



Foreign Direct Investment or Outsourcing:
A Supply Chain Decision Model

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Abstract

Strategically deciding between various global expansion alternatives at the various stages of the supply chain of a large multinational firm is a very challenging problem. The firm's supply chain manager decide between Foreign Direct Investment (FDI), outsourcing and other global expansion strategies at the various stages of the supply chain, in order to reduce costs and satisfy the demand for its products or services in different countries (or regions). The choice between the various alternatives could save millions of dollars. We model this problem by considering the alternatives FDI and outsourcing, without loss of generality. The problem is modeled 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, and the fixed cost (or interest on fixed cost), if any, at the various stages and the transportation cost between the stages. The analysis of the proposed model on a 8-stage supply

chain, validates some intuition on the FDI-outsourcing strategies that are obtained by including fixed and transport costs to the model.

Index terms - Global expansion strategies, global sourcing, foreign direct investment, outsourcing, and MINLP model.

1 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 industrialized 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) (Antras and Helpman (2004)) and firm's decision to serve foreign markets through exporting or FDI (Helpman et. al. (2004)). Grossman and Helpman (2002,2004) have 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. Grossman

and Helpman (2003) study instead 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, Grossman and Helpman (2003) 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. 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 (2004) contributes with some refinements to the Grossman and Helpman (2003) model 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. (2004), have done an econometric study on outsourcing using Irish manufacturing plant data. For more details on FDI and outsourcing studies we refer to Antras (2003), Domberger (1998), Feenstra (1998), Feenstra and Hanson (2001), Groot (2001), and Hummels et. al. (2001).

1.1 Contribution and organization

Globalization is not an option but a matter of survival for companies. There are several ways in which companies can enter foreign markets including obtaining a stake in foreign companies, franchising, joint ventures, setting up its own entire supply operations (horizontal integration), investing in setting up subassembly operations (vertical integration) and finally sourcing the subassemblies from foreign suppliers (outsourcing). From a supply chain network design view point the vertical integration or outsourcing options are interesting. 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 economics literature to study FDI versus outsourcing (Antras and Helpman (2004), Helpman et al.(2004), Grossman and Helpman (2002,2003,2004)). Even though, 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 and outsourcing alternatives in general acyclic global supply chains. The proposed model is also applicable when other global expansion alternatives such as franchising, joint venture, acquisition, are to be considered by a decision manager.

There is a significant amount of literature existing on component vendor selection from the manufacturers perspective, which is closely related to the area of strategic sourcing, in the operations research and management science literature. In the area of strategic sourcing, Narasimhan and Das (1999) present an empirical investigation of the impact of strategic sourcing on manufacturing flexibility and performance. Venkatesan (1992) discusses some of the key issues to be considered in the outsourcing decision for manufacturing activities. In the related area of vendor selection, Weber and Current (1993) discuss a multi-criteria analysis for vendor selection. They develop a model for minimizing total cost, late deliveries and supply rejection given the infrastructure constraints and constraints imposed by the companys policy. Chaudhry et al. (1993), consider the problem of vendor selection where buyers need to choose order quantities with vendors in a multi-sourcing network. Narasimhan and Stoynoff (1986) present a model for optimizing aggregate procurement allocation keeping in mind contract requirements, supplier capacities and economic manufacturing quantity related constraints. The interested reader might find Huang and Wu (2003) useful for a comprehensive classification of publications on supplier selection criteria. In addition, there is some literature in the field of virtual enterprises that is relevant to our work. Tian et al. (2002), present a substantial review of publications relating to infrastructure and system design for internet-based manufacturing. Recently, Gaonkar and Viswanadham (2005) discussed strategic sourcing when product life cycles are short. All these deal with the situation of selection of vendors to minimize the cost when the components sourcing is outsourced. In this paper we are concerned with the higher level issue of whether to outsource to a partner or do it yourself in a low cost country.

