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Foreign Direct Investment or Outsourcing : A Supply Chain Decision Model

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Abstract— **Strategically deciding between Foreign Direct Investment (FDI) and Outsourcing at the various stages of a global supply chain is a very challenging problem for the firm's manager. We model this strategic decision problem as a Mixed Integer Nonlinear Program (MINLP) with the assumption that the good flow is unidirectional, which means the production and distribution networks admit no reverse flow. The proposed model optimizes the overall supply chain costs by taking into account the production cost, the inventory holding cost at the various stages and the transportation cost between the stages. This model is referred as the base model. We also propose some extensions of the base model. The behaviour of the base model is analyzed for a 8-stage, 4-echelon supply chain.**

Index Terms— **Supply chain optimization, FDI, Outsource, and MINLP model.**

I. INTRODUCTION

Trade liberalization and information technology development accelerates firms to trade and invest across national borders. Firms could trade across national borders either by intra-firm-trade (FDI) or arms-length-trade (foreign outsourcing). FDI includes corporate activities such as building plants or subsidiaries in foreign countries, and buying controlling stakes or shares in foreign companies. It is now a competitive requirement that businesses invest all over the globe to access markets, technology, and talent. On the other hand international outsourcing of economic activities has been high on the agenda of decision makers, in the recent trend. Firms located in industrialised countries pursue vertical disintegration of their production processes by outsourcing some stages in foreign countries where economic conditions are more advantageous. A firm that chooses to keep the production of an intermediate input within its boundaries can produce it at home (standard vertical integration) or in a foreign country (FDI). Alternatively, a firm may choose to outsource an input in the home country (domestic outsourcing) or in a foreign country (foreign outsourcing). Intel Corporation provides an example of the FDI strategy; it assembles most of its microchips in wholly-owned subsidiaries in China, Costa Rica, Malaysia, and the Philippines. On the other hand, Nike provides an example of foreign outsourcing strategy; it subcontracts most of its manufacturing to independent producers in Thailand, Indonesia, Cambodia, and Vietnam.

FDI and outsourcing have been studied extensively in the economics literature. Economists have developed theoretical models for investigating the decision of the firms to source abroad either through foreign outsourcing (FO) or foreign direct investment (FDI) [4] and firm's decision to serve foreign markets through exporting or FDI [13]. In [10] and [12], Grossman and Helpman had studied the trade-off between outsourcing and in-house production in a closed economy, and between outsourcing from the home country and from abroad, respectively. Instead, in [11], they study the trade-off between FDI and outsourcing in a foreign country. They assume that the producers of final goods, located in a Northern region, find it convenient to buy inputs from a Southern region, since wages in the South are lower than wages in the North. In addition, they suppose the local suppliers in South to be more efficient with respect to a production unit eventually setup in the Southern region by the final producers through a vertical FDI [11]. However, the eventual relationship with the suppliers is plagued with contractual difficulties, linked to the uncertain legal framework of the South, and therefore for the final producers a trade-off arises between the greater efficiency gained through outsourcing, and the contract incompleteness they might avoid if they produce their required inputs through a FDI. The work by Almonte and Bonassi [1] contributes with some refinements to the Grossman and Helpman model [11] as far as the treatment of the FDI alternative is concerned and explores the extent to which the production strategies of the final producers are sensitive to the degree of contract incompleteness of a host country, and how in turn the latter affects the establishment of linkages between the final producers and the local suppliers. Gorg et al. [8] had done an econometric study on outsourcing using Irish manufacturing plant data. For more details on FDI and outsourcing studies we refer to [3], [5], [6], [7], [9], and [14].

A. Contribution and organisation

Deciding between FDI and outsourcing for various activities of a multi-national firm is a hard decision problem, especially when the number of alternatives to accomplish an activity is many. Theoretical models had been developed in the literature to study FDI versus outsourcing [4], [10], [11], [12], and [13]. Eventhough, these models provide insights in the decision making process, none of them can be applied in the quantitative context (what percentage to make/source using a particular alternative?). In this work we propose a quantitative model for optimally deciding between FDI/outsourcing alternatives in general acyclic global supply chains.

This paper is organised as follows. In Section II, we state the problem. Mixed Integer Nonlinear Programming (MINLP) are proposed in Section III, incorporating (i) supply chain costs due to production, transportation, inventory, duty and partner relationship, and (ii) supply chain risks, due to production delay, production shortfall, transport delay, and sharing of intellectual property. A model is also propoed for the multi-product case in Section III. The base model is analyzed for a 8-stage, 4-echelon supply chain in Section IV.

