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Coordinating operational policy with financial hedging for risk-averse firms☆

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ABSTRACT

A risk-averse firm's financial hedging activity can impact the decision making in its daily operations. We introduce a CE-based approach that can help the firm to simplify the procedure in making hedging-consistent decisions. A key feature of this new approach is that it allows for the existence of nonfinancial random factors, which give rise to the risk exposure that cannot be hedged in the financial market. By using a CE operator, we show that the optimal operational policy can be obtained by maximizing the CE-based value function. Although the CE operator may bring additional nonlinearity to the value function, we find that the commonly desired base-stock policy can remain optimal under specific conditions. We hope that this new approach can help pave the way for future investigation on joint operations management and financial hedging problems in dynamic settings.

1. Introduction

When making procurement, inventory, and production decisions, firms are usually exposed to uncertainties such as volatile commodity price, fluctuating foreign exchange rates, as well as uncertain customer demands. Such risk exposures are undesirable for risk-averse firms, but they could be controlled by financial hedging, typically using available hedging instruments like commodity futures, options, and currency swaps from the financial market. As reported by a recent empirical study [1] on 7319 nonfinancial firms across 50 countries, over half (60.3%) of the surveyed firms have implemented some form of hedging using financial derivatives. These hedging activities are found to have some significant implications on the operational decisions made in firms' daily operations (see, e.g., [10,7]). In particular, financial hedging can reduce at least part of the risk exposure faced by a risk-averse firm. Such reductions in risk exposure, according to Eeckhoudt et al. [12], will then lead to an increase or decrease in the optimal purchasing quantity of the firm. As a result, there is a need to investigate how to make the optimal operational decisions that are consistent with a risk-averse firm's financial hedging activities.

Our interest in studying the aforementioned hedging-consistent operational decisions was motivated by the increasing availability and widely use of financial hedging instruments nowadays. Nevertheless, how to quantify the economic implications of financial hedging on operational decisions remains a challenging problem despite the growing academic and research effort. To simplify the analysis, some researchers have resorted to the complete market assumption; that is, assuming that the risk exposure involved in the firm's operations can be fully replicated by a "perfect" financial hedging portfolio in the market [28]. Given the existence of the replicating portfolio, the well-known risk-neutral valuation method in the finance literature can then be transplanted to "value" the operational decisions [3]. Consequently, the hedging-consistent operational decisions can be made via maximizing the expected value of the profit with the risk-neutral probability measure [14]. Thus, this approach is referred to as the *EV-based* approach (expected-value-based approach) in this paper. The EV-based approach is appealing because it can help substantially reduce the number of decision variables when financial hedging is involved – the decision variables regarding the hedging positions are entirely eliminated from the Bellman equation. However, there is a major obstacle when applying this approach in practice – the complete market assumption may not be entirely justified. As [3] writes, "an investor might only be able to remove part of the market risk and then have some uncontrollable portion that still remain. This remainder would cause a limit to the extent that a market can value our decision". To appropriately account for the "remainder risk", the complete market assumption must be relaxed.

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By relaxing the complete market assumption, we develop a *CE-based* approach (the certainty-equivalent-based approach) for risk-averse firms to make the hedging-consistent operational decisions in dynamic settings. The CE-based approach is a novel extension of the EV-based approach because it allows for the existence of *nonfinancial random factors* in addition to *financial random factors*. For nonfinancial firms, the distinction between the financial random factors and nonfinancial random factors is the key to differentiate the financial risk that can be hedged using derivatives from the remainder risk that cannot. On the one hand, financial random factors refer to the risk factors associated with the price processes of some financial securities/indices, such as the fluctuating commodity price and volatile currency rates. On the other hand, nonfinancial random factors represent the idiosyncratic disturbances (e.g., uncertain customer demand, random production yield) that are unrelated to the financial market. Both types of random factors can disturb a firm's operating profit in significant ways. For example, the operating profit of a multinational firm is exposed to both the volatile currency rates and uncertain global demand. The currency risk can usually be hedged using currency derivatives [10], so it should be recognized as a financial random factor. In contrast, the demand uncertainty is the remainder risk that cannot be hedged in the financial market, and thus should be treated as a nonfinancial random factor. When the nonfinancial random factor exists, the complete market assumption cannot apply, and the EV-based approach is no longer optimal. In this situation, the proposed CE-based approach can still be applied to simplify the procedure of making hedging-consistent operational decisions. The advantage is that the CE-based approach helps reduce the number of decision variables as the EV-based approach does. Moreover, we also investigate some structural properties of the CE-based value function, which allows us to prove that the commonly desired base-stock policy is optimal under a set of sufficient conditions. In addition, we present some straightforward numerical results to show that the CE-based approach dominates the EV-based approach in most of the cases.