This paper is organised as follows. In Section II, we state the FDI-outsourcing decision problem. Mixed integer nonlinear programming (MINLP) models are proposed in Section III, by incorporating (i) supply chain costs due to production, transportation, inventory, and (ii) fixed costs such as capital costs and so forth, incurred due to global expansion. Even though, in

the proposed models, we haven't considered including production, inventory and transport lot sizes, these models can be extended to include them as in Viswanadham and Balaji (2005). The models are analyzed for a 8-stage supply chain in Section IV. In the model with fixed cost, it would be more realistic to include interest on capital cost, rather than the capital cost itself. Taking this into account, we analyzed the model for low and high fixed costs, to represent the scenarios in which interest for capital costs, and the capital costs itself, are considered, respectively. The analysis suggests that the inclusion of fixed cost and transport cost alter the global expansion strategy, that is obtained without taking them into consideration.

2 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, \dots, 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 for personal computers (Arntzen et al. (1995)), 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, \dots, A_K , associated with each stage. 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 referred as FDI-Outsourcing strategy and FDI-Outsourcing decision problem, respectively.

In the following section we propose models for computing optimal FDI-outsourcing strategy. The decision manager input the various parameter values required for the model(s). The model(s) output the optimal FDI-outsourcing strategy for the specified parameter values.

3 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 by including the production cost, the inventory cost, at the various stages (with respect to each alternative), and the transport cost, between the stages (for each stage and alternative combination), for a supply chain. This model is termed as the base model. We extend the base model by including the fixed cost (for each stage and alternative combination), that could be incurred due to, say, capital expenses or interest paid on them, while considering global expansion alternatives for a supply chain.

The inventory, production and transport costs are assumed to be per unit cost. For a supply chain G , assuming the demand distribution at each stage is normal, the mean demand and the standard deviation demand for the non-final stages (non-sink nodes¹) of G are computed as follows, when the mean demand and the standard deviation of the demand are specified for the final stages (sink nodes) of G (Graves and Willems (2000)). Let $A(G)$ denote the set of all directed edges (dependencies between the stages) in the supply chain G . 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 ,

¹A node (or stage) is a sink node if no node depends on it. That is there is no node j such that $(i, j) \in A(G)$. A node which is not a sink node is referred as a non-sink node.

$\mu_i = \sum_{j:(i,j) \in A(G)} \mu_j$, 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 order². 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.

Even though, for a supply chain G , the demand of the non-sink nodes of G can be computed from the demand of the sink nodes of G , as detailed above, the proposed models can also be applied, in the case, in which the demand is specified for each stage explicitly. Factors like backorder and lost sales would perturb the demand, and make the normal distribution assumption for computing the demand of non-sink nodes of G from the demand of sink nodes of G , detailed above, unrealistic. In such cases, it is assumed that the demand, D_i , is specified exactly for each stage of G , by taking the factors like back order, lost sales, and so forth, into account.

With these terminologies and assumptions, we propose the FDI-Outsourcing decision models.

3.1 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 termed the base model.

$$\begin{aligned}
& \text{MINLP1 (Base Model) : } \min \sum_{i=1}^N \sum_{l=1}^K PC_{il} D_i x_{il} \\
& + \sum_{i=1}^N \sum_{l=1}^K \sum_{j:(i,j) \in A(G)} \sum_{m=1}^K \sum_{r=1}^{n_{mode}} TC_{iljmr} D_j y_{iljmr} x_{il} x_{jm} \\
& + \sum_{i=1}^N \sum_{l=1}^K IHC_{il} D_i x_{il} (ILT_{il} + PLT_{il} - OLT_{il}) \\
& \text{subject to } \sum_{l=1}^K x_{il} = 1, \forall 1 \leq i \leq N,
\end{aligned}$$

²A 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.

$$\begin{aligned}
\sum_{r=1}^{n_{mode}} y_{iljmr} &= 1, \forall i, l, j, m, \text{ such that } (i, j) \in A(G), \\
OLT_{il} + TT_{iljmr} - ILLT_{jm} &\leq 0, \forall i, l, j, m, r, \\
&\text{such that } (i, j) \in A(G), \\
0 \leq x_{il} \leq 1, y_{iljmr} &= 0 \text{ or } 1, ILLT_{jm} \geq 0.
\end{aligned}$$

