# Operating Flexibility, Global Manufacturing, and the Option Value of a Multinational Network

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The multinational corporation is a network of activities located in different countries. The value of this network derives from the opportunity to benefit from uncertainty through the coordination of subsidiaries which are geographically dispersed. We model this coordination as the operating flexibility to shift production between two manufacturing plants located in different countries. A stochastic dynamic programming model treats explicitly this flexibility as equivalent to owning an option, the value of which is dependent upon the real exchange rate. The model is extended to analyze hysteresis effects and within-country growth options. We show that the management of across-border coordination has led to changes in the heuristic rules used for performance evaluation and transfer pricing.
(*Multinational Networks; Real Options; Dynamic Programming*)

## Introduction

The theory of the multinational corporation has traditionally sought to explain why a firm can successfully invest in overseas operations. As Hymer (1960) noted, a foreign company operates at a disadvantage relative to local firms; it must control the operations over longer distances and it is at a handicap in a foreign culture. Thus, he concluded, direct investment must be motivated by a competitive asset that provides the foreign firm with an advantage.

Around this central perspective, the work in both economics and management has developed a substantial and complementary body of research. In the field of the economics of the multinational corporation, considerable attention has been paid to the theoretical and empirical investigation of firm-level advantages and foreign direct investment. In the area of management, a principal line of inquiry regards the costs of managing foreign operations due to differences in culture, labor relations, and human resource practices. The management literature, in effect, has investigated in detail Hymer's supposition of the higher costs of managing in foreign countries.

This central perspective, however, loses considerable relevance for the investigation of the economic and competitive behavior of multinational corporations. There is a distinction between the economic and management aspects of a firm's first and subsequent investments in a foreign country. Nor is this distinction minor when it is considered that around 40% of U.S. trade stems from the transfer of goods among affiliates within a corporation and that the predominant proportion of U.S. direct investment is in the form of reinvested earnings in already existing subsidiaries.[1]

An indication of the use of foreign subsidiaries as part of an internationally coordinated strategy is given in Table 1. This table shows the sales of affiliates within the corporation and to the outside. The degree of internal transfers is quite high, especially for the Asian region which provides a platform for global sourcing.

[1] See Kogut (1983) for a discussion.

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**Table 1 Destination of Shipments of U.S. Manufacturing Affiliates Abroad**

| | As Fraction of Total Sales | | |
|---|---|---|---|
| Area | Local Sales | Third Country Sales | U.S. Sales |
| Canada | 61 9% | 3.4% | 34.8% |
| Europe | 60.2% | 34.2% | 5.6% |
| Japan | 83.3% | 7.8% | 8 9% |
| Other Asia and Pacific | 60 9% | 18.0% | 21.1% |
| Latin America | [illegible] | [illegible] | [illegible] |

Source. 1989 Benchmark Survey of U.S. Direct Foreign Investment Abroad.

The coordination of a network of subsidiaries dispersed throughout the world provides an 'operating flexibility' that adds value to the firm. This operating flexibility is an advantage gained by being a multinational corporation. As developed below, it can be conceived as owning the option to respond to uncertain events, such as government policies, competitors' decisions, or the arrival of new technologies in some parts of the world.

The following article develops a formal model of the

relationship between headquarters and subsidiaries to a network structure.

In this sense, our treatment of the option value of a multinational corporation has a more general implication. The network structure of the multinational corporation provides the organizational capability to coordinate subsidiaries flexibly across borders. The economic merits of the international firm as a network are derived from the option value of multinational operating flexibility under the critical condition of uncertainty. The network structure of the multinational firm is an evo-

## 1. Operating Flexibility and Multinational Options

Options are valuable due to three conditions: uncertainty, time dependence, and discretion. That flexibility is valuable only when there is uncertainty is obvious. Yet, often, the problem of understanding the source and properties of the uncertainty is substantial. A simple example is the difficulty of describing the probabilities attached to the arrival of new technologies.

A more subtle feature is time dependence. The application of option analysis to investments is important, because it captures the value in the dependence of de-a brand label or simply knowledge of the market, provides a platform for the introduction of new products. This kind of option applies also to an investment by a domestic firm. The second kind is an "across-country" option provided by operating flexibility.

Within-country options are significant in the international case because of the Hymer condition mentioned above, that is, the first international investments are made by firms which lack the organizational knowledge and supporting assets in the foreign market. The first investment carries, consequently, a large option value, as it opens the market for subsequent expansion. But the creation of these options is not itself an advantage of being international, but rather an aspect of the process by which the firm expands in a foreign country. In fact, as the firm grows in the foreign market, the value of these options to launch new products or to diversify within the country becomes the same as for a purely domestic corporation.[3]

The advantage of operating across borders relative to a purely domestic firm lies, then, not in being international, but in the ownership of options to coordinate flexibly *multinational* activities within a network. The option value of multinationality is different from that of the benefits of geographic diversification. The benefits of diversification are created by the reduction in variance of the overall portfolio of subsidiary results.[4] An option, on the other hand, is valuable because it gives *managerial* *discretion* to respond profitably to the realization of un-

be ignored. A firm must be able to gather the appropriate information to know when the option should optimally be exercised; even when the information is known, exercise may be hindered by organizational features that obstruct flexibility.

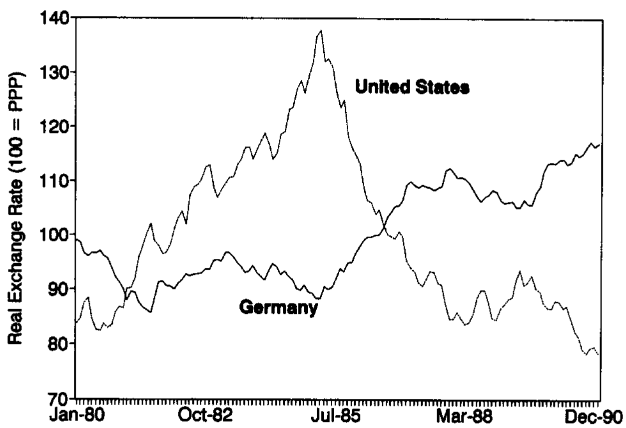
We investigate these issues more formally by analyzing the problem of evaluating the value of manufacturing in two different countries. The source of uncertainty is the fluctuation in the real exchange rate; time dependence arises because the flexibility to shift production can only be realized by investing in two plants; managerial discretion is achieved by creating the proper accounting and organizational practices.

