 1, \ldots, T; \quad (11)$$

$$w_{jt\phi_t} \ge 0, u_{jt\phi_t} \ge 0, y_{jt\phi_t} \ge 0, \phi_t \in \Phi_t, t = 1, \ldots, T; \quad (12)$$

$$w_j^0 \ge 0, u_j^0 \ge 0. \quad (13)$$

The objective function's first term is the cost of the long-term capacity. The second term is the expected revenue from the sales of the products. The third term represents the expected operation cost which consists of material costs and production costs using long-term and short-term capacities. The fourth term is the long-term financing cost. The last term of function (1) includes the expected short-term financing cost as well as the cost of obtaining the short-term capacity.

The manufacturer's optimization problem is also subject to a set of operation, capacity and financing constraints. Equation 2 indicates that the production quantity using the long-term capacity cannot exceed the long-term capacity. Equation 3, in turn, represents that the production quantity using the short-term capacity cannot exceed the short-term capacity. Equation 4 indicates that the total amount of product produced is limited by the materials purchased while equation 5 means that the sales of the product is less than or equal to the total production.

Equation 6 represents the financing constraint that requires that the cost of obtaining the short-term capacities, the production costs, and the procurement cost should be covered by the available working capital. Note that $0 \le a_{jn} \le 1, n = 1, \ldots, 4$in equation 6 represent the contribution factor of the costs to the working capital requirement. For example, if a supplier provides very generous trade credit terms $f$may be close to zero while if the supplier demands full cash payment upon delivery a_{j4} would be equal to 1. Equations 7 and 8 represent the maximum levels of long-term financing and short-term financing available to the firm. Equations 9 and 10 represents the maximum levels of long-term capacity and short-term capacity the firm could obtain. Equations 11-13 are nonnegativity constraints.

Each manufacturer maximizes its own expected profit by optimally determining the long-term and short-term decisions.

4. THE EQUILIBRIUM SOLUTION FOR ALL MANUFACTURERS

We assume that each manufacturer optimizes its own objective function. All firms' optimality conditions should be satisfied simultaneously in the equilibrium, and no player can benefit by changing his or her decisions. Next, we provide the variational inequality that governs the equilibrium of the game. We use "*" to indicate the solution in equilibrium.

Theorem 1

Suppose that each inverse demand function is decreasing and continuously differentiable, and that the firms compete in a non-cooperative fashion. The Nash equilibrium of all manufacturers can be formulated using the variational inequality as follows: Determine $(W^{0*}, W^*, U^{0*}, U^*, X^*, Z^{0*}, Z^*, Y^*) \in \mathcal{K}^0$ *satisfying:*

$$\sum_{j=1}^{J} g_j^0 \times [w_j^0 - w_j^{0*}] + \sum_{t=1}^{T}\sum_{j=1}^{J} r_j^0 \times [u_j^0 - u_j^{0*}] + \sum_{t=1}^{T}\sum_{\phi_t \in \Phi_t}\sum_{j=1}^{J} f(\phi_t) v \times [x_{ij\phi_t} - x_{ij\phi_t}^*] + \sum_{t=1}^{T}\sum_{\phi_t \in \Phi_t}\sum_{j=1}^{J} f(\phi_t) c_j^0 \times [z_{jt\phi_t}^0 - z_{jt\phi_t}^{0*}] + \sum_{t=1}^{T}\sum_{\phi_t \in \Phi_t}\sum_{j=1}^{J} f(\phi_t) c_j \times [z_{jt\phi_t} - z_{jt\phi_t}^*] + \sum_{t=1}^{T}\sum_{\phi_t \in \Phi_t}\sum_{j=1}^{J} f(\phi_t) r_{jt\phi_t} \times [u_{jt\phi_t} - u_{jt\phi_t}^*] + \sum_{t=1}^{T}\sum_{\phi_t \in \Phi_t}\sum_{j=1}^{J} f(\phi_t) h_j \times [w_{jt\phi_t} - w_{jt\phi_t}^*] - \sum_{t=1}^{T}\sum_{\phi_t \in \Phi_t}\sum_{j=1}^{J} f(\phi_t) [\rho_{jt\phi_t}(Y_{t\phi_t}^*) + \frac{\partial \rho_{jt\phi_t}(Y_{t\phi_t}^*)}{\partial y_{jt\phi_t}} y_{jt\phi_t}^*] \times [y_{jt\phi_t} - y_{jt\phi_t}^*] \ge 0, \quad (14)$$

where $\mathcal{K}^0 \equiv ((W^0, W, U^0, U, X, Z^0, Z, Y) | (W^0, W, U^0, U, X, Z^0, Z, Y) \in R_+^{2J+6J|\Phi|T}$ *and* (2) *to* (10) *hold*)

Proof: The results can be directly obtained using the standard theory of variational inequality (cf. Nagurney, 2013; Gabay and Moulin, 1980).

Theorem 2

Variational inequality (14) has a solution if each inverse demand function is continuously differentiable.

