Supply Chain Outsourcing Under Exchange Rate Risk and Competition

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Abstract: This paper studies the impacts of foreign exchange risk and competition intensity on supply chain companies who are involved in offshore outsourcing activities. In particular, we develop a variational inequality model that considers firms' decision-making regarding pricing, offshore outsourcing, transportation, and in-house production under competition and foreign exchange uncertainty. We also use a series of simulation examples to answer questions regarding outsourcing and pricing strategies of supply chain firms with different risk attitudes, and explore numerically their associated profits and incurred risks.

Keywords: Supply Chain Management, Variational Inequality, Outsourcing, Exchange Rate Risk

1. Introduction

Offshore outsourcing refers to the practice of procuring goods or services from outside foreign suppliers rather than producing them in-house. Since outsourcing manufacturing to lower-wage countries generally reduces production costs it has been growing rapidly in the past decade. From 2000 to 2007, 70 percent of U.S. non-oil import growth was driven by imports from developing countries with imports from China alone accounting for 39 percent of the growth [1]. However, although offshore outsourcing can provide significant cost reduction opportunities it also exposes supply chain firms to various risks including: foreign exchange risk, production disruption risk, quality risk, supplier default risk, etc. Among these risks, foreign exchange risk is consistently considered to be on the list of top concerns of supply chain executives. For example, a study conducted by The Economist, which surveyed 500 global company executives with responsibility for risk management, showed that, in 2009, exchange rate uncertainty was ranked as the second most important risk factor next to demand uncertainty due to the economic recession. Moreover, the executives ranked foreign exchange risk as their number one concern for the subsequent twelve months [2]. In particular, in 2010, the high volatility of the euro and possible appreciation of the Chinese yuan have posed significant risks to many companies involved in offshore outsourcing and global trades.

The management of foreign exchange risk of supply chains has drawn considerable attention from researchers. Huchzermeier and Cohen [3] developed dynamic programming models to study the value of operational flexibility of global supply chains under exchange rate risk. Cohen and Huchzermeier [4] further applied a lattice programming model to evaluate the benefit of supply chain flexibility under exchange risk and demand uncertainty. In particular, the authors used real option theory to estimate the values of operational flexibility and managerial flexibility, respectively. Dasu and Li [5] investigated firms' optimal operating strategies under foreign exchange risk. That research studied the network of plants located in different countries, and used linear programming to facilitate the development of the optimal policy. Kazaz, Dada, and Moskowitz [6] examined the impact of foreign exchange risk on the choice of production policies when the allocation decision can be postponed. The authors modeled the production planning problem as a two-stage recourse program where both production hedging and allocation hedging strategies are considered.

Goh, Lim, and Meng [7], in turn, developed a stochastic model of the multi-stage global supply chain network problem where foreign exchange risk, demand and supply risk as well as disruption risk are considered. The authors also provided a new solution methodology to solve the supply chain network problem with profit maximization and risk minimization objectives. These studies, however, focused on the optimal decisions of an individual firm and did not consider the impact of competition on the behaviors of supply chain players. Nagurney, Cruz, and Matsypura [8], in contrast, proposed a modeling framework to analyze the dynamics of global supply chains. The authors assumed competitive firms and modeled three tiers of decision-makers: manufacturers, retailers, and consumers and derived a variational inequality formulation to investigate the global supply chain network, along with qualitative properties. They utilized projected dynamical systems theory to track the evolution of product flows and prices. Subsequently, Nagurney and Matsypura [9] extended the results to include risk and uncertainty and different speeds of adjustment. Cruz, Nagurney, and Wakolbinger [10] later integrated social networks with global supply chains with risk management and explored their co-evolution.

Our paper differs from the above-mentioned studies in that we focus on the impacts of competition and exchange rate uncertainty on the decision-making of firms with different risk attitudes. Our model explicitly considers the firms' optimal pricing, production, and outsourcing decisions, and studies how the firms with different risk attitudes behave when competition intensity and exchange rate uncertainty vary, and how such decisions affect their profits and risks. In particular, we use simulation examples to answer the following: How do competition intensity and foreign exchange uncertainty affect:

- the offshore-outsourcing decisions of risk-neutral firms and those of risk-averse firms?
- the pricing strategies of risk-neutral firms and those of risk-averse firms?
- the profits of risk-neutral firms and those of risk-averse firms?
- the risks of risk-neutral firms and those of risk-averse firms?

In our paper, we utilize the classic mean-variance framework to model the decision makers' behaviors. We assume that each firm maximizes its expected profit and minimizes its risk where the risk is proxied by the variance of the profit. We allow each firm to assign different weights to the variance term in its objective function to reflect different risk-aversion levels of the firms.

The mean-variance (MV) framework, which was originally introduced in the seminal work of the Nobel laureate Harry Markowitz, provides an intuitive and practical approach to analyze the risk-return tradeoff, and has become one of the pillars of modern finance theory. The MV approach has also been increasingly used in supply chain management studies to model the behaviors of decision-makers under risk and uncertainty. Lau [11] first examined the optimal order quantity that maximized an objective function consisting of both the profit and standard deviation of the profit for the newsvendor problem. Hodder [12], Hodder and Jucker [13, 14], and Hodder and Dincer [15] also used an MV method to study facility location problems under risk and uncertainty. Lau and Lau [16] studied a two-echelon supply chain where both the manufacturer and the retailer analyzed the return policy under the MV framework. Chen and Federgruen [17], on the other hand, assumed a quadratic utility function and utilized MV analysis to construct the efficient frontier of a single echelon inventory problem. Gan, Sethi, and Yan [18, 19] first investigated a supply chain coordination problem using the MV approach. The MV approach has also been utilized to study the newsvendor problem where the decision-maker was assumed to be risk-averse [20, 21]. Kim, Cohen, and Netessine [22] studied performance-based contracting in after-sale supply chains where the decision makers behaved under the MV assumption. Choi, et al. [23, 24] also investigated channel coordination problems and return policies of supply chains using the MV approach. Choi and Chow [25] analyzed the quick response program in fashion supply chains via a mean-variance method. Tsay [26] investigated how risk-sensitivity affects the manufacturer-retailer relationship under various scenarios of strategic power, and how these dynamics are influenced by a manufacturer return policy. Wei and Choi [27] studied the wholesale pricing and profit sharing scheme in supply chains using a mean-variance approach. For additional research that analyzed risk-averse supply chain decision-makers using the MV framework as well as other risk measures, see [28, 29, 30, 31, 32, 33]. For a variational inequality approach for the assessment of multitiered supply chain network supply side and demand side risk, in the presence of electronic commerce and general risk functions, see Nagurney et al. [34].

This paper is organized as follows: In Section 2, we develop the supply chain model under foreign exchange risk and competition. We model the decision-makers with different risk attitudes, and construct the equilibrium conditions, along with the variational inequality formulation. In Section 3, we provide the model's qualitative properties, and propose a computational procedure.

In Section 4, we present a series of simulation examples to study the impacts of competition intensity and foreign exchange risk on supply chain firms with different risk attitudes. Our results suggest that executives first evaluate the levels of risks that their investors can tolerate before making supply chain decisions since risk-aversion levels may lead to completely different pricing, production, and outsourcing decisions, and result in different levels of profit and risk. For example, our simulation results indicate that in general risk-averse firms have lower profitability and lower risk than risk-neutral firms. When the competition intensity increases, the risks of both risk-neutral and risk-averse firms will increase which is consistent with the recent empirical findings in [35]; the profits of risk-averse firms will always decrease; and the profits of risk-neutral firms will decrease if exchange rate uncertainty is relatively low and will increase if exchange rate uncertainty is high. On the other hand, when exchange rate volatility increases, the average profits of risk-neutral firms will first increase and then become stable, while the profits of risk-averse firms will always decrease. Moreover, as the exchange rate variability becomes higher risk-averse firms will reduce their outsourcing activities while risk-neutral firms may increase their outsourcing activities. These results explain the phenomenon regarding how exchange rate uncertainty affects imports of developed countries [36, 37, 38, 39]. Section 5 highlights the managerial insights and concludes the paper.