As our intention is not to model the extant manufacturing location problem, we focus only on the aspects of interest to our argument, that is, the increase in value gained through operating flexibility. We lay out first the formal model of the value of shifting production in response to exchange rates. We extend the results to consider a generalized global sourcing from more than two countries, hysteresis and growth options. Then, we turn to examining the accounting and pricing rules required to support the exercise of operating flexibility in a multinational network.

## 2. Global Manufacturing and Production Shifting

The literature on global manufacturing planning models

**Figure 1 Trade Weighted Real Exchange Rates**




An attempt to capture the value of flexibility under uncertainty is provided in the one-period stochastic model of production shifting of de Meza and van der Ploeg (1987). A multiperiod stochastic model explicitly incorporating the option valuation of production shifting in a network is qualitatively described in Kogut (1983, 1985) and formally analyzed in Kogut and Kulatilaka (1988). It is this multiperiod stochastic formulation that is explored below.[5]

To analyze the value of multinational coordination of manufacturing, consider a firm with assets dispersed to various parts of the world. The decision facing the firm is to minimize total cost producing in a single location or switch flexibly between two sites located in different countries. Factor prices and final demand are given and known. Uncertainty arises through fluctuations in exchange rates. By treating prices and output as given, we are able to focus on the effect of location switching on value.[6]

Though a number of factors generate economic shocks which are likely to influence the value of investing in flexibility, fluctuations in exchange rates are certainly one of the more potent sources of disturbance. The variance in real exchange rates is illustrated in Figure 1 which shows the (trade weighted movement) of the Deutsche mark and dollar over the period 1976 to August 1992. The monthly variance of these rates about the mean of 1.00 (i.e. if PPP holds true) is in the order of magnitude of 8% and the total band is given by the range (0.6, 1.4). These violations of PPP point to substantial disparities in prices in the real-goods markets. Clearly, in the absence of arbitrage between-goods markets—an assumption which is eminently reasonable for labor and for sticky energy pricing—there is a value in investing in the option of where to produce.

### 2.1. The Simple Formulation: Costless Switching

The principal elements of our argument can be most clearly examined by modeling a simple example. Consider a firm which is evaluating a project to invest in two manufacturing plants—one in the U.S. and the other in Germany. The plants are identical in their technological characteristics and differ only in the prices (evaluated in dollars) of the local inputs. The firm carries redundant production capacity, so that total demand, which is known and nonstochastic, can be met with either plant. (This formulation also accommodates the case where only part of the production is shifted in response to changing exchange rates.) The product of the firm is priced in a world market, say in U.S. dollars, and fluctuations of the DM/$ exchange rate do not affect the dollar market price.[7]

Suppose some input factors of production are also priced in the world market. Other inputs (e.g., labor) are priced in the local currency and their prices do not comply with the law of one price, due to institutional and government regulatory factors. Since short-term wage movements tend to be independent of short-term movements in exchange rates, the law of one price frequently is violated for the case of labor. Consequently,

[5] This model has been expanded to explore critical exchange rates at

where $w_\$$ is the wage rate in the U.S. expressed in \$, $w_G = w_M S(\$/M)$ is the dollar value of wage rate in Germany, $w_M$ is the German wage rate in Deutsche marks, $S(\$/M)$ is the nominal exchange rate, and $\theta$ is the effective *real* exchange rate (i.e., deviation from the law of one price). In such a world, if the firm could shift its production between the two plants, the production location will be determined by the relative price of the locally sourced input. In addition, taxes (subsidies), tariffs, trade and financial barriers, and transportation costs can affect the dollar value of the locally-sourced input.

### 2.2. Modelling Uncertainty

The option value to switch production can be affected by a number of sources of uncertainty, including labor unrest, government policies or threats, or local suppliers'

greater than one, it is cheaper to produce in Germany. However, as discussed below, when switching is costly, the decision rule is not simply to switch when the threshold of $\bar{\bar{\theta}}$ is crossed.

The discrete-time mean reverting stochastic process for the real exchange rate can be written as

$$\Delta\theta_t = \lambda(\bar{\bar{\theta}} - \theta_t)\Delta t + \sigma\theta_t \Delta Z_\theta \tag{2}$$

where $\Delta Z_\theta$ are the increments of a discrete-time Wiener process and are normally distributed with mean 0 and variance $\Delta t$, $\sigma\theta_t$ is the standard deviation of $\theta$ per unit of time, and $\lambda$ is the mean reverting parameter. Randomness is introduced via the $\Delta Z$ term. The parameter $\lambda$ acts as an elastic force which serves to bring the price indices in the two countries towards parity. For example, when $\lambda = 1$, any random shock which affects the real and revenues are held constant. Notice that when $\theta < 1$, $\psi^{\$} > \psi^{G}$, making the firm choose to produce in Germany; when $\theta > 1$, $\psi^{\$} < \psi^{G}$ and the firm will produce in the U.S. Hence it is the relative cost of production that determines the production location choice.

Without loss of generality, we normalize the costs of the U.S. plant as one: $\psi(P_{\$}) = 1$. If *all* input prices are locally determined then the dollar value of the German costs equals

$$\psi^{G}(\theta) = \psi(\theta P_{\$}) / \psi(P_{\$}) = \theta.$$

In general, when only some of the input factors are locally priced the normalized cost function of German production can be expressed as $\psi^{G}(\theta)$.

# 3. Value of Flexibility

Given the above macro and microeconomic description, the option value of flexibility can be solved as a dynamic program. To be evaluated are the stream of costs from the plants each with an economic life of $T$ periods of length $\Delta t$. At the beginning of a period, the firm knows with certainty the realized values of all relevant variables, including the real exchange rate $\theta$, for that period.