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 unit production cost (PC), transportation cost (TC), and the inventory holding cost (IHC), respectively. The number of transport modes available between any two nodes is assumed to be n_{mode} . In a case where a certain transport mode is not available between a pair of nodes, a huge cost could be added with respect to that mode. Since, the base model is a minimization problem this mode would never be included in the optimal solution. It is also assumed that exactly one mode is used to transport goods from stage i to stage j , with alternatives l and m , respectively. This implies, that the decision variables, $y_{iljmr} = 1$, 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, $y_{iljmr} = 0$. The term, D_i , denotes the demand at stage i . Without loss of generality, D_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} , $ILLT_{il}$, and OLT_{il} , respectively. 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. The terms PLT_{il} , OLT_{il} , $ILLT_{jm}$, and TT_{iljmr} , are assumed to be in days (without loss of generality). The terms $ILLT_{jm}$ are decision variables in the base model. The decision variables $ILLT_{jm}$ should be non-negative, for any non-source node ³. For source nodes i , $ILLT_{il}$ can be set to 0.

The objective function of the base model is the sum of the production cost, the inventory cost and the transport cost. The production cost is the sum of the cost of the production units produced at a stage i using an alternative

³A node (or stage) j is a source node, if it is not dependent on any other node. That is there is no node i such that, $(i, j) \in A(G)$. A non-source node is a node which is not a source node.

l . The inventory cost is computed based on the number of days of inventory that need to be held for (i, l) , that is $(ILLT_{il} + PLT_{il} - OLT_{il})$. The transport cost is the sum of the cost of the units transported from a stage i to a stage j with their corresponding alternatives l and m , using the transport mode r . For a stage i , the first constraint of the base model should be interpreted as, the sum of the percentage of demand sourced through various alternatives at stage i should sum to 100%. The second constraint is to ensure that exactly one mode of transport is chosen between stage i and j with alternatives l and m , respectively. The third constraint ensures that the inbound lead time of an alternative m at stage j is atleast the sum of the outbound lead time of stage i , such that $(i, j) \in A(G)$, and the transport time from i to j . This has to hold for all such stages i and its alternatives.

The input parameters to the base model could be classified as in Table 1, where, (a) Type I denotes the parameter values to be specified for each stage i , (b) Type II denotes the parameter values to be specified for each stage i and its alternative l , and (c) Type III denotes the parameter values to be specified for a combination, stage i with an alternative l , stage j with an alternative m , and transport mode r .

Parameters	Type
D_i	I
$PC_{il}, IHC_{il}, PLT_{il}, OLT_{il}$	II
TC_{iljmr}, TT_{iljmr}	III

Table 1: Grouping of the input parameters of the base model

Having proposed the base model in the next section we propose an extension of the base model.

3.2 Base Model with Fixed Cost

In this section, we extend the base model by including fixed cost to the objective function. This model is termed as the base model with fixed cost.

$$\begin{aligned} \text{MINLP2 (Base Model with Fixed Cost)} : \min & \sum_{i=1}^N \sum_{l=1}^K FC_{il} \delta_{il} + PC_{il} D_i x_{il} \\ & + \sum_{i=1}^N \sum_{l=1}^K \sum_{j:(i,j) \in A(G)} \sum_{m=1}^K \sum_{r=1}^{n_{mode}} TC_{iljmr} D_j y_{iljmr} x_{il} x_{jm} \end{aligned}$$

$$\begin{aligned}
& + \sum_{i=1}^N \sum_{l=1}^K IHC_{il} D_i x_{il} (ILLT_{il} + PLT_{il} - OLT_{il}) \\
& \text{subject to } \sum_{l=1}^K x_{il} = 1, \forall 1 \leq i \leq N, \\
& \sum_{r=1}^{n_{mode}} y_{iljmr} = 1, \forall i, l, j, m, \text{ such that } (i, j) \in A(G), \\
& OLT_{il} + TT_{iljmr} - ILLT_{jm} \leq 0, \forall i, l, j, m, r, \\
& \text{such that } (i, j) \in A(G), \\
& \delta_{il} = 0, \text{ if } x_{il} = 0, \text{ and } 1, \text{ otherwise, } \forall i, l, \\
& 0 \leq x_{il} \leq 1, y_{iljmr} = 0 \text{ or } 1, ILLT_{jm} \geq 0.
\end{aligned}$$