2. The Supply Chain Model Under Foreign Exchange Risk and Competition

The model that we develop in this paper is based on variational inequality theory. Recall that the finite-dimensional variational inequality problem, VI$(F, \mathcal{K})$, is to determine a vector $X^* \in \mathcal{K} \subset R^n$, such that

$$\langle F(X^*)^T, X - X^* \rangle \geq 0, \quad \forall X \in \mathcal{K}, \tag{1}$$

where F is a given continuous function from $\mathcal{K}$ to R^n, $\mathcal{K}$ is a given closed convex set, and $< \cdot, \cdot >$ denotes the inner product in n-dimensional Euclidian space.

The variational inequality formulation allows for a unified treatment of equilibrium and optimization problems, and is closely related to many mathematical problems, such as: constrained and unconstrained optimization problems, fixed point problems, and complementarity problems. For an introduction to finite-dimensional variational inequality theory, we refer the reader to the book by Nagurney [40].

Variational inequality models provide a great level of flexibility which allows one to model complex network equilibrium problems in supply chain, transportation, and finance (see, for example, [41, 42, 43]). Moreover, when system-wide data is available the model proposed in this paper can be directly applied to perform large-scale empirical research. For instance, Liu and Nagurney [44] conducted a large-scale empirical study for the New England fuel and electric power supply chain network based on a variational inequality model extended from the work in Matasypura et al. [45] and Nagurney et al. [46].

We now develop the supply chain model that focuses on the impact of exchange rate risk and competition. We consider M firms that sell partially substitutable products in the market of a developed country (e.g. the U.S. market), and have choices of manufacturing the products in-house and/or outsourcing the manufacturing to suppliers in up to J countries. Producing the products in-house will require K raw materials and vendor-supplied parts. We assume that each firm can decide the product price, the outsourced quantities, and the in-house production quantity. The notation of the model is defined in Table 1. An equilibrium solution is denoted by "*". All vectors are assumed to be column vectors, except where noted otherwise.

Multi-Criteria Decision-Making Behavior of the Supply Chain Firms and Their Optimality Conditions

The firms produce partially substitutable products and compete in the market of a developed country (e.g. the U.S. market). Each firm decides the product price, the in-house production quantity, the material procurements, and the offshore outsourced quantities. We assume that the firms consider both profits and risks in their operations, where firm m's total cost at country j (in country j's currency), S_{mj}, can be expressed as:

$$S_{mj} = \sum_{k=1}^{K} c_{kj} u_{mkj} + h_{mj} v_{mj} + \sum_{k=1}^{K} t^1_{kj} u_{mkj} + t^2_j v_{mj}. \tag{2}$$

where the first, second, third, and fourth terms in (2) represent the material procurement cost, the purchasing cost of finished products, the transportation cost of materials and vendor-supplied parts, and the transportation cost of finished products, respectively. We group the S_{mj}s over all countries into the vector S_m.

The expected total profit (in U.S. dollars) of firm m can, hence, be expressed as follows:

$$Profit_m = p_m d_m(P) - \sum_{k=1}^{K} \hat{c}_k \hat{u}_{mk} - \hat{h}_m \hat{q}_m - \sum_{j=1}^{J} \theta_j S_{mj}, \tag{3}$$

where the first term in (3) represents the total revenue from the market; the second and third terms represent the domestic material procurement cost and the in-house production cost, respectively; the last term represents the expected cost incurred in other countries.

In addition, the firms consider exchange rate risk induced by offshore outsourcing activities using a mean-variance framework. In particular, if we calculate the variance of firm m's profit, since the revenue and cost in U.S. dollars are not subject to exchange rate uncertainty the variance of the profit is equal to the variance of the total cost incurred in other countries, which can be expressed as: $r_m(U_m, V_m) = S_m^T COV_\theta S_m$, where COV_θ denotes the covariance matrix of exchange rates.

The optimization problem faced by firm m is:

$$MAX_{p_m, U_m, \hat{U}_m, V_m, \hat{q}_m} \; p_m d_m(P) - \sum_{k=1}^{K} \hat{c}_k \hat{u}_{mk} - \hat{h}_m \hat{q}_m - \sum_{j=1}^{J} \theta_j S_{mj} - \beta_m S_m^T COV_\theta S_m, \tag{4}$$

subject to:

$$\sum_{j=1}^{J} u_{mkj} + \hat{u}_{mk} = w_{mk} \hat{q}_m, \quad k = 1, \ldots, K; \tag{5}$$

$$\hat{q}_m \leq CAP_m; \tag{6}$$

$$d_m(P) = \hat{q}_m + \sum_{j=1}^{J} v_{mj}; \tag{7}$$

$$d_m(P) = a - (1+\gamma) p_m + \frac{\gamma}{(M-1)} \sum_{n \neq m} p_n, \tag{8}$$

$$p_m \geq 0, u_{mkj} \geq 0, \; \hat{u}_{mk} \geq 0, \; v_{mj} \geq 0, \; \hat{q}_m \geq 0, \quad j = 1, \ldots, J; \; k = 1, \ldots, K. \tag{9}$$

Note that β_m in the objective function reflects the risk-aversion level of the firm. If β_m is equal to zero firm m is risk-neutral and is not concerned about risk. Constraint (5) models the conversion from raw materials to finished goods at the firm's in-house production facility. Constraint (6) is the production capacity constraint. Constraint (7) states that the demand is satisfied by outsourced productions and in-house productions. Constraint (8) models the demand for firm m's product under competition where γ represents the substitutability of the products which indicates the competition intensity between the firms. The same form of demand functions has been widely used in supply chain and marketing studies to model the demands for partially substitutable products (see, for example, [47, 48]).

Note that, the higher the γ, the higher the competition intensity, and that if γ is zero, the firms' products are completely differentiated and there is no competition. We can generalize the model by specifying a parameter, $\gamma_{m_1 m_2}$, for any pair of firms m_1 and m_2. However, since the focus of this paper is to study the general impacts of the overall competition level on supply chains under exchange rate risk, we use a single γ to represent the general competition intensity of the industry to keep the model simpler and more focused. Moreover, as pointed out by Li and Zhang [48], the total demand, $Ma - \sum_{m=1}^{M} p_m$, does not depend on γ directly, which keeps the market potential unchanged for different values of γ. Note that we can simplify the constraint set by combining constraints (7) and (8), which yields:

$$a - (1+\gamma)p_m + \frac{\gamma}{(M-1)} \sum_{n \neq m} p_n = \hat{q}_m + \sum_{j=1}^{J} v_{mj}; \tag{10}$$

We assume that the firms compete in a noncooperative manner in the sense of Nash [49, 50]. The optimality conditions for all firms simultaneously, under the above assumptions, can be expressed using the variational inequality formulation in Theorem 1.

