A Tax Integrated Approach for Global Supply Chain Network Planning

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Abstract—Globalization is here to stay. Companies source, manufacture, and sell across borders. There are several destinations available for undertaking these activities offering varying degrees of incentives and at each destination the company incurs a different delivery cost. Multinational companies need to make more realistic decisions about where to make, source, locate, move, and store products to minimize the total cost of delivery keeping in mind the incentives offered by the governments and the logistics costs at and from the location. Current literature on supply chain optimization does not emphasize on tax. To attract foreign investment, many developing economies have included tax-holidays in their export-import (EXIM) policy for companies operating in free trade zones (FTZs). In this paper, we propose a tax integrated mixed integer model, for optimally deciding the foreign direct investment (FDI)-outsourcing (the choice of establishing captive production centers versus complete outsourcing) alternatives at the various stages of a global supply chain. For a general acyclic supply chain, this decision problem is NP-hard and obtaining analytical results on optimal FDI-outsourcing strategy may be difficult. We linearize the tax integrated model by introducing exactly one hub at each stage. In this case, termed hub-based sourcing—single hub case, we prove that the greedy strategy is an optimal FDI-outsourcing strategy. However, by associating multiple hubs at each stage the decision problem remains NP-hard. Finally, we empirically analyze the tax integrated model (for the general case) on a use-case scenario in which some locations in the choice have free trade zones offering tax incentives.

Note to Practitioners—Global outsourcing is a common practice now in manufacturing and service industries. India and China with their skilled and low-cost human resources are potential destinations for outsourcing. Multinational firms making efforts to exploit these opportunities, have several alternatives before them. They can start a fully owned subsidiary or buy components or subassemblies from suppliers in low-cost countries or have joint ventures. Leading firms need to evaluate between the possible alternatives keeping in mind the logistics and other delivery costs as well as the taxes and tariffs. In this paper, we develop an optimization model to choose between the two extreme alternatives at each stage in the supply chain: FDI which implies establishing a fully owned subsidiary or outsourcing. Integrating tax policy while deciding between FDI versus outsourcing at the various stages of a supply chain would lead to the design of a cost competitive supply chain. In view of the importance of this strategic problem, economists and business analysts have started looking at it in an analytical way.

Our paper is of immense practical utility for companies to make optimal entry decisions at each stage in its supply chain that minimizes the total cost which includes taxes and tariffs and meets the demand for its products or services in different countries (or regions). Tax integrated supply chain planning could save millions of dollars for companies operating globally.

Index Terms—Foreign direct investment, global sourcing, mixed integer nonlinear programming (MINLP) model, outsourcing, tax aligned supply chain.

I. INTRODUCTION

TRADE liberalization and information technology development accelerates trade and investment by firms across national borders. Firms can trade across national borders either by intra-firm-trade (FDI) or arms-length-trade (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 in different regions of the globe to access markets, technology, and talent. 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 by establishing captive production centers (FDI). Alternatively, a firm may choose to outsource the production to a supplier 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.

For a multinational firm, FDI is the alternative to establish captive production centers for its operations *vis-à-vis* outsourcing in which case the production activity is completely outsourced. Various levels of global operational strategies between FDI and outsourcing, like licensing, franchising, joint venture, acquisition, can be included in global supply chain network planning. Even though this study is applicable for various globalization strategies, for simplicity, we consider only the two extreme levels of globalization, namely, FDI and outsourcing. FDI and outsourcing have been studied extensively in the economics literature. Economists have developed theoretical models for investigating the decision of firms to

source abroad either through FDI or outsourcing [4]. In [15] and [17], Grossman and Helpman studied the tradeoff between outsourcing and in-house production in a closed economy. In [16] they studied the tradeoff between FDI and outsourcing by developing a global model with Northern and Southern regions. 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 set up 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 tradeoff 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 [16] 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.* in [11] had done an econometric study on outsourcing using Irish manufacturing plant data. For more details on FDI and outsourcing studies we refer to [3], [7], [9], [10], [13], [18], and [19].

A. Contribution

Globalization, cost pressures, and market demands for new and innovative products, are key factors behind many complex supply chain challenges today. When planning a global supply chain, understanding and effectively managing tax liabilities can result in tens or hundreds of millions of dollars in savings [20].

Stand-alone supply chain initiatives, such as network optimization, strategic sourcing, and lean manufacturing, reduce operating expenses and working capital requirements, as well as improve cash flow and asset utilization. They can also lead to the development of new intangible assets and improved profits. Yet because standalone supply chain initiatives focus only on pre-tax cost reduction, they overlook the fact that for each dollar of operating savings generated, only a limited portion of the benefit as little as sixty cents on the dollar, depending on the tax jurisdiction will be the actual reduction in cost after taxes. Similarly, when tax planning is performed independently from supply chain planning, it may lead to suboptimal strategies with respect to operating cost and profit.

Either type of initiative, undertaken in isolation, prevents companies from achieving a greater after-tax return from their supply chain improvements. Conversely, when the two initiatives are integrated the combination can achieve better results. Companies can enjoy the expanded benefits of enhanced supply chain profitability and lower compliance risks without the burden of high tax rates or exposure to tax compliance risks.

