Exchange Rate Risk Hedging for a Global Supply Chain of Nonstorable Commodity in Presence of a Spot Market

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Abstract

Exchange rate fluctuation increases the risk of global supply chain management. In this paper, we study a global supply chain of a nonstorable commodity, which involves transactions to be settled at a foreign currency between a manufacturer and a supplier. Both parties are risk-averse, and they negotiate a supply contract through a Nash bargaining process. To hedge against the exchange rate risk, they can purchase forward exchange rates in the financial market. In addition, the manufacturer can also procure the commodity from a local supplier. This avoids the exchange rate risk, but incurs another risk because the quantity available from the local supplier is not very certain. We formulate the problem as a Nash bargaining game where the two players have mean-variance preferences over their profits. We derive the unique equilibrium supply contract under a random exchange rate and a random local supply, from which we can characterize the optimal forward exchange rate level and the local procurement level.

Keywords:
Global supply chains, nonstorable commodity, exchange rate hedging; Nash bargaining game

1. Introduction

Due to globalization of the economy, many firms are engaged in transactions in foreign countries through global supply chains. These include trades of large nonstorable commodities, such as crude oil, natural gas, agricultural produces, etc. The prices of these commodities are, however, more volatile than those of other products. Indeed, price uncertainty of nonstorable commodities, whether caused by government policy, currency rates, climatic disasters, or political/civil instability, is inherent in commodity markets (Kang & Mahajan, 2006). For nonstorable commodities, suppliers and buyers usually commit their transactions through bilateral contracts so as to avoid the possible price fluctuations in the spot markets (Grey et al., 2005). Industrial firms with transactions in such a global supply chain may, therefore, have to hedge the exchange rate risks through appropriate operational strategies and/or financial instruments. How should a firm ameliorate the exchange rate risk by operational and financial instruments? How should a firm determine the optimal supply contract in presence of spot markets and unreliable local suppliers? How should a firm adjust its supply contract and risk hedging mechanism according to market conditions and risk preference?

This paper aims to investigate these questions from the perspective of a Nash bargaining game. We examine the equilibrium supply contract and the optimal hedging mechanism for a supplier and a manufacturer located in two different countries, who negotiate a bilateral contract for the manufacturer to procure a nonstorable commodity from the supplier. A liquid spot market for the commodity is available, where the price is fluctuating. The manufacturer may also purchase the commodity from a local supplier, which avoids the problem of foreign exchange, but the local supplier is not reliable in terms of his supply quantity. To capture the essence of a bilateral contract, we assume that the supplier and the manufacturer negotiate the supply contract through a Nash bargaining process, with respective bargaining powers (Dong and Liu, 2007). The supplier produces the commodity and faces uncertainties in exchange rate in the currency market and commodity price in the spot market. The manufacturer uses the commodity to produce a final product at some future time and faces uncertainties in the exchange rate, and the price of and the demand for the final product in the final market. In addition, we assume that both the supplier and manufacturer are risk averse and have mean-variance preference over their future profits.

This paper is related to two different areas: operations management (OM), and finance. In terms of OM studies, this paper is related to risk management involving exchange rate, which needs to be addressed by using financial and/or operational hedging instruments. Allayannis et al.(2001) empirically show that the more geographically dispersed a multinational firm, the more likely it is to use financial hedges. They also find that operational hedging strategies benefit the shareholders only when used in combination with financial hedging strategies. Kazaz et al. (2005) examine the impact of exchange rate uncertainty on the optimal production policies of a global manufacturing firm when the allocation decision can be deferred until the realization of exchange rates. Ding et al. (2007) investigate the integrated operational and financial hedging decisions faced by a global firm who sells to both home and foreign markets in a newsvendor context. Arcelus et al. (2013) deal with the impact of foreign exchange transaction exposure within a newsvendor setting. All the above literature focuses on the decisions of profit maximization and/or risk minimization for multinational firms, by developing stochastic models or newsvendor models.

In the finance literature, there have been many studies on exchange rate derivatives. These studies have empirically proven that firms can use financial hedge strategies, such as foreign currency derivatives and foreign denominated debts etc., to alleviate the impacts of unexpected exchange rate fluctuations; see, e.g., Geczy et al. (1997), Allayannis and Ofek (2001), Nguyen and Faff (2003), Elliott et al. (2003), Chiang and Lin (2005), Al-Shboul and Alison (2009), Aysun and Guldi (2011). Our research uses the structural approaches to optimize a firm's decisions and provides quantitative results on how to hedge the exchange rate risk.