Theorem 1: Variational Inequality Formulation of the Supply Chain Equilibrium Under Exchange Rate Risk and Competition

The equilibrium conditions governing the supply chain under exchange rate risk and competition coincide with the solution of the variational inequality given by:
determine $(P^*, U^*, \hat{U}^*, V^*, Q^*) \in \mathcal{K}^1$ *satisfying*

$$\sum_{m=1}^{M} \left[2(1+\gamma)p_m^* - a - \frac{\gamma}{(M-1)} \sum_{n \neq m} p_n^* \right] \times [p_m - p_m^*]$$

$$+ \sum_{m=1}^{M} \sum_{k=1}^{K} \sum_{j=1}^{J} \left[\theta_j c_{kj} + \theta_j t_{kj}^1 + \beta_m \frac{\partial r_m(U^*, V^*)}{\partial u_{mkj}} \right] \times [u_{mkj} - u_{mkj}^*]$$

$$+ \sum_{m=1}^{M} \sum_{k=1}^{K} \hat{c}_k \times [\hat{u}_{mk} - \hat{u}_{mk}^*]$$

$$+ \sum_{m=1}^{M} \sum_{j=1}^{J} \left[\theta_j h_{mj} + \theta_j t_j^2 + \beta_m \frac{\partial r_m(U^*, V^*)}{\partial v_{mj}} \right] \times [v_{mj} - v_{mj}^*]$$

$$+ \sum_{m=1}^{M} \hat{h}_m \times [\hat{q}_m - \hat{q}_m^*] \geq 0, \quad \forall (P, U, \hat{U}, V, Q) \in \mathcal{K}^1, \tag{11}$$

where $\mathcal{K}^1 \equiv \{(P, U, \hat{U}, V, Q) | (P, U, \hat{U}, V, Q) \in R_+^{M+MKJ+MK+MJ+M}$ *and* (5), (6), *and* (10) *hold*$\}$.

Proof: The formulation is developed using the standard variational inequality theory (see [40, 51, 52, 53]). Note that we have substituted the demand function (8) into the objective function.

Remark

Note that, in the above model, we allowed each firm to consider exchange rate risk in decision-making depending on its degree of risk aversion denoted by β_m; $m = 1, \ldots, M$. We will use numerical examples to compare how risk-averse firms and risk-neutral firms make supply chain decisions under competition and foreign exchange risk.

The variational inequality problem (11) can be rewritten in standard form as follows: determine $X^* \in \mathcal{K}$ satisfying

$$\left\langle F(X^*)^T, X - X^* \right\rangle \geq 0, \quad \forall X \in \mathcal{K}, \tag{12}$$

where $X \equiv (P, U, \hat{U}, V, Q)^T$, $\mathcal{K} \equiv \mathcal{K}^1$, and

$$F(X) \equiv (F^P_m, F^U_{mkj}, F^{\hat{U}}_{mk}, F^V_{mj}, F^Q_m), \tag{13}$$

with indices $m = 1, \ldots, M$; $k = 1, \ldots, K$; and $j = 1, \ldots, J$, and the functional terms preceding the multiplication signs in (11), respectively. Here $< \cdot, \cdot >$ denotes the inner product in Ω-dimensional Euclidian space where $\Omega = M + MKJ + MK + MJ + M$.

3. Qualitative Properties and the Computational Method

In this Section, we derive qualitative properties of the solution and the function that enters the variational inequality problem of concern. In addition, for the sake of convenience for the reader, we also provide the computational method.

3.1 Qualitative Properties

We now present some qualitative properties of the model. In particular, we provide conditions for existence of a solution to variational inequality (11). We also show that, in our model, the $F(X)$ given by (13) that enters the variational inequality (12) is monotone, and the Jacobian of $F(X)$ is positive semidefinite.

Theorem 2: Existence

There exists a solution to variational inequality (11).

Proof: We first prove that the feasible set is compact. Since all variables are nonnegative, the lower bounds of the variables are zero. The in-house production quantities, $\hat{q}_m$s, are directly bounded by the production capacities, which means that the domestic and global procurements of materials, $\hat{u}_m$s and u_{mj}s, are also bounded due to constraint (5).

We now show that the prices, p_ms, are also bounded by the set of the constraints. First, we sum up constraint (10) over all firms, and we obtain that the total demand of all firms, $Ma - \sum_{m=1}^{M} p_m$, is equal to the sum of all firms' in-house production quantities and outsourcing quantities, $\sum_{m=1}^{M} \hat{q}_m + \sum_{j=1}^{J} v_{mj}$. Since the q_ms and v_{mj}s are nonnegative, the total demand, $Ma - \sum_{m=1}^{M} p_m$, must be nonnegative, which implies that all p_ms are bounded by Ma. On the other hand, since all p_ms are nonnegative, $Ma - \sum_{m=1}^{M} p_m$ is less than or equal to Ma, which implies that all $\hat{q}_m$s and v_{mj}s are bounded by Ma. Therefore, the feasible set is compact.

Since the feasible set $\mathcal{K}^1$ is compact and nonempty, and the functions that comprise $F(X)$ are continuous, according to the standard theory, variational inequality (11) admits a solution (see [40, 54]). Q.E.D.

Theorem 3: Monotonicity

The vector $F(X)$ that enters the variational inequality (12) as expressed in (11) is monotone, that is,

$$\left\langle (F(X') - F(X''))^T, X' - X'' \right\rangle \geq 0, \quad \forall X', X'' \in \mathcal{K}, X' \neq X''. \tag{14}$$

Proof: See the Appendix.

3.2 The Computational Method

We now consider the computation of solutions to variational inequality (11). In particular, we recall the modified projection method (cf. [40, 55]). The method converges to a solution of the model provided that $F(X)$ is monotone and Lipschitz continuous, and a solution exists, which is the case for our model. Next, we present the modified projection method.

The Computational Procedure

Step 0: Initialization

Start with an $X^0 \in \mathcal{K}$ and select ω, such that $0 < \omega \leq \frac{1}{L}$, where L is the Lipschitz constant for function $F(X)$. Let $\mathcal{T} = 1$.

Step 1: Construction and Computation

Compute $\bar{X}^{\mathcal{T}-1}$ by solving the variational inequality subproblem:

$$\left\langle (\bar{X}^{\mathcal{T}-1} + (\omega F(X^{\mathcal{T}-1}) - X^{\mathcal{T}-1}))^T, X' - \bar{X}^{\mathcal{T}-1} \right\rangle \geq 0, \quad \forall X' \in \mathcal{K}. \tag{15}$$

Step 2: Adaptation

Compute $X^{\mathcal{T}}$ by solving the variational inequality subproblem:

$$\left\langle (X^{\mathcal{T}} + (\omega F(\bar{X}^{\mathcal{T}-1}) - X^{\mathcal{T}-1}))^T, X' - X^{\mathcal{T}} \right\rangle \geq 0, \quad \forall X' \in \mathcal{K}. \tag{16}$$

Step 3: Convergence Verification

If $||X^{\mathcal{T}} - X^{\mathcal{T}-1}||_\infty \leq \epsilon$ with $\epsilon > 0$, a pre-specified tolerance, then stop; otherwise, set $\mathcal{T} := \mathcal{T} + 1$ and go to Step 1. (We set the parameter $\omega = 0.1$ and the tolerance $\epsilon = 0.00001$ for all computations of the numerical examples in Section 4.)

Note that the subproblems in Steps 1 and 2 above are separable quadratic programming problems and, hence, there are numerous algorithms that can be used to solve these embedded subproblems.

4. Simulation Examples

In this section we study the impacts of foreign exchange uncertainty and competition intensity on the decision-making of the supply chain firms with different risk attitudes. In particular, we utilize a series of simulation examples to answer the questions raised in the Introduction.

We answer questions 1 and 2 by comparing the pricing and outsourcing strategies of risk-neutral and risk-averse firms under exchange rate uncertainty and competition in the examples. We then answer questions 3 and 4 by discussing the consequences of the firms' strategies in the examples.

