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Corporate Risk Management for Multinational Corporations: Financial and Operational Hedging Policies

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Abstract. Under what conditions will a multinational corporation alter its operations to manage its risk exposure? We show that multinational firms will engage in operational hedging only when both exchange rate uncertainty and demand uncertainty are present. Operational hedging is less important for managing short-term exposures, since demand uncertainty is lower in the short term. Operational hedging is also less important for commodity-based firms, which face price but not quantity uncertainty. When the fixed costs of establishing a plant are low or the variability of the exchange rate is high, a firm may benefit from establishing plants in both the domestic and foreign location. Capacity allocated to the foreign location relative to the domestic location will increase when the variability of foreign demand increases relative to the variability of domestic demand or when the expected profit margin is larger. For firms with plants in both a domestic and foreign location, the foreign currency cash flow generally will not be independent of the exchange rate and consequently the optimal financial hedging policy cannot be implemented with forward contracts alone. We show that the optimal financial hedging policy can be implemented using foreign currency call and put options and forward contracts.

1. Introduction

Multinational corporations often sell products in various countries with prices denominated in corresponding local currencies. It is widely recognized that as the volatility in exchange rates has increased dramatically after the breakdown of the Bretton Woods system of fixed exchange rates (see Smith, Smithson and Wilford (1990)), multinational corporations may have become increasingly vulnerable to

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exchange risk since the short term movements in exchange rates are often not accompanied by offsetting changes in prices in the corresponding countries (see Shapiro (1992), for example).

Of course, in perfect capital markets, corporations need not hedge exchange risk at all since investors can do it on their own (see Aliber (1978)). Market imperfections, such as taxes, agency problems, asymmetric information, dead-weight costs associated with financial distress, however, may provide incentives for corporations to hedge the exchange risk (see Dufey and Srinivasulu (1983), Stulz (1984), Shapiro and Titman (1985), Smith and Stulz (1985), Froot, Scharfstein and Stein (1992) and DeMarzo and Duffle (1995)). A number of finance scholars and practitioners have discussed how firms could use financial instruments to hedge financial price risk (see, among others, Giddy (1983), Lewent and Kearney (1990), Smith, Smithson and Wilford (1990), Froot, Scharfstein and Stein (1994) and two popular textbooks Shapiro (1992) and Eiteman, Stonehill and Moffett (1995)).

In addition to using financial contracts, a firm could manage its risk exposure through operational hedging. An example of an operational hedging policy would be to locate production in a country where significant sales revenues in the local (i.e., foreign) currency are expected. The effect of unexpected changes in exchange rates and foreign demand conditions on domestic currency value of sales revenues is hedged by similar changes in the the domestic currency value of local production costs. Operational hedging motives thus may provide a reason for direct foreign investment by firms and may further explain the existence of multinational firms with production facilities at several foreign locations.

When should a multinational corporation adopt financial hedging policies to manage risk? Under what conditions should it resort to operational hedging? When should it use both simultaneously and what should be the extent of each type of policy? A systematic analysis of these questions, to our knowledge, does not exist in the literature. This paper attempts to fill this gap.

The costs of implementing a financial hedge are likely to be an order of magnitude smaller than those of implementing an operational hedge. After all, in order to implement an operational hedge, a firm may be required to open a production plant in another country whereas to implement a financial hedge may simply require a phone call to the firm's bank. What could, then, be the advantages of operational hedging policies?

If the quantity of foreign currency revenues the firm is expected to generate is certain, it is easy to hedge the exchange risk exposure associated with it by using a forward contract for that certain quantity. This eliminates the associated transaction exposure completely with a relatively simple financial hedge. However, fluctuating foreign currency cash flow represents an additional source of uncertainty for many multinationals. For certain products, demand conditions can swing dramatically from year to year, inducing large changes in foreign currency revenues. If the quantity of foreign currency revenues is uncertain (and not perfectly correlated with the exchange rate), no financial contract (that must be agreed upon *ex ante*) that is contingent only on *ex post* observable and non-manipulable variables such as the exchange rate, can completely eliminate the exchange risk.[1] We argue that one of the advantages of an operational hedge is that it allows the firm to align domestic currency production costs and revenues more closely. It is as if the firm had a forward contract whose quantity is contingent upon sales in the foreign country. Clearly, this dominates a fixed quantity forward contract. An operational hedge, by aligning local costs with local revenues amounts to self-insurance by the firm against demand uncertainty; market insurance for demand uncertainty is not feasible because of the severe moral hazard problem since sales can be manipulated by the firm.

Unlike financial hedging contracts, a firm's operational policies are likely to affect expected profits. For example, having plants in several countries allows the firm to shift some production to the location where costs, after observing the exchange rate movements, are the smallest in domestic currency terms. Creating this production flexibility may have a positive expected payoff. This benefit has been discussed in the literature (see Dasu and Li (1994) and the textbooks Shapiro (1992) and Eiteman, Stonehill and Moffett (1995)). Production flexibility may also affect the variance of profits, an effect that has been neglected in the literature. We contend that firms concerned with managing risk will want to take this hedging effect into account, and are likely to adopt operational policies that differ from those that maximize expected profits.

Mello, Parsons, and Triantis (1995) consider the design of an optimal financial hedging policy for a multinational with production flexibility. Financial hedging helps alleviate the agency problem associated with the firm's outstanding debt and moves equity owners to closer to the first best operating policy. Mello, Parsons, and Triantis analyze a model in which exchange rate movements are the only source of risk. In such a setting, production flexibility raises firm value but does not confer a hedging benefit. We examine a setting in which there is also uncertainty regarding the quantity of foreign currency cashflow It is this additional source of risk that creates a risk management rationale for production flexibility.