II. Problem Statement

A global supply chain spans several countries and regions of the globe. We consider a multi-stage global supply chain network where each stage represents an activity such as, production, assembly, transport, distribution or retail. We assume that the supply chain has N stages, say, $S_1, S_2, \ldots, S_N$. At each stage, the activity could be accomplished using either of the different FDI/Outsourcing alternatives that are possible. For example, in the DEC global supply chain of [2], for the demand in UK, the memory manufacturing activity could be accomplished by either of these FDI/Outsourcing alternatives: (a) outsourcing to a partner in Singapore or Malaysia, or (b) setting up a plant of the company in China to exploit the skilled and low cost labour. Let there be K such different alternatives, $A_1, A_2, \ldots, A_K$, associated with each stage (the number K could be different for different alternatives). A 0-1 FDI-Outsourcing strategy, S, is obtained by choosing exactly one FDI/Outsourcing alternative (among the K alternatives) for each stage S_i, $1 \leq i \leq N$. The strategy S can be represented by a $N \times K$ matrix (s_{il}), where $s_{il} = 1$, if for the stage i, alternative l is chosen, $s_{il} = 0$, otherwise. This implies, $\sum_{l=1}^{K} s_{il} = 1$, for each stage i. Let the cost matrix (c_{il}) be an $N \times K$ matrix, where c_{il} is the cost associated to the alternative l for the stage i. For a 0-1 FDI-Outsourcing strategy S, the cost $c(S)$ associated with it is defined as, $\sum_{i=1}^{N} \sum_{l=1}^{K} c_{il} s_{il}$. An optimal 0-1 FDI-Outsourcing strategy would have the minimum cost. By definition, an optimal 0-1 FDI-Outsourcing strategy minimizes the overall supply chain cost. The problem of determining the optimal 0-1 FDI-Outsourcing strategy is termed as the 0-1 FDI-Outsourcing decision problem.

We consider the relaxed version of the 0-1 strategy, S, in which $0 \leq s_{il} \leq 1$ (possibly with some, s_{il} set to 0 or 1). In this context, the 0-1 FDI-Outsourcing strategy and the 0-1 FDI-Outsourcing decision problem are refered as FDI-Outsourcing strategy and FDI-Outsourcing decision problem, respectively.

III. Modeling

A supply chain could be acyclic or cyclic. The production and distribution networks are examples of acyclic supply chains. The distribution network along with the stage(s) in which the distributed products that are defective are subsequently recalled, repaired, and redistributed, is an example of a cyclic supply chain.

For acyclic supply chains, in this section, we propose MINLP models for the FDI-Outsourcing decision problem. First, we propose a model for the single product case termed as the base model. We extend the base model to, (i) a model for the multi-product case, (ii) a model incorporating the duty (import tax) for transferring the intermediate goods between the countries, and (iii) a model incorporating risks due to production shortfall, production or transport delay, and other types of risks like losing of proprietary rights on intellectual property and so forth.

In all the models, every stage has production and inventory costs. In the case of FDI the capital costs are absorbed in the production cost. In the case of outsourcing the production cost is equivalent to the procurement cost. The transport cost between the various stages of the supply chain is also captured in the models. The inventory, production and transport costs are assumed to be per lot cost, if their respective lot sizes are specified. Otherwise, the cost corresponds to the per unit cost with lot size set to 1. When the mean demand and the standard deviation of the demand are specified for the final stages (sink nodes) in the supply chain, the mean demand and the standard deviation demand for the non-final stages (non-sink nodes) are computed as follows. Let G be a supply chain network. Let $A(G)$ denote the set of all directed edges (dependencies between the stages) in the supply chain. For a stage i in the supply chain, let μ_i and σ_i be the mean and standard deviation of demand. For a non-sink node i, $\mu_i = \sum_{j:(i,j)\in A(G)} \mu_j$, and, $\sigma_i = \sqrt{\sum_{j:(i,j)\in A(G)} \sigma_j^2}$, assuming for all js' either both μ_j and σ_j are specified (in the case of sink nodes) or computed apriori. This can be achieved by computing μ_i and σ_i for the non-sink nodes in reverse topological order[1]. Assuming the demand distribution is normal, the demand of stage i is computed as, $D_i = \mu_i + k\sigma_i$, where k is the service-level.