In order to present detailed results we keep the supply chain network in the example simple and focused. In particular, the supply chain consists of two supply chain firms (M=2), one offshore-outsourcing country (J=1), and one raw material (K=1). Since this paper focuses on the impacts of competition intensity and foreign exchange uncertainty on the decision-making of supply chain players with different risk attitudes, in the examples we assume that one firm is risk-neutral ($\beta_1 = 0$) and the other firm is risk-averse ($\beta_2 = 0.25$). We also control the other firm-specific factors where we assume that all firms have the same cost and production parameters. The parameters are specified in Table 2.

We set the values of various cost parameters based on the recent PRTM global supply chain trends study which surveyed three hundred international firms, and reported relative savings in total costs, labor costs, material costs, and other costs due to offshore-outsourcing [56]. The cost parameters are also consistent with the cost reduction information of a typical labor-intensive industry studied in [57]. Our cost and demand function parameters lead to 12% to 35% price-cost markups across different parameter combinations in the simulation results, which is consistent with the average markups of the manufacturing industries in various countries [58,59,60]. Based on the exchange rate volatilities in several normal and crisis periods [61], we assume that the exchange rate variance, σ^2, varies from 0 to 0.07 where σ^2 =0 and 0.005 represents low exchange variability; σ^2 =0.01 and 0.03 represents medium exchange rate uncertainty; and σ^2 =0.05 and 0.07 represents high foreign exchange risk.

For each combination of the exchange rate variability σ^2 and competition intensity γ, the firms' strategic outsourcing and pricing decisions are first determined based on the expected exchange rate as well as the exchange rate uncertainty. We then estimate the profitabilities and risks of these decisions by randomly generate a sample 1000 exchange rate values from the normal distribution where the mean is equal to the expected exchange rate and the variance is equal to σ^2. The profitability and risk measures are calculated based on the generated sample and the firms' decisions. We repeat this simulation process for all combinations of exchange rate uncertainty and competition intensity. The results are shown in Tables 3 to 7.

Before discussing the detailed results we first briefly summarize how Firm 1 and Firm 2 behave under exchange rate uncertainty in the examples. Since Firm 1 is risk-neutral it only maximizes its profit and is not concerned about the risk. Firm 2, which is risk-averse, has two strategies to mitigate the impact of increasing exchange rate volatility:

- Strategy 1: To reduce outsourcing quantity and to increase the price of the product where the incremental price is used to compensate the foreign exchange risk;
- Strategy 2: To use more in-house production and to reduce the outsourcing quantity to lower the foreign exchange risk.

We find that Firm 2 mainly uses the first strategy when exchange rate uncertainty is low and mainly relies on the second strategy when the foreign exchange uncertainty is high. Note that Firm 2 chooses the strategies by optimally balancing between profit and risk. The decision shift between the two strategies can be observed in the trends of Firm 2's outsourcing activities, pricing plans, profitability, and risks.

Table 3 shows the outsourcing decisions of the risk-neutral and risk-averse firms under exchange rate risk and competition, and answer the first question posted in the Introduction.

We can see that the risk-neutral firm's in-house production is always 0 since it always chooses the offshore productions to lower costs. The risk-averse firm, on the other hand, only uses offshore productions when the uncertainty is relatively low, and starts using Strategy 2 to switch to in-house productions when the exchange rate uncertainty becomes higher. For example, when the competition intensity is 0.40, the in-house production of the risk-averse firm remains zero till the exchange rate uncertainty is 0.010 and then start to increase. It is also interesting to observe the trends of offshore-outsourcing activities of the two firms when the exchange rate risk increases. The risk-averse firm always reduces its offshore-outsourcing activities as the exchange rate variability increases since it needs to reduce the risk exposure when uncertainty becomes higher. The outsourcing activities of the risk-neutral firm, on the other hand, keep unchanged when the competition intensity is zero. If there is competition Firm 1's outsourcing activity level first increases with the exchange rate variability when the exchange rate variability is low to medium, and then become stable when the exchange rate variability is high. For example, when the competition intensity is 0.80, the outsourcing activities of the risk-neutral firm increase from 4.821 to 5.347 as the exchange rate variability increases from 0.000 to 0.030, and remain 5.347 when the variability becomes higher. The reason is that when the exchange uncertainty is low or medium, the risk-averse firm will reduce its outsourcing level which will also reduce it's total supply to the market. This supply reduction from the risk-averse firm provides opportunities for the risk-neutral firm to sell more products, and increase its markets share. Therefore, in order to provide more products to the market, the risk-neutral firm increases its offshore-outsourcing activities. When the exchange rate variability is high, the risk-averse uses the second strategy where it keeps the total market supply unchanged, and starts to switch to in-house productions. Hence, the opportunity for the risk-neutral firm disappears and its outsourcing activity becomes stable.

In summary when the exchange rate variability increases, the outsourcing activities of the risk-averse firm always decrease while the outsourcing activities of the risk-neutral firm are always nondecreasing, and will increase when the exchange risk is low to medium.

These simulation results provide explanations to phenomenons of import activities of developed countries under exchange risk. Since risk-aversion is the prevalent decision-making behavior in business and economics we expect that in most cases increasing exchange rate variability should reduce overall offshore-outsourcing activities. For example, various empirical studies found that rising exchange rate variability significantly reduces imports in U.S., U.K., and European Union (see, for example, [36,37,38]). However, our results also indicate that in certain circumstances or periods if there are more decision-makers who are relatively risk insensitive, the offshore-outsourcing activities may not be greatly affected by the increase of exchange rate uncertainty. Indeed, some empirical studies reported weak impacts of exchange rate volatility on imports to developed countries [39].

Table 4 presents the pricing strategies, the average costs of the product, and the price-cost markups, and answers the second question raised in the Introduction. First, the markups of the two firms across different scenarios range from 12% to 35%, which is consistent with the reported average markups of the manufacturing industries in different countries (see, for example, [58,59,60]).

From Table 4, we observe that at each exchange rate variability level, for both risk-neutral and risk-averse firms the market prices and the markups consistently decrease as the competition intensity increases. For example, if the exchange rate variability is 0.010 when the competition intensity increases from 0.00 to 2.00 the markup of the risk-neutral declines from 30.00% to 17.20%, and the markup of the risk-averse firm decreases from 34.90% to 21.56%. This indicates that higher competition intensity leads to lower profit margins for both firms at all uncertainty levels.

The results also show that as the exchange rate uncertainty becomes higher the prices in general do not respond significantly. We can see that only when the exchange rate variability is from low to medium the product prices slightly increase with the exchange uncertainty. Such marginal increase is due to the fact the risk-averse firm uses the first strategy to cope with the risk.

Table 5 and 6 compare the average profitabilities of the two firms in different scenarios, and answer the third question posed in the Introduction. In particular, Table 5 shows the average profits as well as the 95% confidence interval for the *average* profit estimations. For example, if the competition intensity is 0.80 and the exchange rate variability is 0.010, the point estimate of the average profit of the risk-neutral firm is 14.582, and the probability that the true average profit is between the lower limit, 14.196, and the upper limit, 14.969, is 95%.

We can see that when the exchange rate uncertainty is zero, the two firms's profits are equal and certain since they make identical decisions. However, when the exchange rate variability is non-zero, the risk-neutral firm always has a significantly higher *average* profit than the risk-averse firm except when the competition is 0.00 and the exchange rate variability is less than or equal to 0.030.

The rightmost column of Table 5 shows the sensitivity (regression slope) of the average profits to the competition intensity. It is interesting to see that all the slopes in Panel 2 of Table 5 are significantly negative which imply that the competition intensity always has a significantly negative impact on the risk-averse firm's average profit at all uncertainty levels.

