Int. J. Production Economics 122 (2009) 534–546

Contents lists available at ScienceDirect

Int. J. Production Economics

journal homepage: www.elsevier.com/locate/ijpe

A tax savings model for the emerging global manufacturing network

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ARTICLE INFO

Article history:
Received 3 August 2007
Accepted 11 May 2009
Available online 21 June 2009

Keywords:
Global manufacturing network
International logistics zone
After-tax profit
Tax savings model
Logistics behavior

ABSTRACT

The emerging global manufacturing network involves nodal location features of tax areas and international logistics zones, manufacturing procedures of simple process and deep process, as well as transportation arcs. Since choosing tax savings locations and manufacturing procedures that increase after-tax profit is important to global manufacturers, this study aims to present several tax savings approaches and to develop a tax savings model for maximizing after-tax profit in the emerging network. Numerical illustration demonstrates that the proposed model is an effective approach for global manufacturers to achieve tax savings. The proposed model elucidates the crucial logistics behavior associated with tax savings.

1. Introduction

Global logistics can be conceptualized as the geographic expansion of domestic logistics to markets abroad (Bowersox and Closs, 1996; Sheu, 2004). Fierce competition in a rapidly changing global market has imposed tremendous pressure on manufacturing enterprises to transform and adjust their supply chain operations abroad (Chia et al., 2002). A necessary policy for managing resources is to negotiate at a global level and at a local level supply chain (Albino et al., 2002; Hülsmann et al., 2008). Accordingly, global manufacturers are currently integrating their operations in different countries to achieve manufacturing efficiency across markets and operating units worldwide (Cavusgi et al., 2004).

Manufacturers are increasingly capable of dealing with full system production, and currently seek to add value to existing production systems (Zhai et al., 2007). Minimizing manufacturing cost and production time combined with increasing quality and shipment reliability are important challenges to all production systems (Mezgár et al., 2000). Specifically, manufacturers must devise effective global logistics strategies that maximize profit and fulfill customer orders within manufacturing networks (Hammami et al., 2003; Jodlbauer, 2008). Hameri and Paatela (2005) also observed that contract manufacturers focus on integrating value added operations in networks to maintain and recreate profitable business in markets with narrow margins.

Each manufacturing base only produces special ancestor goods (e.g. components) for the total demand in participating countries, and ships these ancestor goods to other manufacturing bases for further transformation of ancestor goods into descendant goods (e.g. finished products) (Arntzen et al., 1995; Hiraki, 1996). Consequently, a distributed product often has its manufacturing activities dispersed throughout many locations (Lakhal et al., 2005). Once goods transfer from one place to another, complicating tax factors arise such as import duties, corporate taxes, value added taxes, sales taxes, etc. (Goetschalckx et al., 2002; Sheu, 2003; Meixell and Gargeya, 2005; Power, 2005; Tsiakis and Papageorgiou, 2008; Das and Sengupta, 2009).

Some of these tax factors have been examined in previous studies. Arntzen et al. (1995) proposed a global supply chain model for minimizing total cost at the Digital Equipment Corporation considering duty drawback and duty relief. Since a differential tax structure contributes to

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doi:10.1016/j.ijpe.2009.05.019

distribution network decisions that cause logistic inefficiency, Avittathur et al. (2005) developed a model for determining locations of distribution centers (DCs) which considered the impact of differential sales taxes applicable in inter-state trade. Nonetheless, corporate taxes are not easily incorporated into a profit-maximizing model, mainly because some subsidiaries of a global manufacturer may operate at a loss. Restated, unprofitable subsidiaries are not required to pay corporate taxes, but others are subject to corporate tax. Accordingly, Vidal and Goetschalckx (2001) constructed a global supply chain model to cope with the above problem. Their model maximized the after-tax profit of a multinational enterprise by considering transfer pricing and transportation cost allocation. Thereafter, Fandel and Stammen (2004) and Vila et al. (2006) extended previous research to construct an after-tax profit-maximizing model that reflects similar tax factors such as duties and corporate taxes with an emphasis on product life cycles and divergent process industries, respectively. Nonetheless, there has been little research performed to develop a model by simultaneously considering import duty, value added tax and corporate tax.

Governments recognize that most global enterprises pay much attention to the impact of tax factors on their global profit. Therefore, a common governmental strategy is developing "international logistics zones" (Lu and Yang, 2007) offering tax-exemption strategies (e.g. exemptions from corporate tax or import duties) to attract investment and ideally to spark economic growth. Examples of these logistics zones are free trade zones, export processing zones, free port zones, bonded zones and customs-free zones (Prasad and Sounderpandian, 2003; Lee and Yang, 2003; Oum and Park, 2004; Lu and Yang, 2007). For the purposes of this study, "international logistics zones" are defined as zones offering tax-exemptions while "tax areas" are defined as areas which do not offer tax preferences. Taking advantage of preferential taxation is extremely important for global manufacturers to achieve tax savings. Herein, tax savings mean that the amount enterprises save in taxes. Additionally, global enterprises have typically used transfer price to manipulate profit distribution among their subsidiaries. However, enterprises utilizing transfer price as a means of tax mitigation are easy prey for costly audits and litigation (Lakhal et al., 2005). Many countries now have international logistics zones that reduce taxes for global enterprises. Thus, discussing legitimate tax savings approaches associated with international logistics zones is worthwhile.

Facilities functioning only as manufacturing centers or only as distribution centers are less responsive to rapid changes in global commerce than facilities capable of both. Simchi-Levi et al. (2003) pointed out that intense competitive pressure has forced manufacturers to add manufacturing capability at DCs. Sheu (2004) also noted that manufacturers with combined production and distribution facilities have significant advantages in global logistical management. Furthermore, DCs in international logistics zones can be classified as "deep process" and "simple process" facilities (DHL, 2006). Deep processing DCs have manufacturing functions proceeding with serious manufacture producing added value, while simple processing DCs cannot manufacture and merely own the functions of simple and convenient processes (e.g. assembling). For clarity, DCs serving the functions of either simple or deep processing, or both are defined as "processing DCs" in our study. In practice, DCs can be divided into three types: deep processing DCs, simple processing DCs and non-bonded DCs, depending on their locations and manufacturing procedures. Deep processing DCs located in international logistics zones have both deep process and simple process functions. Although located in international logistics zones, simple processing DCs only have the simple process function. Non-bonded DCs perform the same functions as deep processing DCs, but they are located in tax areas. Accordingly, the emerging global manufacturing network comprises nodal location characteristics of tax areas and international logistics zones, manufacturing procedures of simple process and deep process in these nodes, as well as transportation arcs. Therefore, manufacturers must review their global manufacturing activities.

Once both processing DCs and international logistics zones are incorporated in the global manufacturing network, global manufacturers have difficulty in determining the optimal tax savings route and manufacturing procedure for each order. Simchi-Levi et al. (2003) noted that implementing a strategy in which the manufacturing process is completed in a local DC can reduce costs associated with duties as duties are lower for semi-products than for finished products. Accordingly, manufacturers must decide whether to: (1) import semi-products and then convert these products into finished products in tax areas to reduce duties, or (2) manufacture finished products in international logistics zones and then import the finished products to tax areas to reduce corporate tax. Moreover, to identify the best tax savings route and manufacturing procedure, an after-tax model should allow goods free transfer among processing DCs. Restated, a finished product may be processed via simple or deep processing, or both, in various DCs.

Nevertheless, few studies have investigated the choice of tax savings locations and manufacturing procedures to increase after-tax profit for a global manufacturer in the emerging global manufacturing network. The purpose of this study was to represent several tax savings approaches and eventually to develop a tax savings model that maximizes a global manufacturer profit. Furthermore, the proposed model determines the optimal tax savings route and manufacturing procedure for each order.

The rest of this paper is organized as follows. Section 2 presents tax savings approaches concerning the characteristics of international logistics zones. Section 3 describes the problem statement to clarify the scope of the study and to facilitate model formulation. Section 4 provides a model with tax savings, incorporating the emerging global manufacturing network, to find after-tax profit-maximizing solutions. Section 5 tests the problem-solving effectiveness of the proposed model and discusses the findings of the numerical results. Finally, Section 6 summarizes the conclusions of the study.

2. Tax savings approaches

According to in-depth interviews with global manufacturers, the three key tax factors contributing to operating income are the following: import duty, value added tax and corporate tax. Furthermore, considering the characteristics of international logistics zones, the charge condition of import duty, value added tax and corporate tax in the emerging network has become more complex than that in a typical network. The tax savings approaches for these three taxes are outlined below.

2.1. Import duty

Import duties are tariffs paid to the relative government as goods pass into tax areas. Issues of import duties can be divided into the following three dimensions.

1. *Charge condition*: As situation depicted in Fig. 1, the charge condition of import duty is that for the same country original flows are in international logistics zones and destination flows are in tax areas, while for different countries destination flows are in tax areas.
2. *Import from low duty rate country*: Since duty rates may differ between countries for the same goods, enterprises can reduce costs by importing goods from countries with lower duties. As Fig. 2 shows, import duties from country *B* ($80 = $800 * 10%) are lower than from country *A* ($400 = $800 * 50%) for the same goods ($800). Consequently, assuming all other conditions are equal, the enterprise can save import duties by importing via the low duty country.

