Global Multiproduct Production–Distribution Planning with Duty Drawbacks

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Duty drawback refers to a full or partial refund of paid import duties when an imported merchandise is destroyed, exported, or consumed as a raw material to produce an export. Despite their extensive international trading operations, many manufacturers fail to save costs by claiming duty drawbacks. In the United States alone, estimates of unclaimed duty drawbacks range from US$1.5–10 billion per annum. In light of this hefty sum of unclaimed duty drawbacks, it is astounding that only one existing production–distribution model in the literature has attempted to include duty drawback. This article is the first to address this neglect of duty drawback in supply chain research by industry practitioners and academicians. To this end, it introduces the key concepts of duty drawback and explains its importance in the new economic era. Second, it presents a linear programming model incorporating three key regulatory factors—corporate taxes, import duties, and duty drawbacks—for solving a production–distribution problem in the chemical industry. Finally, through illustrative examples, it demonstrates the importance of incorporating duty drawback and other regulatory factors in production–distribution planning models. *AIChE J,* 52: 595–610, 2006
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Introduction

Most chemical companies are global primarily as a result of the multinational spread of their manufacturing facilities as well as their extensive international trading activities. Over the years, this global characteristic has been accentuated by the growth in the value of world merchandise exports by the chemical industry (see Table 1). The chemicals cluster has been the primary engine of export growth in the global manufacturing industry in recent years. It remains the only manufacturing cluster that achieved positive annual growth in world merchandise exports from 1995 to 2002. Because only a quarter of the output[1] from the chemical industry goes directly to end users, the majority of chemical exports is used as raw materials by manufacturers from both chemical and nonchemical industries. With most chemical manufacturers relying on their chemical industry counterparts for raw materials, it is evident that chemical companies import their raw materials as significantly as they export their finished products. The markets, in which chemical companies compete and source their raw materials, are certainly not confined to countries or regions that host their manufacturing facilities.

Despite enjoying a healthy growth in the total export value in recent years, it is not all a bed of roses for the chemical companies. The economic downturn that hit the Asian region in 1997 and subsequently the economic powerhouses such as the

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Table 1. Shares of Manufacturing Exports among Clusters and Their Annual Growths*

Manufacturing Cluster	Value of Manufacturing Exports in 2002 (US$ Billions)	Share of Total Manufacturing Exports in 2002 (%)	Annual Percentage Change		
			1995–2000	2001	2002
Iron and steel	142	3.0	−1	−6	7
Chemicals	660	14.1	4	3	10
Other semi-manufactures	460	9.8	3	−2	6
Machinery and transport equipment	2539	54.2	6	−6	3
Textiles	152	3.2	0	−5	4
Clothing	201	4.3	4	−2	4
Other consumer goods	553	11.4	5	−2	4

**Source:* International Trade Statistics 2003 by World Trade Organization.

United States, Europe, and Japan in the early 2000s has spawned a flurry of mergers and acquisitions (M&A) in the chemical industry (see Figure 1). Marriages of chemical companies are primarily motivated by the opportunity of realizing cost synergies upon their successful unification. Examples of major recent M&As include the merger of Exxon and Mobil, the merger of Chevron and Texaco, and acquisitions of Aventis CropScience by Bayer, Dupont Textiles & Interiors by Koch Industries, Albright & Wilson by Rhodia, BTP by Clariant, and Aventis by Sanofi-Synthelabo. Although the dollar volume of worldwide chemical company acquisitions appears to be falling in recent years, sales of chemical businesses are likely to remain active in the short term before the dollar volume returns to the low level of the early 1990s when there was only US$5–6 billion in deals per year. Inevitably, the spate of recent M&As in the chemical industry has further entrenched the global roots of chemical businesses.