Proof: Note that all variables in the variational inequality formulation are bounded by the capacity and financing constraints which implies that the feasible set is compact. In addition, the feasible set is nonempty since all variables equal to zero is a feasible solution. Hence, based on the variational inequality theory, variational inequality (14) has a solution (cf. Nagurney, 2013).

5. NUMERICAL CASE STUDIES

In this section, we will use numerical case studies to demonstrate how our model can be applied to investigate complex supply chain equilibrium problems involving financial policies, capacity strategies, and operation decisions. In order to solve the model we first convert it to the equivalent formulation based on the KKT conditions. Then the modified projection method (cf. Nagurney, 2013) was applied to obtain the solutions.

The case studies are designed to provide insights into common demand and credit-market conditions. In particular, they consider situations characterized by variations in the following factors.

a. *Different Market Liquidity*

This setting reflects differences in the ease with which firms can obtain external financing. In practice, low-liquidity scenarios may arise during periods of tightened credit conditions, weaker banking support, or for financially constrained small and medium-sized enterprises. By contrast, high-liquidity scenarios may characterize firms operating in more developed financial markets or during periods of accommodative credit supply. For example, the 2020–2021 pandemic stimulus period may be viewed as a high-liquidity environment, as many economies experienced loose monetary conditions, abundant market liquidity, strong lending support, and relatively low financing frictions. In contrast, the 2008–2009 global financial crisis provides a representative example of a low-liquidity environment, when credit markets tightened significantly, banks became more cautious, and many firms faced severe financing constraints.

b. *Different Product Demand Uncertainty*

This setting captures differences in market predictability. Low-demand-uncertainty cases are representative of mature markets with relatively stable historical demand, whereas high-demand-uncertainty cases are more relevant to new products, seasonal goods, innovative industries, or disruption-prone environments where demand is difficult to forecast. A representative example of high demand uncertainty is the 2020–2022 COVID-19 period, during which firms experienced substantial fluctuations in consumer demand, including panic buying in some sectors, demand collapse in others, and frequent forecasting errors. By comparison, the 2017–2019 pre-pandemic period may be regarded as a low-demand-uncertainty environment in many industries, as demand patterns were generally more stable and easier to predict than during crisis periods.

c. *Different Interest-Rate Uncertainty*

This setting is relevant to a wide range of macro-financial conditions. Periods of relatively low interest-rate uncertainty are typically associated with stable monetary policy environments in which borrowing costs are more predictable. For example, the 2017–2019 period may be viewed as one of relatively moderate interest-rate uncertainty in many economies, as interest-rate movements were comparatively gradual and predictable relative to later years. Similarly, the 2020–2021 period, despite major economic disruption, was characterized in many countries by historically low policy rates and strong monetary accommodation, which reduced financing costs and provided firms with a relatively stable borrowing environment. In contrast, high interest-rate uncertainty is more representative of periods such as 2022–2024, when inflationary pressures led many central banks to raise policy rates rapidly and repeatedly. During such periods, firms faced not only higher borrowing costs but also greater uncertainty regarding future financing conditions, making financial and operational planning more challenging.

More specifically, the first numerical case study presents a competitive setting with moderate demand uncertainty and liquidity risk. The second case study focuses on the impact of different levels of liquidity risk. The third case study examines how demand uncertainty affects firms' decisions, profits, and risk. The final case study illustrates the effects of different levels of interest-rate uncertainty on firms.

In addition to reporting average outcomes, the numerical case studies also present the 5th percentile of profits, production levels, and financing decisions in order to capture the downside risk associated with the model outcomes. While average values summarize the central tendency of the results, they do not fully reflect the dispersion of outcomes or the potential severity of unfavorable realizations under uncertainty. The 5th percentile provides information on the lower tail of the outcome distribution and can be interpreted as a simple stress-case measure, analogous in spirit to downside risk indicators such as Value at Risk used in finance. This is particularly relevant in our setting because firms are concerned not only with expected performance, but also with how production, financing, and profitability may change when market conditions become adverse. As shown in the case studies, decisions and performance under the 5th percentile scenario can differ substantially from those observed at the average level, and therefore reporting both measures provides a more complete assessment of model behavior.

To ensure economic meaningfulness, all stochastic parameters in the simulation, including the liquidity limit, demand function factor, and interest rate, are truncated at zero; that is, each realized parameter value is defined as the maximum of zero and the corresponding draw from its assumed distribution.

Table 3 Parameters for Numerical Case Study 1

Notation	Definition
Φ	$= 100$
LW_j^0	$= 30$; j = 1,2.
LW_j	$= 30$; j = 1,2.
$\rho_{j\phi_t}(Y_{\phi_t})$	$= \alpha - \frac{1}{2}(y_{\phi 1} + y_{\phi 2})$; α follows normal distribution with $\mu = 50$ and $\sigma = 10$
v	$= 20$
c_j	$= 12$; j = 1,2.
c_j^0	$= 10$; j = 1,2.
g_j^0	$= 0.8$; j = 1,2.
h_j	$= 1.5$; j = 1,2.
r_j^0	$= 0.12$; j = 1,2.
$r_{jt\phi_t}$	$= 0.1$; j = 1,2; $\phi \in \Phi$.