We develop a formal model in the following section to analyze the issues discussed above. For concreteness, Section 3 then presents a numerical example of the model. Implications of the model are discussed in Section 4, which is followed by some concluding remarks.

2. The model

Consider a firm based in the U.S. that produces a single good for sale at a future date (time 1) in a foreign market. Demand for the good at time 1, denoted

[1] Chowdhry (1995) and Kerkvliet and Moffett (1991) analyze optimal financial hedging policies for multinational firms facing uncertain future foreign currency cash flow. However, they focus on financial hedging policies and do not consider the possibility of operational hedging. Earlier treatments of hedging under price and quantity uncertainty include Anderson and Danthine (1978).

$x \in [0, x_{\max}]$ in the U.S. and $x^* \in [0, x^*_{\max}]$ in the foreign market, is uncertain at time 0. There is no demand for the good after time 1. The time 0 exchange rate between the two currencies is normalized to 1. Let s denote the time 1 price of one unit of foreign currency in terms of domestic currency units. For simplicity, we normalize $E[s] = 1$. Assume further that s, x and x^* are stochastically independent. Let p and p^* denote the sale prices of the good in the U.S. and in the foreign market respectively. The assumption of stochastic quantities sold at exogenously fixed prices can be rationalized as a result of a firm facing (downward sloping) demand curves whose locations are uncertain at the time of setting prices. Similarly let c and c^* denote per unit costs of production in the U.S. and the foreign location respectively. For simplicity and analytical tractability, we assume that per unit sale prices and costs at time 1 are known with certainty at time 0. We further normalize $p = p^* > c = c^*$ so that there are no expected differences *ex ante* in sale prices and marginal costs at the two locations.

At time 0, the firm decides to build plants with capacities k and k^* respectively at the U.S. and the foreign location. We assume that the total capacity is enough to meet the maximum demand at the two locations, i.e., $k + k^* = x_{\max} + x^*_{\max}$. At time 1, the firm can produce up to its capacity at each location. Let q and q^* denote the quantities of the good produced at each location at time 1 to satisfy the total demand.[2] Thus,

$$q + q^* = x + x^*. \tag{1}$$

Let y and y^* denote the cash flows in US$ and the foreign currency respectively. Then,

$$y = px - cq, \tag{2}$$

$$y^* = px^* - cq^*. \tag{3}$$

The firm's profits (excluding any fixed costs of establishing plants), without any financial hedging contract, at time 1, thus can be written as:

$$\pi = y + sy^*. \tag{4}$$

There are some features of our setup that may appear restrictive at first glance. First, it would be more natural to assume downward sloping demand curves where firms can set prices *after* observing the demand conditions at each location. Second, firms may be able to adjust the prices charged at each location *after* observing the exchange rate s.[3] Third, one could specify more general cost functions in

[2] It will be optimal to satisfy total demand if $p/c \geq s \geq c/p$. If this condition does not always hold, then under certain circumstances meeting demand fully in one of the markets is not optimal. Consideration of this additional "abandonment" option would complicate the analysis somewhat and not affect the basic results.

[3] These were brought up by the referee commenting on an earlier draft.

which costs are increasing and convex in quantities produced and decreasing in the installed capacities at each location.

An important feature that we are trying to capture in our model is uncertainty about the quantity of foreign currency cash flow y^*. Our setup allows us to capture this uncertainty in a particularly tractable manner since revenues at each location (in local currencies), px and px^*, are independent of the exchange rate s. This makes domestic currency value of revenues at the foreign location, spx^*, sensitive to foreign exchange rate fluctuations which is another feature that we are trying to capture in our model. Generalizing the model in which prices are set after observing the demand states at each location as well as the exchange rate will preserve the features that cash flow in foreign currency y^* will be uncertain and the domestic currency value of revenues at the foreign location, sp^*x^* will be sensitive to the exchange rate fluctuations (except in some very special and restrictive cases[4] but the local currency revenues at each location, px and p^*x^* will no longer be independent of the exchange rate. This complicates the model and makes it somewhat cumbersome. But, as we shall later explain, the central results of the paper are likely to go through in a much richer framework that accomodates some of the generalizations.[5]

At time 0 the firm may enter into forward and option contracts on the time 1 exchange rate. The use of both forwards and options allows the firm to construct a financial hedging instrument whose payoff is any arbitrary (possibly nonlinear) function of the time 1 exchange rate. Let $h(s)$ denote the time 1 payoff on this contract. Assume that the firm has a competitive risk-neutral counterparty and that the contract has no credit risk so that $Eh(s) = 0$. The firm's profits at time 1 with the financial hedging contract can be written as:

$$\pi^h = \pi + h(s).$$

We assume that the firm is a mean variance optimizer so that its objective function takes the form

$$E[\pi^h] - \frac{\gamma}{2}\text{Var}[\pi^h].$$

Since the expected payoff on any financial hedge contract is zero, the optimal financial hedge contract solves

$$\text{Min}_{h(s)}\text{Var}[\pi + h(s)] \text{ s.t. } Eh(s) = 0.$$

[4] For instance, if the firm faces demand curves with constant elasticities and is able to pass on the exchange rate changes completely in its pricing decisions, the domestic currency value of its revenues in the foreign market may be completely insensitive to exchange rate changes. In this paper, our focus is on situations when firms face significant exchange rate exposure in revenues generated at the foreign location.

[5] We will he more precise later about the exact nature of these generalizations.