With these terminologies we propose the base model.

A. Model for single product scenario (Base Model)

For a supply chain network, G, N denotes the number of nodes (stages), and $A(G)$ denotes the set of all directed edges (dependencies between the stages) in the supply chain. The number of possible alternatives at each stage is denoted by K. We propose the following MINLP model for single product scenario.

[1]A reverse topological ordering is an ordering of the nodes of an acyclic graph such that for any directed arc (u, v), v appears before u in the ordering.

$$\text{MINLP (Base Model) : min} \sum_{i=1}^{N}\sum_{l=1}^{K} PC_{il}\lceil \frac{D_i x_{il}}{PLS_{il}} \rceil$$

$$+\sum_{i=1}^{N}\sum_{l=1}^{K}\sum_{j:(i,j)\in A(G)}\sum_{m=1}^{K}\sum_{r=1}^{n_{mode}} TC_{iljmr}\lceil \frac{D_j x_{iljmr} x_{il} x_{jm}}{TLS_{iljmr}} \rceil$$

$$+\sum_{i=1}^{N}\sum_{l=1}^{K} IHC_{il}\lceil \frac{D_i x_{il}}{IHLS_{il}} \rceil (ILT_{il} + PLT_{il} - OLT_{il}) x_{il}$$

$$\text{subject to} \sum_{l=1}^{K} x_{il} = 1, \forall 1 \le i \le N,$$

$$\sum_{r=1}^{n_{mode}} x_{iljmr} = 1, \forall i, l, j, m, \text{ such that } (i,j) \in A(G),$$

$$ILT_{jm} x_{jm} = max\{OLT_{il} x_{il} + TT_{iljmr} x_{iljmr} x_{il} x_{jm} : (i,j) \in A(G)\},$$
$$\forall j, m$$

$$0 \le x_{il} \le 1, x_{iljmr} = 0 \text{ or } 1.$$

The above model can also be written as,

$$\text{MINLP1 : min} \sum_{i=1}^{N}\sum_{l=1}^{K} PC_{il}\lceil \frac{D_i x_{il}}{PLS_{il}} \rceil$$

$$+\sum_{i=1}^{N}\sum_{l=1}^{K}\sum_{j:(i,j)\in A(G)}\sum_{m=1}^{K}\sum_{r=1}^{n_{mode}} TC_{iljmr}\lceil \frac{D_j x_{iljmr} x_{il} x_{jm}}{TLS_{iljmr}} \rceil$$

$$+\sum_{i=1}^{N}\sum_{l=1}^{K} IHC_{il}\lceil \frac{D_i x_{il}}{IHLS_{il}} \rceil (ILT_{il} + PLT_{il} - OLT_{il}) x_{il}$$

$$\text{subject to} \sum_{l=1}^{K} x_{il} = 1, \forall 1 \le i \le N,$$

$$\sum_{r=1}^{n_{mode}} x_{iljmr} = 1, \forall i, l, j, m, \text{ such that } (i,j) \in A(G),$$

$$OLT_{il} x_{il} + TT_{iljmr} x_{iljmr} x_{il} x_{jm} - ILT_{jm} x_{jm} \le 0, \forall i, l, j, m, r,$$
$$\text{such that } (i,j) \in A(G),$$