If switching between locations is costless, then the time $T$ present value of the costs under the flexible production arrangement obtained by choosing the location with the minimum costs over the last time period is

$$\mathcal{F}(\theta_T) = \min[1, \psi^{G}(\theta_{T-1})]. \qquad (3)$$

At any previous time $t$, the value of the project will be the sum of costs from the optimal operation in the period beginning at time $t$ and the (minimized) value function at time $t + 1$. By this logic, we arrive at the following recursive equation for $\mathcal{F}(\theta_t)$:

$$\mathcal{F}(\theta_t) = \min[1, \psi^{G}(\theta_t)] + \rho E_t \mathcal{F}(\theta_{t+1}), \qquad t = 0, \ldots, T, \quad (4)$$

where $E_t$ is the expectations operator conditional on information at time $t$ and $\rho$ is the one-period risk-free discount factor.[10] This recursive system of equations states the fundamental proposition in our model. It expresses the value of the project as the discounted flow of a temporal series of options.[11]

## 3.1. When Switching is Costly

In practice, it is costly to switch between plants due to costs associated with shutdowns and startups, labor contracting, and managerial time commitments. If the decision to switch production takes into account the costs of switching multiple times over the life of the plants, the switching decision becomes also a function of the current mode of operation. Compared to the costless case, cost differences must move sufficiently to justify switching production. We denote the cost to switch from location $i$ to $j$, as $\kappa_{ij}$. When the U.S. is defined as location 1 and Germany as location 2, $\kappa_{12}$ is the cost of switching manufacturing from the U.S. to Germany.

This problem is more complex than the previous one, as it involves solving a compound option where the value function depends on the operating location chosen during the previous period. For example, if the firm operated at location 1 during the period $t - 1$, then the value function at $t$ is given by

$$\mathcal{F}(\theta_t, 1) = \min\left\{ \begin{array}{l} \underbrace{[1 + \rho E_t \mathcal{F}(\theta_{t+1}, 1)]}_{\text{cost of using location 1}}, \\ \underbrace{[-\kappa_{12} + \psi^{G}(\theta_t) + \rho E_t F(\theta_{t+1}, 2)]}_{\text{cost if switch to location 2}} \end{array} \right\} \quad (5)$$

where $\mathcal{F}(\theta_t, l)$ is the value of the flexible project at time $t$ (when $\theta_t$ is realized) when the location $l$ was in operation during the period $t - 1$. The first argument of the minimum operator is the cost if the firm chooses to use location 1 for the period beginning at time $t$, and is computed in a manner similar to Equation (6). The second argument of the minimum operator gives the

[10] Cox et al. (1985), have shown that when $\theta$ is the price of a traded security or if does not contain systematic risk the appropriate discount rate is the risk-free rate. Furthermore, even when $\theta$ is not the price of a traded asset and when it contains systematic risk, a simple adjustment to the transition probabilities allows the use of risk-neutral discounting. See Hull (1989) for a good intuitive discussion of this point.

[11] In order to solve this recursive system we must specify a stochastic process for $\theta$, such as in Equation (2). Under certain very restrictive assumptions about the process we can obtain closed-form solutions for $F$. See Kulatilaka and Marcus (1988) where the option values are derived in closed form when $\theta$ follows geometric Brownian motion.

cost when the firm switches to employ location 2 and incurs a cost $\kappa_{12}$.

Similarly, the value of the project when operating in location 2 during the previous period is

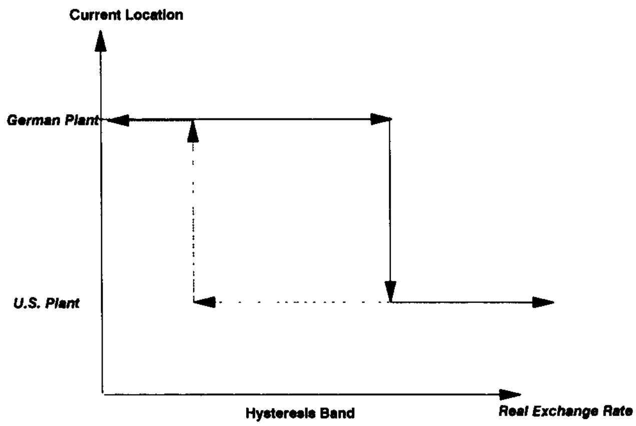
$$\mathcal{F}(\theta_t, 2) = \min\left\{ \underbrace{[1 - \kappa_{21} + \rho E_t \mathcal{F}(\theta_{t+1}, 1)]}_{\text{cost if switch to location 1}}, \underbrace{[\psi^G(\theta_t) + \rho E_t \mathcal{F}(\theta_{t+1}, 2)]}_{\text{cost of using location 2}} \right\}. \quad (6)$$

Another way to think about the problem of coordinating two plants located in different countries is to consider what are the optimal exchange rates at which production is shifted. If switching costs are zero (i.e., $\kappa_{12} = \kappa_{21} = 0$), then the optimal exchange rate would be independent of the current operating mode. No matter, then, if Equation (5) or (6) were to govern the value of the project, the timing of switching between the two plants would occur at the same optimal exchange rate. At this threshold exchange rate, the value of the two cost functions are identical.[12]

However, when costs are incurred, the boundary conditions are not the same. These costs cause the threshold exchange rates for shifting production to deviate from the break from the break-even rate for costless switching.

If it were not for switching costs, the solution to the optimization problem would be simple: choose in each period the location $l$ that maximizes $\psi^l(\theta_t)$ in that period. However, switching costs make a forward-looking analysis necessary. A firm may decline to switch locations if the possibility of a reversal in the relative cost advantage due to subsequent exchange rate movements is high. The probability distribution of *future* real exchange rates affects the *current* choice of technology. This band of inaction is commonly called a *condition of hysteresis*. In Figure 2, we provide a stylized representation of hysteresis in production switching between two locations. Except for a few degenerate processes, this band widens with the degree of uncertainty and switching costs.[13]

**Figure 2 Hysteresis and Real Exchange Rates**




### 3.2. Global Sourcing: The General Formulation

In general, when there is a set $\mathcal{L} = \{1, \ldots, L\}$ possible production locations with associated cost functions $\psi^l$, the valuation equations can be written as

$$\mathcal{F}(\theta_t, l) = \min_{m \in \mathcal{L}} [-\kappa_{l,m} + \psi^m(\theta_t) + \rho E_t \mathcal{F}(\theta_{t+1}, m)], \quad l \in \mathcal{L}. \quad (7)$$

Parenthetically, the model becomes intractable for multiple-exchange rate processes, but it should be recalled that since most currencies are pegged to the dollar, ECU, or yen, the model can be reduced to considering two exchange rates.[14]

Neglecting transportation and factor cost differentials, the intuitive solution to this more generalized problem is to choose to locate a plant in a country whose exchange rate is the most volatile. Given plants in $n - 1$ countries, the selection of a new site will be influenced by its correlation with the portfolio of current and potential operating locations as well as volatilities. The lower the correlation, the greater the contribution to overall volatility and to increasing the value of the underlying options. In this sense, correlations matter: pure volatility contributes directly to increase the project values.