On the other hand, in Panel 1 of Table 5 the slope is significantly negative (-1.83 and -0.88) when the exchange rate variability is less than or equal to 0.005, is insignificant when the variability is equal to 0.010, and is significantly positive when the variability is greater than or equal to 0.030 (1.08, 1.53, and 1.43). The signs and the significance of the slopes imply that the average profit of the risk-neutral firm is significantly negatively influenced by the competition intensity when the exchange rate variability is low while it is significantly positively affected by the competition when the exchange uncertainty is high.

Such results indicate that the risk-averse firm should always benefit from more product differentiation while the risk-neutral firm may benefit from more intense competition when the exchange rate uncertainty is high. The intuition is that if the exchange rate variability is large, when the products are less differentiated the risk-neutral firm may be able to take more advantage of the risk-averse firm's declining total production to get more market share and more profits.

From Table 5, we can also observe trends of the average profits of the two firms when the exchange uncertainty increases. We can easily see that the risk-averse firm's profit always decreases as the exchange uncertainty rises. We can also observe that if the competition intensity is non-zero the profit of the risk-neutral firm will increase with the exchange rate variability when the uncertainty is less than 0.050, and will not change significantly when the uncertainty is greater than or equal to 0.050.

Franke [62] used a real option approach to argue that higher exchange rate volatility may present profit opportunities for risk-neutral exporters. Our results in Table 5 show that risk-insensitive importing firms may also benefit from higher exchange rate uncertainty due to the competition with more risk-averse firms.

Table 6 exhibits the probability that the risk-neutral firm has higher profit than the risk-averse firm as well as the 95% confidence interval for the probability estimations. For example, when the competition intensity is 0.40 and the exchange variability is 0.070, the point estimate of the probability that the risk-neutral firm has higher profitability is 70.40%, and with 95% chance, the true probability is between 67.57% and 73.23%.

Similar to Table 5, the results in Table 6 show that the risk-neutral firm has significantly higher probability to obtain more profit than the risk-averse firm across all combinations of exchange rate variability and competition intensity. The point estimate of the probability ranges from 66% to 93%.

Table 7 presents various risk measures for the two firms, and provides the answer to the fourth question raised in the Introduction. In Table 7 the coefficient of variation (CV) is defined as the ratio of the standard deviation over the mean. We also report the 5^{th} and the 1^{st} percentiles of the profits of the two firms for each combination of the parameters where negative numbers represent losses. Note that the 5^{th} and the 1^{st} percentiles of the profits can represent the downside risk and the worse scenario for the two firms, respectively. All three measures indicate that the risk-averse firm consistently has lower risk than the risk-neutral firm across all scenarios. For example, when the competition intensity is 0.80 and the exchange rate variability is 0.030 the coefficient of variation (CV) of the risk-neutral firm is 0.785 which is higher than that of the risk-averse firm (0.523); the 5^{th} and the 1^{st} percentiles of the profit of the risk-neutral firm are equal to -4.514 and -11.250, respectively, and are both lower than the 5^{th} and 1^{st} percentiles of the profit of the risk-averse firm (+1.211 and -1.475).

The rightmost column of Table 7 shows the sensitivity (regression slope) of various risk measures to the competition intensity. We can see that for both firms, the slopes for CV are significantly positive and the slopes for the 5^{th} and 1^{st} percentiles are significantly negative. The signs and the significance of the slopes suggest that the exchange risks significantly increase with the competition intensity. The reason is that intense competition can lower the profit margins (see the markups Table 4) and/or force the firms to increase their offshore-outsourcing activities (see the outsourcing activities in Table 3) which result in higher exchange risk exposure. These results provide explanations to the recent empirical findings in Francis et al. [35] where the study found that the industry competition intensity significantly increases American firms' exchange risks related to developing countries.

In addition, we observe that, for the risk-neutral firm, all risk measures become worse as the exchange rate variability increases while for the risk-averse firm when the exchange rate uncertainty goes up the three risk measures first get worse till the variance is equal to 0.030, and then become better or mixed when the variability gets higher. The reason is that after the exchange rate uncertainty is greater than 0.030 the risk-averse firm starts to use the second strategy to switch back to in-house production (see Panel 2 of Table 3) which reduces its exposure to the exchange uncertainty.

5. Managerial Insights and Conclusions

This paper studied the impact of foreign exchange rate uncertainty and competition intensity on supply chain firms who are involved in offshore outsourcing activities. In particular, we developed a variational inequality model that considers firms' decision-making regarding pricing, material procurement, offshore-outsourcing, transportation, and in-house production under competition and foreign exchange rate uncertainty. Our model also allowed the firms to have different attitudes toward risk. We provided important qualitative properties for the model and presented an algorithm that was guaranteed to converge. We then utilized a series of simulation examples to answer four interesting questions regarding supply chain firms' pricing and outsourcing decisions, and the associated profits and risks.

In summary, our simulation results indicate that in general the risk-averse firm has lower profitability and lower risk than the risk-neutral firm. When the competition intensity increases, the exchange rate risks of both risk-neutral and risk-averse firms will increase which is consistent with the recent empirical findings in [35]; the profit of the risk-averse firm will always decrease; and the profits of the risk-neutral firm will decrease if exchange rate uncertainty is relatively low and will increase if exchange rate uncertainty is high. On the other hand, when exchange rate volatility increases, the average profit of the risk-neutral firm will first increase and then become stable while the profits of risk-averse firms will always decrease. As exchange rate variability increases, the risk of the risk-neutral firm will always increase, and the risk of the risk-averse firm will increase when the firm increase prices to compensate the risks, and will decrease if the firm switches from outsourcing to in-house production. Moreover, as the exchange rate variability becomes higher the risk-averse firm will reduce its outsourcing activities while the risk-neutral firm may increase its outsourcing activities. These results explain the phenomenon regarding how exchange rate uncertainty affects imports of developed countries [36,37,38,39].

Our results reveal important managerial insights for supply chain decision-makers involved in offshore outsourcing. The supply chain managers should first evaluate the risk tolerance level of the firm. If the firm is more concerned about risk they should try to differentiate their products from their competitors since intense competition will both reduce their profitability and increase their risk. In addition, they should also maintain certain in-house production capacity for operational hedging purposes when the exchange rate uncertainty is high. For the firms that are not sensitive to risk high exchange rate uncertainty may provide opportunity for them to get an edge on the competition with more risk-averse firms. For example, when the exchange rate variability is relatively high they should expand their outsourcing operations in order to gain more market share from more risk-sensitive competitors which may help them increase average profits. However, the firms that exploit these opportunities should understand that such strategies can also cause significant risk and loss.

This research can be extended in several directions. First, the model can be directly applied for large-scale empirical studies when system-wide data is available (see, for example, [44]). Secondly, the model can further incorporate supply disruption risk and demand uncertainty to study how these risks interact with exchange rate risk and affect decision-making in supply chains. Additionally, we can expand our model to consider and compare the decision-making of the supply chain firms based on different risk measures (see, for example, [63]).

