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Optimal Operating Policies for a Multinational Company under Varying Market Economics

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ABSTRACT

This paper proposes a mathematical programming model for Multi-National Corporations (MNCs) by considering both the flexibility of exchange rate and market price uncertainties. The results show that the factory in a host country should supply the products demanded by the home country for the next period when exchange rate decreases. The quantity of products being produced and shipped should be adjusted according to the variation of market-price. Conversely, a MNC in the host country should produce products ahead of time when exchange rate increases and must adjust quantity of production and inventories according to the variation of market-price.

Keywords: Exchange Rate Uncertainties; Multi-National Corporations; Market Price Uncertainties

1. Introduction

Previous reports have showed a significant increase in the number of Multi-National Corporations (MNCs) and a tremendous growth in foreign direct investment in recent two decades. A MNC is defined as the corporation that owns or controls production or service facilities outside the host country and operates in two or more countries. However, a fundamentally different form of international commercial activity has developed since World War II. The form has greatly increased worldwide economic and political interdependence. The MNCs now make direct investments in fully integrated production process including production planning and distribution under varying environments. Due to the current trend of market and economic globalization, multinational corporations must face more ambiguities such as different cultures, values, rules, varying degrees of business, political and economical uncertainties. Investments of a MNC under uncertainty have been studied in several literatures which show that sunk costs and the revenue of a MNC can be affected by the exchange-rate uncertainty [1-4] and the government policy uncertainty [5,6].

With market and economic globalization, MNCs now gradually tend to design and manage their supply chains more efficiently on a worldwide basis. The network activities of a corporation's supply chain such as sourcing, manufacturing, and distribution are based on handling all flows of materials, information, and funds effectively and efficiently within and across the chain. When a firm faces a more complicated market environment, the multinational Supply Chain Management (SCM) becomes more and more important. The managerial issues cover problems with strategic and operational dimension such as design and location of facilities, specification of supply contracts, choice of product variety, management of inventories, and selection of transportation forms.

Many researchers have focused on how the flexibility of exchange rate may affect a MNC's operation; however, they seldom consider the variability of market prices at the same time. In this paper, we extend Huchzermeier and Cohen's [2] and Mohamed's [4] model to develop a new multi-period production-distribution model with varying exchange rate and market price. Then, we use quantitative approach to investigate for a MNC's supply chain design process for finding its optimal operating decision by emphasizing the effects of uncertainties in exchange rate and product price. The uncertainties of exchange rate and product price are defined as stochastic dynamic processes. Using stochastic dynamic programming, we simulate the changes, the volatility, and the variation speed of exchange rate and market price.

The goal of this research is to understand that the production and distribution decisions for a MNC are over a finite planning horizon. In other words, we would like to determine a firm's decision when facing to the variations in market price and exchange rate. Therefore, the objective function is to maximize the profit of a MNC by reducing production, distribution, and inventory costs under the variations in exchange rate and market price. By exercising this model, we can provide useful guidance for a MNC to make operating decisions which involve uncertainties in exchange rate and market price.

This paper is organized as follows. Section 1 provides a brief literature review for SCM related to MNCs. In Section 2, we develop an integrated production planning and distribution model for a MNC suitable for varying exchange rate and market price. In Section 3, we establish a stochastic dynamic programming model by incorporating seven parameters including exchange rate and market price. We verify the correctness of this model and its optimal operation through a numerical example in Section 4. Finally, conclusions are given in Section 5.

2. Literature Review

The previous studies on SCM for multinational operations within a network have largely involved the upstream and downstream flows of products, services, information, and finance. The term SCM was originally introduced by consultants in the early 1980s and has subsequently received much attention in manufacturing operations. SCM was described by the logistic literature as a new integrated logistic management approach across different business processes such as purchasing, manufacturing, distribution, and sales. Later on, many manufacturing companies are willing to locate their facilities in any part of the world in order to obtain cheap labor, more reliable materials, parts, and subassemblies [7]. This integrated approach is extended outside the firm's boundaries to customers and suppliers. Such a trend has incurred the problem of managing global operations for a firm in different cultures, values, rules, and politics. Also, since the Bretton Woods System was broken up, the stability of the competitive environment in the early 1970s has been replaced by increasing uncertainty. Thus, a MNC must face more ambiguities in the internal and external environment such as shorter product life cycle, quick change of customer's preference, and many competing rivals.