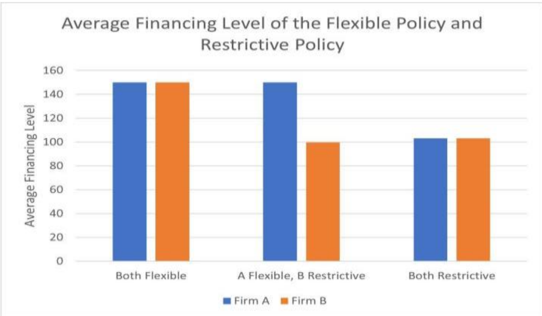

Figure 1 Average Financing Levels of Case 1

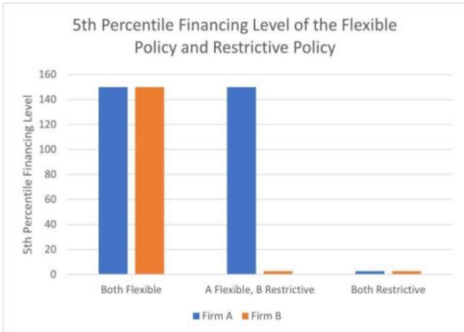

Figure 2 The 5th Percentile Financing Levels of Case 1

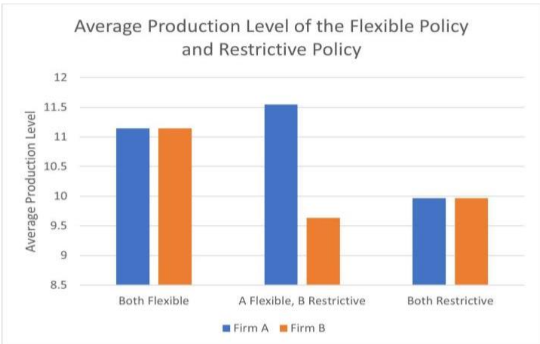

Figure 3 Average Production Levels of Case 1

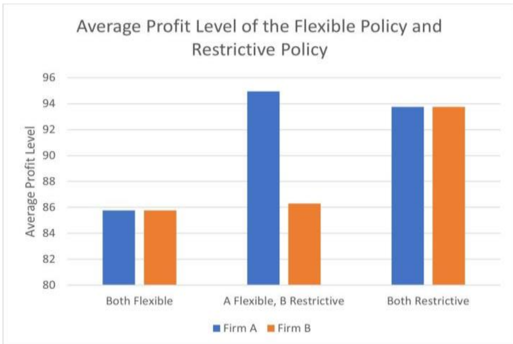

Figure 4 Average Profit Levels of Case 1

5.1 Numerical Case Study 1: A Potential Dilemma

We assume that there are two firms (J=2). We also assume that T=1 and suppress subscript t. In addition, we let β_ϕ denote the random variable with mean equal to 150 and standard deviation equal to 30. Both firms use the flexible financial policy in Example 1($LU_j^0 = 150;\ j = 1,2; LU_{j\phi} = 0;\ j = 1,2; \forall\phi$), and the restrictive financial policy in Example 3($LU_j^0 = 0;\ j = 1,2; LU_{j\phi} = \beta_\phi;\ j = 1,2; \forall\phi$), In Example 2, one firm uses the flexible policy and the other firm uses the restrictive policy ($LU_1^0 = 150; LU_2^0 = 0; LU_{1\phi} = 0; LU_{2\phi} = \beta_\phi; \forall\phi$). Note that β_ϕ represent the availability of short-term financing resources which reflects the market liquidity risk.

Note that in this case study we allow both demand risk (α in the demand function) and liquidity risk (β). The results are presented in Figures 1 - 5. Figure 1 shows the average financing level of the two firms in three examples. One can see that when a firm uses the flexible financial policy it has a higher average financing level compared to the firm with the restrictive financial policy. The main reason is that the firm with restrictive financial policy uses short-term financing the availability of which is affected by the liquidity risk. In some scenarios where the credit market liquidity is low the firm with restrictive financial policy may not be able to secure sufficient financing to support the operations or expand production. Meanwhile, the firm with flexible financial policy uses long-term financing which is not affected by the short-term liquidity risk in the credit market, and can even take advantage of the opportunity to expand its