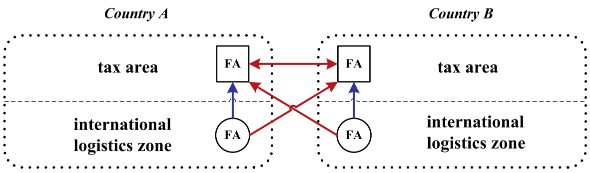

Fig. 1. Charge condition of import duty.

3. *Import duty and product forms*: Duty rates change with respect to product form, and manufacturers must then determine the most advantageous trade-off between import duty and processing cost. For instance, assuming country *B* requires the finished products in Fig. 3, manufacturers must decide whether to: (1) convert raw materials into finished products in country *A* and then import the finished products to country *B* or (2) import raw materials from country *A* and then convert the raw materials into finished products in country *B*.

2.2. Value added tax

Assessment of value added tax (VAT) is based on the incremental increase in the value of goods from raw materials to finished products. For each transaction, VAT is levied on the increased value of a product after input from previous chain members. Value added tax is generally formulated as follows:

$$VATcost = p^s \times q^s \times VAT - p^i \times q^i \times VAT + p^o \times q^o \times (VAT - DRT) \quad (1)$$

where *VATcost* implies the cost of VAT; p^s, p^i, p^o represent the prices associated with sale, input and export, respectively; q^s, q^i, q^o denote the quantities associated with sale, input and export, respectively; *VAT* indicates VAT rate (%) on the value of goods; *DRT* signifies VAT drawback rate (%) on the value of goods.

The first term in Eq. (1) represents sales VAT, and the second term denotes input VAT. Sales VAT can be offset by input VAT. Further, the third term is regarded as export VAT which refers to the VAT imposed on certain exported goods in some countries, e.g. China. Thus, governments adopt strategies for regulating the VAT drawback rate for exports. For example, a country may increase the VAT drawback rate to promote the exporting of certain goods (e.g. mechanical and electrical products) whereas a country may decrease the VAT drawback rate for goods that were restricted to exporting (e.g. natural resources).

As Fig. 4 illustrates, according to a DC in tax areas or in international logistics zones, the charge condition of sales VAT is that destination flows are in tax areas for the same

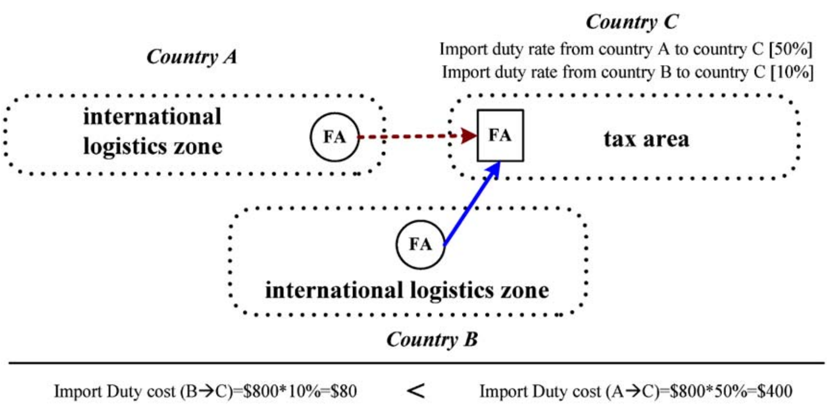

Fig. 2. Import from low duty country.

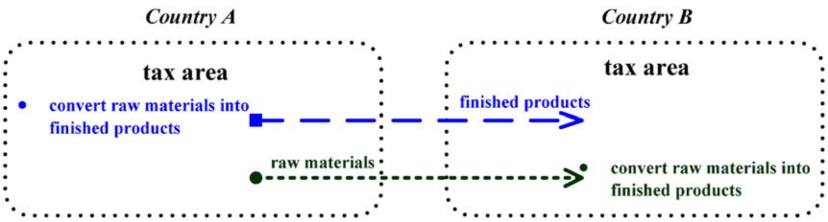

Fig. 3. Import duty and product forms.

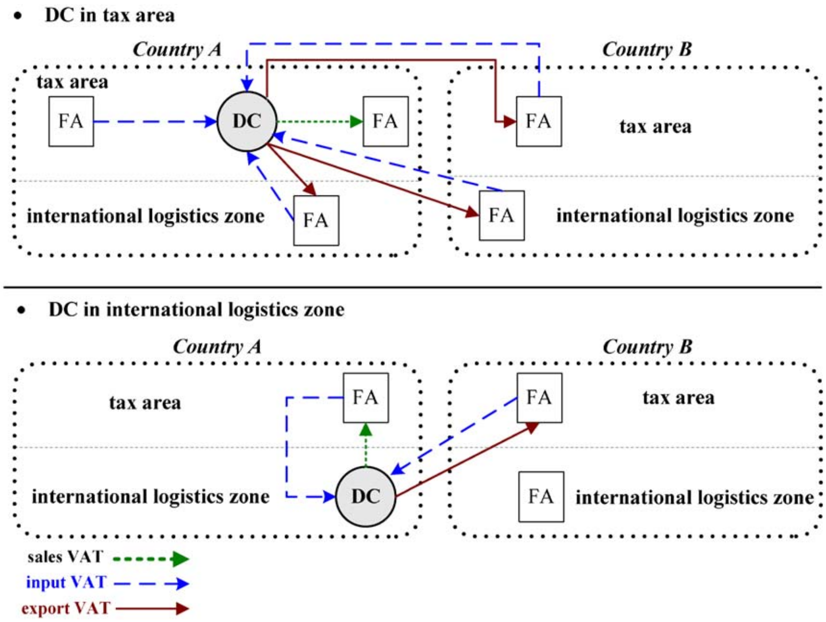

Fig. 4. Charge condition of VAT.

country, while the charge condition of input VAT is that neither original nor destination flows are in international logistics zones. Further, the charge condition of export VAT is that, in the same country, original flows are in tax areas, and destination flows are in international logistics zones; for different countries, both original and destination flows are not in international logistics zones. Consequently, international logistic zones enable enterprises to avoid government regulation strategies of export VAT.

2.3. Corporate tax

Corporate tax is the tax paid by enterprises on the profit they earn. For tax savings, goods completely manufactured in international logistics zones are exempt from corporate tax. Nevertheless, manufacturers must identify the most advantageous trade-off between corporate tax and other costs (e.g., import duties).

3. Problem statement

To clarify the study scope and facilitate model formulation, the problem statement is postulated as follows: (1) types of goods, (2) supply chain members and flow of goods, and (3) transactions.

3.1. Types of goods

Goods, ancestral to descendent, are classified in this study as modular components, semi-products and finished products. Modular strategy has been discussed in detail elsewhere (Lamothe et al., 2006).

3.2. Supply chain members and flow of goods

Supply chain members include internal and external supply chain members responsible for different global logistics functions. Internal supply chain members are manufacturing centers and processing DCs, while external supply chain members are vendors and brand companies. Moreover, the number and location of all supply chain members are given. Nevertheless, Kerbache and MacGregor Smith (2004) indicated that manufacturers link their internal processes to external supply chain members and the resulting supply chain often comprises a very large network of activities and resources. Modeling and optimization of such complex systems is very difficult.

Manufacturing centers receive modular components from the vendors and then transform modular components into semi-products or finished products. Further, manufacturing centers send semi-products or finished products to DCs.

The basic functions of DCs are consolidating and distributing finished products from manufacturing centers to brand companies. Nevertheless, processing DCs may have simple or deep processing functions or both depending on their locations in international logistics zones or tax areas. Accordingly, DCs can be divided into three types: deep processing DCs, simple processing DCs and non-bonded DCs. As Fig. 5 illustrates, deep processing DCs located in international logistics zones have both deep process and simple process functions. Here, deep process involves transforming modular components into semi-products, transforming modular components into finished products and transforming semi-products into finished products, while simple process involves simple processes of semi-products and finished products (e.g. transfer, assembling, and packaging). Although located in international logistics zones, simple processing DCs only have the functions of a simple process for semi-products and finished products. Non-bonded DCs perform the same functions as deep processing DCs, but they are located in tax areas. Based on the function of DCs mentioned above, deep processing DCs and non-bonded DCs receive modular components from vendors. DCs may also receive semi-products or finished products from manufacturing centers. Further, semi-products or finished products can be transferred between all kinds of DCs.

This analysis assumes venders are below the top upstream suppliers in a typical supply chain. They receive and then process raw materials from upstream suppliers to manufacture modular components, which are then sent to manufacturing centers, deep processing DCs or non-bonded DCs.

Brand companies will request global manufacturers to distribute finished products to assigned locations around the world. Assigned locations could be DCs or warehouses owned by brand companies.