In the above model, the terms FC_{il} denote the fixed cost corresponding to the i th node and l th alternative. The fixed cost is accounted only when an alternative corresponding to a node i is chosen, otherwise, it is not accounted. This is ensured by introducing the variables δ_{il} in the model, for all nodes i and alternatives l . The terms δ_{il} are implicit decision variables, as they can be computed from the values assumed by the decision variables x_{il} . We note that FC_{il} is specified for each stage i and alternative l , and classified as Type II variable in Table 1.

The fourth constraint of the base model with fixed cost introduces non-linearity to the constraints of the base model. Otherwise, only the objective function of the base model is nonlinear. This can be resolved by restating the model as detailed in A.1 of the appendix.

We note that the base model with fixed cost can be extended to include production, inventory and transport lot sizes as in Viswanadham and Balaji (2005).

4 Analysis of the model

In this section, we analyze the base model with fixed cost and compare the FDI-Outsourcing strategies obtained by, (i) excluding fixed cost and transport cost, (ii) excluding fixed cost and including transport cost, (iii) including low fixed cost and excluding transport cost, and (iv) including high fixed cost and excluding transport cost. The scenarios (i), (ii), (iii), and (iv), are referred as s1, s2, s3, and s4, respectively. Scenario 3 (s3) models the case

in which interest paid due to capital expenses are considered. On the other hand, Scenario 4 (s4) models the case in which the capital expenses itself are considered. Further, in the analysis we relaxed the non-linear constraint of the base model with fixed cost by setting, $\delta_{il} = x_{il}$. The analysis is done for a 8-stage supply chain shown in Figure 1. For analysis, we assume a two-country (North and South) model, as in Grossman and Helpman (2003). We also assume the home country of the company to be North. With this assumption, for each stage of the 8-stage supply chain, the different alternatives could be,

- (i) Outsource South - outsourcing to a low cost country in the South,
- (ii) Outsource Home - outsourcing to low cost supplier(s) at home,
- (iii) FDI South - FDI in low cost country in the South,
- (iv) Home - manufacturing/assembling at home (in-house).

These are referred as alternatives 1-4, respectively. The FDI-Outsourcing decision problem was studied with these alternatives. We grouped the various stages of the 8-stage supply chain into two groups as follows.

- (a) Group 1 - Disk, memory, motherboard, and processor manufacturing, personal computer assembling, and software development,
- (b) Group 2 - System building.

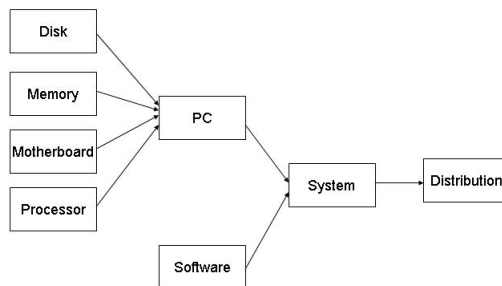


Figure 1: A 8-stage supply chain

Alternative/Demand Type	High	Medium	Low
Outsource South	50	100	150
Outsource Home	150	200	250
FDI South	100	150	200
Home	200	250	300

Table 2: Production cost

The parameters of the base model with fixed cost were set as detailed in the following sub-section 4.1.

4.1 Parameters setting

The base model with fixed cost was 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 $\sigma_{Dist} = 100$.

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 3. Production lead time, PLT_{il} , and outbound lead time, OLT_{il} , were set to 1 and 0, respectively, for all i and l . 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 2. 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, were set to be 500 and 1, respectively. Transport cost and transport time within North or South were set to 0. In the case of s3 and s4, the fixed costs FC_{il} were set as shown in Table 3 and 4, respectively.

With these settings the results obtained by solving the base model with fixed cost are detailed in the following sub-section 4.2.