Writing the Lagrangian, we get

$$L = EE[\pi^2 + 2\pi h(s) + h(s)^2|s] - (E\pi)^2 - \lambda Eh(s),$$

where λ denotes the Lagrangian multiplier. Rearranging, we get

$$L = EE[\pi^2 + 2\pi h(s) + h(s)^2 - \lambda h(s)|s] - (E\pi)^2.$$

The first order condition for the minimum gives

$$h(s) = \frac{\lambda}{2} - E[\pi|s].$$

Imposing the constraint that $Eh(s) = 0$, we get $\lambda/2 = E[\pi]$. The optimal financial hedging contract thus is given by:

$$h(s) = E[\pi] - E[\pi|s]. \tag{5}$$

The expression for π in (4) can be rewritten as:

$$\pi = (y + y^*) - (1 - s)y^*. \tag{6}$$

From (1)–(3),

$$y + y^* = p(x + x^*) - c(q + q^*) = (p - c)(x + x^*). \tag{7}$$

Notice that $y + y^*$ is independent of s. Substituting from (6) into (5) and simplifying, the optimal financial hedging contract can be rewritten as

$$h(s) = (1 - s)E[y^*|s] + \mathrm{Cov}(s, y^*). \tag{8}$$

Notice that if the foreign currency cash flow y^* is independent of the exchange rate realization s, the optimal financial hedging contract is a forward contract in which the firm sells a quantity of foreign currency equal to Ey^* in the forward exchange market. But, if y^* is not independent of s, then in general, the optimal financial hedging contract will not be a forward contract but some claim that is non-linearly contingent on s.

The firm's profits at time 1 with the financial hedging contract can now be rewritten as:

$$\pi^h = (y + y^*) - (1 - s)\{y^* - E[y^*|s\} + \mathrm{Cov}(s, y^*). \tag{9}$$

2.1. CASE 1: LARGE FIXED COSTS

Suppose that there are large fixed costs associated with establishing a plant so that the firm will choose to establish a plant at only one location. Then there are two possibilities:

1. The firm establishes the plant domestically. In this case:

$$q = x + x^*, \quad q^* = 0.$$

2. The firm establishes the plant at the foreign location. In this case:

$$q = 0, \quad q^* = x + x^*.$$

In either case, since q^* is independent of the realization of s, the foreign currency cash flow y^* will also be independent of s. The optimal hedge contract in (8) then simplifies to

$$h(s) = (1 - s)Ey^*.$$

If $Ey^* > 0$, this is a contract to sell forward Ey^* units of foreign currency at a price of 1 unit of domestic currency per unit of foreign currency. If $Ey^* < 0$ then the contract would involve purchasing forward Ey^* foreign currency units at the same price.

The firm's profits after financial hedging, specified in (9), simplify to

$$\pi^h = (y + y^*) - (1 - s)[y^* - Ey^*]. \qquad (10)$$

Notice that the expected hedged profits (from (7))

$$E\pi^h = E(y + y^*) = (p - c)E(x + x^*)$$

are the same whether the firm locates its plant domestically or at the foreign location. The decision of where to locate the plant, therefore, is determined solely by which location leads to a smaller variance of hedged profits. From (10),

$$\mathrm{Var}[\pi^h] = \mathrm{Var}(y + y^*) + \mathrm{Var}\, s\ \mathrm{Var}\, y^*. \qquad (11)$$

First, from (7), we notice that $\mathrm{Var}(y + y^*)$ is independent of the plant location decision. Second, the location decision – which is the operational hedging decision – matters only if both $\mathrm{Var}\, s$ as well as $\mathrm{Var}\, y^*$ are not equal to zero. This indicates that operational hedging decisions matter only when there is both exchange rate uncertainty and quantity uncertainty. Given $\mathrm{Var}\, s$, the plant location decision is determined by which location leads to a smaller $\mathrm{Var}\, y^*$.

1. If the firm establishes the plant domestically,

$$y^* = px^*, \quad \mathrm{Var}\, y^* = p^2\, \mathrm{Var}\, x^*. \qquad (12)$$

2. If the firm establishes the plant at the foreign location,

$$y^* = px^* - c(x + x^*),$$
$$\operatorname{Var} y^* = p^2 \operatorname{Var} x^* + c^2 \operatorname{Var}(x + x^*) - 2pc \operatorname{Cov}(x^*, x + x^*). \tag{13}$$

The firm will choose to produce at the foreign location if and only if the expression in (12) exceeds the one in (13) or equivalently if:

$$p^2 \operatorname{Var} x^* > p^2 \operatorname{Var} x^* + c^2 \operatorname{Var} x + c(c - 2p) \operatorname{Var} x^*.$$

The above condition simplifies to:

$$\left[1 + 2\left(\frac{p-c}{c}\right)\right]\left[\frac{\operatorname{Var} x^*}{\operatorname{Var} x}\right] > 1. \tag{14}$$

The first term on the left hand side of the above condition is positively and linearly related to expected profitability and the second term represents relative total variability of foreign demand to total variability of domestic demand.

2.2. CASE 2: SMALL FIXED COSTS

Now suppose that the fixed costs of establishing a plant with a given capacity are small enough so that the firm is indifferent between dividing the total capacity between plants at two locations based only on the costs of establishing the plants. Suppose that at time 0, the firm decides to build plants with capacities k and k^* respectively at the U.S. and the foreign location. At time 1, the firm can produce up to its capacity at each location.