2. **Model**

We consider a global supply chain system consisting of a risk-averse supplier and a risk-averse manufacturer located respectively in two different countries. The supplier and the manufacturer negotiate a supply contract for the price w and quantity Q of a certain commodity at a lead time (denoted as time L hereafter) before the market reveals the relevant information. The negotiation gives rise to a Nash bargaining game. The manufacturer uses the commodity as a component to produce a final product and sells it in a market at price r at the selling season (denoted as time S hereafter). The commodity is assumed to be economically or physically nonstorable. Examples of such include electricity, natural gas etc., which require excessive storage costs, or agriculture commodities, which may deteriorate quickly. In addition to the supply contract, both the supplier and the manufacturer can also trade in a spot market for the component at price p.

Although the supply contract reduces the risk caused by the randomness of the spot price, it exposes the participants to the other risk: the random fluctuations of the exchange rate. We assume that the exchange rate of the supply contract for the manufacturer and the supplier are s_m^s and s_s^m respectively. If the supply contract specifies the manufacturer's (resp. supplier's) currency as the payoff currency, then $s_m^s = 1$ (resp. $s_s^m = 1$). The manufacturer and the supplier can buy forward exchange rate to ameliorate the exchange rate risk. Forward exchange rate is an agreement between two parties to buy or sell a foreign currency at a pre-specified price (i.e., forward price) at a specific point of time in the future.

In addition, there is an additional option for the manufacturer, which is to purchase the component from a local supplier. This may allow the manufacturer to avoid the exchange rate risk. However, the supply of the local supplier is not reliable. This may be caused by many reasons, including uncertainties in raw materials, labor, electricity, and other random events and processes. One uncertainty is caused by fluctuations in the credit market which is not well developed in many developing countries.

The local procurement, therefore, would suffer from the risk of local supplier unreliability. Let τ represent the local supply reliability in our model, in the sense that if the manufacturer orders q_L units of the component from the local supplier at time L, then he will obtain τq_L units of the component at time S. The reliability factor τ takes value in [0,1], with $\tau = 0$ representing the case where the manufacturer gets no component from the local supplier, and $\tau = 1$ representing the case where the manufacturer gets all the component that he ordered from the local supplier.

We assume that in both the spot market for the component and the final product market, the supplier and the manufacturer are small participants and are thus only price takers. The demand D and the price r for the final product, the price p and the supply reliability τ for the component at the local market, and the exchange rate are all possibly correlated random variables with bounded supports and means and variances, respectively. All random variables are realized and observed at the selling time S.

The sequence of events is summarized as follows:

1) At time L, the manufacturer and the supplier negotiate the supply quantity Q and the supply price w through a Nash bargaining game with respect to their respective utility gains.

2) After the supply agreement is reached, the manufacturer and the supplier determine, respectively, the optimal forward exchange rate level, to hedge against their respective risks of exchange rate fluctuations.

3) The manufacturer determines the optimal local procurement level, to reduce his exchange rate risk.

4) At time S, the final product demand D, the final product price r, the component spot price p, the local supply reliability τ, and the exchange rate, are realized and observed.

5) Both the supplier and the manufacturer exercise their forward exchange rates.

6) The supplier chooses the optimal component production quantity to maximize his profit at time S.

7) The supply quantity and the local procurement quantity are settled by physical delivery and the corresponding payment. Both the supplier and the manufacturer trade in the component spot market.

8) The manufacturer chooses the optimal final product level to maximize his profit and sells the final product to the market, where the unit cost of not meeting the realized demand D is assumed to be g.

3. Nash Bargaining

To capture the risk-averse characteristics of the manufacturer and the supplier, we assume that they have mean-variance preferences over their profits. The mean-variance analysis was first proposed by Markowitz (1959) to deal with the risk associated with the return of assets. It uses a parameter λ ($\lambda \geq 0$) to characterize a decision maker's risk averseness, which is a quantitative balance between the mean profit and the risk measured by the variance. The coefficient $\lambda = 0$ denotes the special case of maximizing the mean profit function only. An increase in λ indicates the decision maker's increasing willingness to sacrifice the mean profit to avoid the risk of seeking the return. Note that, for any given λ, a solution is optimal in the sense that we cannot improve the mean profit without bearing more risk, or reduce the risk without decreasing the mean profit. Under the mean-variance framework, the objective functions of the participants become much more complicated. Let π_i be firm i's profit at time S. Then firm's utility at time L is:

$$U_i(\pi_i) = E[\pi_i] - \lambda_i V[\pi_i], \tag{1}$$

where λ_i is the corresponding risk-aversion coefficient, and E and V denote, respectively, the expectation and variance.