$$0 \le x_{il} \le 1, x_{iljmr} = 0 \text{ or } 1, ILT_{jm} \ge 0.$$

In the above model, the decision variables x_{il}, correspond to the percentage of demand satisfied for a stage i through an alternative l. For any two stages i and j, such that $(i, j) \in A(G)$, and alternatives l and m, respectively, we define the following for the above model. The terms PC_{il}, TC_{iljmr}, IHC_{il}, denote the per lot production cost (PC), transportation cost (TC), and the inventory holding cost (IHC), respectively. The production lot size (PLS), transport lot size (TLS), and inventory holding lot size (IHLS), are denoted by PLS_{il}, TLS_{iljmr}, and $IHLS_{il}$, respectively. The number of transport modes available between any two nodes is assumed to be n_{mode}. In case, some transport mode is not available between a pair of nodes, a huge cost could be added with respect to that mode. Since, MINLP1 is a minimisation problem this mode would never be included in the optimal solution. It is also assumed that exactly one mode is used to tranport goods from stage i to stage j, with alternatives l and m, respectively. The decision variables, $x_{iljmr} = 1$, if the goods that has to be transported between stage i and stage j with alternatives l and m, respectively, is transported using the transport mode, r. Otherwise, the decision variables, $x_{iljmr} = 0$. The term, D_i, denotes the demand at stage i. Without loss of generality, the demand D_i at stage i, is assumed to be per day demand. For a stage i and an alternative l, the production lead time (PLT), the inbound lead time (ILT) and the outbound lead time (OLT) are denoted by PLT_{il}, ILT_{il} and OLT_{il}, respectively. The terms PLT_{il} and OLT_{il} are assumed to be specified based on the requirement (D_i) at stage i, for all the stages i and alternatives l. Also at every stage i, we assume that PLT_{il} and OLT_{il} are linearly proportional to the percentage of demand satisfied by an alternative l (x_{il}). The decision variables ILT_{il} should be non-negative, for any non-source node i. Without loss of generality, for source nodes i, ILT_{il} can be set to 0. The term TT_{iljmr} denotes the transport time (TT) from i to j with alternatives l and m, respectively, and r is the mode of transport. For a real number α, the term $\lceil \alpha \rceil$ denotes the smallest integer greater than or equal to α.

Having proposed the base model, in the following subsections B,C and D, we propose various extensions of it.

B. Model for multi-product scenario

Let $\mathcal{P}$ be the set of all products that are demanded. Let P be an element of $\mathcal{P}$. For a stage i and alternative l we identify whether this combination is capable of supplying a component of P. If it is capable then $\delta_{il}^{P} = 1$, otherwise, $\delta_{il}^{P} = 0$. Let $\mathcal{P}_{il}$ be the set of all P such that $\delta_{il}^{P} = 1$. With these terminologies we propose the following MINLP model for the multi-product scenario. The following model is an extension of MINLP1.

$$\text{MINLP2 : min} \sum_{i=1}^{N}\sum_{l=1}^{K}\sum_{P\in\mathcal{P}_{il}} PC_{ilP}\lceil \frac{D_{iP} x_{ilP}}{PLS_{ilP}} \rceil$$

$$+\sum_{i=1}^{N}\sum_{l=1}^{K}\sum_{j:(i,j)\in A(G)}\sum_{m=1}^{K}\sum_{P\in\mathcal{P}_{il},\mathcal{P}_{jm}}$$

$$\sum_{r=1}^{n_{mode}} TC_{iljmPr}\lceil \frac{D_{jP} x_{iljmPr} x_{ilP} x_{jmP}}{TLS_{iljmPr}} \rceil$$

$$+\sum_{i=1}^{N}\sum_{l=1}^{K}\sum_{P\in\mathcal{P}_{il}} IHC_{ilP}\lceil \frac{D_{iP} x_{ilP}}{IHLS_{ilP}} \rceil (ILT_{ilP} + PLT_{ilP} - OLT_{ilP}) x_{ilP}$$

$$\text{subject to} \sum_{l=1}^{K} x_{ilP} = 1, \forall 1 \le i \le N, P \in \mathcal{P}_{il},$$

$$\sum_{r=1}^{n_{mode}} x_{iljmPr} = 1, \forall i, l, j, m, P,$$

$$\text{such that } (i,j) \in A(G), P \in \mathcal{P}_{il}, \mathcal{P}_{jm},$$

$$OLT_{ilP}x_{ilP} + TT_{iljmPr}x_{iljmPr}x_{ilP}x_{jmP} - ILT_{jmP}x_{jmP} \leq 0,$$

$$\forall i, l, j, m, r, P, \text{ such that } (i,j) \in A(G), P \in \mathcal{P}_{il}, \mathcal{P}_{jm},$$

$$0 \leq x_{ilP} \leq 1, x_{iljmPr} = 0 \text{ or } 1, ILT_{jmP} \geq 0.$$

The model terminologies are similar to the terminologies of MINLP1, except for interpreting these with respect to a product P.