Based on the realization of the exchange rate, the firm, in order to satisfy demand, will produce as much as possible at the location where it is cheaper to do so. If the exchange rate $s > 1$, it is cheaper to produce domestically. If the total demand is less than the domestic capacity, the firm will produce everything domestically. If the total demand exceeds the domestic capacity, the firm will produce up to its capacity domestically and produce the rest at the foreign location. Similarly, if $s < 1$ it is cheaper to produce at the foreign location and analogous production decisions will be made by the firm. The quantities produced at each location are thus:

$$(q, q^*) = \begin{cases} (k, x + x^* - k) & \text{if} \quad x + x^* > k,\ s > 1 \\ (x + x^*, 0) & \phantom{\text{if}} \quad x + x^* < k,\ s > 1. \\ (x + x^* - k^*, k^*) & \phantom{\text{if}} \quad x + x^* > k^*,\ s < 1 \\ (0, x + x^*) & \phantom{\text{if}} \quad x + x^* < k^*,\ s < 1 \end{cases} \tag{15}$$

Suppose the firm chooses the capacities at time 0 to maximize expected profits, i.e., suppose it chooses k to maximize $E\pi^h$ which is equivalent to maximizing $E\pi$. The first order condition is:

$$\frac{\mathrm{d}}{\mathrm{d}k} E\pi = E\frac{\mathrm{d}\pi}{\mathrm{d}k} = E\left[\frac{\mathrm{d}y}{\mathrm{d}k} + s\frac{\mathrm{d}y^*}{\mathrm{d}k}\right] = 0. \tag{16}$$

Now, from (2) and (3),

$$\frac{\mathrm{d}y}{\mathrm{d}k} = -c\frac{\mathrm{d}q}{\mathrm{d}k},$$

$$\frac{\mathrm{d}y^*}{\mathrm{d}k} = -c\frac{\mathrm{d}q^*}{\mathrm{d}k},$$

Thus, from (15),

$$\left(\frac{\mathrm{d}y}{\mathrm{d}k}, \frac{\mathrm{d}y^*}{\mathrm{d}k}\right) = -c\begin{cases} (1, -1) & \text{if} \quad x + x^* > k,\ s > 1 \\ (0, \quad 0) & \phantom{\text{if}} \quad x + x^* < k,\ s > 1. \\ (1, -1) & \phantom{\text{if}} \quad x + x^* > k^*,\ s < 1 \\ (0, \quad 0) & \phantom{\text{if}} \quad x + x^* < k^*,\ s < 1 \end{cases}$$

Therefore,

$$\frac{\mathrm{d}\pi}{\mathrm{d}k} = -c\begin{cases} 1 - s & \text{if} \quad x + x^* > k,\ s > 1 \\ 0 & \phantom{\text{if}} \quad x + x^* < k,\ s > 1. \\ 1 - s & \phantom{\text{if}} \quad x + x^* > k^*,\ s < 1 \\ 0 & \phantom{\text{if}} \quad x + x^* < k^*,\ s < 1 \end{cases}$$

It is clear that the first order condition in (16) is satisfied if $k = k^*$. In other words, if the firm were concerned only with maximizing expected profits it would divide the capacity equally between the two plants.[6]

We will call this solution the benchmark solution that does not take into consideration any hedging considerations. But what if the firm were also concerned about the variance of its profits? We will now see that hedging considerations will, in general, move the firm away from choosing equal capacity. This deviation from the benchmark capacity solution is tantamount to operational hedging.

Whether the firm chooses a larger domestic or foreign capacity compared to the bench-mark solution of equal capacity depends on the sign of the following expression:

$$\frac{\mathrm{d}}{\mathrm{d}k}\mathrm{Var}\,\pi^h = 2E\left[\pi^h\frac{\mathrm{d}\pi^h}{\mathrm{d}k}\right]. \tag{17}$$

[6] The first order condition is sufficient for a maximum because expected profits are globally concave in k, provided the distribution of s is symmetric. If s is distributed symmetrically then

$$E\left[\frac{\mathrm{d}^2\pi}{\mathrm{d}k^2}\right] = \frac{c}{2}E[s-1|s>1]\left(-\frac{\mathrm{d}F(k)}{\mathrm{d}k} + \frac{\mathrm{d}F(k^*)}{\mathrm{d}k}\right) < 0,$$

where F is the joint probability distribution function for x and x^* (assumed to be differentiable).

The right hand side of the above equation obtains since $\mathrm{d}/\mathrm{d}k\, E\pi^h = 0$.[7] The expression in (17), after simplifying, equals:

$$2E\left[(1-s)^2 \frac{\mathrm{d}}{\mathrm{d}k}\mathrm{Var}(y^*|s)\right]. \tag{18}$$

The firm will choose a larger foreign capacity if the sign of the above expression is positive. As in the case in the previous subsection, the above expression will equal zero if either there is no exchange rate uncertainty or if there is no quantity uncertainty. Thus operational hedging decisions matter only when there is both exchange rate uncertainty and quantity uncertainty.[8]

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[7] The above condition obtains in general, not just in the setup we have developed in our model.

[8] This result obtains even in a more general framework that we now describe more precisely. Notice that the hedged profits can in general be written as follows:

$$\pi^h = y + sy^* + E(y + sy^*) - E(y + sy^*|s).$$

The condition in (17) can be expanded as:

$$\begin{aligned} E\left[\pi^h \frac{\mathrm{d}\pi^h}{\mathrm{d}k}\right] &= E\left[\{y - E(y|s)\}\frac{\mathrm{d}}{\mathrm{d}k}\{y - E(y|s)\}\right] \\ &\quad + E\left[s^2\{y^* - E(y^*|s)\}\frac{\mathrm{d}}{\mathrm{d}k}\{y^* - E(y^*|s)\}\right] \\ &\quad + E\left[s\{y - E(y|s)\}\frac{\mathrm{d}}{\mathrm{d}k}\{y^* - E(y^*|s)\}\right] \\ &\quad + E\left[s\{y^* - E(y^*|s)\}\frac{\mathrm{d}}{\mathrm{d}k}\{y - E(y|s)\}\right] \end{aligned}$$