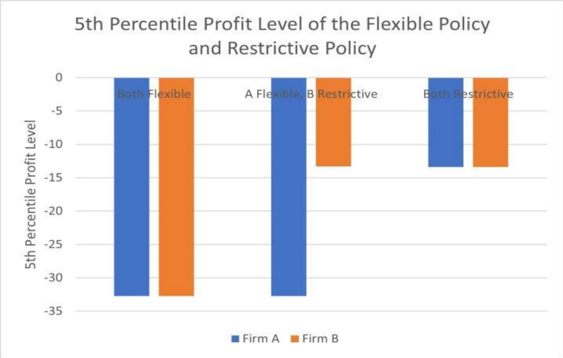

Figure 5 The 5th Percentile Profit Levels of Case 1

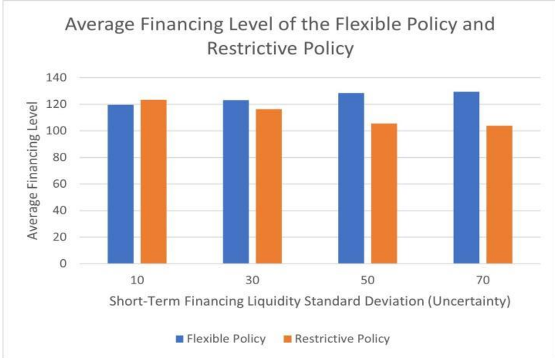

Figure 6 Average Financing Levels of Case 2

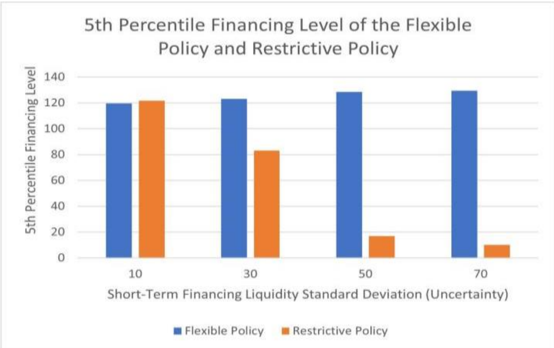

Figure 7 The 5th Percentile Financing Levels of Case 2

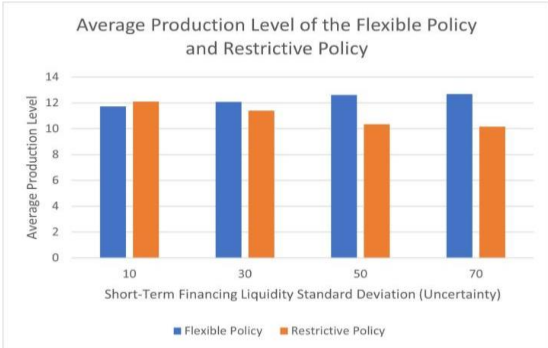

Figure 8 Average Production Levels of Case 2

operations when the production of the firm with restrictive financial policy is limited by liquidity.

The second reason is that the firms with flexible financial policy must decide the financing level before the uncertain demand factor is revealed. Thus, firms with flexible financial policy must make sure to cover higher demand scenarios which results in higher financing level. However, when the demand level is average or relatively low, the firm with flexible financial policy may not use all of its working capital efficiently. The firm with restrictive financial policy, on the other hand, is able to obtain short-term financing after the demand has been observed. It can borrow less when demand turns out to be low. Therefore, it doesn't have to maintain a high financing level in low demand scenarios which also causes its average financing level to be lower. Figure 2 exhibits consistent results, which shows that a firm with flexible financial policy maintains high financing level even in the lowest 5th percentile scenarios while a firm with restrictive financial policy reduces its financing level to almost zero in the lowest 5th percentile scenarios.

Figure 3 shows the average production level of the two firms in the three examples, which exhibits the similar pattern. Firms with flexible financial policy have higher average production levels compared to firms with restrictive financial policy. The main reason is that the firms with restrictive financial policy may have limited liquidity to support production in some scenarios. In particular, in Example 2 where firm A uses the flexible financial policy and firm B uses the restrictive financial policy, firm A significantly produces more than firm B. We did not present the figure for the lowest 5th percentile production levels because the firms with both policies completely stop production when extremely low demand factor results in insufficient market price (e.g. 5th percentile).

Figure 4 shows the profits of the two firms in the three examples. One can observe that the profits of both firms are low when they both use the flexible policy. This is due to the overproduction caused by the excessive working capital from both firms lead to low margins and low profits in some scenarios. When both firms use the restrictive financial policy, the profits are high since they could maintain higher profit margins in most scenarios. It is interesting to see that in Example 2, firm A with the flexible financial policy outperforms firm B with the restrictive financial policy. This is due to the reason we discussed previously where firm A is able to take advantage of the opportunity when firm B's production is limited due to the insufficient working capital. Figure 5 shows the 5th percentile profit levels of the firms in three examples. We can see that the firms with the restrictive financial policy has lower risk (loss) due to its flexibility during low demand scenarios.