C. Model incorporating duty (import tax)

Duty (import tax) contributes considerably to the supply chain costs when the intermediate goods are produced/procured from Low Cost Centers (LCCs) [2]. We propose a model incorporating duty (MINLP3) by extending the base model.

$$\text{MINLP3 : min } \sum_{i=1}^{N}\sum_{l=1}^{K} PC_{il}\lceil \frac{D_i x_{il}}{PLS_{il}} \rceil$$

$$+\sum_{i=1}^{N}\sum_{l=1}^{K}\sum_{j:(i,j)\in A(G)}\sum_{m=1}^{K}\sum_{r=1}^{n_{mode}} TC_{iljmr}\lceil \frac{D_j x_{iljmr} x_{il} x_{jm}}{TLS_{iljmr}} \rceil$$

$$+\sum_{i=1}^{N}\sum_{l=1}^{K}\sum_{j:(i,j)\in A(G)}\sum_{m=1}^{K}\sum_{r=1}^{n_{mode}} DUTY_{iljmr} D_j x_{iljmr} x_{il} x_{jm}$$

$$+\sum_{i=1}^{N}\sum_{l=1}^{K} IHC_{il}\lceil \frac{D_i x_{il}}{IHLS_{il}} \rceil (ILT_{il} + PLT_{il} - OLT_{il}) x_{il}$$

$$\text{subject to } \sum_{l=1}^{K} x_{il} = 1, \forall 1 \leq i \leq N,$$

$$\sum_{r=1}^{n_{mode}} x_{iljmr} = 1, \forall i, l, j, m, \text{ such that } (i,j) \in A(G),$$

$$OLT_{il}x_{il} + TT_{iljmr}x_{iljmr}x_{il}x_{jm} - ILT_{jm}x_{jm} \leq 0, \forall i, l, j, m, r,$$

$$\text{such that } (i,j) \in A(G),$$

$$0 \leq x_{il} \leq 1, x_{iljmr} = 0 \text{ or } 1, ILT_{jm} \geq 0.$$

In the above model $DUTY_{iljmr}$ denotes the duty (import tax) incurred per unit for transferring the good from stage i with alternative l to stage j with alternative m using the transport mode r. The remaining terms are as defined in the base model.

D. Model incorporating risk

At various stages of the supply chain, risk can arise due to production shortfall, production or transport delay. In the context of FDI versus Outsourcing, risk due to sharing of the proprietary information plays a major role. When the core business of a firm (Firm A) is outsourced to another firm (Firm B), the partnering firm (Firm B) is expected to maintain confidentiality of Firm A′s intellectual property. In this scenario, risk of losing the properietary rights may come up, vis-a-vis, the FDI approach.

In the model below (MINLP4) SR_i (shortfall risk) is the risk penalty at stage i, associated to the shortfall y_i. The partner relationship cost associated with the alternative l at stage i is denoted by R_{il}. The term PR_{il} (production risk) is the risk penalty at the stage i, associated with production delay, IPR_{il} (intellectual property risk), risk penalty at stage i, associated to intellectual property/proprietary rights, and, TR_{iljmr} (transport risk) is the penalty associated to transportation risk for transporting goods from stage i (with alternative l), to stage j (with alternative m), using the transport mode-r. The partner relationship cost and the risk penalties are assumed to be per unit cost.

$$\text{MINLP4 : min } \sum_{i=1}^{N}\sum_{l=1}^{K} PC_{il}\lceil \frac{D_i x_{il}}{PLS_{il}} \rceil$$

$$+\sum_{i=1}^{N}\sum_{l=1}^{K}\sum_{j:(i,j)\in A(G)}\sum_{m=1}^{K}\sum_{r=1}^{n_{mode}} TC_{iljmr}\lceil \frac{D_j x_{iljmr} x_{il} x_{jm}}{TLS_{iljmr}} \rceil$$

$$+\sum_{i=1}^{N}\sum_{l=1}^{K} IHC_{il}\lceil \frac{D_i x_{il}}{IHLS_{il}} \rceil (ILT_{il} + PLT_{il} - OLT_{il}) x_{il}$$

$$+\sum_{i=1}^{N} SR_i D_i y_i + + \sum_{i=1}^{N}\sum_{l=1}^{K} (R_{il} + PR_{il} + IPR_{il}) D_i x_{il}$$

$$+\sum_{i=1}^{N}\sum_{l=1}^{K}\sum_{j=i+1}^{N}\sum_{m=1}^{K}\sum_{r=1}^{n_{mode}} TR_{iljmr} D_j x_{il} x_{jm} x_{iljmr}$$

$$\text{subject to } \sum_{l=1}^{K} x_{il} \leq 1, \forall 1 \leq i \leq N,$$

$$\sum_{r=1}^{n_{mode}} x_{iljmr} = 1, \forall i, l, j, m, \text{ such that } (i,j) \in A(G),$$

$$y_i = 1 - \sum_{l=1}^{K} x_{il}, \forall 1 \leq i \leq N,$$

$$OLT_{il}x_{il} + TT_{iljmr}x_{iljmr}x_{il}x_{jm} - ILT_{jm}x_{jm} \leq 0, \forall i, l, j, m, r,$$

$$\text{such that } (i,j) \in A(G),$$

$$0 \leq x_{il} \leq 1, x_{iljmr} = 0 \text{ or } 1, ILT_{jm} \geq 0.$$

The other terminologies in the model remain the same as in the base model.