Given the global nature of chemical companies, it is only natural that the operations and earnings of these companies are influenced by the legislative measures and international trade policies imposed by governmental agencies. These legislations and trade policies are implemented primarily to boost a country's coffer or protect the interests of local businesses. In our previous article,[3] we termed these legislative measures and international trade policies collectively as *regulatory factors*. Examples of regulatory factors include, but are limited to, import tariffs (or duties), corporate taxes, duty drawback, offset requirements, and quantitative import restrictions. Despite the variety and complexity of regulatory factors imposed by different governmental bodies, it is surprising that many of the existing models in the literature that have addressed production–distribution problems (PDPs) fail to account for the effect of these regulatory factors. On the other hand, among the few production–distribution models that have accounted for regulatory factors, only one of them has considered duty drawback. This is especially astounding because duty drawback regulations have been legislated in a majority of countries around the globe for many years and the global manufacturing companies can garner significant cost savings from duty drawback schemes. Moreover, the only production–distribution model that has accounted for duty drawback is not suitable for all clusters of manufacturing industry. Inevitably, this limits its application in practice, particularly among the multiproduct chemical manufacturing companies.

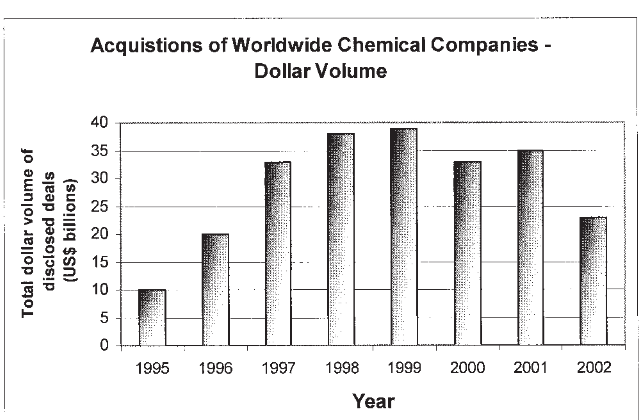

Figure 1. Dollar volume of acquisitions of chemical companies (Source: Chang[2]).

The aim of the study reported in this article is to address the deficiencies in the production–distribution planning research in three ways. First, it introduces the main concepts of duty drawback regulations and highlights their importance in production–distribution planning. Second, it presents a new deterministic model that accounts for three main regulatory factors—corporate taxes, import duties, and duty drawbacks—to address the PDPs in the multiproduct chemical industry. The new model not only ensures that duty drawbacks are duly claimed in accordance with the drawback regulations, a critical feature that previous work has overlooked, but also provides an effective basis for handling uncertainty in problem parameters. Finally, we use our model to solve a realistic problem to illustrate the importance of incorporating regulatory factors when addressing the PDPs.

We first review extensively the existing work on PDPs in both the operations research and chemical engineering literature. We then present a comprehensive introduction and overview of duty drawback regulations. After that, we describe a PDP that accounts for import duty, corporate tax, and duty drawback, and present a linear programming (LP) formulation for its solution. Subsequently, we use an illustrative example to demonstrate the importance of incorporating these regulatory factors in production–distribution planning. Finally, we discuss the distinguishing features of our model relative to the existing ones.

Previous Work

A normative PDP entails the determination of production plans of manufacturing facilities and the distribution plans of products across their supply chain network. PDPs arise mainly because all manufacturing companies, including those in the chemical industry, are driven by the goal of meeting customer demands in a most profitable way. Essentially, production–distribution planning decisions determine the flow plans of raw materials and finished products across all supply chain entities of a manufacturing company as well as the production levels of its manufacturing facilities over a given planning horizon. Manufacturing companies normally base their production–distribution planning decisions on available business data such as customer orders, product prices, production costs, available production capacities, suppliers' production capacities, forecasted orders, and product prices. Basically, the quality of production–distribution planning decisions depends strongly on (1) the accuracy of available and forecasted business data and (2) the effectiveness of the planning techniques that assist the business decision making processes.