3.3. *Transactions*

Since many brand companies often contract with global manufacturers for delivered duty paid (DDP) transactions, transactions in our model are based on the DDP value of the shipment. Herein, DDP means that the seller bears the risks and costs, including taxes, duties and other charges of transporting the goods until they have been delivered.

4. Modeling

Given the problem statement, a tax savings model is formulated to derive after-tax solutions that maximize profit in the emerging global manufacturing network. The proposed model is based on models developed by Vidal and Goetschalckx (1998), Vidal and Goetschalckx (2000), Vidal and Goetschalckx (2001), Fandel and Stammen (2004) and Vila et al. (2006). Nevertheless, once the after-tax model considers the emerging global manufacturing network, determining the optimal tax savings route and manufacturing procedure for each order is difficult. Furthermore, three principal tax factors—import duty, value added tax and corporate tax—are considered simultaneously in the proposed model. This section is divided into two subsections—(1) objective function and (2) constraints. Appendix A summarizes notations and definitions, and Appendix B presents the equations of the proposed model.

4.1. *The objective function*

The objective function maximizes global after-tax profit in dollars for the period of analysis. The after-tax profit of internal supply chain members involved in the objective function are expressed in Eq. (2). The operating

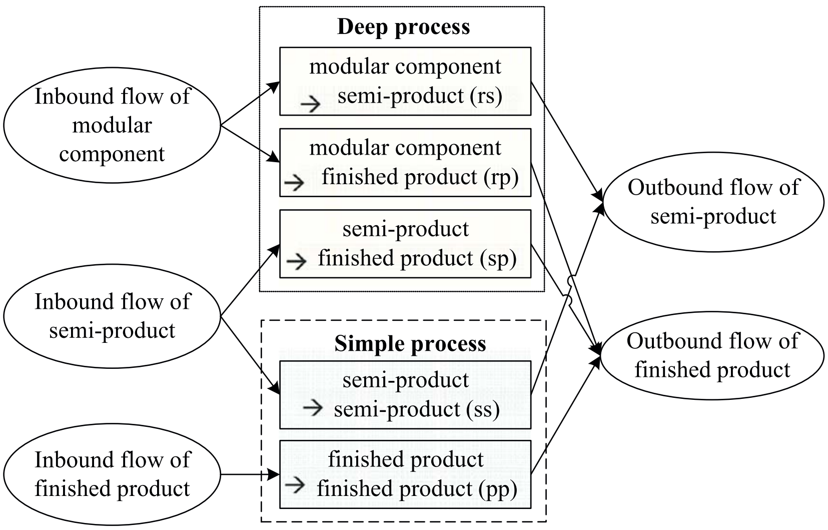

Fig. 5. Deep process and simple process functions.

income variables oi_{θ^x} are free variables since operating income may be positive, zero or negative. Accordingly, each variable is treated as the difference between a plus non-negative variable (operating profit) $oi^+_{\theta^x} = oi_{\theta^x}$ and a minus non-negative variable (operating loss) $oi^-_{\theta^x} = -oi_{\theta^x}$ (Vidal and Goetschalckx, 1998, 2001; Fandel and Stammen, 2004; Vila et al., 2006).

Each operating income variable is measured by subtracting the corresponding aggregate costs $cost_{\theta^x} = (\sum_{k=1}^{24} z^k_{\theta^x})$ from the respective aggregate revenues $revenue_{\theta^x}(= \pi^1_{\theta^x} + \pi^2_{\theta^x})$, as Eq. (3) demonstrates.

Trading with internal supply chain members and brand companies produces the corresponding aggregate revenue, as expressed in Eqs. (4) and (5), respectively. Here, transfer price $TP_{\theta^x \lambda^y \alpha}$ is given to avoid costly auditing and litigation. An effective method for obtaining market-driven transfer prices was proposed in Lakhal et al. (2005).

The aggregate cost is composed of 24 items. They are the corresponding aggregate costs in terms of transforming modular components into semi-products (Eq. (6)), transforming modular components into finished products (Eq. (7)), transforming semi-products into finished products (Eq. (8)), simple process of semi-products (Eq. (9)), simple process of finished products (Eq. (10)), transportation cost of trading with internal supply chain members (Eq. (11)), transportation cost of trading with brand companies (Eq. (12)), inventory cost of trading with internal supply chain members (Eq. (13)), inventory cost of trading with brand companies (Eq. (14)), procurement cost of raw materials (Eq. (15)), procurement cost of semi-products or finished products (Eq. (16)), fixed cost (Eq. (17)), sales VAT trading with internal members (Eq. (18)), sales VAT trading with brand companies (Eq. (19)), input VAT trading with vendors (Eq. (20)), input VAT trading with internal members (Eq. (21)), export VAT trading with internal members in the same country (Eq. (22)), export VAT trading with brand companies in the same country (Eq. (23)), export VAT trading with internal members in different countries (Eq. (24)), export VAT trading with brand companies in different countries (Eq. (25)), import duty trading with internal members in the same country (Eq. (26)), import duty trading with brand companies in the same country (Eq. (27)), import duty trading with internal members in different countries (Eq. (28)), import duty trading with brand companies in different countries (Eq. (29)). Note that Eqs. (20) and (21) are minus items as mentioned in Section 2. Furthermore, the term $[TT_{\theta^x \lambda^y m} + CSF \times FS_{\theta^x \lambda^y m} + SSF_{\theta^x \alpha}\sqrt{TT_{\theta^x \lambda^y m}}]$ in Eqs. (13) and (14) is the total time required to calculate inventory costs (Vidal and Goetschalckx, 2000). Herein, the first term is the time required to measure the pipeline inventory; the second term is the time required to measure the cycle inventory; the third term is the time required to measure the safety stock (Vidal and Goetschalckx, 2000). The gamma distribution was adopted in the safety stock for modeling stochastic lead times and inventory problems (Vidal and Goetschalckx, 2000). Additionally, Vidal and Goetschalckx (2000) performed a more exhaustive study of Eqs. (13) and (14).

4.2. Constraints

Given that corresponding logistics conditions are limited by operating requirements, eleven groups of constraints are the following: flow conservation of deep and simple process, inbound flow conservation, outbound flow conservation, identifying goods transformations, maximum goods transformation, assignment of goods, brand company requirements, capacity of chain members, subtour breaking constraints, binary constraints, and non-negative constraints. These constraints are further elaborated below.

1. *Flow conservation of deep and simple process*: As Fig. 5 shows, deep process, including transforming modular components into semi-products, transforming modular components into finished products and transforming semi-products into finished products, are expressed as Eqs. (30)–(32), respectively. Simple process involving simple processing of semi-products and finished products are expressed as Eqs. (33) and (34), respectively.
2. *Inbound flow conservation*: Fig. 5 shows three inbound flows: modular components, semi-products, and finished products. Consequently, the corresponding inbound flow constraints are expressed as Eqs. (35)–(37), respectively.
3. *Outbound flow conservation*: As Fig. 5 shows, two outbound flows are semi-products and finished products. Regarding finished products, manufacturing centers only can convey finished products to DCs, while DCs convey finished products to brand companies or other DCs. Consequently, the corresponding outbound flow constraints are expressed as Eqs. (38)–(40), respectively.
4. *Identifying goods transformations*: For the sake of rational goods transformations and assignments, the expression $gotr_{\theta^x \alpha\beta}$ represents good transformations, including transformations from modular components into semi-products, from modular components into finished products and from semi-products into finished products. Accordingly, the corresponding constraints on goods transformations are expressed in Eqs. (41)–(43), respectively.
5. *Maximum goods transformation*: Eqs. (41)–(43) ensure only that if goods transformation occurs, the sum of $gotr_{\theta^x \alpha\beta}$ equals or exceeds one. Consequently, it is necessary to limit the maximum number of goods transformations, including those from modular components into semi-products, from modular components into finished products, and from semi-products into finished products. Thus, these constraints are expressed as Eqs. (44)–(46), respectively.
6. *Assignment of goods*: Each modular component can only be used once. Only one of two manufacturing procedures, including from modular components into either semi-products or finished products, can be used. Therefore, the corresponding constraint is given by Eq. (47). Similarly, since each semi-product can only be used once, the corresponding constraint is

given by Eq. (48). Finished products can be transferred among DCs, but one finished product only can be assigned once to a brand company. Restated, one company can only receive one unique finished product during the assignment process. Accordingly, the corresponding constraint is given by Eq. (49).

7. *Brand company requirements*: To meet brand company requirements, the corresponding constraint is given by Eq. (50).
8. *Capacity of chain members*: In addition to vender capacity to supply modular components (Eq. (51)), there are five capacities of internal supply chain members for goods transformation, including from modular components into semi-products, from modular components into finished products, from semi-products into finished products, simple process of semi-products and simple process of finished products. Accordingly, the corresponding constraints on five capacities of internal supply chain members are expressed as Eqs. (52)–(56), respectively.
9. *Subtour breaking constraints*: Since goods can transfer among DCs, Eq. (57) prohibits a formation of any subtour among them.
10. *Binary constraints*: Constraints denoted by Eqs. (58)–(62) indicate that those variables are binary.
11. *Non-negative constraints*: Constraints denoted by Eqs. (63) and (64) indicate that operating income variables are non-negative variables.