Remark: The three examples in Figure 4 present an interesting dilemma for the two firms. Suppose that both firms are currently using the restrictive financial policy and are allowed to change to the flexible financial policy. What should they do? If they act simultaneously, both firms will switch to the flexible policy since the firm with the flexible policy will generate higher profit in Example 2. However, if both firms switch to the flexible policy they end up in Example 1 where they both have the lowest profits. This is similar to the prisoner's dilemma. Moreover, the two firms in Example 1 still have the option to switch back to the

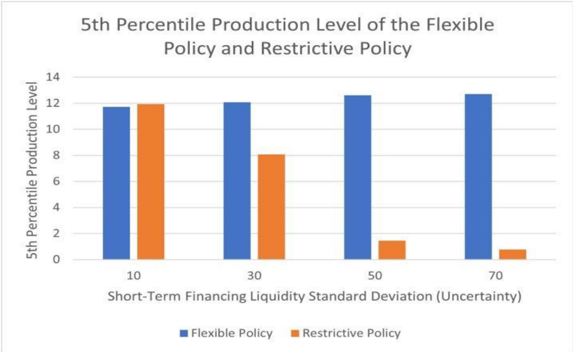

Figure 9 The 5th Percentile Production Levels of Case 2

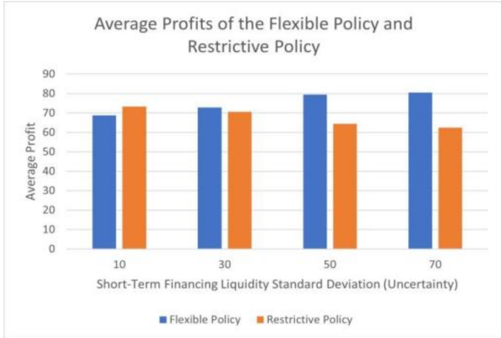

Figure 10 Average Profit Levels of Case 2

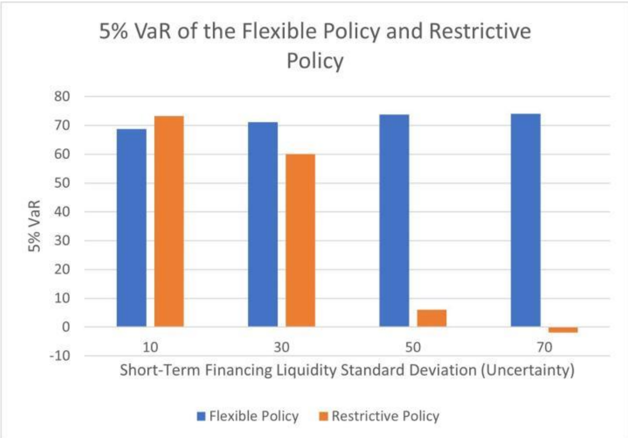

Figure 11 The 5th Percentile Profit Levels of Case 2

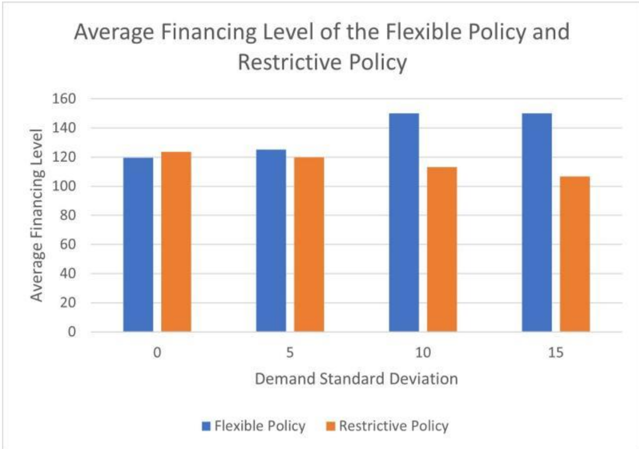

Figure 12 Average Financing Levels of Case 3

restrictive policy. The optimal strategy for either firm now is actually wait for the other firm to switch. One can see that although a firm can increase its profit marginally by switching back to the restrictive policy it can gain much more profit if it stays with the flexible policy while the other firm switches to the restrictive policy. This case study demonstrates the capability of our model to investigate complex interactions of firms when financial, capacity and operational decisions are all considered.

5.2 Numerical Case Study 2: Increasing Liquidity Risk

The second numerical case study focuses on the impact of increasing liquidity risk on the firms. We now assume that the demand factor α is fixed and equal to 50. We let the mean of the liquidity factor β_ϕ equal to 150 and increase its standard deviation from 10 to 70. The values of other parameters are as same as those in the first case study. We assume that one firm uses the flexible financial policy while the other firm uses the restrictive financial policy. The results are presented in Figures 6 - 11.

Figure 6 shows the average financing levels of the two firms. We can see that as the liquidity risk increases the average financing level of the firm with the restrictive financial policy decreases while the firm with the flexible financial policy increases. The reason is that as the liquidity risk rises the firm with restrictive policy may not be able obtain sufficient financing in some scenarios which reduced its average financing level. The firm with the flexible financing policy, in turn, is able to take the opportunity to increase its average financing level and expand production.

Figure 7 shows the 5th percentile financing level of the two firms. Note that because the firm with the flexible financial policy determines its financing level before the uncertainty factor is revealed, it has the same financing level in all scenarios. So, its 5th percentile financing level is equal to its average financing level. The 5th percentile of the financing level of the firm with the restrictive financial policy, on the other hand, declines significantly as the liquidity risk increases. Figures 8, 9, 10, and 11 exhibit consistent patterns as Figures 6 and 7. In summary, with increasing liquidity risk, the firm with restrictive financial policy will be worse off while the firm with the flexible financial policy will be able to take advantage of the opportunity to expand its operations and increase the profit.