The PDPs have received some attention in the operations research literature for the last two decades. We classify the PDPs according to (1) whether the model parameters are deterministic or stochastic and (2) whether the problem formulation considers regulatory factors. For brevity, we use a suffix R (that is, PDP-R) to denote a PDP that addresses regulatory factors; on the other hand, PDP-C refers to a conventional PDP that ignores them. Based on this classification, we identify four main classes of PDPs and review the past work in these four classes.

Deterministic PDPs (DPDPs)

Williams[4] was one of the pioneers to venture into an in-depth research on the deterministic PDP-C (DPDP-C). His problem consisted of a conjoined assembly–arborescence network of production and distribution facilities. He proposed seven heuristic algorithms to solve this problem and compared them. Cohen and Moon[5] reported a mixed integer linear programming (MILP) model to address a special class of DPDP-C that has a concave cost function attributed to the economy of scale and diseconomy of scope. They also developed a solution algorithm based on Benders decomposition to solve their model. Martin et al.[6] presented a large-scale linear programming (LP) model to represent a DPDP-C of a company in the flat glass business. Without reporting any mathematical formulation, the authors claimed that their model accounted for the operational issues of running the flat glass business. Chandra and Fisher[7] presented a computational study to illustrate the value of solving the production and distribution problems as an integrated problem (that is, DPDP-C) relative to solving them separately. They studied a wide range of conditions by varying the problem parameters such as the numbers of products and customers and the length of planning horizon. Dhaenens-Flipo and Finke[8] developed a multiperiod MILP model to represent a DPDP-C in which each production facility produces multiple products sequentially. Their model accounts for the possibility of product switch at the individual production lines within each period of the planning horizon. The entire problem is formulated as a network flow problem with relatively few binary variables to keep the real-size problems computationally manageable.

The DPDPs have received limited attention from the chemical engineering community. Wilkinson et al.[9] presented a large-scale DPDP-C that considers important features such as finite intermediate storage in the form of multipurpose storage silos and equipment changeovers among multiple products with different recipes and packaging needs. Recently, Gjerdrum et al.[10] approached a DPDP-C with intercompany transfer prices as model decision variables. They used a separable programming approach that uses logarithmic differentiation and approximations of the variables in the objective function to solve the resultant mixed integer nonlinear programming (MINLP) model. van den Heever et al.[11] rigorously accounted for taxes, tariffs, and royalties in a multiperiod MINLP model for the strategic design and production planning of hydrocarbon field infrastructures. They proposed a Lagrangian decomposition heuristic that solves their model more efficiently compared to a full-space search for solution. They clearly demonstrated the significant savings obtained by embedding taxes, tariffs, and royalties within an optimization model as opposed to considering them after the fact, a message that this paper also shares strongly. Jackson and Grossmann[12] introduced a multiperiod nonlinear programming (NLP) model for the planning and coordination of production and distribution activities of geographically distributed multiplant facilities. They proposed two solution methodologies (that is, spatial and temporal decomposition schemes) based on Lagrangian decomposition to solve the large-scale nonlinear problem. Chen et al.[13] presented a MINLP model for a DPDP-C with multiple objectives such as maximizing the profit of each member enterprise, the customer service level, and minimizing safe inventory level. To cope with the multiple objectives that have different dimensions, they expressed each of these objectives as a fuzzy function based on a fuzzy set concept. They also introduced a two-phase fuzzy decision method to solve the model, which has the objective of maximizing the overall degree of satisfaction for the multiple fuzzy objectives.

To date, Arntzen et al.[14] presented probably the most comprehensive model for a DPDP-R in the computer industry. Their model incorporated several regulatory factors that influence the operations and profitability of a company, including import tariff, duty drawback, duty relief, local content rule, and offset requirement. They minimized a composite function of weighted activity time and costs and proposed a solution algorithm that uses row-factorization to solve their model. Vidal and Goetschalckx[15] presented an alternative approach to address a DPDP-R by taking the intercompany transfer prices and transportation cost allocations between subsidiaries to be the decision variables. Their model accounted for the effects of corporate tax and import tariff, and they used a heuristic algorithm based on successive linear programming. They sought to maximize the after-tax profit of the multinational company.