5. Numerical illustration

To test the applicability and the solvability of the proposed model, a simplified numerical study was conducted by interview. Table 1 outlines the main characteristics of the basic scenario. Moreover, country 1 has a lower logistics cost (such as deep processing costs) and greater processing capacity (such as deep processing capacity) than countries 2 and 3 in the basic scenario.

Fig. 6 displays five main patterns of the numerical results of logistics behavior. First, modular components were shipped from vendor (no. 2) to deep processing DC (no. 7) or deep processing DC (no. 8). Second, deep processing take place at deep processing DC (no. 7) or deep processing DC (no. 8) to transform modular components into semi-products. Third, semi-products were shipped from deep processing DC (no. 7) to another deep processing DC (no. 8), and simple processing of semi-products then took place at deep processing DC (no. 8). Fourth, semi-products were shipped from deep processing DC (no. 7) to non-bonded DC (no. 9) or from deep processing DC (no. 8) to non-bonded DC (no. 10) for further transformation of semi-products into finished products. Finally, finished products are shipped from non-bonded DC (no. 9) to brand company (no. 11) or from non-bonded DC (no. 10) to brand company (no. 12). Furthermore, some internal supply members operate at a profit (nos. 7, 9, 10), and others operate at a loss (nos. 3–6, 8).

More precisely, Table 2 presents an example of the steps in the creation of the finished product (no. 33) to meet the requirement of the brand company (no. 12). Herein, Fig. 7 displays an example of the deep process and the simple process regarding deep processing DC (no. 8).

To further examine logistics behavior, three extended scenarios and their numerical results are briefly narrated as follows. First, if tax areas were exempt from corporate tax as international logistics zones, most finished products would be directly manufactured at non-bonded DCs located close to brand companies (extended scenario) rather than at deep processing DCs in international logistics zones (basic scenario). Second, if tax areas were exempted from import duty as international logistics zones, most finished products would be directly manufactured in international logistics zones (extended scenario) rather than in tax areas (basic scenario). Third, if country 2 has the same logistics cost and processing capacity as country 1, then semi-products would not be shipped from country 1 to country 2 (extended scenario).

Based on the numerical results of logistics behavior mentioned above, some important findings are summarized and discussed as follows. First of all, most semi-products are manufactured in international logistics zones. The main reason for this result may be that goods manufactured in those zones are exempt from corporate tax. Secondly, most domestic (non-bonded) DCs import semi-products from international logistics zones, since import duties are lower for semi-products than for finished products. A similar concept was discussed in Simchi-Levi et al. (2003). Finally, the model demonstrates that most manufacturing behavior occurs in country 1, and semi-products are then shipped from country 1 to country 2. In reality, this may be owing to that manufacturers relocated their main processing capacity to low-cost zones (e.g. China) and has a lower processing capacity in the proximity of customers or in R&D zones (e.g. Taiwan). Similar situations are apparent elsewhere (Chia et al., 2001, 2002; Sheu, 2003).

Fig. 8 presents the results of sensitivity analysis conducted by varying tax parameters such as corporate tax rate, duty, VAT rate and VAT drawback rate. Expectedly, lower corporate tax rate, lower VAT rate and lower

Table 1
Main characteristics of the basic scenario.

Characteristics	Design value
Set of supply chain members	$FA^V=\{1,2\}$; $FA^M=\{3\}$; $FA^{Ds}=\{4,5,6\}$; $FA^{Dd}=\{7,8\}$; $FA^{Dn}=\{9,10\}$; $FA^B=\{11,12\}$
Set of goods	$G^r=\{1,\ldots,20\}$; $G^s=\{21,\ldots,30\}$; $G^p=\{31,\ldots,35\}$
Set of countries	$N=\{1,2,3\}$
Set of simple and deep process product lines	$SN_I^{rs}=\{1\}$; $SN_I^{rp}=\{2\}$; $SN_I^{sp}=\{3\}$; $SN_I^{ss}=\{4\}$; $SN_I^{pp}=\{5\}$; $SN_O^{rs}=\{6\}$; $SN_O^{rp}=\{7\}$; $SN_O^{sp}=\{8\}$; $SN_O^{ss}=\{9\}$; $SN_O^{pp}=\{10\}$
Set of transportation modes	$\Omega=\{$air transportation: 1, sea transportation: 2, truck: 3$\}$
Required finished products	$BR_{11^1}=3$ (orders); $BR_{12^2}=2$ (orders)
Equivalent of goods	$BOM_{rs}=2$; $BOM_{sp}=2$; $BOM_{rp}=4$

Note: Per order of 100 goods.

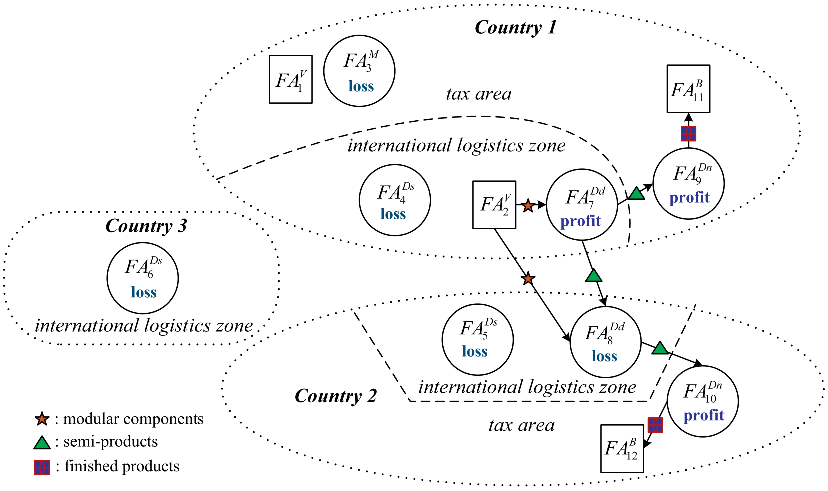

Fig. 6. Numerical results of logistics behavior.

Table 2
Behavior of *P*33 for delivering finished products to brand company 12.

*R*6–*S*23: *qu*(2, 8, 1, 6)→*gt*(8, 6, 1)→*gotr*(8, 6, 23)→*gt*(8, 23, 6)
*R*10–*S*23: *qu*(2, 8, 1, 10)→*gt*(8, 10, 1)→*gotr*(8, 10, 23)→*gt*(8, 23, 6)
*R*7–*S*24: *qu*(2, 7, 1, 7)→*gt*(7, 7, 1)→*gotr*(7, 7, 24)→*gt*(7, 24, 6)
*R*13–*S*24: *qu*(2, 7, 1, 13)→*gt*(7, 13, 1)→*gotr*(7, 13, 24)→*gt*(7, 24, 6)
*S*24–*S*24: *qu*(7, 8, 2, 24)→*gt*(8, 24, 4)→*gt*(8, 24, 9)
*S*23–*P*33: *qu*(8, 10, 3, 23)→*gt*(10, 23, 3)→*gotr*(10, 23, 33)→*gt*(10, 33, 8)
*S*24–*P*33: *qu*(8, 10, 3, 24)→*gt*(10, 24, 3)→*gotr*(10, 24, 33)→*gt*(10, 33, 8)
*P*33: *qu*(10, 12, 3, 33)

Note: *R* indicates modular components; *S* indicates semi-products; *P* indicates finished products. One dash linking two goods means deep process (e.g., *R*6–*S*23) or simple process (e.g., *S*24–*S*24) while single goods indicates shipping goods (e.g., *P*33). Here, *qu*, *gu* and *gotr* are main decision variables. Four terms within the *qu* bracket represent former member (origin), latter member (destination), transportation mode and goods, respectively. Three terms within the *gt* bracket denote chain member, goods and product line, respectively. Three terms within the *gotr* bracket indicate chain member, ancestor goods, and descendant goods, respectively.

duty all tend to increase after-tax profit. Notably, the VAT drawback rate does not affect after-tax profit, since lack of logistics behavior meets the charge condition of VAT drawback rate in the basic scenario. This finding also reveals that manufacturers can avoid government regulation strategies of VAT drawback rate through operating in international logistics zones. Overall, the sensitivity analysis demonstrates the robustness of the proposed model, and most tax factors are sensitive to after-tax profit. The above tax factors would be of importance to manufacturers seeking to maximize profit by global logistics strategies.

6. Conclusion

The emerging global manufacturing network involves nodal location features of tax areas and international logistics zones, manufacturing procedures of simple process and deep process in these nodes, as well as transportation arcs. This study presented several tax savings approaches and developed a tax savings model for the emerging global manufacturing network. The numerical illustration demonstrates that the model is valid and viable as an analytical tool for global manufactures. The major decision-making parameters can be tailored to specific global manufacturers.

The numerical illustration reveals the following crucial findings. First, manufacturers can produce goods in international logistics zones to save corporate tax. Second, manufacturers can import ancestor goods (e.g. semi-products) with lower duty rates and transform them into descendant goods (e.g. finished products) in tax areas to save duty. Third, manufacturers can operate in international logistics zones to avoid government regulation of VAT drawback rate. Finally, most manufacturing behavior occurs in zones with lower logistics costs and greater processing capacity to maximize their global profit.