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Table 1: Notation for the Supply Chain Model

Notation	**Definition**
u_{mkj}	The quantity of material/part k purchased by firm m from supply market in country j. We group all u_{mkj}s of firm m into the KJ-dimensional vector U_m, and group all u_{mkj}s into the MKJ-dimensional vector U.
$\hat{u}_{mk}$	The quantity of material/part k purchased by firm m from supply market in the U.S. We group all $\hat{u}_{mk}$s of firm m into the K-dimensional vector $\hat{U}_m$, and group all $\hat{u}_{mk}$s into the MK-dimensional vector $\hat{U}$.
v_{mj}	The quantity of finished products purchased by firm m from country j. We group all v_{mj}s of firm m into the J-dimensional vector V_m, group all v_{mj}s into the MJ-dimensional vector V.
$\hat{q}_m$	The quantity of the product produced by firm m in-house. We group all $\hat{q}_m$s into the M-dimensional vector Q.
p_m	The price of the product of firm m. We group all $\hat{q}_m$s into the M-dimensional vector P
$d_m(P)$	The demand function of the product of firm m
c_{kj}	The unit purchasing cost of material/part k in country j
$\hat{c}_k$	The unit purchasing cost of material/part k in the U.S.
h_{mj}	The unit purchasing cost of the product from suppliers in country j
$\hat{h}_m$	The unit production cost of the product at firm m's manufacturing plant
t^1_{kj}	The unit transportation cost of the material/part k from country j
t^2_j	The unit transportation cost of the product from country j
CAP_m	The capacity of the production facility of firm m
w_{mk}	The quantity of material/part k needed to produce one unit of the product at firm m's manufacturing plant
θ_j	The expected exchange rate between the U.S. dollar and the currency of country j
COV_θ	The covariance matrix of the exchange rates between the U.S. dollar and the other countries' currencies
β_m	Firm m's degree of risk aversion
γ	The competition intensity level

Table 2: Values of Simulation Parameters

Notation	**Value**
Demand fuction	$d_m(P) = 20 - (1+\gamma)p_m + \gamma \sum_{n=1,n\neq m}^{2} p_n$, $\forall m$.
Material Cost in Country j	$c_{kj} = 8$, $\forall k, j$
Local Material Cost	$\hat{c}_k = 10$, $\forall k$
Purchasing Cost in Country j (including Country j's material cost, labor cost, and other costs)	$h_{mj} = 11.5$, $\forall m, j$
In-House Production Cost (including labor and other costs)	$\hat{h}_m = 5$, $\forall m$
Product Transportation Cost	$t^1_{kj} = 1$, $\forall k, j$
Material Transportation Cost	$t^2_j = 2$, $\forall j$
Material-Product Conversion Ratio	$w_{mk} = 1$, $\forall k, j$
Capacity	$CAP_m = 50$, $\forall m$
Expected Exchange Rate	$\theta_i = 1$, $\forall j$
Risk-Aversion Parameter	$\beta_1 = 0$, $\beta_2 = 0.25$
Competition Intensity	γ varies from 0 to 2 with the interval 0.4

Table 3: Outsourcing and In-House Production Decisions

Panel 1: Risk-Neutral Firm		Competition Intensity					
Exchange Rate Variance		0.00	0.40	0.80	1.20	1.60	2.00
0.000	Outsourced	3.750	4.375	4.821	5.156	5.417	5.625
	In-House	0.000	0.000	0.000	0.000	0.000	0.000
	Total	3.750	4.375	4.821	5.156	5.417	5.625
0.005	Outsourced	3.750	4.452	4.991	5.429	5.798	6.117
	In-House	0.000	0.000	0.000	0.000	0.000	0.000
	Total	3.750	4.452	4.991	5.429	5.798	6.117
0.010	Outsourced	3.750	4.513	5.119	5.624	6.059	6.442
	In-House	0.000	0.000	0.000	0.000	0.000	0.000
	Total	3.750	4.513	5.119	5.624	6.059	6.442
0.030	Outsourced	3.750	4.630	5.347	5.967	6.521	7.031
	In-House	0.000	0.000	0.000	0.000	0.000	0.000
	Total	3.750	4.630	5.347	5.967	6.521	7.031
0.050	Outsourced	3.750	4.630	5.347	5.967	6.521	7.031
	In-House	0.000	0.000	0.000	0.000	0.000	0.000
	Total	3.750	4.630	5.347	5.967	6.521	7.031
0.070	Outsourced	3.750	4.630	5.347	5.967	6.521	7.031
	In-House	0.000	0.000	0.000	0.000	0.000	0.000
	Total	3.750	4.630	5.347	5.967	6.521	7.031
Panel 2: Risk-Averse Firm		Competition Intensity					
Exchange Rate Variance		0.00	0.40	0.80	1.20	1.60	2.00
0.000	Outsourced	3.750	4.375	4.821	5.156	5.417	5.625
	In-House	0.000	0.000	0.000	0.000	0.000	0.000
	Total	3.750	4.375	4.821	5.156	5.417	5.625
0.005	Outsourced	3.416	3.859	4.133	4.306	4.413	4.477
	In-House	0.000	0.000	0.000	0.000	0.000	0.000
	Total	3.416	3.859	4.133	4.306	4.413	4.477
0.010	Outsourced	3.137	3.451	3.616	3.696	3.724	3.719
	In-House	0.000	0.000	0.000	0.000	0.000	0.000
	Total	3.137	3.451	3.616	3.696	3.724	3.719
0.030	Outsourced	2.133	2.133	2.133	2.133	2.133	2.133
	In-House	0.367	0.528	0.555	0.494	0.373	0.210
	Total	2.500	2.662	2.688	2.627	2.507	2.344
0.050	Outsourced	1.280	1.280	1.280	1.280	1.280	1.280
	In-House	1.220	1.381	1.408	1.347	1.227	1.064
	Total	2.500	2.662	2.688	2.627	2.507	2.344
0.070	Outsourced	0.914	0.914	0.914	0.914	0.914	0.914
	In-House	1.586	1.747	1.774	1.713	1.592	1.429
	Total	2.500	2.662	2.688	2.627	2.507	2.344

Table 4: Pricing Strategy, Average Costs, and Markups

Panel 1: Risk-Neutral Firm		Competition Intensity					
Exchange Rate Variance		0.00	0.40	0.80	1.20	1.60	2.00
	Price	16.250	15.625	15.179	14.844	14.583	14.375
0.000	Avg Cost	12.500	12.500	12.500	12.500	12.500	12.500
	Markup	30.00%	25.00%	21.43%	18.75%	16.67%	15.00%
	Price	16.250	15.680	15.273	14.968	14.730	14.539
0.005	Avg Cost	12.451	12.508	12.560	12.453	12.477	12.513
	Markup	30.51%	25.36%	21.60%	20.19%	18.05%	16.19%
	Price	16.250	15.723	15.344	15.057	14.831	14.647
0.010	Avg Cost	12.500	12.531	12.495	12.473	12.486	12.498
	Markup	30.00%	25.48%	22.80%	20.72%	18.77%	17.20%
	Price	16.250	15.807	15.471	15.212	15.008	14.844
0.030	Avg Cost	12.547	12.447	12.660	12.590	12.495	12.526
	Markup	29.52%	26.99%	22.20%	20.83%	20.12%	18.50%
	Price	16.250	15.807	15.471	15.212	15.008	14.844
0.050	Avg Cost	12.508	12.486	12.386	12.465	12.572	12.281
	Markup	29.92%	26.60%	24.91%	22.04%	19.38%	20.87%
	Price	16.250	15.807	15.471	15.212	15.008	14.844
0.070	Avg Cost	12.555	12.772	12.554	12.622	12.509	12.491
	Markup	29.43%	23.76%	23.23%	20.52%	19.97%	18.84%
Panel 2: Risk-Averse Firm		Competition Intensity					
Exchange Rate Variance		0.00	0.40	0.80	1.20	1.60	2.00
	Price	16.250	15.625	15.179	14.844	14.583	14.375
0.000	Avg Cost	12.500	12.500	12.500	12.500	12.500	12.500
	Markup	30.00%	25.00%	21.43%	18.75%	16.67%	15.00%
	Price	16.584	16.010	15.603	15.298	15.059	14.867
0.005	Avg Cost	12.452	12.508	12.560	12.453	12.477	12.513
	Markup	33.18%	28.00%	24.23%	22.85%	20.69%	18.81%
	Price	16.863	16.313	15.922	15.624	15.387	15.192
0.010	Avg Cost	12.500	12.531	12.495	12.473	12.486	12.498
	Markup	34.90%	30.19%	27.43%	25.26%	23.23%	21.56%
	Price	17.500	16.901	16.494	16.194	15.964	15.781
0.030	Avg Cost	12.906	12.954	13.143	13.043	12.868	12.748
	Markup	35.59%	30.47%	25.50%	24.16%	24.06%	23.79%
	Price	17.500	16.901	16.493	16.194	15.964	15.781
0.050	Avg Cost	13.724	13.791	13.755	13.765	13.760	13.515
	Markup	27.52%	22.55%	19.91%	17.65%	16.02%	16.77%
	Price	17.500	16.901	16.494	16.194	15.964	15.781
0.070	Avg Cost	14.106	14.235	14.168	14.173	14.092	14.021
	Markup	24.06%	18.73%	16.41%	14.26%	13.29%	12.55%