Stochastic PDPs (SPDPs)

An early attempt to address the stochastic PDPs (SPDPs) without accounting for regulatory factors was by Cohen and Lee.[16] They introduced a comprehensive modeling framework that accounted for uncertainty in the demands of finished products, replenishment lead times of materials from vendors to plants, and lead times for delivering goods from warehouse to distribution centers. They proposed a hierarchical heuristic to determine the operating policies of various supply chain entities. In a later work, Pyke and Cohen[17] addressed a SPDP-C that involves one factory, one warehouse, and one retailer with the demands of multiple products being stochastic and independent. Their problem differed from others in that it permitted the option of expediting production at the factory whenever the stock level at the warehouse falls to a specified expedite-reorder point. Holmberg and Tuy[18] accounted for economies of scale in their SPDP-C with uncertain demands by assigning a concave function to represent the production cost at each manufacturing plant. They used a solution methodology based on a branch-and-bound algorithm to solve their nonconvex optimization problem.

In the chemical engineering literature, Clay and Grossmann[19] presented a multistage stochastic linear programming (MSLP) model to represent a SPDP-C with uncertainties in model parameters. They introduced a sensitivity-based successive disaggregation algorithm for its solution. Tahmassebi[20] presented a probabilistic model to manage a SPDP-C with uncertainty in demand and supply chain configuration. This model allows the user to explore and evaluate multiple alternative decisions under different scenarios. Tsiakis et al.[21] developed a MILP model to represent a SPDP-C combined with a facility location problem. They used the scenario planning approach to account for the uncertainty in product demands. Gupta and Maranas[22] introduced a production–distribution model that accounts for stochastic demand, interplant shipment of intermediate products, and multiproduct nature of each plant. They presented a two-stage stochastic programming framework to solve their model.

There is a clear paucity of research on the SPDP-R. To the best of our knowledge, only one study has been reported in the literature. Cohen et al.[23] introduced a normative modeling framework to represent a SPDP-R with uncertainty in the currency exchange rate. They proposed a hierarchical solution methodology with the aim of maximizing the after-tax profit of an entire global firm in numeraire currency. They accounted for the effects of corporate tax, tariffs, and local content rule, and modeled the economies of scales in production and raw materials acquisition.

From the discussion in the current and previous subsections, we conclude that research on both deterministic and stochastic PDPs with regulatory factors is still in its infancy, and few models and methodologies account for regulatory factors in the PDPs. More surprisingly, even though duty drawback can represent significant savings for many manufacturing companies, only one production–distribution model[14] has attempted to include this regulatory factor. However, the model has limited application in the manufacturing industry for two main reasons. First, it was developed for the computer-maker companies that generally have single-product manufacturing operations. Because duty drawback computations for single-product and multiproduct manufacturing operations are different, their model is not applicable to all manufacturing companies. Herein we define multiproduct manufacturing operation explicitly as a manufacturing process that manufactures multiple products simultaneously. This is to be distinguished from manufacturing processes that manufacture multiple products sequentially. An example of a multiproduct manufacturing company is a typical petrochemical company that owns an oil refinery and petrochemical plants as shown in Figure 2. Second, their model does not use sufficiently in-depth data on manufacturing drawback distribution, essential for duty refund claims. The manufacturing drawbacks in their model are explicitly based on the total import and export quantities over the planning horizon and do not identify the linkages between the batches of imported materials and exported finished products. As such, their model solution does not provide details that are crucial for inventory management and duty drawback claims, especially when product substitution (see Table 2) is not permitted.