[12] The equivalence of the two cost functions satisfies one of two boundary conditions; the other condition is smooth-pasting See the Appendix for a discussion.

time invariant only when the horizon is infinite. In a finite-time horizon problem, as the firm approaches the terminal time the band widens since the firm has a shorter time period to recoup the switching costs

Differences among firms in the covariance structure of the cost movements of their international plant locations will influence competitive interactions among multinational corporations in a nontrivial way. Much of the anecdotal discussion of the effects of exchange rates on Japanese and American competitors is a reflection of this influence. A more complete rendering of the influence of exchange rates on the competition among international firms requires a specification of pricing and production decisions as dependent on exchange rates and competitors' responses.[15] Other variations of this model include differences in the technology, uncertainty arising from more than one source, restrictions imposed by host governments on some factor use, transportation costs, and multiple-product manufacturing strategies. Each of these modifications complicates the implementation of the above model, but the fundamental results are conceptually similar to the simple version above.

## 4. A Numerical Example

Insight into the significance of the option value to switch can be gained by a numerical analysis. Through the numerical solutions, the magnitude of the value in across-border coordination is analyzed by varying the parameter values of the exchange rate variance and adjustment coefficient. The major issues in specifying the simulations is to characterize the technologies (cost functions), the nature of uncertainty, and the associated parameter values.

For the purpose of identifying the contribution of changes in exchange rate variance to the option value, we specify a linear cost function of the form $\psi(\theta) = -\alpha + \beta\theta$, where $\alpha$ and $\beta$ are constant coefficients (i.e., Leontief functional form). More complex functional specifications, such as scale economies and carrying-costs of excess capacity, would give essentially the same results, though dampened in magnitude. (Some of the dampening effect is captured in our switching costs parametrization.) Since total demand is treated as constant, revenues are not affected by switching. Thus, the cost side is driving the location choice.

When we use a characterization of uncertainty such as the mean reverting process given by Equation (2) the expectations must be computed numerically. We do so by discreting the statespace.[16] Suppose at any time $t$, $\theta_t$ can only take one of $M$ discrete values, $\theta^1, \theta^2, \ldots, \theta^M$ (say between 0.5 and 1.5). If we observe $\theta_t$ to be $\theta^i$ (e.g., $\theta_t = 0.95$), then the probability $\theta_{t+1} = \theta^j$ (e.g., $\theta_{t+1} = 1.05$) is the transition probability from state $i$ to $j$ which we denote by $p_{ij}$.[17]

In this discrete state-space we can rewrite Equation (7) as

$$\mathcal{F}(\theta_t = \theta^j, l) = \min_{m \in \mathcal{L}} \left[ -\kappa_{l,m} + \psi^m(\theta^j) + \rho \sum_{i=1}^{M} \mathcal{F}(\theta_{t+1} = \theta^i, m) p_{j,i} \right]. \quad (8)$$

The parameter values consist of five factors: time horizon, duration of the intervals during which switching is not possible, switching costs, variance of the real exchange rate ($\sigma$), and the adjustment coefficient ($\lambda$). The first three factors are fixed at 20 years, quarterly intervals, and 2.5% of mean (i.e., when $\theta = 1$) quarterly costs per switch for all the simulations.[18] Switching costs capture expenses associated with adjusting labor schedules, inventory, and start-up.

Because our central focus is on the effect of the real exchange rate variance and, though less so, the PPP adjustment coefficient, we vary $\sigma$ and $\lambda$ over simulations. In the initial runs, we set $\lambda = 0.05$, and let $\sigma$ vary from 5% to 10% (base case) and 20%. These exchange rate variances are not substantially different from the estimated variances given by Figure 1. In the second set of simulations, we let the adjustment coefficient vary from 5% to 20%, with $\sigma$ set to 10%.[19]

[16] See Appendix for details.

[17] For stationary processes $p_{ij}$ is time independent.

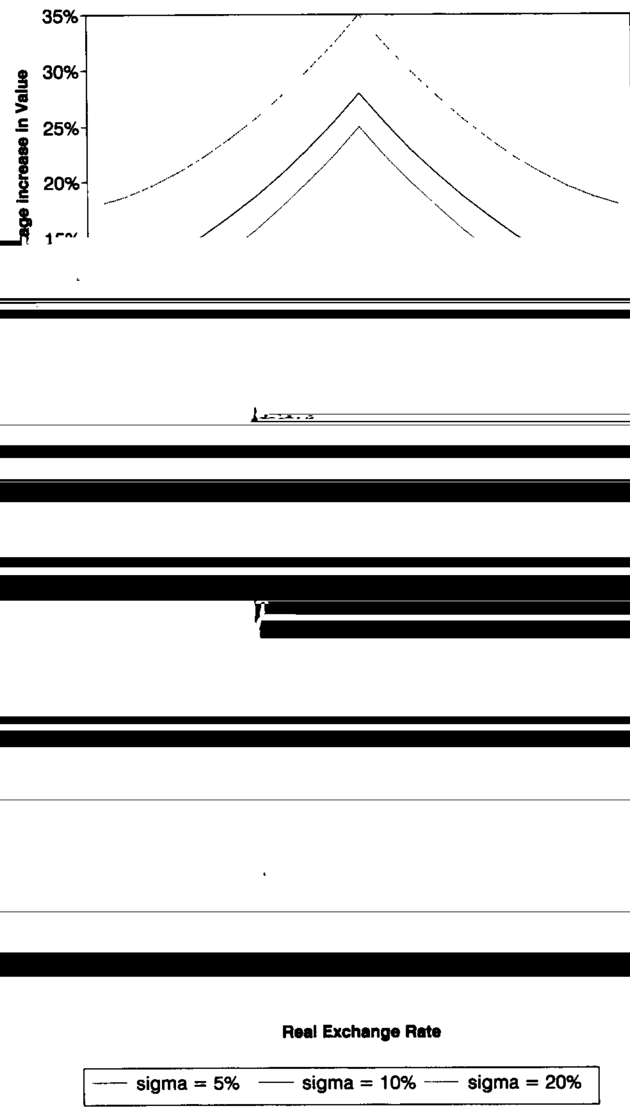
[18] Quarterly intervals were suggested by discussions with plant managers and are longer, in fact, than those attributed to Japanese production planning. See Abegglen and Stalk (1985). We can very easily reduce the intervals and permit continuous switching. This situation can also be thought of as a way of endogenizing the switching intervals.