In this research, we propose a mixed integer nonlinear programming (MINLP) model for deciding the optimal FDI-outsourcing alternatives at the various stages of a global acyclic supply chain by taking into account the export and import tax liabilities. This model is termed the tax integrated model. The tax integrated model is a quantitative model, which would output what percentage to make or source using a particular FDI-outsourcing alternative. Integration of taxes and various other regulatory factors in global supply chain design had also been studied in [2], [6], [12], [21], and [22].

Even though, the tax integrated model is applicable with a more general tax structure, we analyze the model by incorporating tax-holidays enjoyed by locating the various stages of a global supply chain in free trade zones (FTZs).

FTZs are special economic zones where export bound goods can be manufactured, assembled and inventoried with generous tax-holidays on customs duty and import/export taxes. These zones are introduced in many countries, specifically developing economies, as part of their export and import (EXIM) policy to encourage exports and FDI on export sector. For the purposes of trade operations, duties and tariffs, the FTZs are considered as a foreign territory. So, goods supplied to FTZ from Domestic Tariff Area (DTA) are treated as exports and goods brought from FTZ to DTA are treated as imported goods. Recently, many developing economies have created FTZs to attract FDI for exports. In [5], it is observed that China's FDI for the export sector has grown rapidly by the creation of FTZs. It is quite interesting to study the strategic location of the various stages of a global supply chain in the presence of FTZs. In this research we address this strategic problem.

Logistics hubs are common now. Singapore, Hong Kong, Shanghai, Rotterdam, and Dubai are logistics hubs with world class infrastructure. Companies source through these hubs to get the advantage of quality freight handling capability because of their world-class infrastructure and also to save on the logistics costs because of the friendly tax policies of these locations. In fact, many suppliers locate themselves in these places for better access to the logistics and other facilities. In the special case, when sourcing of all the material requirements in a stage are all done through a single hub, we get an analytical solution to the sourcing problem. We deal with this in Section IV.

B. Organization

Deciding between FDI and outsourcing for various activities of a firm is a hard problem, especially when the number of alternatives to accomplish an activity is many. In Section II, we state this problem. Theoretical models had been developed in the literature to study FDI versus outsourcing [4], [15]–[18]. 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 Section III-A, we propose a quantitative and weighted MINLP model. The MINLP model allows the optimal decisions to be obtained by weighing the various objectives. The impact of taxes and tariffs is enormous in the design of a global supply chain. It is critical that the tax consequences and opportunities of introducing business change into the supply chain are included as an integral part of the change process. In Section III-B, we propose a tax integrated model for optimally deciding the FDI-Outsourcing alternatives for the various stages of a global supply chain. In Section IV, we prove that the greedy FDI-Outsourcing strategy is an optimal strategy, in the case of hub-based

sourcing with single hub at each stage. Most supply chain managers already employ various options for sourcing from locations like FTZs to save on customs duties and export/import taxes. In Section V, we analyze the tax integrated model by emploving the option of sourcing from FTZs.

II. PROBLEM STATEMENT AND MOTIVATION

A global supply chain spans several countries and regions of the globe. We consider a multistage 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 for personal computers [2], for the demand in U.K., 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. 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 with 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 FDI-Outsourcing related costs for the entire supply chain. The problem of determining the optimal 0-1 FDI-Outsourcing strategy is termed the 0-1 FDI-Outsourcing decision problem. Further, in this work, for a supply chain network, we consider the problem of minimizing the production and inventory costs associated with stages and transport costs and taxes associated between the stages. The 0-1 FDI-Outsourcing strategy and 0-1 FDI-Outsourcing decision problem are referred in more general context by taking these costs into account.

We consider the relaxed version of the 0-1 strategy, S, in which s_{il} takes the (real) value between 0 and 1 ($0 \leq s_{il} \leq 1$). 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.

For example, we consider the 4-stage supply chain shown in Fig. 1. The system building stage procures PC and software, builds the system, and distributes to the consumers in USA, through a distribution center in the U.S. The PC procurement stage has two alternatives, namely, procuring from China and Taiwan with procurement costs, 150 US\$ and 100 US\$ per unit, respectively. The software procurement stage also has two alternatives, namely, procuring from China and India with procurement costs, 150 US\$ and 120 US\$ per unit, respectively. The system building stage could procure using any of these alternatives and build the system in Singapore by outsourcing to
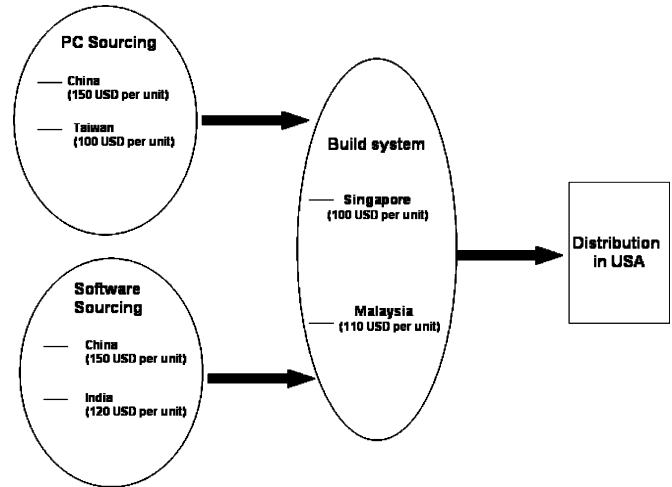