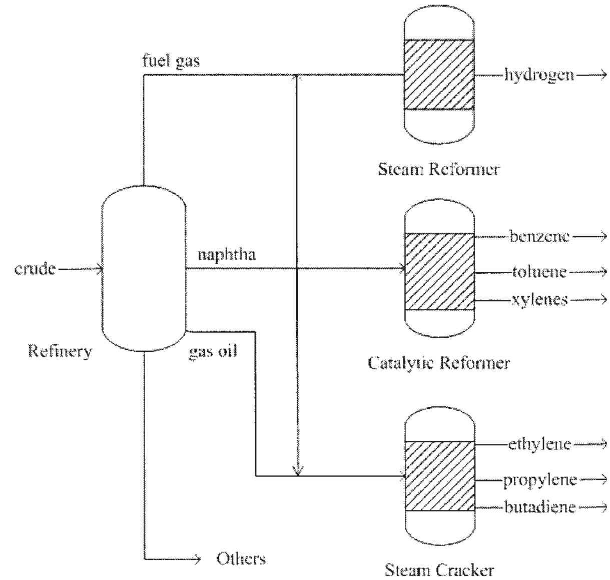

Figure 2. Material flows among the facilities of a typical petrochemical plant.

This completes our review of past work on the PDPs. We now present an overview of the duty drawback regulations to introduce their key concepts and to highlight their importance in PDPs.

What Is Duty Drawback?

When a company imports a material, it may pay duties to the customs or revenue authorities based on the quantity or value of that material. The underlying goal of levying such a duty on imported materials is to boost a country's coffer or protect the interests of local businesses. However, consider for example a manufacturer who imports various PC parts, pays duties, assembles PCs, and exports them. Although import duties are good for the country, they are not good for this manufacturer because he/she could be at a disadvantage in the global market due to extra costs from import duties. Thus, discouraging imports and encouraging exports involve a trade-off that most countries must balance. This led to the idea of duty drawback, which is a refund of import duty, when the material is destroyed, exported, or consumed as a raw material to produce an exported material. Its primary goal is to assist domestic manufacturers to compete in foreign markets. The World Trade Organization (WTO) Agreement on Subsidies and Countervailing Measures clearly reflects the relevance of duty drawback in the world economy and its global acceptance. The agreement contains specific provisions that allow WTO members to offer duty drawback. It also specifies the conditions that could make duty drawback an impermissible export subsidy so that errant countries could be subject to the disciplines of WTO, which

Table 2. Examples of Drawback Regulations

Regulation Subject	Examples
Process registration	Under the Brand Rate of Duty Drawback Scheme (an individual drawback system) in India, an exporter must make an application to the Directorate of Drawback in a prescribed format along with documentary evidence on the quantities of inputs employed to manufacture the export, payment of duties, etc. within 60 days from the date of export of goods. After verifying documentary evidence, the Directorate of Drawback will authorize a basis of drawback claim to the exporter. This basis, which defines how the duty refund is computed, is valid for the particular export shipment and may be extended to future shipments subject to the availability of necessary supporting evidence.
Product substitution	Manufacturers in the U.S. and EU nations may substitute domestic inputs for imported inputs in producing merchandise destined for export and still receive a refund of duty paid on the imported inputs. Such substitution is permitted, only if the domestic and imported inputs are of the same commercial quality, technical characteristics, or tariff classification.
Drawback computation	Taiwan uses four methods to compute duty drawback rates. They are based on raw material criteria, fixed amount (specific duty) criteria, fixed percentage (ad valorem duty) criteria, and special provisions for certain components. For the computation of MD, EU nations adopt three main methods: quantitative scale method based on compensating products, quantitative scale method based on import goods, and value scale method.
Drawback transfer	In the U.S. and EU nations, there are provisions that permit a manufacturer to transfer its right to claim the drawback for its product to another party.
Time limits	In general, duty drawback is available in the U.S., when imported merchandise is destroyed or used to manufacture an article that is exported within 5 years of import. However, U.S. companies can claim for MD on petroleum derivatives, only if the export of finished products occurs within 180 days of manufacture.
Export destinations	Both Common Market of Southern Cone (Mercosur) and NAFTA members have eliminated duty drawbacks to goods subsequently exported to their regional partner's markets.

has a history of being less forgiving to government policies that subsidize exporters.