Notice that in any general framework in which the parameters in the two countries are symmetric, and the distribution of the exchange rate s is symmetric around its mean of 1, the last two terms will cancel each other and the first term:

$$E\left[\{y - E(y|s)\}\frac{\mathrm{d}}{\mathrm{d}k}\{y - E(y|s)\}\right] = -E\left[\{y^* - E(y^*|s)\}\frac{\mathrm{d}}{\mathrm{d}k}\{y^* - E(y^*|s)\}\right].$$

Making these substitutions and simplifying, we obtain:

$$\begin{aligned} E\left[\pi^h \frac{\mathrm{d}\pi^h}{\mathrm{d}k}\right] &= E\left[(s^2-1)\{y^* - E(y^*|s)\}\frac{\mathrm{d}}{\mathrm{d}k}\{y^* - E(y^*|s)\}\right] \\ &= E(s^2-1)E\left[\frac{\mathrm{d}}{\mathrm{d}k}\mathrm{Var}(y^*|s)\right] + \mathrm{Cov}\left[(s^2-1), \frac{\mathrm{d}}{\mathrm{d}k}\mathrm{Var}(y^*|s)\right] \\ &= \mathrm{Var}(s)E\left[\frac{\mathrm{d}}{\mathrm{d}k}\mathrm{Var}(y^*|s)\right] + \mathrm{Cov}\left[(s^2-1), \frac{\mathrm{d}}{\mathrm{d}k}\mathrm{Var}(y^*|s)\right]. \end{aligned}$$

Notice that if there is no exchange rate uncertainty the above expression equals zero. We know that $\mathrm{d}/\mathrm{d}k\,\mathrm{Var}(y^*|s)$ is positive because increasing domestic capacity implies that the firm produces less at its foreign location which increases the variability of profits in the foreign currency. Therefore, when $\mathrm{Var}(s) > 0$, the first term in the expression above is positive. The second covariance term will be

The above expression can be further rewritten as:

$$2E\left[(1-s)^2\frac{\mathrm{d}}{\mathrm{d}k}\{p^2\operatorname{Var}x^* + c^2\operatorname{Var}[q^*|s] - 2pc\operatorname{Cov}[x^*, q^*|s]\}\right].$$

If Prob[$s > 1$] = Prob[$s < 1$] and $E[(1-s)^2|s > 1] = E[(1-s)^2|s < 1]$ – a sufficient condition for these is that the distribution of s be symmetric around its mean of 1 – then the sign of the above expression is positive if and only if:

$$\left[1+2\left(\frac{p-c}{c}\right)\right]\left[\frac{E[x^*|x+x^*>k]-Ex^*}{E[x|x+x^*>k]-Ex}\right] > 1. \tag{19}$$

Notice the similarity between the above condition to the condition in (14). The first term on the left hand side of the above condition – which is identical to the corresponding term in (14) – is positively and linearly related to expected profitability. The second term in (19) is analogous to the corresponding term in (14) and represents relative variability of foreign demand to variability of domestic demand.

In addition to operational hedging, the firm will also engage in financial hedging through the contract specified in (8). This contract can be constructed using forward and option contracts. Option contracts must be used because $E[y^*|s]$ in (8) depends on s. Specifically the conditional expectation can take two values: $E[y^*|s \geq 1]$ and $E[y^*|s < 1]$, with $E[y^*|s \geq 1] > E[y^*|s < 1]$. The optimal financial hedging contract is therefore

$$h(s) = (1-s)E[y^*|s \geq 1] + \operatorname{Cov}(s, y^*) \quad s \geq 1,$$

$$h(s) = (1-s)E[y^*|s < 1] + \operatorname{Cov}(s, y^*) \quad s < 1.$$

This expression can be rewritten

$$h(s) = (1-s)E[y^*|s < 1] - \max(s-1, 0)$$
$$\times (E[y^*|s \geq 1] - E[y^*|s < 1]) + \operatorname{Cov}(s, y^*).$$

From the above expression it is evident that a simple method of constructing $h(s)$ is for the firm to: (1) "sell" forward $E[y^*|s < 1]$ units of the foreign currency at a price of 1 unit of domestic currency for each unit of foreign currency;[9] (2) write European call options exercisable at date 1 with a strike price of 1 unit of domestic currency for each unit of foreign currency on $E[y^*|s \geq 1] - E[y^*|s < 1]$ units of

positive if $\mathrm{d}/\mathrm{d}k \operatorname{Var}(y^*|s)$ is not decreasing in s which is likely under fairly general circumstances. The intuitive interpretation is as follows. The increase in variability of foreign currency profits as the firm increases its domestic capacity is more pronounced when the exchange rate is high because the firm shifts its production to the domestic location even more.

[9] If $E[y^*|s < 1] < 0$, then the transaction is a forward purchase.

foreign currency; (3) invest the call premiums at the risk-free rate.[10] The role of the call option in $h(s)$ is to increase the amount of foreign currency sold forward when the exchange rate is high ($s > 1$). When the exchange rate is high expected foreign production and foreign currency production costs are smaller. Net foreign currency cashflow is thus expected to be higher and forward sale of a larger quantity of foreign currency is optimal.