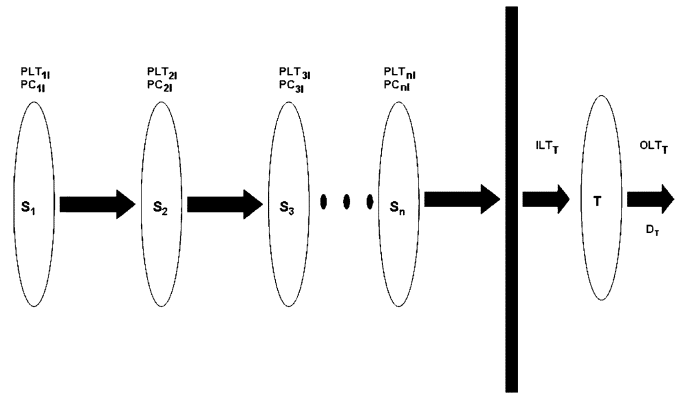Fig. 1. Example to explain 0-1 FDI-Outsourcing strategy.

Fig. 2. Case to show the reducibility to MCKP.

a third-party or in Malaysia by establishing a subsidiary. Their respective costs are 100 US\$ per unit and 110 US\$ per unit. In this example, we note that the strategy of procuring the PC from Taiwan, software from India and building the system in Singapore, is an optimal 0-1 FDI-Outsourcing strategy.

The 0-1 FDI-Outsourcing decision problem is computationally hard as stated in the following theorem.

Theorem 1: The 0-1 FDI-Outsourcing decision problem is NP-hard.

Proof: For some case of supply chain networks (shown in Fig. 2), we prove that the 0-1 FDI-Outsourcing decision problem is polynomially solvable if and only if the multiple-choice knapsack problem (MCKP) is polynomially solvable (of same computational complexity). MCKP is known to be a NP-hard combinatorial optimization problem [8]. So, the 0-1 FDI-Outsourcing problem is NP-hard when restricted to the case of supply chain networks shown in Fig. 2.

In the case of supply chain networks shown in Fig. 2, the stage T produces a product (one unit) after the product (one unit) goes through n subassemblies at the stages $S_1, S_2, S_3, \ldots, S_n$. Let there be K alternatives associated with each S_i, and exactly one alternative associated with T. Let the total demand (per day) for the production at stage T, be D_T. For a stage S_i and an alternative l, let PLT_{il} and PC_{il}, denote the production lead time

(in days) and the production cost (per unit). We also assume $S_{n+1} = T$, and the inventory holding cost at each stage S_i (other than S_{n+1}) with any of the alternatives to be zero. For simplicity, we assume the transport cost, transport time and the taxes between any two stages S_i and S_{i+1} to be zero. Let ILT_T and OLT_T, be the inbound lead time (in days), and outbound lead time (in days), associated with T. Further, assuming that the outbound lead time at T is 0, the sum of the production costs over all the subassemblies inbound to the stage T, is minimized. For a specified ILT_T (which corresponds to bounded inventory at stage T), the computation of optimal 0-1 FDI-Outsourcing strategy for this case, is equivalent to solving the following combinatorial optimization problem:

$$\text{minimize} \sum_{i=1}^{n} \sum_{l=1}^{K} PC_{il} D_T x_{il}$$

$$\text{subject to} \sum_{i=1}^{n} \sum_{l=1}^{K} PLT_{il} x_{il} \leq ILT_T,$$

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

$$x_{il} = 0 \text{ or } 1, \forall 1 \leq i \leq n, 1 \leq l \leq K.$$

MCKP is defined as packing of the items of k classes, $N_1, N_2, \ldots, N_k$ (which is given), in a knapsack of capacity C. Each item $j \in N_i$ has a profit p_{ij} and a weight w_{ij}, and the problem is to choose exactly one item from each class such that the profit sum is maximized without having the weight sum to exceed C. MCKP can be formulated as follows:

$$\textbf{MCKP} : \text{maximize} \quad \sum_{i=1}^{k} \sum_{j \in N_i} p_{ij} x_{ij}$$

$$\text{subject to} \quad \sum_{i=1}^{k} \sum_{j \in N_i} w_{ij} x_{ij} \leq C,$$

$$\sum_{j \in N_i} x_{ij} = 1, i = 1, 2, \ldots, k,$$

$$x_{ij} = 0 \text{ or } 1, \forall 1 \leq i \leq k, j \in N_i.$$

In the above model, p_{ij}, w_{ij}, and C are positive integers. The classes $N_1, N_2, \ldots, N_k$ are mutually disjoint, class N_i having a size n_i. The total number of items is $n = \sum_{i=1}^{k} n_i$.

To reduce 0-1 FDI-Outsourcing problem of Fig. 2 to MCKP, we map a stage S_i to a class N_i and the K alternatives associated with S_i to the items of N_i. The inbound lead time ILT_T is mapped to the capacity C. For a stage i and alternative l, the production lead time PLT_{il} is mapped to weight w_{ij}, and negative of the production cost for the demand at $T (-PC_{il} D_T)$ is mapped to the profit p_{ij}. With these mapping 0-1 FDI-Outsourcing problem (minimization problem) is reduced to a MCKP (a maximization problem).