5.3 Numerical Case Study 3: Increasing Demand Uncertainty

The third numerical case study investigates the effect of increasing demand uncertainty on the firms. We now assume that the mean of the demand factor α is equal to 50 and increase the standard deviation from 0 to 15. We let liquidity factor β_ϕ equal to 150 in all scenarios. The values of other parameters are as same as those in the first case study. Similar to case study 2, we assume that one firm uses the flexible financial policy while the other firm uses the restrictive financial policy. The results are presented in Figures 12-17.

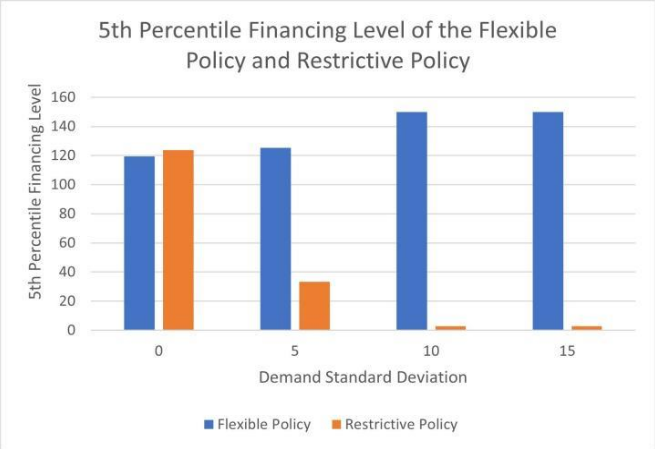

Figure 13 The 5th Percentile Financing Levels of Case 3

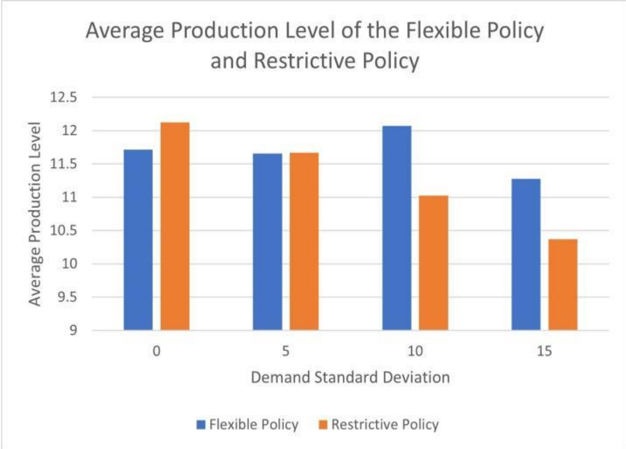

Figure 14 Average Production Levels of Case 3

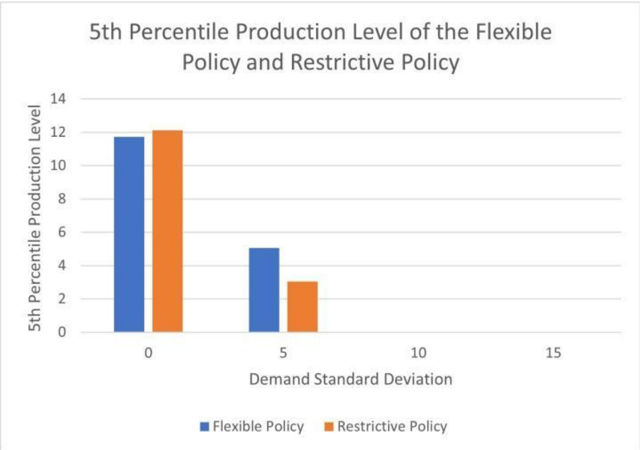

Figure 15 The 5th Percentile Production Levels of Case 3

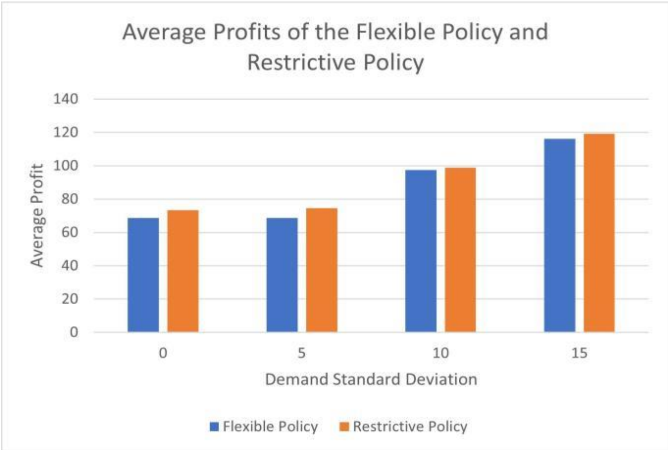

Figure 16 Average Profit Levels of Case 3

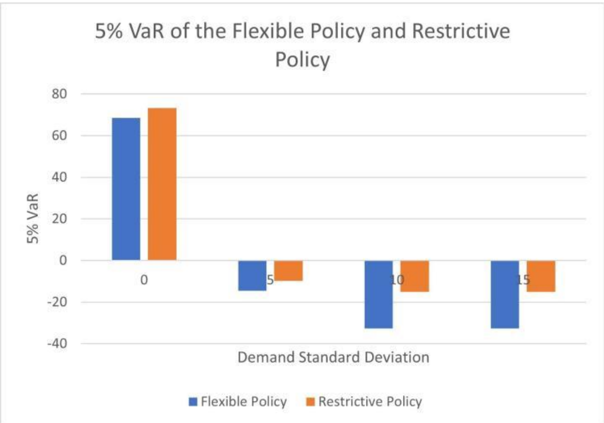

Figure 17 The 5th Percentile Profit Levels of Case 3

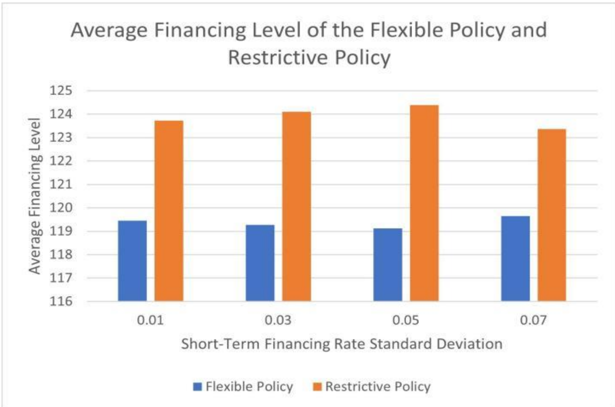

Figure 18 Average Financing Levels of Case 4

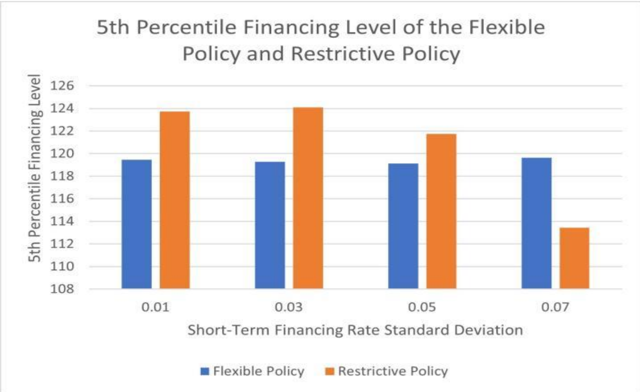

Figure 19 The 5th Percentile Financing Levels of Case 4

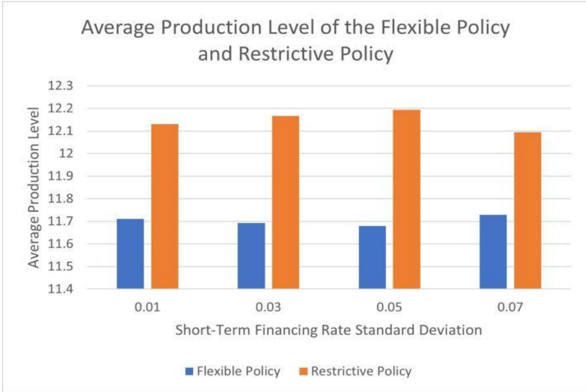

Figure 20 Average Production Levels of Case 4

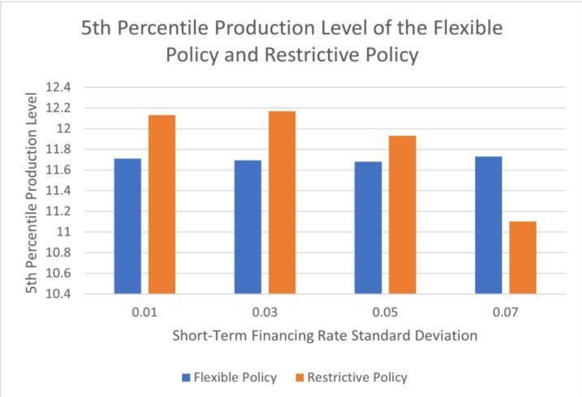

Figure 21 The 5th Percentile Production Levels of Case 4

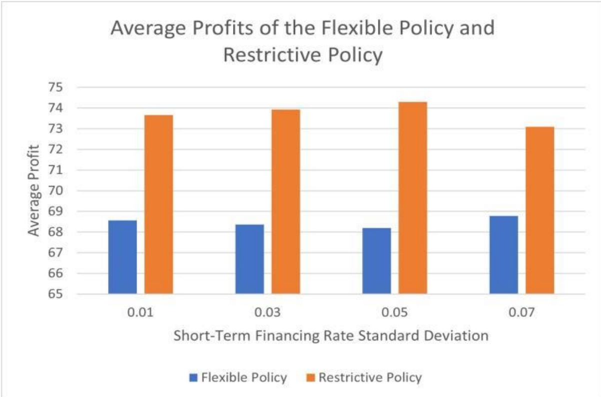

Figure 22 Average Profit Levels of Case 4

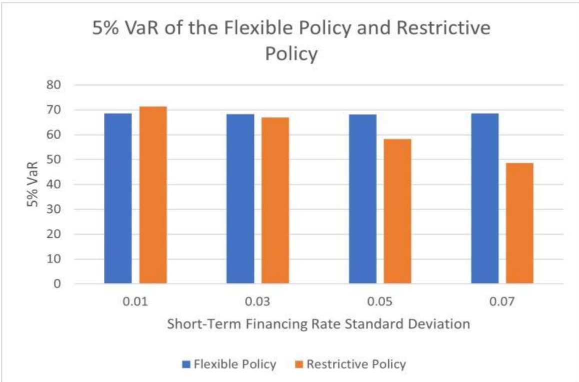

Figure 23 The 5th Percentile Profit Levels of Case 4

Note that the increasing demand standard deviation represents higher chances of both low demand and high demand, which implies not only risk but also opportunity. Figure 12 shows that as the demand standard deviation increases, the average financing level of the firm with flexible policy increases while that of the firm with restrictive financial policy decreases. The reason is that when the demand variation rises the high demand scenarios become more likely. Since the firm with flexible financial policy determines the financing level before the actual demand is observed it needs to raise its financing level to cover increasing high demand opportunities. Such elevated financing level results in excessive cash in other demand scenarios and may lead to overproduction. The overproduction further results in lower profit