Table 5: Profits of the Two Firms

Panel 1: Risk-Neutral Firm		Competition Intensity						
Exchange Rate Variance		0.00	0.40	0.80	1.20	1.60	2.00	slope
0.000	Average	14.064	13.673	12.913	12.086	11.286	10.546	-1.83^{***}
	Lower Limit	14.064	13.673	12.913	12.086	11.286	10.546	
	Upper Limit	14.064	13.673	12.913	12.086	11.286	10.546	
0.005	Average	14.245	14.123	13.540	13.652	13.059	12.394	-0.88^{***}
	Lower Limit	14.030	13.876	13.264	13.361	12.736	12.062	
	Upper Limit	14.460	14.371	13.816	13.943	13.381	12.726	
0.010	Average	14.063	14.407	14.582	14.532	14.204	13.847	-0.12
	Lower Limit	13.765	14.056	14.196	14.104	13.737	13.345	
	Upper Limit	14.360	14.758	14.969	14.961	14.671	14.349	
0.030	Average	13.887	15.557	15.030	15.645	16.391	16.297	1.08^{*}
	Lower Limit	13.388	14.944	14.298	14.851	15.509	15.347	
	Upper Limit	14.386	16.169	15.762	16.440	17.274	17.247	
0.050	Average	14.032	15.377	16.497	16.389	15.888	18.020	1.53^{*}
	Lower Limit	13.380	14.589	15.546	15.355	14.745	16.826	
	Upper Limit	14.685	16.166	17.447	17.423	17.031	19.214	
0.070	Average	13.855	14.052	15.596	15.456	16.295	16.546	1.43^{**}
	Lower Limit	13.078	13.101	14.498	14.227	14.955	15.125	
	Upper Limit	14.632	15.003	16.693	16.684	17.634	17.966	
Panel 2: Risk-Averse Firm		Competition Intensity						
Exchange Rate Variance		0.00	0.40	0.80	1.20	1.60	2.00	slope
0.000	Average	14.064	13.673	12.913	12.086	11.286	10.546	-1.83^{***}
	Lower Limit	14.064	13.673	12.913	12.086	11.286	10.546	
	Upper Limit	14.064	13.673	12.913	12.086	11.286	10.546	
0.005	Average	14.116	13.512	12.576	12.25	11.395	10.54	-1.75^{***}
	Lower Limit	13.920	13.298	12.347	12.019	11.150	10.297	
	Upper Limit	14.312	13.727	12.804	12.481	11.641	10.783	
0.010	Average	13.686	13.054	12.392	11.646	10.799	10.018	-1.85^{***}
	Lower Limit	13.437	12.785	12.119	11.364	10.513	9.728	
	Upper Limit	13.935	13.322	12.665	11.927	11.086	10.308	
0.030	Average	11.484	10.504	9.007	8.278	7.760	7.109	-2.20^{***}
	Lower Limit	11.200	10.222	8.715	7.994	7.471	6.820	
	Upper Limit	11.768	10.787	9.300	8.562	8.048	7.397	
0.050	Average	9.440	8.276	7.362	6.382	5.524	5.312	-2.13^{***}
	Lower Limit	9.217	8.058	7.134	6.160	5.300	5.095	
	Upper Limit	9.662	8.494	7.589	6.603	5.749	5.530	
0.070	Average	8.485	7.096	6.251	5.311	4.692	4.124	-2.14^{***}
	Lower Limit	8.296	6.908	6.063	5.122	4.504	3.939	
	Upper Limit	8.675	7.283	6.438	5.499	4.880	4.309	
***: $p < 0.001$; **: $p < 0.01$; *: $p < 0.05$		The upper and lower limits are based on 95% confidence interval						

Table 6: Probability that the Risk-Neutral Firm Has Higher Profit

		Competition Intensity					
Exchange Rate Variance		0.00	0.40	0.80	1.20	1.60	2.00
	Point Estimate	N/A	N/A	N/A	N/A	N/A	N/A
0.000	Lower Limit	N/A	N/A	N/A	N/A	N/A	N/A
	Upper Limit	N/A	N/A	N/A	N/A	N/A	N/A
	Point Estimate	66.30%	86.90%	89.90%	93.40%	90.50%	89.20%
0.005	Lower Limit	63.37%	84.81%	88.03%	91.86%	88.68%	87.27%
	Upper Limit	69.23%	88.99%	91.77%	94.94%	92.32%	91.13%
	Point Estimate	70.60%	84.30%	89.00%	89.50%	87.00%	85.70%
0.010	Lower Limit	67.77%	82.04%	87.06%	87.60%	84.91%	83.53%
	Upper Limit	73.43%	86.56%	90.94%	91.40%	89.09%	87.87%
	Point Estimate	76.00%	82.60%	79.60%	81.20%	80.50%	81.40%
0.030	Lower Limit	73.35%	80.25%	77.10%	78.78%	78.04%	78.99%
	Upper Limit	78.65%	84.95%	82.10%	83.63%	82.96%	83.82%
	Point Estimate	75.20%	79.40%	76.60%	77.90%	75.10%	78.70%
0.050	Lower Limit	72.52%	76.89%	73.97%	75.33%	72.42%	76.16%
	Upper Limit	77.88%	81.91%	79.23%	80.48%	77.78%	81.24%
	Point Estimate	71.60%	70.40%	72.70%	72.80%	73.00%	72.80%
0.070	Lower Limit	68.80%	67.57%	69.94%	70.04%	70.25%	70.04%
	Upper Limit	74.40%	73.23%	75.47%	75.56%	75.76%	75.56%
The upper and lower limits are based on 95% confidence interval							