Conversely, to reduce MCKP to 0-1 FDI-Outsourcing problem of a supply chain network in Fig. 2, items are added to the classes till the number of items in every class is equal to M, where M is maximum of n_i, the number of elements in class N_i. The items added are assigned a size of $C + 1$ (more than the capacity of the knapsack) and a profit of zero, to avoid

these items to be included in the optimum solution. The classes N_i are mapped to the stages S_i, C is mapped to ILT_T, w_{ij} is mapped to PLT_{il}, and p_{ij} is mapped to $-PC_{il} D_T$. This reduces MCKP to 0-1 FDI-Outsourcing problem.

These prove the result. □

Even though, the 0-1 FDI-Outsourcing decision problem is proved to be NP-hard in general, the computational complexity is reduced by transporting the production at each stage S_i (using various alternatives) through a hub. This is termed hub-based sourcing and dealt in detail in Section IV.

As the taxes vary for different tax jurisdictions, by taking into account the tax information for obtaining optimal FDI-Outsourcing strategy would increase the after-tax return of the company. For the example shown in Fig. 1, the optimal 0-1 FDI-outsourcing strategy would be to procure PC from Taiwan, software from India and building the system in Malaysia, if Malaysia has low taxes for building systems. This example gives an insight of how the tax policies and the tax holidays of special economic zones would have an impact on the supply chain strategy. The importance of tax integration in global supply chains can also be realized from the business case discussed in [20]. In the business case considered by Irving *et al.* [20], a billion-dollar manufacturing firm has the potential of generating an indexed profit of 271 over the baseline of 100 by locating the key businesses, functions and facilities in tax-favorable locations. However, the firm would realize an indexed profit of 175 over the baseline of 100, in the case in which the business achieves efficiencies and cost savings only by considering logistics, sourcing, manufacturing and services in its global strategy. These motivate us to study the FDI-Outsourcing decision problem by including taxes at the various stages of a supply chain.

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 termed the weighted base model. We propose an extension of this model by incorporating tax. This model is referred to as the tax integrated model. It is difficult to obtain any analytical result on the optimal FDI-Outsourcing strategy for general acyclic supply chains. So, we linearize the tax integrated model by introducing hubs at each stage of the supply chain. This is referred to as hub-based sourcing. In the case of hub-based sourcing the greedy strategy is proved to be an optimal strategy.

In the proposed models we associate a decision variable, x (without appropriate subscripts), for the production/procurement and inventory activities. This implies that the models have a decision variable x_i associated with the stage i, which could be interpreted as the production (procurement or inventory activity) of a subcomponent i. The decision variable associated with the transport activity between two production stages i and j, is expressed as a function of the decision variables associated

with i and j, that is x_i and x_j, and a decision variable y associated with the transport modes. 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[1]) in the supply chain, the mean demand and the standard deviation of the demand for the nonfinal stages (nonsink 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 the demand. For a nonsink 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 *a priori*. This can be achieved by computing μ_i and σ_i for the nonsink nodes in reverse topological order.[2] Assuming that 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 weighted base model.

A. Weighted Base Model

The weighted base model proposed in this section is a weighted version of the base model proposed in [22].

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 an MINLP model termed weighted base model for G with K alternative at each of its stage. The objectives production cost (PC), transportation cost (TC), and inventory holding cost (IHC), that have to be minimized are weighted by assigning weights, w_{PC}, w_{TC}, and w_{IHC}, respectively. The weights w_t, where $t \in \{PC, TC, IHC\}$, should satisfy, (i) $0 \le w_t \le 1$, and (ii) $\sum_t w_t = 1$. In the weighted base 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 weighted base 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 index r corresponds to a transport mode between the stages i and j. 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 weighted 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 have to be transported between stage i and stage j with alternatives l and m, respectively, are 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}, ILT_{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 with r as the mode of transport. The terms PLT_{il}, OLT_{il}, ILT_{jm}, and TT_{iljmr}, are assumed to be in days (without loss of generality). The term ILT_{jm} are decision variables in the weighted base model. The decision variables ILT_{jm} should be non-negative, for any nonsource node.[3] For source nodes i, ILT_{il} can be set to 0. For a real number α, the term $\lceil \alpha \rceil$ denotes the smallest integer greater than or equal to α. In the following model, the index j is defined as j such that $(i,j) \in A(G)$.

Weighted Base Model :

$$\text{minimize } w_{PC}\left(\sum_{i=1}^{N}\sum_{l=1}^{K} PC_{il}\left\lceil \frac{D_i x_{il}}{PLS_{il}}\right\rceil\right)$$

$$+ w_{TC}\left(\sum_{i=1}^{N}\sum_{l=1}^{K}\sum_{j}\sum_{m=1}^{K}\sum_{r=1}^{n_{\text{mode}}} TC_{iljmr}\right.$$

$$\left.\times \left\lceil \frac{D_j y_{iljmr} x_{il} x_{jm}}{TLS_{iljmr}}\right\rceil\right)$$

$$+ w_{IHC}\left(\sum_{i=1}^{N}\sum_{l=1}^{K} IHC_{il}\left\lceil \frac{D_i x_{il}}{IHLS_{il}}\right\rceil\right.$$

$$\left.\times(ILT_{il} + PLT_{il} - OLT_{il})\right)$$

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

$$\sum_{r=1}^{n_{\text{mode}}} y_{iljmr} = 1, \forall i, l, j, m,$$

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

$$ILT_{il} + PLT_{il} - OLT_{il} \ge 0, \forall i, l,$$

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

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

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[1] A 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 to as a nonsink node.