[19] In the numerical simulations we restricted the possible range of $\theta$ values between 0.25 and 1.75. In order to avoid distortion from end-point approximations we only report the value of flexibility for the $\theta$

## 4.1. Discussion of Principal Results

The simulations provide an opportunity to investigate the incremental profitability of production shifting to changes in the parameters, especially that of the real exchange rate variance. Figure 2 provides a graphical illustration of the values of flexibility for three values of volatility: $\sigma$ = 5%, 10% and 20%. ($\lambda$ is held at 5%.) As is apparent, the incremental profitability is far from

Figure 3 Value of Flexibility




The explanation of these peaks is transparent on reflection. Since the likelihood of a change in the real exchange rate crossing the boundary (of one) is greatest when the current rate is close to one, the value of the option must also reach a minimum at this boundary. To borrow from the terminology of financial option markets, the option to switch is deepest in the money when $\theta$ = 1. Conversely, as the derivation from PPP increases (i.e., the real exchange rate moves away from 1), the likelihood of a boundary crossing is reduced.

A more precise illustration of the sensitivity of the value of the option to switch production is given in Table 2. The center column gives the numerical values of the percentage increase in profitability shown by Figure 3. At the mean exchange rate ($\theta$ = 1), the value of flexibility increases from about 5.5% when $\sigma$ = 5% to 17.5% when $\sigma$ = 20%. Having the flexibility to move production to locations with lower input prices has the effect of insuring against detrimental movements of the real exchange rate. Increased exchange rate volatility will increase the upside benefits while the insurance feature of value derived from location flexibility is

rule. The project, building the second plant, should be undertaken if the increased value due to flexibility is greater than the required initial investment.

## 4.2. Extension: Hysteresis and Within-country Options

So far, we have analyzed the value of multinationality as arising from the across-country coordination of production. This development has been couched in the context of a *vertical* direct investment decision, that is, whether to build one or two plants. Clearly, there are also implications for the economics of the 'horizontal' direct investment whereby a plant is built in a country to support local sales in that market. The horizontal investment decision can be seen as part of a well-documented sequence by which a firm expands from exporting to investing in local production.[20] The sequence by which a firm expands from exports to local in goodwill (e.g., brand labels and sales force recruitment) to serve a market through exports; these effects have been discussed in Dixit (1989a), Baldwin and Krugman (1989), and Dumas (1988). We call this component 'export hysteresis.'

While the investment in goodwill leads to a condition of hysteresis, it leads to increase the likelihood that the initial export activity will eventually be followed by investments in manufacturing. These observations imply that any subsequent investment can benefit from the initial establishment of goodwill. The accumulation of goodwill generates what Myers (1977) first called a growth option, that is, it serves as a platform by which a firm expands in the future.

Growth options are not acquired per se by the establishment of multinational investments; they represent opportunities gained by investing in a current activity, no matter if this investment is made by a domestic or international firm. However, they are important in underscoring the likelihood that foreign investors will persist in a market once they have initially entered. As general experience and goodwill are gained, the cost of launching new products in the foreign market is reduced. The combination of hysteresis, along with the acquisition of growth options, underscore the argument that the initial entry into a country increases the likelihood of subsequent investments.

Some insight into this pattern can be gained from Table 3, which provides the threshold exchange rates for entry for the first time and subsequent entries. Assuming that later products can enjoy the initial investment in goodwill, then subsequent products can be introduced at a significantly lower critical exchange rate than the case when exporting began. (These values are estimated by assuming the same production function for the initial and subsequent products.) In this sense, the initial investment establishes a growth option for future product entries.

**Table 3 Threshold Values of Real Exchange Rate**

| | Threshold $\theta$ |
|---|---|
| Naive Investment | 1 0 |
| First Entry (when entry can be delayed) | 1.5 |
| Subsequent Switch to German Plant | 0.975 |
| Exit from German Market | 0.575 |

# 5. Heuristic Rules and Operating Procedures

An important objection to the above model is the of question whether labor can be treated as variable. However, the benefits of production shifting rely less on the feasibility of layoffs than on rules for labor flexibility. It is important to recall that direct labor costs are an increasingly insignificant proportion of total production costs (Johnson and Kaplan 1987). The main cost drivers are materials and energy, the prices of which are determined by domestic market forces and government regulations. A more general characterization is to treat $W$ as a vector of those inputs that are priced locally in the country where the plant is located.

Along these lines, an alternative, and more appropriate, way to understand the above model is to treat the investment in two countries as the creation of excess capacity in the overall system. Plants are never closed. Rather, what is shifted is overtime production. Even if the value of production shifting is realized by savings from material and energy usage, labor policy still remains important in terms of creating flexible overtime.

These considerations raise the general question whether this operating flexibility is discretionary. One way to address this question is to consider whether the effect of costs of operating flexibility, e.g., establishing contracts for flexible overtime, on the hysteresis band eliminates the plausibility of switching.[21] But another way to understand this issue is by focusing on the often overlooked question of whether managers have the information and institutional flexibility to identify and exercise these options. It is this avenue we explore by analyzing internal accounting practices, and pricing.

## 5.1. Internal Accounting Practices

What should be the control system appropriate to the coordination of cross-border activities in response to fluctuating exchange rates? Because floating exchange rates only were introduced in the mid-1970s, it is possible by reviewing a few empirical and prescriptive studies to trace how evaluation systems have developed to provide information, and incentives, for across-border

[21] See Kulatilaka and Kogut (1990) for an analysis.

coordination. What is striking is how the heuristic rules of international accountability have changed to meet the environmental pressures of multinational competition and coordination.

The canonical problem in international performance evaluation of foreign subsidiaries is how to treat the effects of exchange rate movements on accounting variances. This problem can be most simply stated as the choice of exchange rate values by which to budget and to monitor performance. Between the time of budgeting and monitoring, exchange rates move. The control problem is what exchange rate should be applied and who should be held accountable for exchange rate effects. Clearly, if the control system removes the effect of exchange rates on operating decisions and results, there is no mechanism by which to trigger the shifting of production.

rates for budgeting and tracking differ, the local subsidiary bears the full risk of exchange rate movements. In this latter case, there is an incentive for the local subsidiary to hedge. Even if not permitted to do so by engaging in financial positions, it may do so by building up inventory or by insisting on local manufacture to support local sales.