margin in average demand scenarios which causes the firm with restrictive financial policy to reduce production to maintain its profit margin. Figure 13 shows the 5th percentile financing level of both firms. Again, for the reason we mentioned in case study 2, the 5th percentile financing level of the firm with flexible financial policy is equal to its average level. The firm with restrictive financial policy, on the other hand, almost reduces its financing level to zero in the 5th percentile scenarios due to extremely low demand.

Figure 14 shows the average production levels as the demand uncertainty increases. The pattern is consistent with the trend in Figure 12 except that the average production of the firm with flexible financial policy declines when the demand standard deviation is equal to 15. The reason is that when the demand standard deviation is 10 in Figure 12, the financing level of the firm with flexible policy already reaches its maximum limit, $LU^0 = 150$. Hence, as the demand standard deviation further increases, the firm is not able to raise the financing level to cover higher demand scenarios. Unfortunately, the increasing demand standard deviation from 10 to 15 also increases the low demand probability. Therefore, the overall effect is reduced average production. In addition, Figure 15 shows that the 5th percentile production levels of both firms drop to zero as the demand standard deviation increases.

Figure 16 shows that the average profits of both firms increase as the demand uncertainty increases which indicates that the firms with either flexible or restrictive financial policy can benefit from the increasing opportunity of higher demand scenarios. Figure 17, in turn, presents the 5th percentile profit/loss of the two firms. We can observe that the increasing demand uncertainty will increase the risk of both firms and the firm with flexible financial policy is more negatively affected.

5.4 Numerical Case Study 4: Increasing Interest-Rate Uncertainty

The fourth numerical case study demonstrates how interest-rate uncertainty affects the two firms. In this study, the demand factor $\alpha = 50$ and the liquidity factor $\beta = 150$ in all scenarios. We assume that the short-term interest rate follows the normal distribution with the mean equal to 0.1. We increase its standard deviation from 0.01 to 0.07. The results are presented in Figures 18 - 23. From Figures 18, 20, and 22, one can