The manufacturer and the supplier negotiate the supply contract (w, Q), which we analyze using the Nash Bargaining Solution (NBS). Consider a bargaining situation between two players: If they cannot reach an agreement to collaborate, they will receive a given pair of payoffs (which may be achieved by applying their own resources without collaboration); But if they reach an agreement to collaborate, they may obtain a (superior) pair of payoffs from a convex set of pairs. NBS is that payoff pair which maximizes the product of the gains of the two players over their disagreement payoffs. For more detailed description of this theory, see Nash (1950). NBS can not only meet the individual rationalities of both the supplier and the manufacturer, but also realize the Pareto dominance of the entire supply chain. We thus select NBS to determine the optimal profit and risk hedging schemes.

As we can see from the model described above, if the negotiation between the supplier and the manufacturer is successful, the supplier (manufacturer) will sell (buy) Q units of the component at price w. If the negotiation is not successful, the supplier will sell all the component to the spot market at price p and the manufacturer will buy the component as needed from the spot market at price p as well as the local supplier at price p_L. Let π_{i0} be firm i's profit at time S if the negotiation results in disagreement. Then, the Nash bargaining solution is the one to maximize the following objective:

$$\max \quad (U_m(\pi_m) - U_m(\pi_{m0}))^{\theta} (U_s(\pi_s) - U_s(\pi_{s0}))^{1-\theta}, \tag{2}$$

subject to the participation constraints (individual rationality condition): $U_m(\pi_m) - U_m(\pi_{m0}) \geq 0$ and $U_s(\pi_s) - U_s(\pi_{s0}) \geq 0$, where $0 \leq \Theta \leq 1$ and $1-\Theta$ represent the relative bargaining powers of the manufacturer and the supplier, respectively.

4. Equilibrium Contract

We have characterized the equilibrium contract, based on the Nash Bargaining Solution. We first analyze the profits of the manufacturer at time S and at time L, and then determine the optimal w and Q to maximize the Nash objective (2). Our main result is given in the Theorem below (The technical proof is available upon request).

Theorem 1. *There exists a unique equilibrium supply contract (w^*, Q^*) for the Nash bargaining game, where*

$$Q^* = \frac{\mu_s^m \mu_m^p - \mu_s^m \mu_m^\tau \Phi_m^\tau + 2\lambda_s \mu_m^s \mathrm{COV}_s - \mu_m^s \mu_s^p + 2\lambda_m \mu_s^m \mathrm{COV}_m}{2[\lambda_m \mu_s^m (\sigma_m^{p2} - \Gamma_m^\tau) + \lambda_s \mu_m^s (\sigma_s^{p2} - \rho_s^{pm2}/\sigma_s^{m2})]},$$

$$w^* = \frac{(1-\theta)\mu_s^m \left\{\mu_m^p Q^* + \mu_m^\tau (q_L^* - q_{L0}) - \lambda_m \Delta \mathrm{var}_m^*\right\} + \theta \mu_m^s \left\{\mu_s^p Q^* + \lambda_s \Delta \mathrm{var}_s^*\right\}}{\mu_s^m \mu_m^s Q^*}$$

and

$$\mathrm{COV}_s = \mathrm{COV}_{sp} - \rho_s^{pm} \mathrm{COV}_{sm}/\sigma_s^{m2},$$

$$\mathrm{COV}_m = \mathrm{COV}_{mp} - \Phi_m^\tau \mathrm{COV}_{m\tau} - \Psi_m^\tau \mathrm{COV}_{ms},$$

$$\Gamma_m^\tau = \frac{\sigma_m^{\tau 2} \rho_m^{ps2} - 2\rho_m^{ps} \rho_m^{s\tau} \rho_m^{p\tau} + \sigma_m^{s2} \rho_m^{p\tau 2}}{\sigma_m^{\tau 2} \sigma_m^{s2} - \rho_m^{s\tau 2}},\ \ \Phi_m^\tau = \frac{\sigma_m^{s2} \rho_m^{p\tau} - \rho_m^{s\tau} \rho_m^{ps}}{\sigma_m^{\tau 2} \sigma_m^{s2} - \rho_m^{s\tau 2}},\ \ \Psi_m^\tau = \frac{\sigma_m^{\tau 2} \rho_m^{ps} - \rho_m^{s\tau} \rho_m^{p\tau}}{\sigma_m^{\tau 2} \sigma_m^{s2} - \rho_m^{s\tau 2}}.$$