The combination that Lessard and Lorange prescribed was the use of forward rates for budgeting and tracking. In this case, the subsidiary and the central controller's office have the incentive to establish accurate forward rates for purposes of budgeting, with the spot rate at the time of tracking or the forward used for evaluation. Empirical studies showed that one of these two combinations tended to prevail during the 1970s. (See, for example, Business International 1976).

It is interesting to note the unstated assumptions of part of the competitive strategy of the firm (Cohen et al. 1989).

The internal sourcing of production as part of a coordinated international strategy conflicts with the assumptions of the original Lessard / Lorange proposals. The evaluation problem is no longer the dyadic control by headquarters of each subsidiary. Rather, the transfers across subsidiaries require that the evaluation of performance be conceived in the context of a network with the flexibility to shift production in response to exchange rates. The decision to transfer production from one country will depress the operating results of that subsidiary, but to the gain of operations elsewhere. Sterilizing operating results from exchange rates removes the incentive to coordinate production multinationally.

Control within a network requires minimally two related changes, as recognized in the subsequent writings [illegible]

[illegible] minimized, the selection of the appropriate exchange rate is much more complicated. One possibility is to budget and track at the PPP rate (Stewart 1983). But while this rate will give a more accurate appraisal over longer periods of time, it fails to provide the incentives for operating flexibility.

The recommendation, made by Lessard and Sharp (1984) and Jacque and Lorange (1984), is to establish the PPP rate as the benchmark, but to work out the implications of deviations from these rates on operating results. Thus, the second change proposed by Lessard

### 5.2. Market and Transfer Pricing

Despite the substantial impact of exchange rates on operating performance, the diffusion of new evaluation techniques has been slow. Moreover, the internal performance evaluation methods clearly influence other decisions, such as pricing. If effects of exchange rates on comparing operating costs across subsidiaries are ignored, then the tendency will be to use accounting procedures and estimates based on the home market.

The relationship between control systems and pricing has been documented in a number of studies. In his field research, Sharp (1987) found that a number of American multinational operations continued to price by adding a mark-up to the American unit costs. While these practices made sense when the competition was American and all competitors were following similar pricing policies, the persistence of these pricing heuris- [illegible]

These practices show up in a few popular MBA teaching cases. Caterpillar Tractor is described as using cost-plus pricing rules, with the cost estimates derived from U.S. plant experiences. "Because the company used a uniform dollar pricing policy, dealers all over the world were billed in dollars, irrespective of the origin of the machines. The prices were often based on U.S. manufacturing cost, and when the dollar was strong, the company had to engage in price-cutting" (Caterpillar Tractor Co., Harvard Business School 1985). In the mid-1980s, it switched to competitive pricing, as

$= \{1, \ldots, S\}$.[27] Given a value of $\theta_t^i$, the probability of $\theta_{t+1}^j$ in the next period depends on the difference $j - i$. Hence, as the absolute value of $j - i$ increases, the probability falls in accordance with the normal distribution.

Consistent with the discrete version of the normal distribution with parameters $N(\lambda(\bar{\bar{\theta}} - \theta_t)\Delta t,\ \sigma^2\theta_t^2\Delta t)$, a transition from state $i$ to $j$ occurs with probability

where $dZ_\theta$ is a standard Wiener process. This assumption is strong, but necessary for the derivation of the analytical solution.

The general problem we consider is the following: a firm has an investment opportunity which can be undertaken at a cost $F$. If undertaken, it has a continuous payoff rate of $\psi(\theta_t, t)$. In the interim, there is a cash flow $\pi(\theta_t)$ which is no longer received once payoff $\psi(\theta)$ is obtained. Again for the sake of an analytical solution we assume that the investment opportunity is infinitely lived. We ask two ques-

If we let $\theta^*$ denote the value at which it is optimal to act, then the following free boundary condition must be satisfied:

$$V(\theta^*) = \mathrm{PV}[\psi(\theta^*)] - F, \tag{18}$$

where $\mathrm{PV}[\psi(\theta)]$ is the present value of an infinitely-lived stream of cash flow arriving at rate $\psi$. Furthermore, in order to ensure continuity and differentiability of $V$ the derivatives of $V$ and $\psi$ with respect to $\theta$ must also be equal.

This is the Merton-Samuelson *high-contact* condition:[29]

$$V'(\theta^*) = \mathrm{PV}'[\psi(\theta^*)]. \tag{19}$$

**B.1. An Example: Production Location Choice Problem**

Here we will show how the above general model can be used to evaluate a flexible project consisting of plants in the U.S. and Germany. The relevant stochastic variable $\theta$, is the real exchange rate which we assume follows the process in Equation (12).

Let $\psi(\theta_t)$ be the dollar value of the profit flow when producing in Germany and value of U.S and $\pi(\theta_t)$ be the dollar profit flow when producing in the U S The cost of switching from U.S. to German production is $k_1$ and from German to U.S production is $k_2$. Since the only relevant stochastic variable is $\theta$ the value of both production locations will be governed by the partial differential equation (PDE) in Equation (13).

Suppose $V(\theta_t, t)$ and $W(\theta_t, t)$ are the values of the U.S. and German production, respectively. Let $\bar{\theta}$ and $\underline{\theta}$ be the critical real exchange rates at which the firm switches from U.S to German plant and vice versa. At these free boundaries the firm will be indifferent between the continuing at the current operating mode and incurring the switching cost to change the production location, i e ,

$$V(\bar{\theta}) = -k_1 + W(\bar{\theta}),$$

$$V'(\bar{\theta}) = W'(\bar{\theta}),$$

$$W(\underline{\theta}) = -k_2 + V(\underline{\theta}),$$

$$W'(\underline{\theta}) = V'(\underline{\theta}).$$

Examining the limiting cases of $\theta \to 0$ and $\theta \to \infty$, we note that $V_\theta > 0$ and $W_\theta < 0$. Furthermore, since both $V$ and $W$ follows the PDE in (13), the solutions must be of the form

$$V(\theta_t, t) = \underbrace{\gamma_2\theta^{\epsilon_2}}_{\text{option to switch to U.S.}} + \underbrace{\frac{\alpha_\pi}{r} + \frac{\beta_\pi}{r-\delta_\pi}\theta^{c_\pi},}_{\text{value of fixed U.S. production}}$$