[2] 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.

[3] A 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 nonsource node is a node which is not a source node.

TABLE I
GROUPING OF THE INPUT PARAMETERS OF THE WEIGHTED BASE MODEL

Parameters	Type
D_i	I
$PC_{il}, PLS_{il}, IHC_{il}, IHLS_{il}, PLT_{il}, OLT_{il}$	II
$TC_{iljmr}, TLS_{iljmr}, TT_{iljmr}$	III
w_{PC}, w_{TC}, w_{IHC}	IV

TABLE II
GROUPING OF THE INPUT PARAMETERS OF THE TAX INTEGRATED MODEL

Parameters	Type
D_i	I
$PC_{il}, PLS_{il}, IHC_{il}, IHLS_{il},$ PLT_{il}, OLT_{il}	II
$TC_{iljmr}, TLS_{iljmr}, TAX_{iljmr},$ $TXLS_{iljmr}, TT_{iljmr}$	III
$w_{PC}, w_{TC}, w_{TAX}, w_{IHC}$	IV

inventory cost is the sum of the cost of inventory lots inventoried at a stage-alternative combination (i,l). It is computed based on the number of days of inventory (finished) that need to be held for (i,l). For an (i,l), $(ILT_{il}+PLT_{il}-OLT_{il})$ days of finished inventory need to be held to meet the demand at (i,l). In other words, to meet the demand at (i,l) with a delivery lead time of OLT (at (i,l)), the system needs to maintain inventory for the lead time of goods arrival from all its upstream stages, ILT, and the lead time for goods finishing at that stage (stage i with alternative l), PLT, which together adds to $ILT + PLT$, and subtracting out the lead time for delivery, OLT, committed at that stage. The transport cost is the sum of the cost of the transport lots 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 weighted 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 at least 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 fourth constraint is to avoid negative inventory, as any stage could hold zero or positive inventory.

The input parameters to the weighted base model could be classified as in Table I, 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, 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, and d) Type IV denotes the parameter values to be specified on production cost, inventory cost and transport cost.

B. Tax Integrated Model

Inclusion of taxes is being considered in this study, as it is one of the important decision factors that have to be taken into account, while designing a global supply chain. Integrating tax in supply chain decisions of a multinational firm would result in a competitive advantage for the firm. For example, resourcing or relocating part of the supply chain to a tax advantageous jurisdiction of the globe would certainly allow generating huge profits for the firm. Therefore, taking the tax information into account can lead to recommend changes in supply chain structure, in sourcing rules, in supplier base, and other factors. It is also better to include tax information at strategic level decision making rather than at a tactical level. In this we propose a strategic decision model by including tax.

This model is termed the tax integrated model and obtained by extending the weighted base model. In the tax integrated model proposed below, TAX_{iljmr} denotes the tax incurred per tax lot (which is denoted by $TXLS_{iljmr}$) for transferring the goods from stage i with alternative l to stage j with alternative m through the transport mode r. The term w_{TAX} is the weight associated with respect to the tax objective. The remaining terms are as defined in the weighted base model. The weights w_t, $t \in \{PC, TC, TAX, IHC\}$, are assigned such that i) $0 \leq w_t \leq 1$ and ii) $\sum_t w_t = 1$

Tax Integrated Model :
$$\text{minimize } w_{PC}\left(\sum_{i=1}^{N}\sum_{l=1}^{K} PC_{il}\left\lceil\frac{D_i x_{il}}{PLS_{il}}\right\rceil\right)$$
$$+ w_{TC}\left(\sum_{i=1}^{N}\sum_{l=1}^{K}\sum_{j}\sum_{m=1}^{K}\sum_{r=1}^{n_{\text{mode}}} TC_{iljmr}\right.$$
$$\left.\times\left\lceil\frac{D_j y_{iljmr} x_{il} x_{jm}}{TLS_{iljmr}}\right\rceil\right)$$
$$+ w_{TAX}\left(\sum_{i=1}^{N}\sum_{l=1}^{K}\sum_{j}\sum_{m=1}^{K}\sum_{r=1}^{n_{\text{mode}}} TAX_{iljmr}\right.$$
$$\left.\times\left\lceil\frac{D_j y_{iljmr} x_{il} x_{jm}}{TXLS_{iljmr}}\right\rceil\right)$$
$$+ w_{IHC}\left(\sum_{i=1}^{N}\sum_{l=1}^{K} IHC_{il}\left\lceil\frac{D_i x_{il}}{IHLS_{il}}\right\rceil\right.$$
$$\left.\times(ILT_{il} + PLT_{il} - OLT_{il})\right)$$
$$\text{subject to } \sum_{l=1}^{K} x_{il} = 1, \forall 1 \leq i \leq N,$$
$$\sum_{r=1}^{n_{\text{mode}}} y_{iljmr} = 1, \forall i, l, j, m,$$
$$OLT_{il} + TT_{iljmr} - ILT_{jm} \leq 0, \forall i, l, j, m, r,$$
$$ILT_{il} + PLT_{il} - OLT_{il} \geq 0, \forall i, l,$$
$$0 \leq x_{il} \leq 1, y_{iljmr} = 0 \text{ or } 1, ILT_{jm} \geq 0.$$

The objective function of the tax integrated model is obtained by including tax in the objective function of the weighted base model, whereas the constraints are exactly same as in the case of the weighted base model.