Alternative	Fixed cost
Outsource South	30000
Outsource Home	10000
FDI South	40000
Home	20000

Table 3: Low fixed cost

Alternative	Fixed cost
Outsource South	3000000
Outsource Home	1000000
FDI South	4000000
Home	2000000

Table 4: High fixed cost

4.2 Results and Discussion

The base model with fixed cost was solved using the CONOPT solver⁴ of GAMS Optimization Suite. The model was solved for the High, Medium and Low demand cases for North and South bound demand. The FDI-Outsourcing strategies for North - High, Medium and Low demand and South - High, Medium and Low demand, are shown in Tables 5-7 and 8-10, respectively.

From the tabulated values, we observe the following.

- (i) If no transport cost or fixed cost is included (scenario 1), for both north and south bound demand the best strategy is to outsource to south.
- (ii) If transport cost is included without adding any fixed cost (scenario 2), for north bound demand outsource to north and for south bound demand outsource to south. Even though, the production cost is low by outsourcing to south the presence of transport cost implies that procuring from north for the north bound demand is a good strategy.
- (iii) If fixed cost is included and set very low, without inclusion of transport cost (scenario 3), for both north and south bound demand it is a good strategy to outsource to south, as the production cost in south is low.

⁴CONOPT is a solver of ARKI Consulting and Development, Denmark, for solving large-scale nonlinear programs (NLPs). CONOPT attempts to find a local optimum satisfying the usual Karish-Kuhn-Tucker optimality conditions. However, CONOPT doesn't guarantee that the local optimum solution obtained by it is a global optimum solution. More details can be found in <http://www.conopt.com>

	Group 1				Group 2			
	s1	s2	s3	s4	s1	s2	s3	s4
Outsource South	100	0	100	0	50	0	50	0
Outsource Home	0	100	0	100	0	100	0	100
FDI South	0	0	0	0	50	0	50	0
Home	0	0	0	0	0	0	0	0

Table 5: 8-stage North-High strategy

	Group 1				Group 2			
	s1	s2	s3	s4	s1	s2	s3	s4
Outsource South	100	0	100	0	50	0	50	0
Outsource Home	0	100	0	100	0	100	0	100
FDI South	0	0	0	0	50	0	50	0
Home	0	0	0	0	0	0	0	0

Table 6: 8-stage North-Medium strategy

	Group 1				Group 2			
	s1	s2	s3	s4	s1	s2	s3	s4
Outsource South	100	0	100	0	50	0	50	0
Outsource Home	0	100	0	100	0	100	0	100
FDI South	0	0	0	0	50	0	50	0
Home	0	0	0	0	0	0	0	0

Table 7: 8-stage North-Low strategy

	Group 1				Group 2			
	s1	s2	s3	s4	s1	s2	s3	s4
Outsource South	100	100	100	0	100	100	100	18
Outsource Home	0	0	0	100	0	0	0	82
FDI South	0	0	0	0	0	0	0	0
Home	0	0	0	0	0	0	0	0

Table 8: 8-stage South-High strategy

	Group 1				Group 2			
	s1	s2	s3	s4	s1	s2	s3	s4
Outsource South	100	100	100	0	100	100	100	0
Outsource Home	0	0	0	100	0	0	0	100
FDI South	0	0	0	0	0	0	0	0
Home	0	0	0	0	0	0	0	0

Table 9: 8-stage South-Medium strategy

	Group 1				Group 2			
	s1	s2	s3	s4	s1	s2	s3	s4
Outsource South	100	100	100	0	100	100	100	0
Outsource Home	0	0	0	100	0	0	0	100
FDI South	0	0	0	0	0	0	0	0
Home	0	0	0	0	0	0	0	0

Table 10: 8-stage South-Low strategy

(iv) If fixed cost is high (scenario 4), for both north and south bound demand it is a good strategy to outsource to north, as the fixed cost dominate the decision.

These results are quite intuitive and validates the developed model.