Types of duty drawback

The types of duty drawback vary from country to country. However, the three most common types of duty drawback, as defined in the U.S. Code of Federal Regulations (Title 19, Part 191), are:

(1) *Rejected merchandise drawback* (RMD): This is available to the importers who paid duty on the merchandise that does not meet the quality specifications originally stated in the purchase order.

(2) *Unused merchandise drawback* (UMD): This is available to the exporters who send abroad the merchandise that was imported, but neither used nor altered.

(3) *Manufacturing drawback* (MD): This is available to the manufacturing companies that export the merchandise produced using the imported raw materials.

For a manufacturer with extensive international trading activities, MD would be of primary interest because it would normally represent the greatest savings among all drawback types.

Importance of duty drawback

Increasingly, more countries are participating in bilateral and multilateral free trade agreements (FTAs) or are in the midst of negotiating such agreements. Some examples of signed free trade pacts are the North American Free Trade Agreement (NAFTA), the Central European Trade Agreement (CETA), and the United States–Singapore Free Trade Agreement (USSFTA). Examples of ongoing FTA negotiations include those between United States and Thailand, China and Singapore, and Canada and Caribbean Community and Common Market (CARICOM). Similarly, a growing number of export processing zones (EPZs) have been established by countries such as the United States, India, Ireland, China, Philippines, and Indonesia with the primary objective of attracting foreign direct investments. Inevitably, the FTAs and EPZs create more avenues of sourcing duty-free raw materials to global manufacturing companies. Although this may potentially mitigate the impact of duty drawback laws, the amount of savings that manufacturers can derive from duty refunds remains significant. This is possible mainly because many existing facilities are still located and new manufacturing facilities constructed in places with no duty-free access to foreign merchandise. The amount of drawback savings that these facilities can garner annually remains substantial. For example, Cerny[24] estimates US$2 billion worth of drawbacks available to U.S. companies annually, out of which almost US$1.5 billion goes unclaimed. In another recent work, Wheatley[25] quoted that the U.S. companies failed to claim as much as US$10 billion worth of duty drawbacks in 2001. These estimates aptly illustrate the potential and significance of drawback savings despite the proliferation of FTAs and EPZs. The hefty sum of unclaimed duty drawback also demonstrates the extent to which companies are neglecting drawbacks in their material procurement and product distribution strategies.

In a recent report,[26] duty drawback has been recommended more favorably than EPZ by the International Monetary Fund (IMF) as one of the indirect tax incentives that developing nations should use to attract foreign direct investments. This is certainly a testimony to the effectiveness of duty drawback as a pro-business policy. Clearly, the importance and significance of duty drawback to the global manufacturing community are unlikely to diminish in the years to come.

Drawback regulations

Many nations have laws governing duty drawback. As reported by Michalopoulos,[27] 42 developing countries have one or more forms of duty drawback with the exception of Benin, Hong Kong, and Singapore. The reason for three countries not offering duty drawback is simple. They do not impose any import tariffs on most (if not all) of their imported manufacturing inputs. The duty drawback incentive is also available among developed countries such as Australia, Canada, Japan, the United States, and several European Union (EU) nations. Some of these countries have had the duty drawback laws in place for as long as three centuries. For example, the history of duty drawback legislation in Great Britain dates back to the reign of William and Mary (1689–1702). The United States first enacted the law of drawback as a part of the Tariff Act of 1789. Details of the drawback regulations are usually available in the publications of government agencies such as the customs or treasury agencies. For example, the Code of Federal Regulations (Title 19, Part 191) details the drawback regulations in the United States. For a simple description of drawback regulations, one can also refer to a web site such as http://www.aseansec.org/14268.html/, which gives a concise overview of customs regulations, including those pertinent to duty drawback among the Association of South-East Asian Nations (ASEAN) countries.