This study differs from previous studies addressing profit-maximizing problems in several ways. First, this study examined three primary tax factors associated with operating income—import duty, value added tax and corporate tax—via in-depth interviews with global manufacturers. Furthermore, tax savings approaches for the emerging global manufacturing network were also discussed. Second, the tax savings model for the emerging global manufacturing network helps manufacturers identify solutions that maximize after-tax profit. The proposed model can determine the optimal tax savings route and manufacturing procedure for each order. For tax savings, the proposed model allows goods free transfer among processing DCs. Additionally, three principal tax factors are considered simultaneously in the proposed model. Global manufacturers can develop strategies using the proposed model for maximizing preferential tax treatment in international logistics zones to achieve tax savings. Moreover, the proposed model identifies the critical logistics behavior associated with tax savings. The proposed model may stimulate further research in the field of global logistics and may help address issues regarding tax savings and international logistics zones.

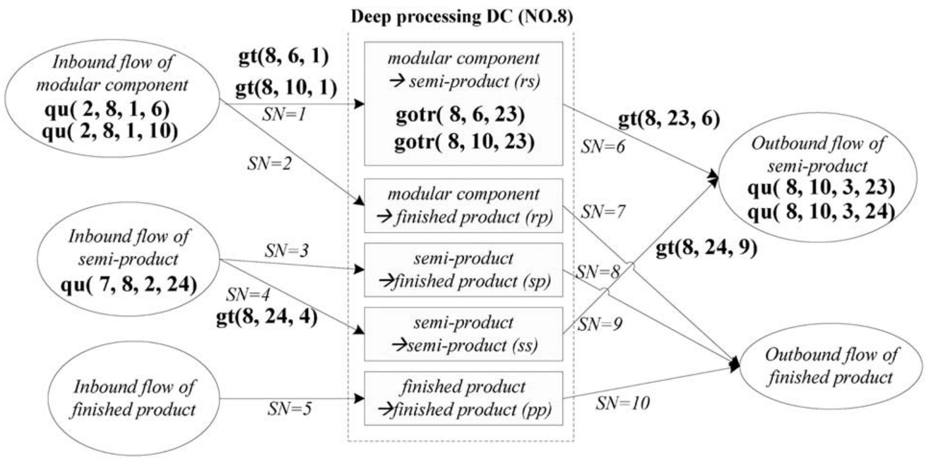

Fig. 7. An illustrative example of the deep process and the simple process.

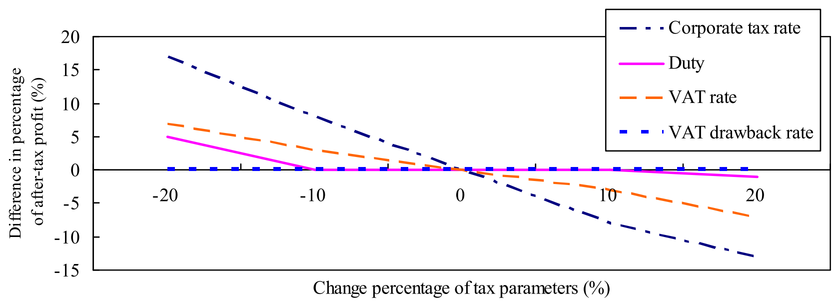

Fig. 8. Sensitivity of after-tax profit with respect to variant tax parameters.

Future studies may also incorporate quotas, certificate of origin and local content into the tax savings model. The model may also be extended to a product family and its bill-of-materials (BOM). Moreover, large-scale instances of profit-maximizing problems in a numerical study should be carefully generated to approximate reality as much as possible. The continuing relevance of the proposed model is expected in further studies.

Acknowledgments

This research was supported by Grant NSC 95-2415-H009-003-MY2 from the National Science Council of Taiwan. The valuable suggestions of Professor Mu-Chen Chen to improve this paper are gratefully acknowledged. Also, special thanks to Professor Marc Goetschalckx for his helpful report in conducting this study. Finally, the authors are deeply indebted to numerous personnel in the examined global manufacturers for their cooperation in interviews and scenario design. Any errors or omissions remain the sole responsibility of the authors.

Appendix A. Notations and definitions

All the notations and definitions for sets, decision variables and parameters are summarized as follows.

A.1. Sets

FA Set of internal and external supply chain members. Herein, FA^V: set of vendors (abbreviated as *V*); FA^M: set of manufacturing centers (abbreviated as *M*); FA^{Ds}: set of simple processing DCs (abbreviated as *Ds*; FA^{Dd}: set of deep processing DCs (abbreviated as *Dd*); FA^{Dn}: set of non-bonded DC (abbreviated as *Dn*); FA^B: set of brand companies (abbreviated as *B*); FA^I: set of all internal supply chain members (abbreviated as *I*); FA^{DC}: set of all DCs, including deep processing DCs, simple processing DCs and non-bonded DCs (abbreviated as *DC*); FA_C: set of chain members in international logistics zones (abbreviated as *C*); FA_T: set of chain members in tax areas (abbreviated as *T*)

G Set of types of goods. Herein, G^r: set of modular components (abbreviated as *r*); G^s: set of semi-products (abbreviated as *s*); G^p: set of finished products (abbreviated as *p*)

N Set of countries

SN Set of simple and deep process product lines. Herein, SN^{rs}: set of product lines involving transformation of modular components *r* into semi-products *s* (abbreviated as *rs*); SN^{rp}: set of product lines involving transformation of modular components *r* into finished products *p* (abbreviated as *rp*); SN^{sp}: set of product lines involving transformation of semi-products *s* into finished products *p* (abbreviated as *sp*); SN^{ss}: set of product lines involving simple processing of semi-products *s* (abbreviated as *ss*); SN^{pp}: set of product lines involving simple processing of finished products *p* (abbreviated as *pp*); SN_I: set of product lines of inbound flow (abbreviated as *I*); SN_O: set of product lines of outbound flow (abbreviated as *O*); SN^R: set of product lines of sum of corresponding modular components (abbreviated as *R*); SN^S: set of product lines of sum of corresponding semi-products (abbreviated as S); SN^P: set of product lines of sum of corresponding finished products (abbreviated as P)

Ω Set of transportation modes. Here, $\Omega(\theta^x, \lambda^y)$ is the set of available transportation modes between a given chain member θ in the country $x \in N$ and another given chain member λ in the country $y \in N$

A.2. Decision variables

$gotr_{\theta^x \alpha\beta}$ Binary decision variable indicates whether goods transformation occurs at a given chain member θ in country $x \in N$ when transferring ancestor goods α into descendant goods β

$gt_{\theta^x \alpha f}$ Binary decision variable indicates whether goods α is in progress in a product line f at a given chain member θ in country $x \in N$

oi_{θ^x} Operating income of a given chain member θ in country $x \in N$ for the period of analysis (dollar/unit of time)

$ord_{\theta^x \alpha}$ Number of nodes visited on the transfer path from the origin up to node θ^x for goods α (i.e., the visit number of the θ^xth node)

$qu_{\theta^x \lambda^y m\alpha}$ Binary decision variable representing whether goods $\alpha \in G$ is shipped from a given chain member θ in country $x \in N$ to another given chain member λ in country $y \in N$, using transportation mode $m \in \Omega(\theta^x, \lambda^y)$.

A.3. Parameters

BR_{λ^y} Required finished products for a given chain member λ in country $y \in N$ (units of p/unit of time)

$BOM_{\alpha\beta}$ Units of ancestor goods $\alpha \in G$ required to make one unit of descendant goods $B \in G$ (α-units/β-unit)

BN A big number

CSF Cycle stock factor (%)

COT_{θ^x} Corporate tax rate (%) of country $x \in N$ of a supply chain member θ

$CPRICE_{\alpha}$ International contract price of goods $\alpha \in G$ (dollar/unit of goods α)

$DRT_{\theta^x \alpha}$ Value added tax drawback rate (%) on the value of goods $\alpha \in G$ of country $x \in N$ of supply chain member θ

$DUTY_{\theta^x \lambda^y \alpha}$ Import duty rate (%) on the value of goods $\alpha \in G$ shipped from a given chain member θ in country $x \in N$ to another given chain member λ in country $y \in N$

E_{θ^x} Exchange rate of country $x \in N$ of supply chain member θ (monetary units of the respective country/dollar)

FIX_{θ^x} Fixed cost associated with a given chain member θ in country $x \in N$ (monetary units of country of member θ per unit of time)

$FS_{\theta^x \lambda^y m}$ Frequency of goods shipments from a given chain member θ in country $x \in N$ to another given chain member λ in country $y \in N$, using transportation mode $m \in \Omega(\theta^x, \lambda^y)$ (units of time)

H Holding cost (\$/(\$. unit of time))

$IV_{\theta^x \alpha}$ Inventory value of goods $\alpha \in G$, given in monetary units of a given chain member θ in country $x \in N$ per unit of goods α