Many literatures have dealt with designing and managing a network of facilities located in different countries in response to growing environmental uncertainty [8-12]. Hodder and Jucker [8] incorporated market price and exchange-rate uncertainty and adopted cost minimization via using a mean-variance objection function to analyze the effect of uncertainty in one-period. De Meza and Van Der Ploeg [9] also tried to capture the value of flexibility under uncertainty stochastic model of shifting production in one-period. Koqut and Kulatilaka [10] analyzed explicitly the net present value of shifting production between two plants which located in two different countries with exchange-rate movement using multi-period stochastic model. Although these approaches have made considerable progress in analyzing cost-minimization or profit-maximization for multinational operations within a network under market price or exchange-rate uncertainty, they did not consider the flexibility of exchange-rate and market price uncertainties over multiple periods.

On the other hand, the importance of global issues in supply chain management and analysis has gradually received more attention in recent literatures [6,13,14]. Cohen and Lee [13] developed a comprehensive mathematical programming model for option valuation of global manufacturing and distributing strategy and constructed a maximizing objective function for after-tax profits. Although their approach included stochastic variables in the sub-models, the facility location, capacity of plant and technology are assumed to be fixed. Thus, they did not consider the random fluctuations of currency's exchange rate on the network operation. Kulatilaka and Koqut [14] explored how a MNC provides incentives to managers to modify production plans appropriately. They developed a stochastic dynamic programming model to evaluate the cost based on varying exchange rate in multi-periods. They also determined the quantity of shifting production between two manufacturing locations in two different countries. However, the decisions about material flow, product distribution, demand and processing time uncertainties were not considered in their model.

Several literatures have proposed models for uncertainty management in global supply chain. Such models emphasize centralized decision-making and optimization [2,15]. Huchzermeier and Cohen [2] extended Cohen and Lee's work [13] by taking exchange-rate uncertainty into account to develop a stochastic dynamic programming formulation for the evaluation of global manufacturing strategy options with switching costs. Their model consists of three sub-models: the stochastic exchange rate sub-model, the valuation sub-model, and the supply chain network sub-model. Moreover, they also considered plant capacity and customer demand in their model. Among these sub-models, the supply chain network sub-model is to maximize the expected discounted after-tax profit of a multinational firm. However, the formulation did not include stochastic market prices and processing time. Dasu and Li [12] analyzed the structure of the optimal policies for a firm with operating plants located in two countries based on a randomly changing exchange rate and switching costs. Their approach can determine when and how much to alter the quantities produced in different countries. However, they failed to consider the inventories carried from one period to the next in their model.

3. The Proposed Model

The MNC decisions discussed in this paper include production strategies, international locations, and operations. Production strategies will determine the levels of products to be made and sold. The operation decisions include the distribution of products to various markets, and different inventory levels of products. In this paper, we would like to develop a stochastic dynamic programming model which includes a stochastic exchange rate sub-model, a pricing sub-model with varying sub-demand, and a supply chain network sub-model to analyze global manufacturing strategies.

Many research works proposed the measures for supply chain performance using objective functions directly based on minimizing cost, maximizing sales, maximizing profit, or maximizing returns from investments. Among these objective functions, cost-minimization and profit-maximization are widely used. In our model, the objective function is to maximize a MNC's profit by considering plant capacity and demand satisfaction.

Profit is total revenue subtracted by total cost. Total cost includes manufacturing cost, inventory cost, and distribution cost. Total revenue and total cost should incorporate exchange rates. We define the related variables shown in **Table 1**.

Table 1. Notations.