IV. Analysis of the model

In this section, we analyze the base model proposed in Section III.A, for a 8-stage supply chain shown in Figure 1. We note that the 8-stage supply chain could also be interpreted as a 4-echelon supply chain by defining the echelons as follows,
(a) Echelon 1 - Disk, Memory, Motherboard, and Processor manufacturing,
(b) Echelon 2 - Personal Computer Assembling and Software Procurement,
(c) Echelon 3 - System building,
(d) Echelon 4 - Distribution of the system.
We assume a two-country (North and South) model, as in [11]. With this assumption, for each stage/echelon of the 8-stage supply chain, the different alternatives could be,

- (i) outsourcing to a low cost country in the South,
- (ii) outsourcing to a low cost country in the North (other than the home country),
- (iii) outsourcing to low cost supplier(s) at home,
- (iv) FDI in low cost country in the South,
- (v) FDI in low cost country in the North (other than the home country),
- (vi) manufacturing/assembling at home (in-house).

We refer to these as Alternative 1-6, respectively. With these alternatives, we studied the FDI-Outsourcing decision problem for North and South bound demands. Other parameters of the base model were set as detailed in the following sub-section A.

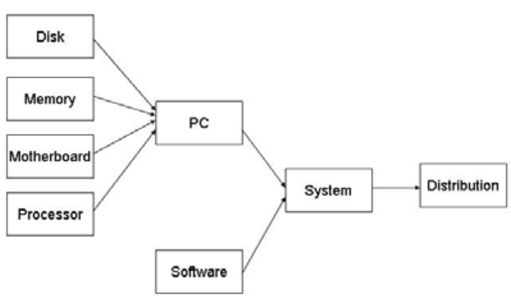

Fig. 1. A 8-stage supply chain

A. Parameters setting

The base model is analyzed for various demand types, namely, High, Medium and Low. For the sink node, Distribution, in the case of High, Medium and Low demand types the mean demand (μ_{Dist}) and standard deviation of demand (σ_{Dist}), are set as follows,
(a) High - $\mu_{Dist} = 10000$ and $\sigma_{Dist} = 1000$,
(b) Medium - $\mu_{Dist} = 5000$ and $\sigma_{Dist} = 500$,
(c) Low - $\mu_{Dist} = 1000$ and $\sigma_{Dist} = 100$.

TABLE 1

Production cost for North bound demand

Alternative/Demand Type	High	Medium	Low
Alternative-1	150	200	250
Alternative-2	100	150	200
Alternative-3	50	100	150
Alternative-4	200	250	300
Alternative-5	150	200	250
Alternative-6	100	150	200

TABLE 2

Production cost for South bound demand

Alternative/Demand Type	High	Medium	Low
Alternative-1	50	100	150
Alternative-2	100	150	200
Alternative-3	150	200	250
Alternative-4	100	150	200
Alternative-5	150	200	250
Alternative-6	200	250	300

By setting the service level to 1, the demand for the various stages with High, Medium, and Low type, are computed as 11000, 5500, and 1100, as detailed in Section III. Production lead time, PLT_{il}, and outbound lead time, OLT_{il}, were set to 1 and 0, respectively, for all i and l. The lot sizes $IHLS_{il}$, PLS_{il}, and TLS_{iljmr}, were set to 1000,100 and 1000, respectively. The inventory holding cost associated to the different alternatives with respect to the North and South bound demand, is set for the various stages of the supply chain as follows . The inventory holding cost, IHC_{il}, is set to 1000 for holding in North, and one-third of its cost, that is 333.33, for holding in South. The production cost, PC_{il}, for the various alternatives, is shown in Table I and II, for the case of North and South bound demand, respectively. From any stage i to any other stage j, we assumed that there is a single mode of transport, that is $n_{mode} = 1$. For any two distinct stages, the transport cost, TC_{iljmr}, and the transport time, TT_{iljmr}, from North to South and vice versa, are set to be 1000 and 2, respectively. Transport cost and transport time within North or South are set to 333.33 (one-third of North-South) and 1 (half of North-South), respectively.