5. Concluding Remarks

Globalization of the economy today motivates firms to be engaged in the global market to earn high profit. This, in turn, is accompanied with high risk. In order to address the spot price fluctuation, firms tend to negotiate a bilateral supply contract to fix the price and/or quantity for future transactions. However, bilateral contracts induce exchange rate risk in the global transactions. We have examined the exchange rate hedging mechanism for a global supply chain of nonstorable commodity in the presence of a spot market, based on Nash bargaining game. Through the financial hedging mechanism, forward exchange rate, and local procurement, we find that there exists a unique equilibrium supply contract for two risk-averse participants with respective market power.

Several extensions can be built upon this model. First, forward exchange rate portfolio hedging can be considered in our framework. Our paper has only considered using the forward exchange rate to hedge the exchange rate risk of the supply contract. If one uses a forward exchange rate portfolio to hedge the exchange rate risk of the spot market, more interesting results may be obtained, although this extended model will be much more complicated and involved. Second, the supplier's capacity reservation can be combined into our model to analyze the supplier's capacity decision equilibrium.

Finally, our model has mainly focused on a one-period two-participant bargaining process. An interesting but challenging extension would be to allow two-participant to negotiate through multiple periods. In that setting, the multiple period negotiations will impact the player's profit and risk. And a more general extension would be to consider multiple sellers and multiple buyers to negotiate through multiple periods.

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References:

Allayannis, G., J. Ihrig, J. P. Weston. 2001. Exchange-rate hedging: Financial versus operational strategies. *The American Economic Review*, Vol. 91, pp. 391-395, 2001.

Allayannis, G., E. Ofek. Exchange rate exposure, hedging, and the use of foreign currency derivatives. *Journal of International Money and Finance*, Vol. 20, No. 2, pp. 273-296, 2001.

Al-Shboul, M., S. Alison. The effects of the use of corporate derivatives on the foreign exchange rate exposure. *Journal of Accounting, Business & Management*, Vol. 16, pp. 72-92, 2009.

Arcelus, F.J., R. Gor , Srinivasan G. Foreign exchange transaction exposure in a newsvendor setting. *European Journal of Operational Research*, Vol. 227, pp. 552-557, 2013.

Aysun, U., M. Guldi. Derivatives market activity in emerging markets and exchange rate exposure. *Emerging Markets Finance & Trade*, Vol. 47, pp. 46-67, 2011.

Chiang, H., J. Lin. The use of foreign currency derivatives and foreign-denominated debts to reduce exposure to exchange rate fluctuations. *International Journal of Management*, Vol. 22, pp. 598-604, 2005.

Dong, L., H. Liu. Equilibrium forward contracts on nonstorable commodities in the presence of market power. *Operations Research*, Vol. 55, pp. 128-145, 2007.

Ding Q., L. Dong, P. Kouvelis. On the integration of production and financial hedging decisions in global markets. *Operations Research*, Vol. 55, No. 3, pp. 470-489, 2007.

Elliott, S.P., S.D Makar. Huffman. Foreign-denominated debt and foreign currency derivatives: complements or substitutes in hedging foreign currency risk ? *Journal of Multinational Financial Management*, Vol. 13, pp. 123-139, 2003.

Geczy, C., B.A. Minton, C. Schrand. Why firms use currency derivatives. *The Journal of Finance*, Vol. 52, No. 4, pp. 1323-1354, 1997.

Grey, W., T. Olavson, D. Shi. The role of e-market places in relationship-based supply chains: A survey. *IBM Systems Journal*, Vol. 44, No. 1, pp. 109-123, 2005.

Kang M. G., N. Mahajan. An introduction to market-based instruments for agricultural price risk management, *Working Paper*, 2006.

Kazaz B., M. Dada, H. Moskowitz. Global production planning under exchange-rate uncertainty. *Operations Research*, Vol. 51, No. 7, pp. 1101-1119, 2005.

Markowitz H. *Portfolio selection, efficient diversification of investments*. New Haven, USA: Yale University Press, 1959.

Nash J. F. The bargaining problem. *Econometrica*, Vol. 18, pp.155-162, 1950.

Nguyen, H., R. Faff. Further evidence on the corporate use of derivatives in Australia: the case of foreign currency and interest rate instruments. *Australian Journal of Management*, Vol. 28, pp. 307-317, 2003.

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