$NODE$ Number of DC nodes

$PROC_{\lambda^y \theta^x \alpha}$ Procurement cost (including total cost and taxes) of goods $\alpha \in G$ shipped from a given chain member λ in country $y \in N$ to another given chain member θ in country $x \in N$ (monetary units of country of member λ/unit of goods α)

PPA_{θ^x} Simple processing capacity of finished products in a given chain member θ in country $x \in N$ (finished product units/unit of time)

PPC_{θ^x} Simple processing cost of finished products in a given chain member θ in country $x \in N$ (monetary units of country of member θ/unit of finished product)

RSA_{θ^x} Capacity to transform goods associated with a given chain member θ in country $x \in N$ for transferring modular components into semi-products (semi-product units/unit of time)

RSC_{θ^x} Cost of transforming goods associated with a given chain member θ in country $x \in N$ for transferring modular components into semi-products (monetary units of country of member θ/unit of semi-products)

RPA_{θ^x} Capacity to transform goods associated with a given chain member θ in country $x \in N$ for transferring modular components into finished products (finished product units/unit of time)

RPC_{θ^x} Cost of transforming goods associated with a given chain member θ in country $x \in N$ for transferring modular components into finished products in country $x \in N$ (monetary units of country of member θ/unit of finished products)

SPA_{θ^x} Capacity to transform goods associated with a given chain member θ in country $x \in N$ for transferring semi-products into finished products (finished product units/unit of time)

SPC_{θ^x} Cost of transforming goods associated with a given chain member θ in country $x \in N$ for transferring semi-products into finished products (monetary units of country of member θ/unit of finished products)

SSA_{θ^x} Simple processing capacity of semi-product in a given chain member θ in country $x \in N$ (semi-product units/unit of time)

SSC_{θ^x} Simple processing cost of semi-product in a given chain member θ in country $x \in N$ (monetary units of country of member θ/unit of s)

$SSF_{\theta^x \alpha}$ Safety stock factor of goods $\alpha \in G$ at a given chain member θ in country $x \in N$

$TP_{\theta^x \alpha}$ Transfer price of goods $\alpha \in G$ shipped from a given chain member θ in country $x \in N$ (monetary units of country of member θ/unit of goods α)

$TRC_{\theta^x \lambda^y m}$ Transportation cost per weight unit of goods shipped from a given chain member θ in country $x \in N$ to another given chain member λ in country $y \in N$, using transportation mode $m \in \Omega(\theta^x, \lambda^y)$ (monetary units of country of member θ/weight unit)

$TT_{\theta^x \lambda^y m}$ Average transportation time from a given chain member θ in country $x \in N$ to another given chain member λ in country $y \in N$, using transportation mode $m \in \Omega(\theta^x, \lambda^y)$ (units of time)

VC_{θ^x} Capacity of a given chain member θ in country $x \in N$ for supplying modular components (modular component units/unit of time)

$VAT_{\theta^x \alpha}$ Value added tax rate (%) on the value of goods $\alpha \in G$ of country $x \in N$ of supply chain member θ

W_{α} Weight of a unit of goods $\alpha \in G$ (weight units/unit of goods)

Appendix B. The equations of the proposed model

The objective function and constraints of the proposed model are presented as follows:

$$\text{Maximize} \sum_{\theta^x \in FA^I} [(1 - COT_{\theta^x}) oi^+_{\theta^x} - oi^-_{\theta^x}] \tag{2}$$

$$oi^+_{\theta^x} - oi^-_{\theta^x} = revenue_{\theta^x} - cost_{\theta^x} \quad \forall \theta^x \in FA^I \tag{3}$$

$$\pi^1_{\theta^x} = \sum_{\lambda^y (\theta^x \neq \lambda^y) \in FA^I} \sum_{m \in \Omega(\theta^x, \lambda^y)} \sum_{\alpha \in G^{sp}} \frac{1}{E_{\theta^x}} \times TP_{\theta^x \alpha} \times qu_{\theta^x \lambda^y m\alpha} \quad \forall \theta^x \in FA^I \tag{4}$$

$$\pi^2_{\theta^x} = \sum_{\lambda^y \in FA^B} \sum_{m \in \Omega(\theta^x, \lambda^y)} \sum_{\alpha \in G^p} CPRICE_{\alpha} \times qu_{\theta^x \lambda^y m\alpha} \quad \forall \theta^x \in FA^{DC} \tag{5}$$

$$z^1_{\theta^x} = \sum_{\alpha \in G^s} \sum_{f \in SN^{rs}_O} \frac{1}{E_{\theta^x}} \times RSC_{\theta^x} \times gt_{\theta^x \alpha f} \quad \forall \theta^x \in \{FA^M, FA^{Dd}, FA^{Dn}\} \tag{6}$$

$$z^2_{\theta^x} = \sum_{\alpha\in G^p}\sum_{f\in SN^{rp}_O}\frac{1}{E_{\theta^x}}\times RPC_{\theta^x}\times gt_{\theta^x\alpha f}\quad \forall\theta^x\in\{FA^M, FA^{Dd}, FA^{Dn}\} \tag{7}$$

$$z^3_{\theta^x} = \sum_{\alpha\in G^p}\sum_{f\in SN^{sp}_O}\frac{1}{E_{\theta^x}}\times SPC_{\theta^x}\times gt_{\theta^x\alpha f}\quad \forall\theta^x\in\{FA^{Dd}, FA^{Dn}\} \tag{8}$$

$$z^4_{\theta^x} = \sum_{\alpha\in G^s}\sum_{f\in SN^{ss}_O}\frac{1}{E_{\theta^x}}\times SSC_{\theta^x}\times gt_{\theta^x\alpha f}\quad \forall\theta^x\in FA^{DC} \tag{9}$$

$$z^5_{\theta^x} = \sum_{\alpha\in G^p}\sum_{f\in SN^{pp}_O}\frac{1}{E_{\theta^x}}\times PPC_{\theta^x}\times gt_{\theta^x\alpha f}\quad \forall\theta^x\in FA^{DC} \tag{10}$$

$$z^6_{\theta^x} = \sum_{\lambda^y(\theta^x\neq\lambda^y)\in FA^I}\sum_{m\in\Omega(\theta^x,\lambda^y)}\sum_{\alpha\in G^{SP}}\frac{1}{E_{\theta^x}}\times TRC_{\theta^x\lambda^y m}\times W_\alpha\times qu_{\theta^x\lambda^y m\alpha}\quad \forall\theta^x\in FA^I \tag{11}$$

$$z^7_{\theta^x} = \sum_{\lambda^y\in FA^B}\sum_{m\in\Omega(\theta^x,\lambda^y)}\sum_{\alpha\in G^P}\frac{1}{E_{\theta^x}}\times TRC_{\theta^x\lambda^y m}\times W_\alpha\times qu_{\theta^x\lambda^y m\alpha}\quad \forall\theta^x\in FA^{DC} \tag{12}$$

$$z^8_{\theta^x} = \sum_{\lambda^y(\theta^x\neq\lambda^y)\in FA^I}\sum_{m\in\Omega(\theta^x,\lambda^y)}\sum_{\alpha\in G^{SP}}\frac{IV_{\theta^x\alpha}\times H}{E_{\theta^x}}[TT_{\theta^x\lambda^y m}+CSF\times FS_{\theta^x\lambda^y m}+SSF_{\theta^x\alpha}\sqrt{TT_{\theta^x\lambda^y m}}]qu_{\theta^x\lambda^y m\alpha}\quad \forall\theta^x\in FA^I \tag{13}$$

$$z^9_{\theta^x} = \sum_{\lambda^y\in FA^B}\sum_{m\in\Omega(\theta^x,\lambda^y)}\sum_{\alpha\in G^P}\frac{IV_{\theta^x\alpha}\times H}{E_{\theta^x}}[TT_{\theta^x\lambda^y m}+CSF\times FS_{\theta^x\lambda^y m}+SSF_{\theta^x\alpha}\sqrt{TT_{\theta^x\lambda^y m}}]qu_{\theta^x\lambda^y m\alpha}\quad \forall\theta^x\in FA^{DC} \tag{14}$$

$$z^{10}_{\theta^x} = \sum_{\lambda^y\in FA^V}\sum_{m\in\Omega(\lambda^y,\theta^x)}\sum_{\alpha\in G^r}\frac{1}{E_{\lambda^y}}\times PROC_{\lambda^y\theta^x\alpha}\times qu_{\lambda^y\theta^x m\alpha}\quad \forall\theta^x\in\{FA^M, FA^{Dd}, FA^{Dn}\} \tag{15}$$

$$z^{11}_{\theta^x} = \sum_{\lambda^y(\theta^x\neq\lambda^y)\in FA^I}\sum_{m\in\Omega(\lambda^y,\theta^x)}\sum_{\alpha\in G^{sp}}\frac{1}{E_{\lambda^y}}\times TP_{\lambda^y\alpha}\times qu_{\lambda^y\theta^x m\alpha}\quad \forall\theta^x\in FA^I \tag{16}$$