Notation	Remark
M	Set of target markets $\{1,2,\cdots,m,\cdots,M\}$
K	Set of facilities $\{1,2,\cdots,k,\cdots,K\}$
J	Set of products $\{1,2,\cdots,j,\cdots,J\}$
T	Set of time periods $\{1,2,\cdots,t,\cdots,T\}$
$P_{jm,t}$	Unit price of sales for product *j* in period *t* for target market *m*
$D_{jm,t}$	Demand quantity for product *j* in period *t* for target market *m*
$e_{m,t}$	The initial exchange rate in period *t* for target market *m*
$p_m(e)$	Probability value of exchange rate for target market *m*
$e_{k,t}$	The initial exchange rate in period *t* for target facility *k*
$p_k(e)$	Probability value of exchange rate for target facility *k*
$CN_{kj,t}$	Manufacturing cost per unit of product *j* at facility *k* in period *t*
$Q_{kj,t}$	Quantity of product *j* at facility *k* in period *t*
$IP_{jk,t}$	Inventory holding cost per unit of product *j* at facility *k* in period *t*
$I_{jk,t}$	Inventory quantity of product j at facility *k* in period *t*
$DP_{jm,t}$	shipping cost of product *j* in period *t* for target market *m*
$DQ_{jmk,t}$	Quantity of product *j* produced from facility *k* to market m in period *t*
a	Constant coefficient (*i.e.* intercept of product-price equation)
b	Constant coefficient (*i.e.* partial adjustment coefficient of product-price)

3.1. The Exchange Rate Function and Total Revenue Sub-Model

According to Harvey and Quinn's model [16] and Mohamed's model [4], we assume that predicted exchange rate $(\hat{e}_{m,t})$ in the *t*-th period for a target market in the *m*-th period is a probability distribution function. Then, the exchange rate can be expressed as $\hat{e}_{m,t} = p_m(e)\cdot e_{m,t}$.

According to Kaihara's [17] argument, we assume that dynamic price of a product is associated with the demand for that product. So, the price of a product $(P_{jm,t})$ depends on its market demand $(D_{jm,t})$. Hence, in any given period, the total revenue (TR_t) from all markets can be described by the following expression:

$$TR_t = \sum_{m=1}^{M}\sum_{j=1}^{J}\left[\hat{e}_{m,t}\cdot P_{jm,t}\cdot D_{jm,t}\right] = \sum_{m=1}^{M}\sum_{j=1}^{J}\left[p_m(e)\cdot e_{m,t}\cdot P\left(D_{jm,t}\right)\cdot D_{jm,t}\right] \quad (1)$$

Based on the total revenue as described above, the price is non-constant and can be expressed as being dependent on the demand. That is, $P_{jm,t} = P\left(D_{jm,t}\right) = a - bD_{jm,t}$, $P' = P'(D) \prec 0$, $P'' = P''(D) \succ 0$.

3.2. The Total Cost Sub-Model

The total cost TC_t can be expressed as

$$TC_t = \sum_{k=1}^{K}\left(\mathrm{DICOST}_{k,t} + \mathrm{MCOST}_{k,t} + \mathrm{INCOST}_{k,t}\right) \quad (2)$$

where $\mathrm{DICOST}_{k,t}$ is the distribution cost, $\mathrm{MCOST}_{k,t}$ is the manufacturing cost, and $\mathrm{INCOST}_{k,t}$ is the inventory cost. Each of these costs is described as follows:

The distribution cost

In any given period, the distribution cost $(\mathrm{DICOST}_{k,t})$ is expressed in dollars as follows:

$$\mathrm{DICOST}_{k,t} = \sum_{m=1}^{M}\sum_{j=1}^{J}\left(\hat{e}_{k,t}\cdot DP_{jm,t}\cdot DQ_{jmk,t}\right) \quad (3)$$

The manufacturing cost

The manufacturing cost is incurred by production cost including labor cost, machine maintenance cost, and other costs directly related to the capacity and raw material purchasing cost. In any given period, manufacturing cost (MCOST_t) is given by the formula:

$$\text{MCOST}_{k,t} = \sum_{j=1}^{J}\left(\hat{e}_{k,t} \cdot CN_{kj,t} \cdot Q_{kj,t}\right) \quad (4)$$

The inventory cost

If a MNC has excess in supply (*i.e.* the quantity of good supply exceeds the quantity of good demand), they will incur inventory expense. The inventory cost ($\text{INCOST}_{k,t}$) can be expressed in dollars by incorporating the exchange rate in any given period as follows:

$$\text{INCOST}_{k,t} = \sum_{j=1}^{J}\left(\hat{e}_{k,t} \cdot IP_{jk,t} \cdot I_{jk,t}\right) \quad (5)$$