see that the increasing interest-rate uncertainty does not significantly change the average financing levels, the average production levels, and the average profits of the two firms. However, Figures 19, 21, and 23 show that the rising interest-rate uncertainty will reduce the 5th percentile of the financing level, production, and profit of the firm with restrictive financial policy.

6. CONCLUSIONS, MANAGERIAL INSIGHTS, AND FUTURE RESEARCH

This paper is the first research that studies the integrated decision-making of financial policy, capacity strategy, and operations. We first developed an optimization model for an individual firm which considered the demand uncertainty, liquidity risk, and interest-rate risk. We then developed the variational inequality formulation to model the equilibrium of the Cournot competition among multiple firms. We proved the existence of the equilibrium solution and presented numerical case studies which provided important managerial insights. Our results show that the liquidity risk has significantly negative impacts on the operations, profit, and risk of the firm with restrictive financial policy and positive impacts on the firm with flexible financial policy while the interest-rate risk does not significantly affect the average profits of the firms with either type of financial policy. Our case study also demonstrates that the average profits of the firms with either financial policy can benefit from increasing demand uncertainty. However, the rising demand uncertainty will also increase the risk of loss for both types of firms with a greater impact on the firm using the flexible financial policy. In addition, we presented a case study which resembled the prisoner's dilemma and showed the complexity of the game between firms who optimized financial policy, capacity strategy and productions in a holistic manner.

This research can be further extended in two directions. First, the equilibria of long-term and short-term credit markets can be incorporated into the model so that the interactions between supply chains and financial markets can be investigated. Second, the research can further consider the suppliers and customers of the manufacturers to model the financial flows of a more complete network.

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CONFLICTS OF INTEREST

This study does not have any conflict of interest.

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