3. Numerical example

For concreteness, this section presents a numerical example of the model for the case of small fixed costs. We assume that demands in the two markets x and x^* are each distributed uniformly on the interval [0, 1], while the exchange rate s is distributed uniformly on the interval [0, 2]. The unit sales price of the product p (= p^*) is 1 domestic currency unit and the unit production cost c (= c^*) is $\frac{1}{2}$ domestic currency unit. We also assume that the firm has 2 units of total capacity that it can distribute between the two markets and that $\gamma = 1$.

The variance of hedged profits under the optimal financial hedging policy for each possible distribution of capacity is depicted in Figure 1. As demonstrated in the previous section, the firm's expected profit is maximized at the point of equal capacity in each country. But notice that at that same point, the variance of financially hedged profits is declining as foreign capacity is increased. We can therefore conclude that the firm's optimal choice of capacity is greater than 1, since a local increase in foreign capacity beyond the equality point reduces the variance of financially hedged profits while not affecting expected profits (a local change in a choice variable will not affect the value of a function at an interior maximum).

We also know that the optimal amount of foreign capacity is smaller than the amount that minimizes the variance of financially hedged profits. We know this because, as demonstrated earlier, expected profits always decline as we move away from the equal capacity point. And of course the variance of profits increases beyond the variance minimizing point. So the firm could not possibly gain from choosing foreign capacity greater than the variance minimizing amount. For the numerical values assumed in this example, the optimal amount of foreign capacity turns out to be 1.06 units, 0.06 units greater than the expected profit maximizing amount.

What form does the optimal financial hedging policy take for this numerical example? Figure 2 depicts the payoff on the optimal financial hedge for the firm's optimal foreign capacity choice of 1.06 units. The hedge can be implemented by selling 0.07 foreign currency units forward at a price of 1 unit of foreign currency per unit of domestic currency, writing a call option contract on 0.33 units of foreign currency at a price of 1 unit of foreign currency per unit of domestic currency, and investing the call premium at the risk free rate.

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[10] Since $Eh(s) = 0$ and there is no credit risk, it, is clear that the present value of $E \max(s - 1, 0)(E[y^*|s \geq 1] - E[y^*|s < 1])$ equals the present value of $\mathrm{Cov}(s, y^*)$.

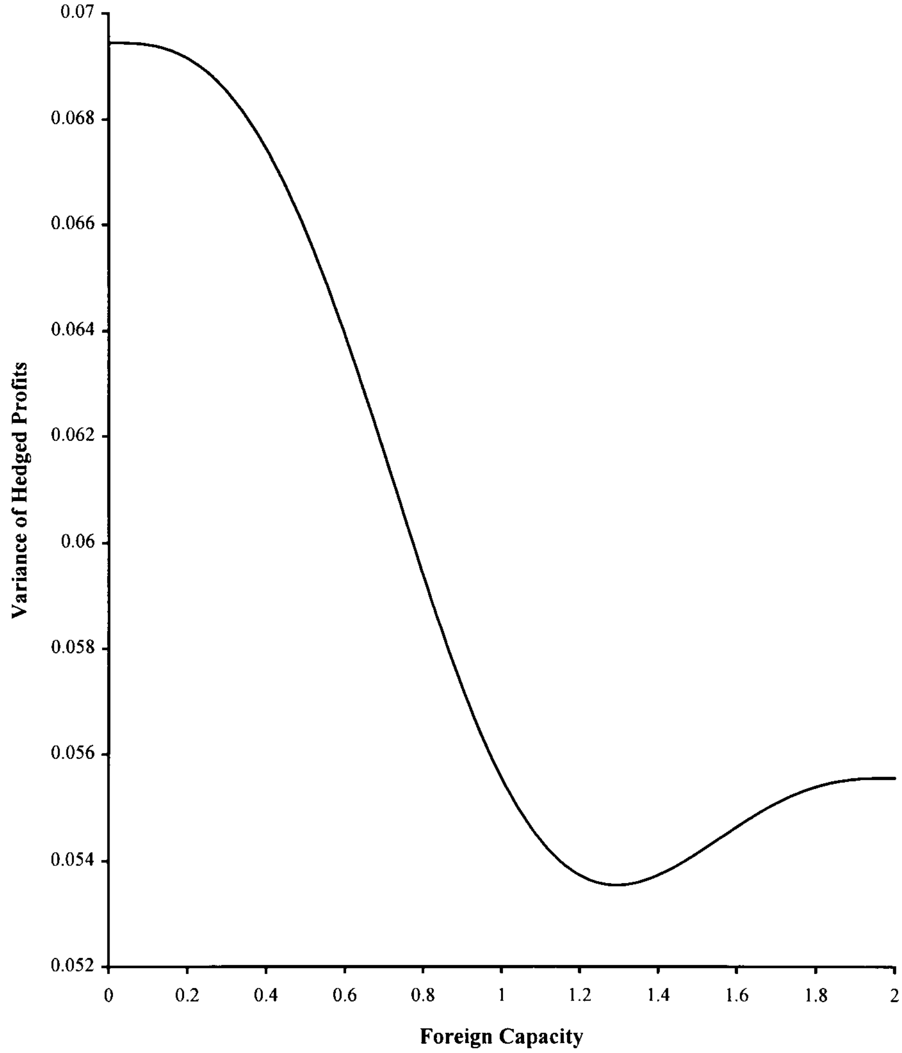

Figure 1. Variance of profits under optimal financial hedging policy.

4. Implications

The model generates several implications that we now discuss.

Implication 1. The optimal financial hedging contract is a forward contract to sell the expected foreign currency cash flow if and, in general, only if the foreign currency cash flow is independent of the exchange rate.