With these settings the results obtained by solving the base model is detailed in the next sub-section B.

B. Results and Discussion

The base model was solved using the CONOPT solver[2] of GAMS Optimization Suite. The model was solved for the High, Medium and Low demand cases for North and South bound demand. The optimal FDI-Outsourcing strategies for North - High, Medium and Low demand and South - High, Medium and Low demand, are shown in Tables III-V and VI-VIII, respectively.

The results obtained suggest that for North and South bound demand the optimal strategy is to produce in North and South, respectively. The strategy is quite intuitive as it saves on the transport and inventory holding

[2]CONOPT is a solver of ARKI Consulting and Development, Denmark, for solving large-scale nonlinear programs (NLPs). More details can be found in http://www.conopt.com

TABLE 3

NORTH-HIGH STRATEGY

Alternative/Echelon	1	2	3
Alternative-1	0.0	0.0	0.0
Alternative-2	38.34	36.07	25.89
Alternative-3	38.34	36.07	25.89
Alternative-4	0.0	0.0	0.0
Alternative-5	0.12	7.43	22.33
Alternative-6	23.19	20.43	25.89

TABLE 4

NORTH-MEDIUM STRATEGY

Alternative/Echelon	1	2	3
Alternative-1	0.0	0.0	0.0
Alternative-2	37.18	35.25	25.25
Alternative-3	37.18	35.25	25.25
Alternative-4	0.0	0.0	0.0
Alternative-5	2.74	9.21	24.26
Alternative-6	22.91	20.30	25.25

TABLE 5

NORTH-LOW STRATEGY

Alternative/Echelon	1	2	3
Alternative-1	0.0	0.0	0.0
Alternative-2	31.78	32.20	25.00
Alternative-3	31.78	30.50	25.00
Alternative-4	0.0	0.0	0.0
Alternative-5	14.77	17.64	25.00
Alternative-6	21.67	19.66	25.00

TABLE 6

SOUTH-HIGH STRATEGY

Alternative/Echelon	1	2	3
Alternative-1	71.13	66.77	56.02
Alternative-2	0.0	0.0	0.0
Alternative-3	0.0	0.0	0.0
Alternative-4	28.87	33.23	43.98
Alternative-5	0.0	0.0	0.0
Alternative-6	0.0	0.0	0.0

TABLE 7

SOUTH-MEDIUM STRATEGY

Alternative/Echelon	1	2	3
Alternative-1	68.92	65.59	54.61
Alternative-2	0.0	0.0	0.0
Alternative-3	0.0	0.0	0.0
Alternative-4	31.08	34.41	45.39
Alternative-5	0.0	0.0	0.0
Alternative-6	0.0	0.0	0.0

TABLE 8

SOUTH-LOW STRATEGY

Alternative/Echelon	1	2	3
Alternative-1	58.67	59.70	50.00
Alternative-2	0.0	0.0	0.0
Alternative-3	0.0	0.0	0.0
Alternative-4	41.33	40.30	50.00
Alternative-5	0.0	0.0	0.0
Alternative-6	0.0	0.0	0.0

cost. We also observe that in both North and South bound demand cases, the percentage of outsourcing decreases and the percentage of FDI increases as we move from the demand type High to Low. This implies that it is cost effective, (i) to outsource when the demand is high, and (ii) manufacture inhouse/FDI when the demand is low, as the capital cost would be low. Finally, we observe that the percentage of outsourcing decreases and the percentage of FDI increases as we move from echelon 1 to echelon 3, in all the cases. This suggests that as we move upstream from the customers the echelons which are closer to the customers should be owned by the company, eventhough, they may opt to outsource echelons that are farther away from the customers.

V. CONCLUSION

In this research we proposed MINLP models for the FDI-Outsourcing decision problem. In the proposed models, various costs/risks were taken into account, namely, production, transport and inventory costs in all the models, duty in MINLP3, and partner relationship cost, production risk, transport risk, production shortfall risk, intellectual property risk, in MINLP4. A model to handle multi-product scenario was also proposed in this paper (MINLP2). The proposed model (base model) was analysed for a 8-stage, 4-echelon supply chain. The analysis suggests that the model is quite intuitive and applicable in practice.

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