$$W(\theta_t, t) = \underbrace{\gamma_1\theta^{\epsilon_1}}_{\text{option to switch to Germany}} + \underbrace{\frac{\alpha_\psi}{r} + \frac{\beta_\psi}{r-\delta_\psi}\theta^{c_\psi},}_{\text{value of fixed German production}}$$

where $\gamma_1$, $\gamma_2$, $\bar{\theta}$, and $\underline{\theta}$ satisfy

$$\gamma_2\bar{\theta}^{\epsilon_2} + \frac{\alpha_\pi}{r} + \frac{\beta_\pi}{r-\delta_\pi}\bar{\theta}^{c_\pi} = -k_2 + \gamma_1\bar{\theta}^{\epsilon_1} + \frac{\alpha_\psi}{r} + \frac{\gamma_\psi}{r-\delta_\psi}\bar{\theta}^{c_\psi},$$

$$\gamma_2\epsilon_2\bar{\theta}^{\epsilon_2-1} + \frac{\beta_\pi c_\pi}{r-\delta_\pi}\bar{\theta}^{c_\pi-1} = \gamma_1\epsilon_1\bar{\theta}^{\epsilon_1-1} + \frac{\beta_\psi c_\psi}{r-\delta_\psi}\bar{\theta}^{c_\psi-1},$$

$$\gamma_1\underline{\theta}^{\epsilon_1} + \frac{\alpha_\psi}{r} + \frac{\beta_\psi}{r-\delta_\psi}\underline{\theta}^{c_\psi} = -k_1 + \gamma_2\underline{\theta}^{\epsilon_2} + \frac{\alpha_\pi}{r} + \frac{\beta_\pi}{r-\delta_\pi}\underline{\theta}^{c_\pi},$$

$$\gamma_1\epsilon_1\underline{\theta}^{\epsilon_1-1} + \frac{\beta_\psi c_\psi}{r-\delta_\psi}\underline{\theta}^{c_\psi-1} = \gamma_2\epsilon_2\underline{\theta}^{\epsilon_2-1} + \frac{\beta_\pi c_\pi}{r-\delta_\pi}\underline{\theta}^{c_\pi-1}. \tag{20}$$

These equations are linear in $\epsilon_i$ but nonlinear in $\underline{\theta}$ and $\bar{\theta}$.[30] The range $[\underline{\theta}, \bar{\theta}]$ forms the hysteresis band.

In search of analytical solutions we consider two special cases. First, consider the case when U.S. profits are normalized to 1 and the German plant has linear profits, i.e., $\pi(\theta, t) = 1$ and $\psi(\theta, t) = \theta_t$. The above nonlinear equations are now simply as follows:

$$\gamma_2\bar{\theta}^{\epsilon_2} + \frac{1}{r} = -k_2 + \gamma_1\bar{\theta}^{\epsilon_1} + \frac{\bar{\theta}}{r-\delta},$$

$$\gamma_2\epsilon_2\bar{\theta}^{\epsilon_2-1} = \gamma_1\epsilon_1\bar{\theta}^{\epsilon_1-1} + \frac{1}{r-\delta},$$

$$\gamma_1\underline{\theta}^{\epsilon_1} + \frac{\underline{\theta}}{r-\delta} = -k_1 + \gamma_2\underline{\theta}^{\epsilon_2} + \frac{1}{r},$$

$$\gamma_1\epsilon_1\underline{\theta}^{\epsilon_1-1} + \frac{1}{r-\delta} = \gamma_2\epsilon_2\underline{\theta}^{\epsilon_2-1}$$

Now we have a simpler set of nonlinear equations to solve for the $\gamma_i$'s and the threshold exchange rates. However, even these equations can not, in general, be solved in closed form. In the very special case, when $k_1 = k_2 = 0$ and $\delta = 0$, we get the obvious solution $\underline{\theta} = \bar{\theta} = 1$ and $\gamma_1 = \gamma_2 = 1/r(\epsilon_1 - \epsilon_2)$

When $\alpha_\psi = 0$ and $c_\psi = b_\psi = 1$, and $a_\pi = b_\pi = c_\pi = 0$, i.e., $\theta$ is the cash flow from the export operation, then we can solve the equations in closed form. This is similar to the problems handled by Dixit (1989a) and McDonald and Siegel (1986).

**B.2. When Real Exchange Rate Follows an Ornstein-Uhlembeck Process**

The general continuous-time analog to the discrete-time stochastic process in Equation (2) is given by the Ornstein-Uhlembeck Process:

[29] It is also known as the *smooth-pasting* condition.

[30] Note that in general, we must solve this set of $2M$ nonlinear equations using numerical techniques.

$$d\theta_t = (\alpha - \beta \ln \theta_t)\theta_t dt + \sigma\theta_t dZ \quad (21)$$

where $dZ$ is a standard Wiener process. The PDE in (13) now becomes

$$\pi(\theta_t, t) - rV(\theta_t, t) + V_t(\theta_t, t) + (\alpha - \beta \ln \theta_t)\theta_t V_\theta(\theta, t) + \tfrac{1}{2}\sigma^2\theta_t^2 V_{\theta\theta}(\theta_t, t) = 0. \quad (22)$$

This is equivalent to having a state-dependent $\delta$ in Equation (13). In general, analytic solutions are not available to this *PDE* and numerical solution techniques must be employed.

## References

Abegglen, James C. and George Stalk, *Kaisha, The Japanese Corporation*, Free Press, New York, 1985.

Badger, (Belgium) N. V., Harvard Business School, Boston (9-481-127), 1981.

Baillie, Richard T. and Tim Bollerslev, "Common Stochastic Trends in a System of Exchange Rates," *J. Finance*, 44 (1989), 167–180.

Baldwin, Richard E., "Sunk Cost Hysteresis," NBER Working Paper, No. 2911, March 1989.

—— and Krugman, Paul, "Persistent Trade Effects of Large Exchange Rate Shocks," *Quart. J. Economics*, 104 (1989), 636–654.

Bartlett, Chris and Sumantra Ghoshal, *Managing Across Borders. The Transnational Solution*, Harvard Business School Press, Boston, 1989.

Brennan, Michael and Eduardo Schwartz, "Finite Difference Methods and Jump Processes Arising in the Pricing of Contingent Claims: A Synthesis," *J. Financial and Quantitative Analysis*, (September 1978), 461–474.