The input parameters to the tax integrated model, shown in Table II, is classified exactly as in the case of weighted base model except to include tax and weight corresponding to it in Type III and Type IV classes, respectively.

IV. HUB-BASED SOURCING

In this section, we analyze the tax integrated model proposed in Section III-B, in the case of hub-based supply chains. Hub-based supply chain is obtained from any acyclic supply chain G, by associating hubs to each stage of G. At every stage of G, either a single hub or multiple hubs could be associated (for sourcing). These supply chain networks arise quite often in practice. As an example, Singapore or Hong Kong serves as a transshipment hub for the Asia Pacific region. So, any production center in the Asia Pacific region of a multinational firm could source its supplies through Singapore or Hong Kong. In the case of such supply chains (hub-based supply chains), with exactly one hub associated with each stage, we prove that the greedy strategy is an optimal strategy. However, in the presence of multiple hubs, even in the case of hub-based sourcing, the FDI-Outsourcing decision problem is NP-hard. This follows from the fact that at each stage a unique hub could be associated to each FDI-Outsourcing alternative, and reducing it to the decision problem of the acyclic supply chain networks, in general. In the remaining part of this section, by hub-based sourcing we mean sourcing through a single hub.

Let G be a supply chain network, and $A(G)$ be the set of directed edges (dependencies) between the stages of G. A stage i of G, is referred to as an hub-based sourcing stage, if every stage j which is dependent on i (that is $(i, j) \in A(G)$) source the components or services through the hub $HUB(i)$ that is associated with i. If i is a hub-based sourcing stage and j is a stage dependent on i, then all the alternatives associated with j would source the components or services through $HUB(i)$. A supply chain G is a hub-based supply chain, if every stage of G is a hub-based sourcing stage. For a stage i of G, an alternative q is called a minimum cost alternative if its associated cost c_{iq} is minimum (that is $c_{iq} \leq c_{il}$ for all $1 \leq l \leq K$). For G, a greedy sourcing strategy $x = (x_{il})$ is a 0-1 FDI-Outsourcing strategy in which for all the stages i of G, $x_{iq} = 1$, for a minimum cost alternative q, and $x_{il} = 0$, for $1 \leq l \neq q \leq K$.

Let G be a hub-based supply chain. For an alternative l, of a hub-based sourcing stage i, its outbound hub is $HUB(i)$. An inbound hub of an alternative m of a stage j, is the hub $HUB(i)$ that is associated with a stage i of G, such that $(i, j) \in A(G)$. Transport cost (per lot) to stage j with alternative m from an inbound hub $HUB(i)$ is denoted by $TC_{jm}^{HUB(i)}$. Transport cost (per lot) from stage i with alternative l to an outbound hub $HUB(j)$ is denoted by $TC_{il}^{HUB(j)}$. Tax incurred (per lot) to transport goods to stage j with alternative m from an inbound hub $HUB(i)$ is denoted by $TAX_{jm}^{HUB(i)}$. Tax incurred (per lot) to transport goods from stage i with alternative l to an outbound hub $HUB(j)$ is denoted by $TAX_{il}^{HUB(j)}$. For a stage i of G, and its alternative l, let I and O denote the set of all its inbound and outbound hubs, respectively. We define, $TC_{il}^I = \sum_{h \in I} TC_{il}^h$, $TC_{il}^O = \sum_{h \in O} TC_{il}^h$, $TAX_{il}^I = \sum_{h \in I} TAX_{il}^h$, and $TAX_{il}^O = \sum_{h \in O} TC_{il}^h$.

Lemma 1: Let the sourcing for all stages of a supply chain be hub-based (single hub case). Let $n_{\text{mode}} = 1$, the lot sizes, $PLS_{il} = TLS_{iljmr} = IHLS_{il} = TXLS_{iljmr} = LS$, and the demand $D_i = D$ in the Tax Integrated Model. Then, the

objective function of the Tax Integrated Model can be written as

$$\sum_{i=1}^{N} \sum_{l=1}^{K} \left\lceil \frac{Dx_{il}}{LS} \right\rceil \left(w_{PC} PC_{il} + w_{TC} \left(TC_{il}^I + TC_{il}^O \right) \right.$$
$$+ w_{TAX} \left(TAX_{il}^I + TAX_{il}^O \right)$$
$$+ w_{IHC} IHC_{il} (ILT_{il} + PLT_{il} - OLT_{il}))$$
$$+ \sum_{i=1}^{N} \left\lceil \frac{D}{LS} \right\rceil \left(w_{PC} PC_{HUB(i)} + w_{IHC} IHC_{HUB(i)} \right.$$
$$\times \left(ILT_{HUB(i)} + PLT_{HUB(i)} - OLT_{HUB(i)} \right)).$$

Proof: We note that at a stage i, the contribution to the objective function of the tax integrated model, would include the production and inventory costs at each alternative l of i, and its outbound hub, HUB(i). Apart from these it would also include transport costs and taxes for receiving the goods to stage i (with alternative l) from its inbound hubs and sending the processed goods to its outbound hub. Therefore, the result. □

The tax integrated model is linearized, that is the objective function and the constraints reduce to a linear (piecewise linear) function of the input variables, and the following results are obtained for hub-based sourcing—single hub case.