Table 7: Risks of the Two Firms

Panel 1: Risk-Neutral Firm		Competition Intensity						
Exchange Rate Variance		0.00	0.40	0.80	1.20	1.60	2.00	slope
0.000	CV	0.000	0.000	0.000	0.000	0.000	0.000	
	5th Percentile	14.064	13.673	12.913	12.086	11.286	10.546	
	1st Percentile	14.064	13.673	12.913	12.086	11.286	10.546	
0.005	CV	0.244	0.282	0.329	0.343	0.398	0.432	0.09^{***}
	5th Percentile	8.636	7.498	6.036	5.986	4.348	3.462	-2.53^{***}
	1st Percentile	5.443	4.131	3.086	1.941	0.857	0.069	-2.70^{***}
0.010	CV	0.341	0.393	0.427	0.475	0.530	0.584	0.12^{***}
	5th Percentile	6.156	4.963	4.934	3.211	2.110	0.732	-2.67^{***}
	1st Percentile	3.104	1.254	0.814	-1.587	-1.338	-3.862	-3.21^{**}
0.030	CV	0.580	0.634	0.785	0.818	0.867	0.939	0.18^{***}
	5th Percentile	0.564	-0.905	-4.514	-5.669	-7.098	-8.525	-4.66^{***}
	1st Percentile	-4.965	-6.104	-11.247	-13.621	-17.389	-19.570	-7.80^{***}
0.050	CV	0.749	0.826	0.928	1.017	1.159	1.068	0.19^{**}
	5th Percentile	-2.848	-5.651	-7.956	-10.458	-12.429	-13.369	-5.39^{***}
	1st Percentile	-11.168	-14.739	-16.645	-22.139	-28.160	-28.175	-9.34^{***}
0.070	CV	0.904	1.091	1.134	1.281	1.325	1.383	0.23^{***}
	5th Percentile	-6.554	-10.613	-14.162	-17.705	-19.537	-20.663	-7.20^{***}
	1st Percentile	-15.446	-20.051	-30.441	-28.872	-35.111	-36.108	-10.49^{**}
Panel 2: Risk-Averse Firm		Competition Intensity						
Exchange Rate Variance		0.00	0.40	0.80	1.20	1.60	2.00	slope
0.000	CV	0.000	0.000	0.000	0.000	0.000	0.000	
	5th Percentile	14.064	13.673	12.913	12.086	11.286	10.546	
	1st Percentile	14.064	13.673	12.913	12.086	11.286	10.546	
0.005	CV	0.224	0.256	0.293	0.303	0.347	0.372	0.07^{***}
	5th Percentile	9.006	7.770	6.362	6.170	4.764	4.002	-2.44^{***}
	1st Percentile	6.097	4.852	3.920	2.962	2.107	1.519	-2.29^{***}
0.010	CV	0.293	0.331	0.355	0.390	0.428	0.466	0.08^{***}
	5th Percentile	7.071	5.831	5.576	4.206	3.367	2.447	-2.28^{***}
	1st Percentile	4.518	2.995	2.665	1.053	1.249	-0.204	-2.18^{**}
0.030	CV	0.399	0.433	0.523	0.553	0.599	0.653	0.13^{***}
	5th Percentile	3.905	2.920	1.211	0.657	0.076	-0.422	-2.19^{**}
	1st Percentile	0.759	0.524	-1.475	-2.186	-3.291	-3.773	-2.49^{***}
0.050	CV	0.380	0.424	0.498	0.560	0.654	0.659	0.15^{***}
	5th Percentile	3.678	2.464	1.509	0.623	-0.033	-0.402	-2.06^{***}
	1st Percentile	0.838	-0.049	-0.571	-1.884	-3.121	-3.097	-2.16^{***}
0.070	CV	0.360	0.426	0.484	0.571	0.645	0.722	0.18^{***}
	5th Percentile	3.510	2.226	1.163	0.230	-0.331	-0.714	-2.12^{***}
	1st Percentile	1.342	0.362	-1.620	-1.482	-2.515	-2.722	-2.06^{**}
***: $p < 0.001$; **: $p < 0.01$; *: $p < 0.05$								

Appendix: Proof of Theorem 3

The Jacobian of $F(X)$ that enters (12) can be written as

$$Jacobian = \begin{pmatrix} A & 0 & 0 \\ 0 & B & 0 \\ 0 & 0 & C \end{pmatrix}, \qquad (A.1)$$

where A is the $M \times M$ submatrix corresponding to F_m^P, $m = 1, \ldots, M$; B is the $(MKJ + MJ) \times (MKJ + MJ)$ submatrix corresponding to F_{mkj}^U and F_{mj}^V, $m = 1, \ldots, M$; $k = 1, \ldots, K$; and $j = 1, \ldots, J$, and C is the $(MK + M) \times (MK + M)$ submatrix corresponding to $F_{mk}^{\hat{U}}$ and F_m^Q, $m = 1, \ldots, M$ and $k = 1, \ldots, K$. We can easily verify that C is zero.

We now show A is positive semidefinite.

$$A = \begin{pmatrix} 2(1+\gamma) & -\frac{\gamma}{(M-1)} & \cdots & \cdots & -\frac{\gamma}{(M-1)} \\ -\frac{\gamma}{(M-1)} & \ddots & \cdots & \cdots & -\frac{\gamma}{(M-1)} \\ \vdots & \cdots & 2(1+\gamma) & \cdots & \vdots \\ -\frac{\gamma}{(M-1)} & \cdots & \cdots & \ddots & -\frac{\gamma}{(M-1)} \\ -\frac{\gamma}{(M-1)} & \cdots & \cdots & -\frac{\gamma}{(M-1)} & 2(1+\gamma) \end{pmatrix}. \qquad (A.2)$$

Since $2(1+\gamma) > \sum_{m=1}^{M-1} |-\frac{\gamma}{(M-1)}| = \gamma$ A is symmetric and diagonally dominant A is positive semidefinite.

We now show B is also positive semidefinite. First the covariance matrix of the exchange rate can be written as:

$$COV_\theta = \begin{pmatrix} \sigma_{11} & \cdots & \cdots & \sigma_{1J} \\ \sigma_{21} & \sigma_{22} & & \vdots \\ \vdots & & \ddots & \vdots \\ \sigma_{J1} & \cdots & \cdots & \sigma_{JJ} \end{pmatrix}. \qquad (A.3)$$

We now can write B as

$$B = \begin{pmatrix} B_1 & 0 & \cdots & \cdots & 0 \\ 0 & \ddots & \cdots & \cdots & 0 \\ \vdots & \cdots & B_m & \cdots & \vdots \\ 0 & \cdots & \cdots & \ddots & 0 \\ 0 & \cdots & \cdots & 0 & B_M \end{pmatrix}, \qquad (A.4)$$

where $B_m = 2Z_m \times \Phi \times Z_m$. Z_m is a diagonal matrix

$$Z_m = \begin{pmatrix} Z_m^1 & 0 & \cdots & \cdots & 0 \\ 0 & \ddots & & & \vdots \\ \vdots & & Z_m^j & & \vdots \\ \vdots & & & \ddots & \vdots \\ 0 & \cdots & \cdots & \cdots & Z_m^J \end{pmatrix}, \tag{A.5}$$

where the submatrix Z_m^j is a $(K+1) \times (K+1)$ diagonal matrix:

$$Z_m^j = \begin{pmatrix} c_{1j} + t_{1j}^1 & 0 & \cdots & 0 \\ 0 & \ddots & & \vdots \\ \vdots & & c_{Kj} + t_{Kj}^1 & \vdots \\ 0 & \cdots & \cdots & h_{mj} + t_j^2 \end{pmatrix}, \tag{A.6}$$

The matrix Φ is a $J(K+1) \times J(K+1)$ matrix:

$$\Phi = \begin{pmatrix} \Phi_{11} & \Phi_{12} & \cdots & \cdots & \Phi_{1J} \\ \Phi_{21} & \ddots & & & \vdots \\ \vdots & & \Phi_{j_1 j_2} & & \vdots \\ \vdots & & & \ddots & \vdots \\ \Phi_{J1} & \cdots & \cdots & \cdots & \Phi_{JJ} \end{pmatrix}, \tag{A.7}$$

where the submatrix $\Phi_{j_1 j_2}$ is a $(K+1) \times (K+1)$ matrix with all entries equal to $\sigma_{j_1 j_2}$. Note that the matrix Φ is identical to the covariance matrix of the vector of random variables where elements $(j-1)(K+1)+1$ to $j(K+1)$ are equal to the exchange rate of country j, $j = 1, \ldots, J$. Hence, Φ is positive semidefinite.

Since Z_m is a diagonal matrix and $B_m = 2Z_m \times \Phi \times Z_m$, B_m is also positive semidefinite, which implies that B is positive semidefinite.

Since matrices A, B, and C are all positive semidefinite, the Jacobian matrix is also positive semidefinite. Therefore, $F(X)$ is monotone. **Q.E.D.**