This implication follows directly from the optimal financial hedging contract specified in (8). The intuition for this result is straightforward. The payoff on a forward

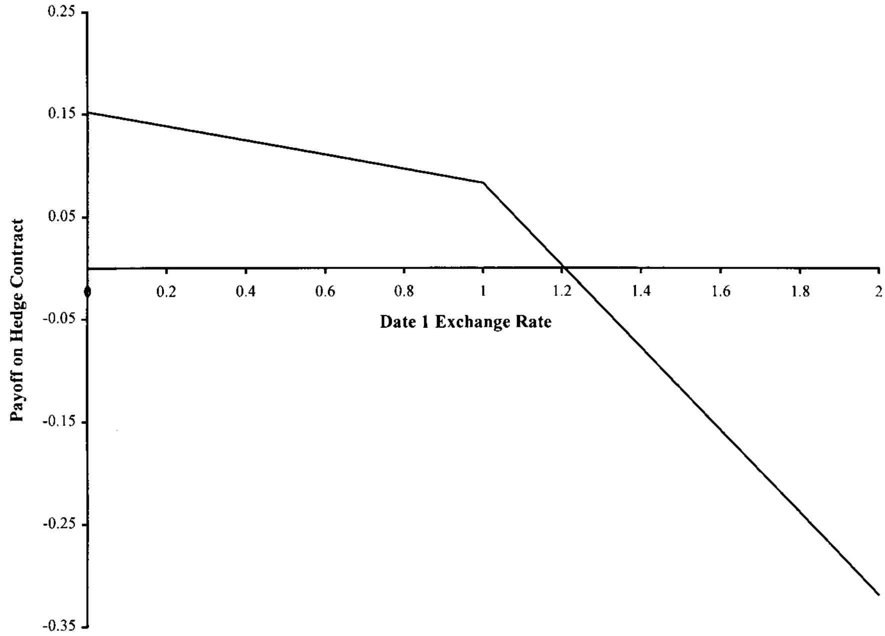

Figure 2. Payoff on optimal financial contract.

contract on foreign currency is linear in the exchange rate. A forward contract will optimally hedge the underlying exposure if the underlying exposure is also linear in the exchange rate. When the foreign currency cash itself is contingent on the exchange rate then the dollar value of it will, in general, be a non-linear function of the exchange rate. Clearly, a financial instrument that is also non-linear In the exchange rate is needed to hedge the exposure.

Implication 2. The firm will engage in operational hedging only when both exchange rate uncertainty and demand uncertainty are present.

This is the key insight in the paper. It follows from expressions (11) and (18) in the model. The intuition is clear. If there is no exchange rate uncertainty, the realized prices and costs are identical in the two countries. The only residual uncertainty is demand uncertainty which can be hedged only if we can create an instrument that is correlated with demand; it cannot be hedged by operational production decisions of the type considered in the paper. Now, consider the case when there is exchange rate uncertainty but there is no demand uncertainty. In this case, the exchange rate can be hedged entirely by using financial contracts – i.e., forward contracts – which obviates the need for relatively expensive operational hedging.

Implication 3. The firm is more likely to establish plants in both the domestic as well as the foreign location if the fixed costs of establishing a plant are lower or if the variability in the exchange rate is higher.

Clearly, creating production flexibility may be relatively expensive, as establishing plants at two locations rather than one may involve additional fixed costs. The benefits of having multiple plants at different locations derive from two distinct mechanisms. In the presence of demand uncertainty, the firm will often find it prudent to build aggregate capacity that can handle demand larger than the smallest possible demand realization. As a result, there will often be situations in which the firm has excess capacity because demand is low. In these situations, the firm has the option to switch production to the location where costs are lowest. Variability in exchange rates is precisely the mechanism that creates differences in costs over time that the firm can take advantage of. In effect, the firm has a real option when there is excess capacity. The value of this real option is increasing in the volatility of the exchange rate. This is the expected cost effect. The second mechanism derives from hedging considerations. It is precisely when the variability of the exchange rate is higher that the variance of profits will be higher and consequently the benefits of hedging will be higher for a firm that is concerned about the variability of profits (for reasons discussed by the finance scholars mentioned in the introduction).

Implication 4. If the firm establishes plants in both the domestic as well as the foreign location, the foreign currency cash flow will, in general; will not be independent of the exchange rate and therefore the optimal financial hedging contract will not be a forward contract.

As we discussed above, creating plants at multiple locations creates production flexibility in some instances when there is demand uncertainty. This production flexibility can be exploited when cost differences arise. Movements in exchange rates often create these cost differences. In these instances, the firm may switch production to a low cost location, which in turn lowers foreign currency cash flow. Clearly then, foreign currency cash flow will not be independent of the exchange rate. As we discussed above, this results in an underlying exposure that is non-linear in the exchange rate, making forward contracts unsuitable for optimal hedging.

In the case of our model, the use of written option contracts in addition to forward contracts allows implementation of the optimal hedging policy. Written call options allow the firm to reduce the amount of foreign currency sold forward when the the real value of the domestic currency appreciates. The reduction is desirable because domestic currency appreciation induces the firm to shift more production abroad, increasing expected foreign currency costs and thus lowering expected net foreign currency cashflow.

Implication 5. The firm is more likely to establish larger capacity in the foreign location if the variability of foreign demand relative to the variability of domestic demand is larger or if the expected profit margin is larger. If the variability of foreign demand is equal to the variability of domestic demand, the firm will still establish larger capacity in the foreign location as long as expected profit margin is positive.