Total profit can be maximized by total revenue subtracted by total cost. Therefore, the complete integrated production and distribution model can be described as follows:

$$\text{Max} \quad \Pi = \sum_{t=1}^{T} TR_t - \sum_{t=1}^{T} TC_t$$

subject to

$$TR_t = \sum_{m=1}^{M}\sum_{j=1}^{J}\left[\hat{e}_{m,t} \cdot P_{jm,t} \cdot D_{jm,t}\right]$$

$$TC_t = \sum_{k=1}^{K}\left(\text{MCOST}_{k,t} + \text{INCOST}_{k,t} + \text{DICOST}_{k,t}\right)$$

$$\text{MCOST}_{k,t} = \sum_{j=1}^{J}\left(\hat{e}_{k,t} \cdot CN_{kj,t} \cdot Q_{kj,t}\right)$$

$$\text{INCOST}_{k,t} = \sum_{j=1}^{J}\left(\hat{e}_{k,t} \cdot IP_{jk,t} \cdot I_{jk,t}\right)$$

$$\text{DICOST}_{k,t} = \sum_{m=1}^{M}\sum_{j=1}^{J}\left(\hat{e}_{k,t} \cdot DP_{jm,t} \cdot DQ_{jmk,t}\right)$$

$$D_{jm,t} = \sum_{k=1}^{K} DQ_{jmk,t}$$

$$Q_{kj,t} + I_{jk,t-1} = \sum_{m=1}^{M} DQ_{jmk,t} + I_{jk,t}$$

$$\hat{e}_{m,t} = p_m(e) \cdot e_{m,t}$$

$$\hat{e}_{k,t} = p_k(e) \cdot e_{k,t}$$

$$P_{jm,t} = p\left(D_{jm,t}\right) = a - bD_{jm,t}$$

$$e_{k,t}, e_{m,t}, P_{jm,t}, D_{jm,t}, CN_{kj,t}, Q_{kj,t}, IP_{jk,t},$$
$$I_{jk,t}, DP_{jm,t}, DQ_{jmk,t}, I_{jk,t-1}, a, b \geq 0$$

4. An Example

We demonstrate the usefulness of our proposed model through a numerical example. The following scenario is considered in this example. Assume that manufacturing facilities exist (or to be built) in both home and host countries and there is no capacity requirement. Any manufacturing facility only produces one kind of products and supplies both home and host countries without any arbitrage. There are two planning periods and two types of demand function for products in our example. In addition, the unit manufacturing cost, unit distribution cost, and unit inventory cost are kept constant in each same period. However, product unit price is uncertain in each individual market since this price must depend on market demand.

Before simulating the effects of exchange rate and market price function, we list all given parameters in **Table 2**. The model is simulated using LINGO simulation language.

5. Results and Discussion

The simulation results can be classified into three categories. The first category is the effect of production behavior when exchange rate has no significant change while the market price is changing. The second category is the effect of production behavior when exchange rate decreases while the market price is changing. The third category is the effect of production behavior when exchange rate increases while the market price is changing. The simulation results for the above three categories are given in **Tables 3-5**, respectively.

5.1. Exchange Rate Insignificant Change but Market Price Changes

As we can see from Type A in **Table 3**, the optimal products for home country and host country are 1470 and 1476 units, respectively, in both periods. The optimal

Table 2. Input parameters.

	Home country		Host country	
Unit manufacturing cost	$59.73		$23.28	
Unit distributing cost	$22		$20	
Unit inventory holding cost of product	$4.57		$3.88	
Price function for product	$P_t = 3000 - D_t$ $P_t = 3000 - D_t$		$P_t = 1500 - 0.5 \times D_t$ $P_t = 2000 - D_t$	
Value of exchange rate in initial period	$2			
The type of flexibility exchange rate in next period	no significantly change	Increasing	Decreasing	
The composite type of flexibility exchange rate in next period	($1 $2 $3)	($2 $3 $4)	($0.5 $1 $2)	
Probability value of exchange rate occurring in second period	(0.2 0.6 0.2)	(0.2 0.6 0.2)	(0.1 0.8 0.1)	

Note: the value of exchange rate is exchange rate of currency of home country.

Table 3. Results for no significantly changing exchange rates.