The customs authorities normally impose different regulations for different drawback types. These regulations include, but are not limited to, the requirements to register the manufacturing process for duty drawback, to destroy or export merchandise under customs supervision, and to claim duty refund within a specified time after the import. In addition, these regulations also stipulate methods for computing duty refund, product identification mechanism for drawback claim, export destinations eligible for refund, and paperwork requirements such as filing the evidence of import, manufacture, or export, and records of the waste generated in a manufacturing process. See Table 2 for examples of drawback regulations imposed by some countries to govern their respective duty drawback mechanisms.

Overall, duty drawback regulations lay out only the terms and conditions that companies must fulfill to receive duty drawbacks. The ability of a duty drawback system to achieve its primary objective of assisting domestic manufacturers to compete in foreign markets also depends strongly on how efficiently the system administers the duty drawback scheme. Hinkle et al.[28] identified inefficient drawback administration as the primary cause of many African nations' failure to boost their economies by duty drawback schemes. In contrast, many countries such as those in East Asia have used duty drawback very effectively to boost the global competitiveness of their domestic producers and their exports. These countries achieve the underlying objective of duty drawback mainly through efficient administration of a duty drawback system that ensures (1) duty refunds are assessed fairly and systematically, (2) companies receive their duty refunds with minimal delays, and (3) fraudulent misuse of duty drawback system is effectively kept in check to maintain a sustainable system. From these two contrasting examples, it is obvious that drawback regulations lay out only the ground rules for systematic refund of paid import duties. An efficient duty drawback administration is necessary to ensure the effectiveness of drawback schemes in helping the domestic manufacturers to compete on the global stage.

Two drawback systems[29] exist for computing the amount of refundable duties: the fixed drawback system (FDS) and the individual drawback system (IDS). We now describe the essence of these two refund systems in the following two subsections.

Fixed drawback system (FDS)

In this system, computing MD is simple and straightforward. It simply depends on the amount or value of the export. The FDS simplifies the administration of duty refund by offering refund to all exporters, irrespective of whether their exports use imported feed materials. It sets refund rates based on the estimated duties that contribute to the cost of production of exports in a preset schedule. To ensure that their drawback systems do not allow an impermissible export subsidy under the WTO Agreement on Subsidies and Countervailing Measures, a country using FDS must set its refund rates such that the total duty refund does not exceed the total import duty collected.

However, it is clear that the FDS does not provide a fair mechanism for MD, especially to the manufacturers with extensive amounts of imports. To cater to the needs of such manufacturers, countries such as Taiwan and India that use FDS to manage their duty refunds also provide IDS as an alternative refund mechanism so that companies can opt for the most favorable system, subject to the conditions stipulated by relevant drawback regulations.

The fixed amount (specific duty) and fixed percentage (ad valorem duty) criteria that Taiwan uses are good examples of the FDS. The former refunds a predetermined amount per unit (weight or quantity) of the export, whereas the latter refunds a predetermined percentage of its free-on-board (FOB) value.

Individual drawback system (IDS)

The IDS offers a more accurate methodology for assessing MD because it considers the actual amount of imported materials utilized in manufacturing an export. Typically, a manufacturer must abide by the registration requirements of the relevant drawback regulations before it can claim MD for a manufacturing process. This essentially entails (1) submitting a bill of materials (BOM) that stipulates the quantitative relationship between the inputs and outputs (including recoverable and irrecoverable wastes) of the manufacturing process and (2) providing evidence to substantiate the numbers in the proposed BOM. Examples of countries using the IDS include Australia, the United States, and EU nations.