$$z^{12}_{\theta^x} = \frac{1}{E_{\theta^x}}\times FIX_{\theta^x}\quad \forall\theta^x\in FA^I \tag{17}$$

$$z^{13}_{\theta^x} = \sum_{\lambda^y(\theta^x\neq\lambda^y\&x=y)\in FA^I_T}\sum_{m\in\Omega(\theta^x,\lambda^y)}\sum_{\alpha\in G^{sp}}\frac{1}{E_{\theta^x}}\times TP_{\theta^x\alpha}\times qu_{\theta^x\lambda^y m\alpha}\times VAT_{\theta^x\alpha}\quad \forall\theta^x\in FA^I \tag{18}$$

$$z^{14}_{\theta^x} = \sum_{\lambda^y(x=y)\in FA^B_T}\sum_{m\in\Omega(\theta^x,\lambda^y)}\sum_{\alpha\in G^P} CPRICE_\alpha\times qu_{\theta^x\lambda^y m\alpha}\times VAT_{\theta^x\alpha}\quad \forall\theta^x\in FA^{DC} \tag{19}$$

$$z^{15}_{\theta^x} = \sum_{\lambda^y\in FA^V,\theta^x\&\lambda^y\notin FA_C}\sum_{m\in\Omega(\lambda^y,\theta^x)}\sum_{\alpha\in G^r}\frac{1}{E_{\lambda^y}}\times PROC_{\lambda^y\theta^x\alpha}\times qu_{\lambda^y\theta^x m\alpha}\times VAT_{\lambda^y\alpha}\quad \forall\theta^x\in\{FA^M, FA^{Dd}, FA^{Dn}\} \tag{20}$$

$$z^{16}_{\theta^x} = \sum_{\lambda^y(\theta^x\neq\lambda^y)\in FA^I,\theta^x\&\lambda^y\notin FA_C}\sum_{m\in\Omega(\lambda^y,\theta^x)}\sum_{\alpha\in G^{sp}}\frac{1}{E_{\lambda^y}}\times TP_{\lambda^y\alpha}\times qu_{\lambda^y\theta^x m\alpha}\times VAT_{\lambda^y\alpha}\quad \forall\theta^x\in FA^I \tag{21}$$

$$z^{17}_{\theta^x} = \sum_{\lambda^y(\theta^x\neq\lambda^y\&x=y)\in FA^I_C}\sum_{m\in\Omega(\theta^x,\lambda^y)}\sum_{\alpha\in G^{sp}}\frac{1}{E_{\theta^x}}\times TP_{\theta^x\alpha}\times qu_{\theta^x\lambda^y m\alpha}\times(VAT_{\theta^x\alpha}-DRT_{\theta^x\alpha})\quad \forall\theta^x\in FA^I_T \tag{22}$$

$$z^{18}_{\theta^x} = \sum_{\lambda^y(\theta^x\neq\lambda^y\&x=y)\in FA^B_C}\sum_{m\in\Omega(\theta^x,\lambda^y)}\sum_{\alpha\in G^p} CPRICE_\alpha\times qu_{\theta^x\lambda^y m\alpha}\times(VAT_{\theta^x\alpha}-DRT_{\theta^x\alpha})\quad \forall\theta^x\in FA^{DC}_T \tag{23}$$

$$z^{19}_{\theta^x} = \sum_{\lambda^y(\theta^x\neq\lambda^y\&x\neq y)\in FA^I,\theta^x\&\lambda^y\notin FA_C}\sum_{m\in\Omega(\theta^x,\lambda^y)}\sum_{\alpha\in G^{sp}}\frac{1}{E_{\theta^x}}\times TP_{\theta^x\alpha}\times qu_{\theta^x\lambda^y m\alpha}\times(VAT_{\theta^x\alpha}-DRT_{\theta^x\alpha})\quad \forall\theta^x\in FA^I \tag{24}$$

$$z^{20}_{\theta^x} = \sum_{\lambda^y(\theta^x\neq\lambda^y\&x\neq y)\in FA^B,\theta^x\&\lambda^y\notin FA_C}\sum_{m\in\Omega(\theta^x,\lambda^y)}\sum_{\alpha\in G^p} CPRICE_\alpha\times qu_{\theta^x\lambda^y m\alpha}\times(VAT_{\theta^x\alpha}-DRT_{\theta^x\alpha})\quad \forall\theta^x\in FA^{DC} \tag{25}$$

$$z^{21}_{\theta^x} = \sum_{\lambda^y(\theta^x\neq\lambda^y\&x=y)\in FA^I_T}\sum_{m\in\Omega(\theta^x,\lambda^y)}\sum_{\alpha\in G^{sp}}\frac{1}{E_{\theta^x}}\times(TP_{\theta^x\alpha}+TRC_{\theta^x\lambda^y m}\times W_\alpha)\times qu_{\theta^x\lambda^y m\alpha}\times DUTY_{\theta^x\lambda^y\alpha}\quad \forall\theta^x\in FA^I_C \tag{26}$$

$$z^{22}_{\theta^x} = \sum_{\lambda^y(\theta^x\neq\lambda^y\&x=y)\in FA^B_T}\sum_{m\in\Omega(\theta^x,\lambda^y)}\times\sum_{\alpha\in G^p}\left(CPRICE_\alpha+\frac{1}{E_{\theta^x}}\times TRC_{\theta^x\lambda^y m}\times W_\alpha\right)\times qu_{\theta^x\lambda^y m\alpha}\times DUTY_{\theta^x\lambda^y\alpha}\quad \forall\theta^x\in FA^{DC}_C \tag{27}$$

$$z^{23}_{\theta^x} = \sum_{\lambda^y(\theta^x\neq\lambda^y\&x\neq y)\in FA^I_T}\sum_{m\in\Omega(\theta^x,\lambda^y)}\sum_{\alpha\in G^{SP}}\frac{1}{E_{\theta^x}}\times(TP_{\theta^x\alpha}+TRC_{\theta^x\lambda^y m}\times W_\alpha)\times qu_{\theta^x\lambda^y m\alpha}\times DUTY_{\theta^x\lambda^y\alpha}\quad \forall\theta^x\in FA^I \tag{28}$$

$$z^{24}_{\theta^x} = \sum_{\lambda^y(\theta^x\neq\lambda^y\&x\neq y)\in FA^B_T}\sum_{m\in\Omega(\theta^x,\lambda^y)}\times\sum_{\alpha\in G^P}\left(CPRICE_\alpha+\frac{1}{E_{\theta^x}}\times TRC_{\theta^x\lambda^y m}\times W_\alpha\right)\times qu_{\theta^x\lambda^y m\alpha}\times DUTY_{\theta^x\lambda^y\alpha}\quad \forall\theta^x\in FA^{DC} \tag{29}$$

$$\sum_{\alpha\in G^r}\sum_{f\in SN^{rs}_I} gt_{\theta^x\alpha f} = \sum_{\beta\in G^s}\sum_{f\in SN^{rs}_O} gt_{\theta^x\beta f}\times BOM_{\alpha\beta}\quad \forall\theta^x\in\{FA^M, FA^{Dd}, FA^{Dn}\} \tag{30}$$

$$\sum_{\alpha\in G^r}\sum_{f\in SN^{rp}_I} gt_{\theta^x\alpha f} = \sum_{\beta\in G^p}\sum_{f\in SN^{rp}_O} gt_{\theta^x\beta f}\times BOM_{\alpha\beta}\quad \forall\theta^x\in\{FA^M, FA^{Dd}, FA^{Dn}\} \tag{31}$$

$$\sum_{\alpha\in G^s}\sum_{f\in SN^{sp}_I} gt_{\theta^x\alpha f} = \sum_{\beta\in G^p}\sum_{f\in SN^{sp}_O} gt_{\theta^x\beta f}\times BOM_{\alpha\beta}\quad \forall\theta^x\in\{FA^{Dd}, FA^{Dn}\} \tag{32}$$

$$\sum_{f\in SN_I^{ss}} gt_{\theta^x\alpha f} = \sum_{f\in SN_O^{ss}} gt_{\theta^x\alpha f} \quad \forall\theta^x \in \{FA^{Dd}, FA^{Ds}, FA^{Dn}\} \quad \forall\alpha \in G^s \tag{33}$$

$$\sum_{f\in SN_I^{pp}} gt_{\theta^x\alpha f} = \sum_{f\in SN_O^{pp}} gt_{\theta^x\alpha f} \quad \forall\theta^x \in \{FA^{Dd}, FA^{Ds}, FA^{Dn}\} \quad \forall\alpha \in G^p \tag{34}$$

$$\sum_{\theta^x\in FA^V} \sum_{m\in\Omega(\theta^x,\lambda^y)} qu_{\theta^x\lambda^y m\alpha} = \sum_{f\in SN_I^R} gt_{\lambda^y\alpha f} \quad \forall\lambda^y \in \{FA^M, FA^{Dd}, FA^{Dn}\}, \quad \alpha \in G^r \tag{35}$$