	Market	Type A		Type B	
		Period 1	Period 2	Period 1	Period 2
The produced quantity	Home country	1470	1476	1470	1470
	Host country	1470	1476	988	988
The shipped quantity	(From home country to host country)	0	0	0	0
	(From host country to home country)	0	0	0	0
The inventoried quantity	Home country	0	0	0	0
	Host country	0	0	0	0
The quantity of demand for product	Home country	1470	1476	1470	1470
	Host country	1470	1476	988	988
The price of product (expressed by currency of home country)	Home country	$1530	$1530	$1530	$1530
	Host country	$1544	$1544	$2024	$2024
Total profits (expressed by currency of home country)		$8,683,997		$8,230,016	

Notes: Type A: demand function for product is $P_t = 3000 - D_t$ in home country, and $P_t = 1500 - 0.5 \times D_t$ in host country. Type B: demand function for product is $P_t = 3000 - D_t$ in home country, and $P_t = 2000 - D_t$ in host country.

demands for products in home country and host country in both periods are also 1470 and 1476 units, respectively. Type B of **Table 3** shows that the optimal products for home country and host country are 1470 and 988 units, respectively, in both periods. The optimal demands for products in home country and host country are also 1470 and 988 units, respectively, in both periods. Based on the results of Type A and Type B as described above, we find that no matter how the market price changes, the optimal demand is always equal to the production quantity in both demand functions when exchange rate has insignificant changes. However, the production quantity will decrease when the price-function becomes more flexible.

The products of each country are produced internally to supply the demands in both periods when exchange rate has insignificant changes. The production quantity is different as market-price varies. In other words, the best operating decision of a MNC is to make products internally in each country and supply that country's demand without shipping and inventory if there is no significant change in exchange rate. Moreover, a MNC should pay attention to the change in production quantity if market-price varies.

5.2. Exchange Rate Decreases and Market Price Changes

When the currency of a host country is strong (decreasing exchange rate) in the second period, we find that the unit manufacturing cost in host country will decline. At that time, a MNC must face two operating decisions. One is to produce products in host country for both periods and the other is to produce products for home country in the factories at host country in the second period. Based on the above decisions, we find that the first decision derives $62.72 unit cost from the manufacturing cost in home country and the second one derives $45.44 unit cost from the manufacturing and distributing costs. For a MNC, the second decision is more economically efficient than the first. The simulation results are shown in **Table 4**.

As we can see from Type A (Type B) in **Table 4**, the optimal products for home country and host country are 0 and 2954 units (0 and 2465 units), respectively, in second period. In addition, the optimal demands for products in home country and host country are 1478 and 1476 units (1477 and 988 units), respectively, in the second period. The behavior of shipping products from host country to home country occurs in the second period, and the quantity of shipping is 1478 and 1477 units in Type A and Type B, respectively. Hence, the market demand of home country is supplied by the products produced in host country if exchange rate decreases in the second period. In other words, we choose an optimal operating decision that will decrease the quantity of products being produced and shipped according to the variation in market-price in host country for the second period, and supply the market's demand in home country with the products manufactured in host country for the second period. Hence, the quantity of producing and shipping is significantly affected by the price-function forms. Thus, the variation of market-price will affect the operating decisions of a MNC.

5.3. Exchange Rate Increases and Market Price Changes

When the currency of host country is weak (increasing exchange rate) in the second period, we find that the unit manufacturing cost in host country will increase. At that time, a MNC must face two operating decisions. One is that the products demanded by host country in the second period will be produced ahead of time. The other is that the products demanded by host country in the second period will be produced in home country. Based on the above decisions, we find from Type A and Type B in **Table 5** that the first decision derives \$54.32 unit cost from the manufacturing and inventory cost in host country, while the second one derives \$64.3 unit cost from the manufacturing and distributing costs. Thus, for a MNC, the first decision is more economically efficient than the second.

As we can see from Type A (Type B) in **Table 5**, the optimal amount of products produced in host country are 2958 and 0 units (1479 and 0 units) in the first and second period, respectively. In addition, the optimal demands for products in host country are 1470 and 1482 units (988 and 991 units) in the first and second period, respectively. Hence, the products to supply host country in the second period will be produced ahead of time when exchange rate increases. The behavior of inventorying products occurs in the first period and this quantity is 1482 and 991 units in Type A and Type B, respectively. In other words, a MNC in host country should choose the optimal operating decision: decreasing the quantity of products being produced and inventoried according to the market-price change in host county in the first period, and producing products ahead of time for the

Table 4. Results for decreasing exchange rates.