Theorem 2: Let the sourcing for all stages of a supply chain be hub-based. Let $n_{\text{mode}} = 1$, the lot sizes, $PLS_{il} = TLS_{iljmr} = IHLS_{il} = TXLS_{iljmr} = LS$, and the demand $D_i = D$ in the Tax Integrated Model. Then, the greedy sourcing strategy is an optimal strategy.

Proof: By Lemma 1, the objective function of the tax integrated model reduces to linear (piecewise linear function). So, the greedy strategy would be an optimal strategy in this case. □

Theorem 3: Let the sourcing for all stages of a supply chain be hub-based (single hub case). Let the lot sizes, $TLS_{ij} = PLS_{ij} = IHLS_{ij} = LS$, and the demand $D_i = D$, in the Tax Integrated Model. Then, the greedy sourcing strategy is an optimal strategy.

Proof: Follows from Theorem 2. □

V. ANALYSIS OF THE TAX INTEGRATED MODEL

In this section, we analyze the tax integrated model (TIM) proposed in Section III-B, by comparing with the weighted base model (WBM) proposed in Section III-A, for a eight-stage supply chain shown in Fig. 3. A eight-stage supply chain is not general enough to capture all supply chain networks that arise in practice. However, this simple use case was chosen for elegantly presenting the applicability of TIM and the insights derived from it. For the 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 eight-stage supply chain, the different alternatives could be as follows.

   i) Outsource South—outsourcing to a low cost country in the South.
   ii) Outsource Home—outsourcing to low cost supplier(s) at home.
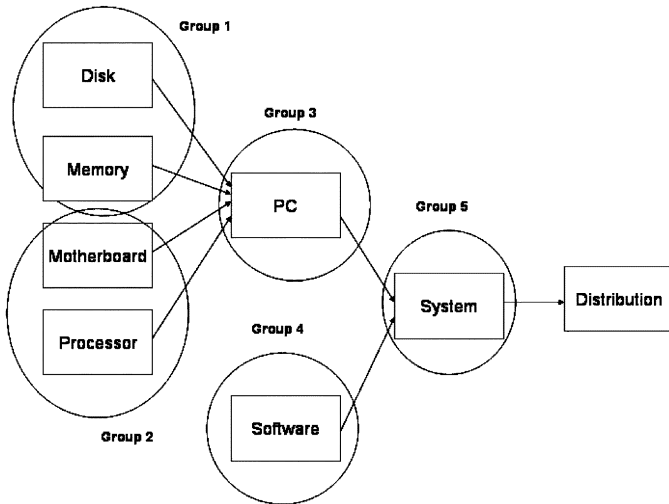   iii) FDI South—FDI in low cost country in the South.

Fig. 3. Eight-stage supply chain.

iv) Home—manufacturing/assembling at home (in-house). The FDI-Outsourcing decision problem was studied with these alternatives. We grouped the various stages of the eight-stage supply chain as shown in Fig. 3. The groups are as follows.

a) Group 1—Disk, and Memory manufacturing.
b) Group 2—Motherboard, and Processor manufacturing.
c) Group 3—Personal Computer assembling.
d) Group 4—Software development.
e) Group 5—System building.

We restricted the groups 1 and 4, to have choices to source only from South. That is Group 1 and 4 has only two alternatives, Outsource South and FDI South. In the results presented in Tables IV–IX, the alternatives that are not considered are denoted by "X". Taxes were included in the model with the following assumptions a) and b).

a) The activities that are executed in South are assumed to be executed in FTZs. That is for the activities that are accomplished using the alternatives, Outsource South or FDI South, we account for tax-holidays enjoyed by the company by manufacturing/assembling in FTZs. The tax-holidays are taken into account only for North bound demand. No tax-exemption was given to South bound demand as it would be considered an import.

b) The activities that are executed in North are assumed to be executed in Domestic Tariff Areas (DTAs). That is, no tax exemption was accounted when the activities were carried out in North.

The parameters of the weighted base model and the tax integrated model were set as detailed in the following Section V-A.

A. Parameters Setting

Both the models were 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 III
PRODUCTION COST

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

By setting the service level to 1, the demand for the various stages with High, Medium, and Low type, are computed as 11 000, 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 III. From any stage i to any other stage j, we assumed that there is a single mode of transport, that is $n_{\mathrm{mode}} = 1$. 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. The taxes TAX_{iljm} of the tax integrated model were set to 20% of $\lceil PC_{il}/PLS_{il} \rceil$, i) if $l = 2$ or 4, or ii) if $l = 1$ or 3, and $m = 1$ or 3. Otherwise it is set to 0. The objectives are set equal weights. That is, a) $w_i = 1/3$, for all $i \in \{PC, TC, IHC\}$, in the case of weighted base model and b) $w_i = 1/4$, for all $i \in \{PC, TC, TAX, IHC\}$, in the case of tax integrated model.

With these settings the results obtained by solving the tax integrated model are detailed in the following Section V-B.

B. Results and Discussion

The models were solved using the CONOPT solver[4] of GAMS Optimization Suite. Both the models WBM and TIM were 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 IV–VI and VII–IX, respectively.