$$\sum_{\theta^x(\theta^x\neq\lambda^y)\in FA^I} \sum_{m\in\Omega(\theta^x,\lambda^y)} qu_{\theta^x\lambda^y m\alpha} = \sum_{f\in SN_I^S} gt_{\lambda^y\alpha f} \quad \forall\lambda^y \in \{FA^{DC}\}, \quad \alpha \in G^s \tag{36}$$

$$\sum_{\theta^x(\theta^x\neq\lambda^y)\in FA^I} \sum_{m\in\Omega(\theta^x,\lambda^y)} qu_{\theta^x\lambda^y m\alpha} = \sum_{f\in SN_I^P} gt_{\lambda^y\alpha f} \quad \forall\lambda^y \in \{FA^{DC}\}, \quad \alpha \in G^p \tag{37}$$

$$\sum_{f\in SN_O^S} gt_{\theta^x\alpha f} = \sum_{\lambda^y(\theta^x\neq\lambda^y)\in FA^{DC}} \sum_{m\in\Omega(\theta^x,\lambda^y)} qu_{\theta^x\lambda^y m\alpha} \quad \forall\theta^x \in FA^I, \quad \alpha \in G^s \tag{38}$$

$$\sum_{f\in SN_O^P} gt_{\theta^x\alpha f} = \sum_{\lambda^y\in FA^{DC}} \sum_{m\in\Omega(\theta^x,\lambda^y)} qu_{\theta^x\lambda^y m\alpha} \quad \forall\theta^x \in FA^M, \quad \alpha \in G^p \tag{39}$$

$$\sum_{f\in SN_O^P} gt_{\theta^x\alpha f} = \sum_{\lambda^y(\theta^x\neq\lambda^y)\in\{FA^{DC},FA^B\}} \sum_{m\in\Omega(\theta^x,\lambda^y)} qu_{\theta^x\lambda^y m\alpha} \quad \forall\theta^x \in FA^{DC}, \quad \alpha \in G^p \tag{40}$$

$$\begin{cases} \sum_{\alpha\in G^r} gotr_{\theta^x\alpha\beta} \le \sum_{f\in SN_O^{rs}} gt_{\theta^x\beta f} * BN \\ \sum_{f\in SN_O^{rs}} gt_{\theta^x\beta f} \le \sum_{\alpha\in G^r} gotr_{\theta^x\alpha\beta} * BN \end{cases} \quad \forall\theta^x \in \{FA^M, FA^{Dd}, FA^{Dn}\}, \quad \beta \in G^s \tag{41}$$

$$\begin{cases} \sum_{\alpha\in G^r} gotr_{\theta^x\alpha\beta} \le \sum_{f\in SN_O^{rp}} gt_{\theta^x\beta f} * BN \\ \sum_{f\in SN_O^{rp}} gt_{\theta^x\beta f} \le \sum_{\alpha\in G^r} gotr_{\theta^x\alpha\beta} * BN \end{cases} \quad \forall\theta^x \in \{FA^M, FA^{Dd}, FA^{Dn}\}, \quad \beta \in G^p \tag{42}$$

$$\begin{cases} \sum_{\alpha\in G^s} gotr_{\theta^x\alpha\beta} \le \sum_{f\in SN_O^{sp}} gt_{\theta^x\beta f} * BN \\ \sum_{f\in SN_O^{sp}} gt_{\theta^x\beta f} \le \sum_{\alpha\in G^s} gotr_{\theta^x\alpha\beta} * BN \end{cases} \quad \forall\theta^x \in \{FA^{Dd}, FA^{Dn}\}, \quad \beta \in G^p \tag{43}$$

$$\sum_{\theta^x\in\{FA^M,FA^{Dd},FA^{Dn}\}} \sum_{\alpha\in G^r} gotr_{\theta^x\alpha\beta} \le \sum_{\alpha\in G^r} BOM_{\alpha\beta} \quad \forall\beta \in G^s \tag{44}$$

$$\sum_{\theta^x\in\{FA^M,FA^{Dd},FA^{Dn}\}} \sum_{\alpha\in G^r} gotr_{\theta^x\alpha\beta} \le \sum_{\alpha\in G^r} BOM_{\alpha\beta} \quad \forall\beta \in G^p \tag{45}$$

$$\sum_{\theta^x\in\{FA^{Dd},FA^{Dn}\}} \sum_{\alpha\in G^s} gotr_{\theta^x\alpha\beta} \le \sum_{\alpha\in G^s} BOM_{\alpha\beta} \quad \forall\beta \in G^p \tag{46}$$

$$\sum_{\theta^x\in\{FA^M,FA^{Dd},FA^{Dn}\}} \sum_{\beta\in G^s} gotr_{\theta^x\alpha\beta} + \sum_{\theta^x\in\{FA^M,FA^{Dd},FA^{Dn}\}} \sum_{\omega\in G^p} gotr_{\theta^x\alpha\omega} \le 1 \quad \forall\alpha \in G^r \tag{47}$$

$$\sum_{\theta^x\in\{FA^{Dd},FA^{Dn}\}} \sum_{\beta\in G^p} gotr_{\theta^x\alpha\beta} \le 1 \quad \forall\alpha \in G^s \tag{48}$$

$$\sum_{\theta^x\in FA^{DC}} \sum_{\lambda^y\in FA^B} \sum_{m\in\Omega(\theta^x,\lambda^y)} qu_{\theta^x\lambda^y m\alpha} = 1 \quad \forall\alpha \in G^p \tag{49}$$

$$\sum_{\theta^x\in FA^{DC}} \sum_{m\in(\theta^x,\lambda^y)} \sum_{\alpha\in G^p} qu_{\theta^x\lambda^y m\alpha} = BR_{\lambda^y} \quad \forall\lambda^y \in FA^B \tag{50}$$

$$\sum_{\lambda^y\in\{FA^M,FA^{Dd},FA^{Dn}\}} \sum_{m\in\Omega(\theta^x,\lambda^y)} \sum_{\alpha\in G^r} qu_{\theta^x\lambda^y m\alpha} \le VC_{\theta^x} \quad \forall\theta^x \in FA^V \tag{51}$$

$$\sum_{\alpha\in G^s} \sum_{f\in SN_O^{rs}} gt_{\theta^x\alpha f} \le RSA_{\theta^x} \quad \forall\theta^x \in \{FA^M, FA^{Dd}, FA^{Dn}\} \tag{52}$$

$$\sum_{\alpha\in G^p} \sum_{f\in SN_O^{rp}} gt_{\theta^x\alpha f} \le RPA_{\theta^x} \quad \forall\theta^x \in \{FA^M, FA^{Dd}, FA^{Dn}\} \tag{53}$$

$$\sum_{\alpha\in G^p} \sum_{f\in SN_O^{sp}} gt_{\theta^x\alpha f} \le SPA_{\theta^x} \quad \forall\theta^x \in \{FA^{Dd}, FA^{Dn}\} \tag{54}$$

$$\sum_{\alpha\in G^s} \sum_{f\in SN_O^{ss}} gt_{\theta^x\alpha f} \le SSA_{\theta^x} \quad \forall\theta^x \in \{FA^{DC}\} \tag{55}$$

$$\sum_{\alpha\in G^p} \sum_{f\in SN_O^{pp}} gt_{\theta^x\alpha f} \le PPA_{\theta^x} \quad \forall\theta^x \in \{FA^{DC}\} \tag{56}$$

$$ord_{\theta^x\alpha} - ord_{\lambda^y\alpha} + NODE \sum_{m\in\Omega(\theta^x,\lambda^y)} qu_{\theta^x\lambda^y m\alpha} \le NODE - 1 \quad \forall\theta^x \neq \lambda^y \in FA^{DC}, \quad \alpha \in \{G^s, G^p\} \tag{57}$$

$$gotr_{\theta^x\alpha\beta} \in \{0,1\} \quad \forall\theta^x \in \{FA^M, FA^{Dd}, FA^{Dn}\}, \ \alpha \in G^r, \ \beta \in G^s \tag{58}$$

$$gotr_{\theta^x\alpha\beta} \in \{0,1\} \quad \forall\theta^x \in \{FA^M, FA^{Dd}, FA^{Dn}\}, \ \alpha \in G^r, \ \beta \in G^p \tag{59}$$

$$gotr_{\theta^x\alpha\beta} \in \{0,1\} \quad \forall\theta^x \in \{FA^{Dd}, FA^{Dn}\}, \ \alpha \in G^s, \ \beta \in G^p \tag{60}$$

$$gt_{\theta^x\alpha f} \in \{0,1\} \quad \forall\theta^x \in FA^I, \ \alpha \in G, \ f \in SN \tag{61}$$

$$qu_{\theta^x\lambda^y m\alpha} \in \{0,1\} \quad \forall\theta^x \in FA, \ \lambda^y \in FA, \ m \in \Omega, \ \alpha \in G \tag{62}$$

$$oi^+_{\theta^x} \ge 0 \quad \forall\theta^x \in FA^I \tag{63}$$

$$oi^-_{\theta^x} \ge 0 \quad \forall\theta^x \in FA^I \tag{64}$$

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