5 Conclusion

Global sourcing strategies are adopted by many large firms to optimize the costs of their products and services. Many large firms are often in the situation to decide between many global expansion alternatives like FDI, outsourcing and so forth. In this research we model the FDI-outsourcing decision problem in Section 3. In Section 4, we analyzed the developed model on a 8-stage supply chain. The analysis validates some of the intuitive FDI-outsourcing strategies the companies would adopt, under certain cost settings, to meet the demand for its products and services across various parts of the globe. For the analysis, we considered North-South model as in Grossman and Helpman (2003) by classifying the North and South bound demand as high, medium, and low. Even though, not much strategic difference is observed over various demand classes (in the case that is considered), difference in strategies were observed for the model by excluding and including transport and fixed costs. In the appendix (A.2,A.3, and A.4), we have presented some extensions of the base model proposed in this work.

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APPENDIX

A.1. Alternate formulation of the base model with fixed cost

The base model with fixed cost proposed in Section 3.2 can be formulated alternatively as follows, to remove the nonlinearity of the constraints.

$$\begin{aligned}
 \text{MINLP3 (Base Model with Fixed Cost)} : \min & \sum_{i=1}^N \sum_{l=1}^K FC_{il} \delta_{il} + PC_{il} D_i x_{il} \\
 & + \sum_{i=1}^N \sum_{l=1}^K \sum_{j:(i,j) \in A(G)} \sum_{m=1}^K \sum_{r=1}^{n_{mode}} TC_{iljmr} D_j y_{iljmr} x_{il} x_{jm} \\
 & + \sum_{i=1}^N \sum_{l=1}^K IHC_{il} D_i x_{il} (ILT_{il} + PLT_{il} - OLT_{il}) \\
 \text{subject to} & \sum_{l=1}^K x_{il} = 1, \forall 1 \leq i \leq N, \\
 & \sum_{l=1}^K \delta_{il} = 1, \forall 1 \leq i \leq N, \\
 & x_{il} \leq \delta_{il}, \forall 1 \leq i \leq N, 1 \leq l \leq K, \\
 & \sum_{r=1}^{n_{mode}} y_{iljmr} = 1, \forall i, l, j, m, \text{ such that } (i, j) \in A(G), \\
 & OLT_{il} + TT_{iljmr} - ILT_{jm} \leq 0, \forall i, l, j, m, r, \\
 & \text{such that } (i, j) \in A(G), \\
 & 0 \leq x_{il} \leq 1, \delta_{il}, y_{iljmr} = 0 \text{ or } 1, ILT_{jm} \geq 0.
 \end{aligned}$$

The equivalence of MINLP2 and MINLP3 follows from the following Theorem.

Theorem : The optimal solutions of MINLP3 are exactly the optimal solutions of MINLP2.

Proof : Let OPT be an optimal solution of MINLP3. Let $x_{il} = 0$, for some i and l of OPT. Then, $\delta_{il} = 0$ in OPT. Otherwise, the fixed cost F_{il} , would get added to the objective function. This would imply OPT is not an optimal solution, since the fixed cost F_{il} can be removed by setting $\delta_{il} = 0$. This contradiction, proves the result. \square

A.2. Model for multi-product scenario

In this section we extend the base model which is applicable for a single product scenario, to a 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.

$$\begin{aligned}
\text{MINLP4 : } & \min \sum_{i=1}^N \sum_{l=1}^K \sum_{P \in \mathcal{P}_{il}} PC_{ilP} D_{iP} x_{ilP} \\
& + \sum_{i=1}^N \sum_{l=1}^K \sum_{j: (i,j) \in A(G)} \sum_{m=1}^K \sum_{P \in \mathcal{P}_{il}, \mathcal{P}_{jm}} \sum_{r=1}^{n_{mode}} TC_{iljmPr} D_{jP} y_{iljmPr} x_{ilP} x_{jmP} \\
& + \sum_{i=1}^N \sum_{l=1}^K \sum_{P \in \mathcal{P}_{il}} IHC_{ilP} D_{iP} x_{ilP} (ILT_{ilP} + PLL_{ilP} - OLT_{ilP}) \\
& \text{subject to } \sum_{l=1}^K x_{ilP} = 1, \forall 1 \leq i \leq N, P \in \mathcal{P}_{il}, \\
& \sum_{r=1}^{n_{mode}} y_{iljmPr} = 1, \forall i, l, j, m, P, \\
& \text{such that } (i, j) \in A(G), P \in \mathcal{P}_{il}, \mathcal{P}_{jm}, \\
& OLT_{ilP} + TT_{iljmPr} - ILT_{jmP} \leq 0, \\
& \forall i, l, j, m, r, P, \text{ such that } (i, j) \in A(G), P \in \mathcal{P}_{il}, \mathcal{P}_{jm}, \\
& 0 \leq x_{ilP} \leq 1, y_{iljmPr} = 0 \text{ or } 1, ILT_{jmP} \geq 0.
\end{aligned}$$