In both the models, we have the following observations. The results obtained suggest that for both North and South bound demand the optimal strategy is to produce in South. The strategy is quite intuitive as it saves on the production cost and the taxes. 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 increases and

TABLE IV
EIGHT-STAGE NORTH-HIGH STRATEGY

	Group 1		Group 2		Group 3		Group 4		Group 5	
	WBM	TIM	WBM	TIM	WBM	TIM	WBM	TIM	WBM	TIM
Outsource South	100	100	100	100	85	85	100	100	50	50
Outsource Home	X	X	0	0	0	0	X	X	0	0
FDI South	0	0	0	0	15	15	0	0	50	50
Home	X	X	0	0	0	0	X	X	0	0

TABLE V
EIGHT-STAGE NORTH-MEDIUM STRATEGY

	Group 1		Group 2		Group 3		Group 4		Group 5	
	WBM	TIM	WBM	TIM	WBM	TIM	WBM	TIM	WBM	TIM
Outsource South	100	100	100	100	83	83	100	100	50	50
Outsource Home	X	X	0	0	0	0	X	X	0	0
FDI South	0	0	0	0	17	17	0	0	50	50
Home	X	X	0	0	0	0	X	X	0	0

TABLE VI
EIGHT-STAGE NORTH-LOW STRATEGY

	Group 1		Group 2		Group 3		Group 4		Group 5	
	WBM	TIM	WBM	TIM	WBM	TIM	WBM	TIM	WBM	TIM
Outsource South	100	100	100	100	72	72	100	100	50	50
Outsource Home	X	X	0	0	0	0	X	X	0	0
FDI South	0	0	0	0	28	28	0	0	50	50
Home	X	X	0	0	0	0	X	X	0	0

TABLE VII
EIGHT-STAGE SOUTH-HIGH STRATEGY

	Group 1		Group 2		Group 3		Group 4		Group 5	
	WBM	TIM	WBM	TIM	WBM	TIM	WBM	TIM	WBM	TIM
Outsource South	100	100	100	100	85	92	100	100	60	67
Outsource Home	X	X	0	0	0	0	X	X	0	0
FDI South	0	0	0	0	15	8	0	0	40	33
Home	X	X	0	0	0	0	X	X	0	0

TABLE VIII
EIGHT-STAGE SOUTH-MEDIUM STRATEGY

	Group 1		Group 2		Group 3		Group 4		Group 5	
	WBM	TIM	WBM	TIM	WBM	TIM	WBM	TIM	WBM	TIM
Outsource South	100	100	100	100	83	89	100	100	58	64
Outsource Home	X	X	0	0	0	0	X	X	0	0
FDI South	0	0	0	0	17	11	0	0	42	36
Home	X	X	0	0	0	0	X	X	0	0

TABLE IX
EIGHT-STAGE SOUTH-LOW STRATEGY

	Group 1		Group 2		Group 3		Group 4		Group 5	
	WBM	TIM	WBM	TIM	WBM	TIM	WBM	TIM	WBM	TIM
Outsource South	100	100	100	100	72	76	100	100	50	51
Outsource Home	X	X	0	0	0	0	X	X	0	0
FDI South	0	0	0	0	28	24	0	0	50	49
Home	X	X	0	0	0	0	X	X	0	0

the percentage of FDI decreases as we move from the system building stage to the manufacturing stage of disk, motherboard, memory and processor (in all the cases). This suggests that as we move upstream from the customers, the echelons which are closer to the customers should be substantially owned by the company, even though, they may opt to outsource stages that are farther away from the customers.

By comparing the weighted base model with the tax integrated model we observe the following. There is no difference in strategy between the two in the case of North bound demand as the tax is 0% when produced in South (FTZ). However, in the case of South bound demand we note that every nonsource node (Groups 3 and 5) has a strategic difference as tax of 20% adds to the cost. This subsequently favors outsourcing to FDI as the cost for outsourcing is low.

For the eight-stage supply chain scenario and few other large scale scenarios (about 100 nodes) that were considered GAMS could solve in a few seconds. The model was run in Windows XP environment with the machine configuration as 1.6 GHz Pentium M processor and 512 MB RAM, for these scenarios. So, in

general, solving the proposed model using the MINLP heuristic built in GAMS like tools is quite practicable. Alternatively, for very large scale problems the greedy heuristic, similar to the one proved to be optimal for hub-based sourcing (single hub case) could be applied for computing the optimal strategy. However, for the scenarios which are not hub-based sourcing through a single hub, it could be far from the exact optimum.

VI. CONCLUSION

Integrating tax in supply chain decision and locating various supply chain activities in tax advantageous jurisdictions would increase the profitability of a multinational firm. This is an important strategic problem, only recently economists and business analysts have started looking at it in an analytical way. However, there were no systematic academic studies on this subject. Our research in this paper is to fill this gap. In this work we proposed a tax integrated decision model for optimally deciding between FDI and outsourcing at each stage of an acyclic supply chain by taking various tax policies into account. For general acyclic supply chains obtaining analytical results on FDI-Outsourcing strategy is difficult. We analyzed FDI-Outsourcing decision with respect to hub-based supply chains and proved that greedy strategies are optimal in the case of hub-based sourcing (single hub case). The tax integrated model was also analyzed empirically for a eight-stage supply chain. Analyzing the model for more realistic data sets and the robustness of the models in these data sets would be an area of research in the future.

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