	Market	Type A		Type B	
		Period 1	Period 2	Period 1	Period 2
The produced quantity	Home country	1470	0	1470	0
	Host country	1476	2954	988	2465
The shipped quantity	(From home country to host country)	0	0	0	0
	(From host country to home country)	0	1478	0	1477
The inventoried quantity	Home country	0	0	0	0
	Host country	0	0	0	0
The quantity of demand for product	Home country	1470	1478	1470	1477
	Host country	1476	1476	988	988
The price of product (expressed by currency of home country)	Home country	\$1530	\$1522	\$1530	\$1523
	Host country	\$1544	\$762	\$2024	\$1012
Total profits = (expressed by currency of home country)		\$7,669,216		\$7,323,056	

Notes: Type A: demand function for product is $P_t = 3000 - D_t$ in home country, and $P_t = 1500 - 0.5 \times D_t$ in host country. Type B: demand function for product is $P_t = 3000 - D_t$ in home country, and $P_t = 2000 - D_t$ in host country.

Table 5. Results for increasing exchange rates.

	Market	Type A		Type B	
		Period 1	Period 2	Period 1	Period 2
The produced quantity	Home country	1470	1476	1470	1470
	Host country	2958	0	1479	0
The shipped quantity	(From home country to host country)	0	0	0	0
	(From host country to home country)	0	0	0	0
The inventoried quantity	Home country	0	0	0	0
	Host country	1482	0	991	0
The quantity of demand for product	Home country	1470	1476	1470	1470
	Host country	1470	1482	988	991
The price of product (expressed by currency of home country)	Home country	\$1530	\$1530	\$1530	\$1530
	Host country	\$1544	\$2277	\$2024	\$3027
Total profits (expressed by currency of home country)		\$9,797,307		\$9,222,230	

Notes: Type A: demand function for product is $P_t = 3000 - D_t$ in home country, and $P_t = 1500 - 0.5 \times D_t$ in host country. Type B: demand function for product is $P_t = 3000 - D_t$ in home country, and $P_t = 2000 - D_t$ in host country.

second period. Hence, quantities of production and inventories are significantly affected by price-functions. This implies that the variation of market-price will affect the operating policies of a MNC.

6. Conclusions

In this paper, we extend and modify the previous global supply chain network models to develop an integrated production and distribution model for a MNC operating under the environment with varying exchange rate and market price. Our model incorporates two new characteristics. First, exchange rate and processing time uncertainties are considered in the model. Second, we allow the market price of products to be dependent on the demand levels and stock of existing products. The results derived from the model show that planning a MNC's cost is the main factor for deciding which operating decision should be chosen. This is similar to Mohamed's [4] results, where the profit will decrease when the exchange rate is decreased under the assumption of constant market price for products. We demonstrate that a MNC can utilize machines in the inventory or distribution to avoid possible fluctuation in exchange rate. Through the computational experiment, a MNC may choose to maintain current operating decisions when exchange rate has no significant change. However, if exchange rate decreases and a flexible price-function form is used, the host country should overproduce and distribute the excess part of products to the home country in order to minimize the total cost. In addition, the host country should pay attention to the change in quantity of products being produced and shipped according to the variation of market-price.

If exchange rate increases and price-function forms change, the firms of a MNC in the host country should produce products ahead of time in order to minimize the total cost and adjust the quantity of products being produced and inventoried according to the change in price-function forms. That is, the firms of a MNC in the host country should choose the optimal operating decision to produce products ahead of time for the second period and the host country should be able to adjust the quantity of products being produced and inventoried, according to the market-price's variety. The potential benefit of this operating strategy increases the firm's profit and reduces its downside risk. An interesting and somewhat surprising outcome of this analysis is that the operating strategy is affected by the fluctuation in exchange-rate and market-price's variety because the quantity of products to be produced, shipped, and inventoried will change based on the variation in market-price when exchange rate is considered. In conclusion, we claim that the contribution of this paper is to provide a manufacturing planning strategy for a MNC to make more accurate operating decisions under the environment with exchange-rate and market-price uncertainties.

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