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

A.3. 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) (Arntzen et. al. (1995)). We propose a model incorporating duty (MINLP4) by extending the base model.

$$\begin{aligned}
\text{MINLP5 : } & \min \sum_{i=1}^N \sum_{l=1}^K PC_{il} D_i x_{il} \\
& + \sum_{i=1}^N \sum_{l=1}^K \sum_{j:(i,j) \in A(G)} \sum_{m=1}^K \sum_{r=1}^{n_{mode}} TC_{iljmr} D_j y_{iljmr} x_{il} x_{jm} \\
& + \sum_{i=1}^N \sum_{l=1}^K \sum_{j:(i,j) \in A(G)} \sum_{m=1}^K \sum_{r=1}^{n_{mode}} DUTY_{iljmr} D_j y_{iljmr} x_{il} x_{jm} \\
& + \sum_{i=1}^N \sum_{l=1}^K IHC_{il} D_i x_{il} (ILLT_{il} + PLT_{il} - OLT_{il}) \\
& \text{subject to } \sum_{l=1}^K x_{il} = 1, \forall 1 \leq i \leq N, \\
& \sum_{r=1}^{n_{mode}} y_{iljmr} = 1, \forall i, l, j, m, \text{ such that } (i, j) \in A(G), \\
& OLT_{il} + TT_{iljmr} - ILLT_{jm} \leq 0, \forall i, l, j, m, r, \\
& \text{such that } (i, j) \in A(G), \\
& 0 \leq x_{il} \leq 1, y_{iljmr} = 0 \text{ or } 1, ILLT_{jm} \geq 0.
\end{aligned}$$

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.

A.4. 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 proprietary rights may come up, vis-a-vis, the FDI approach.

In the model below (MINLP5) SR_i (shortfall risk) is the risk penalty at stage i , associated to the shortfall z_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.

$$\begin{aligned}
\text{MINLP6: } & \min \sum_{i=1}^N \sum_{l=1}^K PC_{il} D_i x_{il} \\
& + \sum_{i=1}^N \sum_{l=1}^K \sum_{j:(i,j) \in A(G)} \sum_{m=1}^K \sum_{r=1}^{n_{mode}} TC_{iljmr} D_j y_{iljmr} x_{il} x_{jm} \\
& + \sum_{i=1}^N \sum_{l=1}^K IHC_{il} D_i x_{il} (ILLT_{il} + PLT_{il} - OLT_{il}) \\
& + \sum_{i=1}^N SR_i D_i z_i + \sum_{i=1}^N \sum_{l=1}^K (R_{il} + PR_{il} + IPR_{il}) D_i x_{il} \\
& + \sum_{i=1}^N \sum_{l=1}^K \sum_{j=i+1}^N \sum_{m=1}^K \sum_{r=1}^{n_{mode}} TR_{iljmr} D_j x_{il} x_{jm} y_{iljmr} \\
& \text{subject to } \sum_{l=1}^K x_{il} \leq 1, \forall 1 \leq i \leq N, \\
& \sum_{r=1}^{n_{mode}} y_{iljmr} = 1, \forall i, l, j, m, \text{ such that } (i, j) \in A(G), \\
& z_i = 1 - \sum_{l=1}^K x_{il}, \forall 1 \leq i \leq N, \\
& OLT_{il} + TT_{iljmr} - ILLT_{jm} \leq 0, \forall i, l, j, m, r, \\
& \text{such that } (i, j) \in A(G), \\
& 0 \leq x_{il} \leq 1, y_{iljmr} = 0 \text{ or } 1, ILLT_{jm} \geq 0.
\end{aligned}$$

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