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Hedging size risk: Theory and application to the US gas market

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ABSTRACT

Many corporate commitments exhibit a combined financial exposure to both market prices and idiosyncratic size components (e.g., volume, load, or business turnover). We design a customized contract to optimally mitigate the risk of joint fluctuations in price and size terms. The hedge is sought out among contingent claims written on price and any quoted index that is statistically dependent on commitment size. Closed-form solutions are derived for the optimal custom hedge pay-off and for the asset holdings of two market strategies, one based on price-linked forwards, the other based on price-linked and index-linked forwards. Analytical hedges are obtained using a stylized lognormal market model. Detailed comparative statics provide a thorough analysis of optimal hedging pay-off functions. Performance assessment is conducted in the context of the US gas market and a prototypical urban region. Results suggest that hedging through suitable custom claims written on price and an additional index *significantly outperforms* standard price-based as well as mixed price-index forward hedging alternatives. Our optimal custom hedge could be adopted as a benchmark for the relative assessment of any risk management solution.

1. Introduction

Enterprise risk management seeks to identify, measure, and mitigate exposure to any uncertainty affecting a firm's operations, value, and performance. A major portion of corporate risk involves the financial value of standing purchase and sale commitments (Fraser and Simkins, 2010). Most of these values stem from cash flows combining market prices with size-related terms. Whereas a price often is a tradable component of value, size generally represents a nontradable random element. Depending on the position in question, size may be assessed as a weight, volume, load, or even monetary value. Examples cover a wide variety of segments in the real economy: a farmer exposed to the future price of a soft commodity times the size of forthcoming harvest; a gas consumer facing risk engendered by unexpected price times fluctuating supply; a power retailer exposed to electricity price variations and load demand shifts; or a merchandise exporter experiencing domestic currency denominated turnover uncertainty, to mention a few.

All these cases share a common feature: risk results from multiplicatively combining unexpected discrepancies of tradable and nontradable components from their target figures. Tradable risk originates from the random movements of prices quoted in organized markets. It is thus natural to manage this source of uncertainty through the use of derivatives written on the price. These latter include futures, swap contracts, and financial options, among others (Eydeland and Wolyniec, 2001; Berg and Westgaard, 2012; and Roncoroni et al., 2015). Nontradable risk primarily concerns the size of industrial or commercial operations in a firm. It most often results from unexpected fluctuations in either supply (e.g., due to physical and/or managerial failure) or demand (e.g., varying consumption needs). Traditionally, size risk has been dealt with by using physical hedging strategies, such as optimal process scheduling, commodity procurement, and storage management (Berling and Martínez-de-Albéniz, 2011; Secomandi and Kekre, 2014; Secomandi and Seppi, 2016). In brief: market practice consists of managing price risk through financial derivatives and size risk through nonfinancial operations. However, this approach may perform poorly for at least two reasons. First, physical risk management is dear to set up, slow to execute, and stiff in comparison to the flexibility required by rapidly changing market conditions. Second, hedging one component of risk independently of others assumes mutual independence: consequently, neither a financial hedge of tradable price risk or a physical hedge of nontradable size exposure alone can guarantee an effective mitigation of combined price-size risk.

An alternative can be found in the literature on energy and commodity risk management. If price and size exhibit some degree of statistical dependence, one may buy or sell *tradable* derivatives written on price and obtain a partial hedge to size risk as a by-product of the deal. This has long been a strategy to manage risk in the

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agricultural, transportation, energy, and manufacturing industries. Rolfo (1989), Lapan et al. (1991), and Lapan and Moschini (1994) focus on agricultural supply and demand risk management using soft commodity forwards; Tomek and Peterson (2001) offer a comprehensive overview of financial risk management in agricultural markets; Treanor et al. (2014) examine the effectiveness of market-based hedging of energy exposure in the airline industry; Näsäkkälä and Keppo (2005) and Huisman et al. (2007, 2009) elaborate on the case of electricity retailers in deregulated power markets; Steil (1993), Adam-Müller (1997), and Brown (2001) explore foreign currency management for cross-country operating corporations; and Adler and Detemple (1988) offer an in-depth analysis of non-traded cash positions.

In the same line of thought, Brown and Toft (2002) offer a major advance. Inspired by Ahn et al. (1999), these authors first focus on the optimal design of *custom* hedging claims. This approach is opposed to deriving optimal positions in existing tradable securities. Their problem is cast as a static maximization of the expected full exposure (i.e., naked position combined with a hedge) revenue, net deadweight costs. Optimal hedge pay-off is selected within an assigned parametric family of functions of the price variable. Surprisingly, even if this proposal represents a major conceptual achievement, little attention has been paid by subsequent research in corporate risk analysis. Korn (2009) develops an extension by relaxing the underlying distributional assumptions and producing a few additional examples. Frestad (2010) investigates the way the natural resource industry dual tax system affects the extent of hedging operations carried out by value-maximizing firms.