Business International, *Operating in a Floating Rate World*, Business International Corporation, New York, 1976

——, *Evaluating the Performance of International Operations*, New York: International Corporation, 1989.

——, *Protecting Profits from Market Turmoil: Strategic Financial Risk Managing for the 1990s*, New York: International Corporation, 1990.

Caterpillar Tractor Co., Harvard Business School, Boston (385-276), 1985.

Cohen, Morris, Marshall Fisher, and Ramchandran Jaikumar, "International Manufacturing and Distribution Networks: A Normative Model Framework," in Kasra Ferdows (Ed.), *Managing International Manufacturing*, North-Holland, Netherlands, 1989, 67–93.

—— and Arnd Huchzermeier, "Valuing Manufacturing Flexibility Under Foreign Exchange Uncertainty," Working Paper, Wharton School, Department of Decision Sciences, University of Pennsylvania, 1991.

—— and Hau Lee, "Strategic Analysis of Integrated Production-Distribution Systems: Models and Methods," *Oper. Res.*, 36 (1989), 216–228.

Dixit, Avinash, "Entry and Exit Decisions Under Uncertainty," *J. Political Econ.*, 97 (1989a), 620–638.

——, "Hysteresis, Import Penetration, and Exchange Rate Pass-through," *Quart. J. Econ*, 104 (1989b), 205–228.

Dornbusch, Rudiger, "Expectations and Exchange Rate Dynamics," *J. Political Econ.* 84 (1976), 1161–76.

——, "Exchange Rates and Prices," *American Econ. Review*, 77 (1987), 93–106.

Doz, Yves, "Managing Manufacturing Rationalization with Multinational Corporations," *Columbia J. World Business*, (1978).

Dumas, Bernard, "Perishable Capital and Hysteresis in Capital Formation," Rodney White Center Working Paper, 1988.

Fine, Charles and Robert Freund, "Optimal Investment in Product-Flexible Manufacturing Capacity," *Management Sci.*, 36 (1990), 449–466.

Flaherty, Therese, "Coordinating International Manufacturing and Technology," M. E. Porter (Ed.), *Competition in Global Industries*, Harvard Business School Press, Boston, MA, 1986.

Flood, Eugene and Donald Lessard, "On the Measurement of Operating Exposure to Exchange Rates: A Conceptual Approach," *Financial Management*, 32 (1986), 25–35.

Hodder, James and James Jucker, "International Plant Location under Price and Exchange Rate Uncertainty," *Engineering and Production Econ.*, 9 (1985a), 225–229.

—— and ——, "A Simple Plant-Location Model for Quantity-Setting Firms Subject to Price Uncertainty," *European J. Oper. Res.*, 21 (1985b), 39–46.

Hedlund, Gunnar, "The Hypermodern MNC: A Heterarchy," *Human Resource Management*, (1986), 9–35.

Huchzermeier, Arnd, "Global Manufacturing Strategy Planning under Exchange Rate Uncertainty," Ph.D. Thesis, University of Pennsylvania, 1990.

Hull, John, *Options, Futures, and Other Derivative Securities*, Prentice-Hall, Englewood Cliffs, NJ, 1989.

Hymer, Stephen, "The International Operations of National Firms," Ph.D Thesis, Massachusetts Institute of Technology, Cambridge, MA, 1960.

Jacque, Laurent and Peter Lorange, "The International Control Conundrum: The Case of 'Hyperinflationary' Subsidiaries," *J. International Business Studies*, 15 (1984), 185–201.

Jacquillat, Bertrand and Bruno H. Solnik, "Multinationals are Poor Tools for Diversification," *J. Portfolio Management*, Winter (1978), 8–12.

Johnson, H. Thomas and Robert Kaplan, *Relevance Lost. The Rise and Fall of Management Accounting*, Harvard Business School Press, Boston, MA, 1987.

Kogut, Bruce, "Foreign Direct Investment as a Sequential Process," Charles P. Kindelberger and David Audretsch (Eds.), *The Mul-*

ginald H. Jones Center for Management Policy, Strategy and Organization, University of Pennsylvania, July 1988.
—— and ——, "Multinational Flexibility, Growth Options, and the Theory of Foreign Direct Investment," mimeo, Wharton School, University of Pennsylvania, 1991.
Kulatilaka, Nalin, "The Value of Flexibility," Working Paper, MIT Energy Laboratory, MIT-EL 86-014, revised May 1987.
—— and Bruce Kogut, "Direct Investment, Hysteresis, and Real Exchange Rate Volatility," mimeo, Wharton School, University of Pennsylvania, 1990.
—— and Alan Marcus, "A General Formulation of Corporate Operating Options," *Research in Finance*, (1988), 183–200.
Lessard, Donald and Peter Lorange, "Currency Changes and Management Control: Resolving the Centralization-Decentralization Dilemma," *Accounting Review*, July 7 (1977), 628–637.
—— and David Sharp, "Measuring the Performance of Operations Subject to Fluctuating Exchange Rates," *Midland Corporate Finance J.*, 2 (1984).
Marston, Richard, "Pricing to Market in Japanese Manufacturing," *J. International Econ.*, 29 (1989), 217–236.
Matsushita Electric Industrial (MEI) in 1987, European Institute of Business Administration (INSEAD), Harvard Business School, Boston (388-144).
McDonald, Robert and Daniel Siegel, "The Value of Waiting to Invest," *Quarterly J. Economics*, 101 (1986), 707–727.
Merton, Robert, "Theory of Rational Option Pricing," *Bell J. Econ. and Management Sci.*, (1973), 41–83.
—— "On the Mathematics and Economics Assumptions of Continuous-time Models," in W. F. Sharpe and C. M. Cootner (Eds.), *Financial Economics: Essays in Honor of Paul Cootner*, 1982; reprinted in *Continuous Time Finance*, Robert Merton, Basil Blackwell Inc., Cambridge, MA, 57–96, 1990.
Prahalad, C. K. and Yves Doz, *The Multinational Mission*, Free Press, New York, 1987.
Sharp, David, *Control Systems and Decision-making in Multinational Firms: Price Management Under Floating Exchange Rates*, Ph.D. Thesis, Massachusetts Institute of Technology, Cambridge, MA, 1987.
Stewart, George, "A Proposal for Measuring International Performance," *Midland Corporate Finance J.*, 1 (1983), 56–71

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