This is a key result in the paper that follows from the conditions (14) and (19) in the model. Notice first that it is not the relative size of the two markets – measured by the ratio of expected demands in the two markets – that matters in determining relative capacity at the two locations. The intuition, of course, is that even if say the size of the foreign market is large but is certain, a financial contract such as a forward contract can adequately hedge the exposure, obviating the need for building extra capacity for operational hedge. The size of the market would matter, however, if there was variability in demand. So, in some sense, both the percent variability and the size of the market jointly matter since it is the product of these that determines the total variability in demand. Second, notice that when the two markets are identical in terms of total variability in demand, the optimal solution for capacity however is not symmetric. In this situation, the optimal solution will yield either larger capacity at the foreign location (for the small fixed costs case) or the entire capacity at the foreign location (for the large fixed costs case) as long as expected profit margin is positive (i.e., $p > c$). The intuition for this asymmetry is as follows. Since the price per unit of the good exceeds the per unit cost at the foreign location (and at the domestic location as well), sales revenues cannot be hedged perfectly by one-to-one matching of the quantity sold and the quantity produced; the profit margin results in a residual foreign currency cash flow. The firm will need to produce a quantity larger than the quantity sold at the foreign location in order to align total costs with total revenues in the foreign currency. The larger the difference between the sale price and the unit cost, the larger will be this asymmetry.

5. Conclusion

The key insight that we develop in the paper is that corporations will engage in operational hedging only when both exchange rate uncertainty and demand uncertainty are present. Firms whose main products are commodities – e.g., oil, copper, grains – are exposed only to price uncertainty not quantity uncertainty. Furthermore, the relevant prices, such as the spot prices of the commodities as well as the exchange rates, cannot be manipulated by any single firm. It follows from our analysis that we would expect such firms to hedge their exposure using mainly financial instruments; operational hedging by such firms would be rare. Some survey evidence in Bodnar, Hayt, Marston and Smithson (1995) indicates that the percentage of firms that use financial derivatives for hedging is the highest for firms that are classified as Commodity Based than for firms in any other classification.

Our insight is also consistent with the empirical observation that firms often seem to use financial instruments to hedge short-term exposure but not long-term exposure. It seems plausible that demand uncertainty will be smaller for shorter horizons than for longer horizons as firms will be able to forecast their sales more accurately in the short term. Our analysis thus predicts that firms are likely to use financial instruments to a greater extent to hedge short term exposure and rely on operational hedging more heavily to hedge long term exposure.

Our model provides several other testable implications. We leave it to future research to generalize our results and to empirical test its predictions. We believe that the analysis in our paper has demonstrated that a framework in which financial as well as operational hedging decisions of firms are analyzed in a unified framework is likely to produce a rich set of positive as well as normative implications for hedging policies of multinational corporations.

References

Aliber, Robert Z. (1978) *Exchange Risk and Corporate International Finance*, Halsted Press, New York.

Anderson, Ronald W. and Danthine, Jean-Pierre (1978) *Hedger Diversity in Futures Markets: Backwardation and the Coordination of Plans*, Working Paper No. 71A, Columbia University Graduate School of Business.

Bodnar, Gordon M., Hayt, Gregory S., Marston, Richard C., and Smithson (1995) Wharton survey of derivatives usage by U.S. Non-Financial Firms, *Financial Management* **24**, 104–114.

Chowdhry, Bhagwan (1995) Corporate hedging of exchange risk when foreign currency cash flow is uncertain, *Management Science* **41**, 1083–1090.

Dasu, Sriram and Li, L. (1994) *Optimal Operating Policies in the Presence of Exchange Rate Variability*, Working Paper, AGSM-UCLA.

DeMarzo, Peter M. and Duffie, Darrell (1995) Corporate incentives for hedging and hedge accounting, *Review of Financial Studies* **8**, 743–771.

Dufey, Gunter and Srinivasulu, S. N. (1983) The case for corporate management of foreign exchange risk, *Financial Management* 54–62.

Eiteman, David K., Stonehill, Arthur I., and Moffet, Michael H. (1995) *Multinational Business Finance*, Seventh Edition, Addison Wesley Publishing Company.

Froot, Kenneth A., Scharstein, David S., and Stein, Jeremy C. (1993) Risk management: coordinating corporate investment and financing policies, *Journal of Finance* **48**, 1629–1658.

Froot, Kenneth A., Scharfstein, David S., and Stein, Jeremy C. (1994) A framework for risk management, *Harvard Business Review*, November–December 1994, 91–102.

Giddy, Ian H. (1983) The foreign exchange option as a hedging tool, *Midland Corporate Finance Journal* **2**(3), 32–42.

Kerkvliet, J. and Moffet, M. H. (1991) The hedging of an uncertain future foreign currency cash flow, *Journal of Financial and Quantitative Analysis* **26**, 565–579.

Lewent, Judy C. and Kearney, A. John (1990) Identifying, measuring and hedging currency risk at Merck, *Journal of Applied Corporate Finance* **2**(4), 19–28.

Mello, Antonio S., Parsons, John E., and Triantis, Alexander (1995) An integrated model of multinational flexibility and financial hedging, *International Economic Review* **39**, 27–51.

Shapiro, Alan C. and Titman, Sheridan (1985) An integrated approach to corporate risk management, *Midland Corporate Finance Journal* **3**(2), 41–56.

Shapiro, Alan C. (1992) *Multinational Financial Management*, Fourth Edition, Allyn and Bacon.

Smith, Clifford W., Jr., Smithson, Charles W., and Wilford, D. Sykes (1990) *Managing Financial Risk*, Harper Collins Publishers.

Smith, Clifford W., Jr. and Stulz, René: (1985), The determinants of firms' hedging policies, *Journal of Financial and Quantitative Analysis* **20**, 391–403.

Stulz, René (1994) Optimal hedging policies, *Journal of Financial and Quantitative Analysis* **19**, 127–140.