A close reading of the Brown and Toft (2002) proposal reveals a number of underlying hypotheses which might have limited a systematic adoption and development of their approach. First, the hedger is assumed to maximize expected profits without any concern to possible aversion to risk. Indeed, concavity of the target functional ensuring a solution to their problem formulation is obtained through a deadweight cost function bounding profit growth. Second, admissible pay-off functions for a hedge are selected from an arbitrarily chosen parametric set of functions. This assumption dramatically simplifies computations, but turns the custom attribute into an oxymoron. One wonders to what extent the hedging quality of their instrument differs from the best possible nonlinear hedge. Third, and more importantly, hedging claims are contingent upon the realization of the sole price component of risk. As long as price and size risk components are assumed to randomly vary and co-vary over time, price hedging solutions seem inadequate in this context. Indeed, combining a price-based hedge with a naked position leaves a potentially relevant portion of standing size risk unaccounted for.

Our contribution in this study is threefold.

1. We *formulate and solve a genuine optimal custom hedge design problem in a fully general framework*. By assuming a risk-averse agent optimizing over a large class of regular pay-off functions written on a tradable price and an ancillary index correlated to size exposure, we elaborate closed-form formulae for the optimal custom hedge as well as two alternative forward-based optimal strategies.
2. We *compute, and experimentally analyze, exact analytical expressions for optimal custom and forward-based hedges in a stylized market model* for the underlying sources of risk. These formulae allow us to conduct a detailed study of the absolute quality of our bespoke hedges: comparative statics show how custom contracts vary over alternative configurations of the underlying parametric setting.
3. We *assess the relative performance of optimal custom hedges and forward-based hedging strategies* in a market context. Model calibration to the US gas market and a regional consumption area allows us to obtain realistic figures to in turn extrapolate prescriptions. We thus *formulate a recipe for benchmarking any hedging claim to the best theoretical solution*.

One may gain further insight into our approach by exploring the way we expunge each of the three major assumptions in Brown and Toft (2002).[1] First, risk aversion may be incorporated into problem formulation by adopting a mean-variance target functional as opposed to a cost-adjusted expected revenue. Second, the class of pay-off functions extends beyond polynomials by considering all square integrable functions of the underlying variables. Third, we improve price-based hedging solutions by exploiting a property we observe in several market instances: position size, which represents a nontradable component of risk, may exhibit some degree of statistical dependence to other market variables. For example, energy consumption data referring to a selected geographical region often show statistical correlation to temperature or humidity index values in the same area; turnover from international commodity sales may exhibit correlation to a commodity price in the foreign importing economy. These observations lead us to seek out a custom hedge in the class of claims whose pay-off function is contingent upon the underlying price and some other quoted variable exhibiting a sharp degree of correlation to the size component of risk.

The paper is organized as follows. Section 2 develops a theory of static hedge design in a general setting. We formulate the problem and derive expressions for the best custom hedge and for the asset holdings of price-based forward and mixed (price-index) forward hedging strategies. Section 3 defines a market model featuring log-normal variables and performs analytical calculations for all our hedges. Section 4 pursues comparative statics of optimal custom and forward-based hedges in a stylized gas market. Section 5 conducts a hedge performance analysis in the empirical context of the US gas market. We also derive a normative recipe for ranking any set of alternative hedging claims. Section 6 concludes with a summary of findings and avenues for future research.

2. General theory

2.1. Problem statement

We consider a one-period setting $\{0, 1\}$, where 0 represents a decision point in time and 1 denotes a future time horizon. Let $(\Omega, \mathcal{F}, \mathbb{P})$ be a complete probability space, where $\mathbb{P}$ represents the real-world measure. This is often referred to as the "historical" probability in an arbitrage pricing framework (Duffie, 2001). An economic agent is holding a *naked position* whose time 1 cash flow $\pi(X, Y)$ depends on two terms: variable X represents a tradable price, while component Y stands for size. As seen from time 0, both variables are random, while at time 1 they define observable samples. We may think of X as the spot price of a tradable energy source, e.g., gas, and Y as demand size which a buyer quantifies in

[1] Id Brik and Roncoroni (2014) tackle the issue in the context of power risk management. They obtain a pair of fully customized hedging securities, one written on a price variable, the other written on a suitable hedging index. However, they do so with the assumptions that full-exposure has zero mean and price series are fully uncorrelated to hedging index series. These hypotheses may dramatically reduce the extent of application of their hedge beyond the case of the power market these authors analyze.