This paper is closely related to the growing research on the interface of operations management and finance. In recent years, it is found that there exists complex interplay between the operational and financial hedging decisions. As shown by Chod et al. [7], financial hedge and operational flexibility can be either complementary or substitutable under different situations. Another interpretation of this complicated relationship is that operational decisions can be significantly affected by financial hedging in different ways. As a consequence, many researchers have investigated how to make the hedging-consistent operational decisions for risk-averse firms. Gaur and Seshadri [13] have shown that a risk-averse newsvendor should increase its order quantity when financial hedging is adopted to mitigate the demand risk. In another contribution, Ding et al. [10] have investigated the implications of a global manufacturer's financial hedging activity against currency risk on its operational decisions. For other examples regarding the impacts of financial hedging on operational policies, see Caldentey and Haugh [5], Caldentey and Haugh [6], and references therein. However, these papers typically assume a newsvendor setting in their models (i.e., single-period problems), which may have limitations in practice. One exception is Kouvelis et al. [19], who have analyzed the role of financial hedging in a multi-period commodity procurement and storage problem using a mean-variance utility criterion. In contrast, we present a new approach that can pave the way for investigating a class of multi-period joint operational and financial hedging problems by using the exponential utility criterion.

This research is also related to the real option literature. This stream of research concerns the valuation of real options embedded in risky projects such as R&D projects [23], supply chain network design [18], and capacity investments [3]. A central assumption in the real options theory, as analogs to ours, is that the cash flows from the real assets are correlated with the stochastic price processes of some traded securities or indices in the financial market. Then, the financial option pricing method is applied to value these risky projects due to the non-arbitrage argument or the existence of replicating portfolios [11]. For more examples on the application of real option theory, see Dentskevich and Salkin [9], Copeland and Antikarov [8], Berling [2]. Our paper differs from this literature in that we do not focus on valuation. Generally speaking, valuation of real options can be performed without virtually trading financial securities in the market. In contrast, we aim at quantifying the economic implications of financial hedging on operational policies when a risk-averse firm can trade securities in an accessible financial market to construct the desired hedging portfolio.

The remainder of this paper proceeds as follows: In Section 2, we introduce a general modeling framework for both the operations management and financial hedging. An illustrative example is provided to show its applicability. In Section 3, the exact procedure of the CE-based approach is introduced and discussed in detail. In Section 4, we numerically compare the CE-based and EV-based approaches. In Section 5, we summarize the main results and present some concluding remarks. Finally, in the Online Appendix we present (i) all the missing proofs, (ii) an introduction of the EV-based approach, and (iii) a discussion on how to identify a pair of independent financial and nonfinancial random factors by transformation.

2. Operational decisions and financial hedging – a general modeling framework

The planning horizon under consideration is $[0, T]$. Without loss of generality, T is assumed to be a positive integer. Then, the entire planning horizon is separated evenly into T periods, each of which contains a unit time and is indexed as $k = 0, 1, \dots, T-1$. For period k, the associated time interval is $[k, k+1]$, whereby the index k also represents the exact time instant at the beginning of that period.

2.1. Operational decision making

For each period k $(0 \le k \le T-1)$, the operations of the firm are characterized by the state vector $\boldsymbol{y}_k$, the operational decision (vector) $\boldsymbol{x}_k$ and the resulting operating profit $\tilde{R}_k(\boldsymbol{x}_k, \boldsymbol{y}_k)$. First, the state $\boldsymbol{y}_k$ is realized at the *beginning* of that period, and updated periodically by a transition function:

$$\boldsymbol{y}_{k+1} = \boldsymbol{y}_{k+1}(\boldsymbol{x}_k, \boldsymbol{y}_k) \tag{1}$$

Secondly, the decision $\boldsymbol{x}_k$ is made at the *beginning* of the period once the realized state vector $\boldsymbol{y}_k$ is observed (For simplicity, we assume that the decision $\boldsymbol{x}_k$ can take value in a feasible region that will not change with k, i.e., $\boldsymbol{x}_k \in \Omega_X$). Thirdly, $\tilde{R}_k(\boldsymbol{x}_k, \boldsymbol{y}_k)$ is realized at the *end* of period k, given that the state $\boldsymbol{y}_k$ has been realized and the decision $\boldsymbol{x}_k$ has been made.

The operations of the firm at period k would be disturbed by both financial and nonfinancial random factors, denoted by ω_{k+1} and ξ_{k+1}, respectively. Note that the subscript $k+1$ here indicates that these factors are realized at the end of period k, or equivalently, the beginning of next period $k+1$; so they should still be regarded as random variables at the beginning of period k. The financial and nonfinancial random factors are distinguished from each other, in a sense that the financial random factors are associated with the random price movement in the financial market, while nonfinancial random factors are not. Intuitively, one can expect that financial hedge can only cover the risk