The IDS offers duty refund strictly based on the amount of imported materials that a manufacturer uses in manufacturing an export. In this system, a manufacturer qualifies for MD if it fulfills two key conditions. First, it must have used imported raw materials in its manufacturing process and must have paid the applicable import duties. The manufacturer could either import the raw materials directly or buy the same from domestic distributors. Second, it must export the finished products of its manufacturing process to countries that are eligible for drawback according to the pertinent drawback regulations. The regulations may also stipulate a secondary condition that the exports must be explicitly manufactured using the imported materials. In other words, product substitution is not permissible (refer to Table 2 for the key requirement for production substitution). The drawback laws of the United States and EU nations do waive this secondary stipulation, subject to pertinent terms and conditions.

Overall, it is obvious that IDS requires a more complex methodology for computing MD and more resources for managing the drawback administration as compared to FDS. Nevertheless, many countries still adopt IDS because it ensures that (1) only the deserving exporters receive duty refunds and (2) the domestic producers with extensive imports and exports receive the maximum possible benefit from the drawback regulations, which would help them compete in the global market.

Computation of MD in IDS

Consider a general, multiproduct chemical manufacturing facility f that procures raw materials from its suppliers (both domestic and international) strictly for production purposes. It pays import duty on the raw materials from its international suppliers and can claim drawback refund on the same. To this end, it has registered its manufacturing process with the customs authority and has an approved BOM given by

$$\sum_{i \in IM_f} \sigma_{if} m_i = \sum_{i \in OM_f} \sigma_{if} m_i \tag{1}$$

where m_i denotes material i that facility f consumes or produces, IM_f denotes the set of raw materials m_i ($i \in \mathrm{IM}_f$) consumed by f, OM_f denotes the set of finished products m_i ($i \in \mathrm{OM}_f$) produced by f, and σ_{if} is analogous to the stoichiometric coefficient of a species i in a reaction except that Eq. 1 is in terms of mass or units rather than moles. Note that σ_{if} is positive even for outputs, in contrast to the standard stoichiometric coefficient in a reaction. Furthermore, OM_f includes waste products as well as unreacted raw materials that are irrecoverably wasted. Although we explained Eq. 1 in terms of materials, we can also use the same for discrete parts. If two pieces of part 1 and four pieces of part 2 produce one piece of product 3, then $\sigma_1 = 2$, $\sigma_2 = 4$, and $\sigma_3 = 1$.

A BOM approved by the customs authority provides the basis for computing MD. A manufacturer must fulfill two primary conditions for claiming a MD for such a BOM. First, it must procure duty-paid raw materials by either importing them directly or through local supplier(s). The quantity of such a raw material and the amount of duty paid together impose an upper bound on the MD that the manufacturer can claim. Second, the manufacturer must export at least one of its finished products in the BOM. In a multiproduct manufacturing process, one or more raw materials may concurrently produce multiple finished products. It would be unfair if a manufacturer can claim the refund of all duties on a raw material simply by exporting a tiny amount of one of its final products. Thus, the amount of export that the manufacturer produces also has a bearing on the claimable MD. Clearly, a fair refund mechanism must apportion the paid duties to all the finished products according to the amounts and values of these products.

According to their respective drawback regulations (Code of Federal Regulations and Community Customs Code), both the United States and EU nations use relative values of finished products to apportion the paid import duty of each raw material among the finished products of a multiproduct manufacturing process in the computation of MD. These relative values are based on the market prices (or other values approved by the customs authorities) at the *time of their manufacture*. Using the aforementioned notation for a facility f, the relative value RV_{jft} of a finished product m_j ($j \in \mathrm{OM}_f$) produced in an arbitrary period t is defined as

$$RV_{jft} = \frac{\sigma_{jf} MP_{jt}}{\sum_{j' \in \mathrm{OM}_f} \sigma_{j'f} MP_{j't}}$$

where MP_{jt} denotes the market price of m_j at t. Finished products m_j ($j \in \mathrm{OM}_f$) with no value or those irrecoverably wasted in a manufacturing process have $MP_{jt} = 0$.

Let us consider a case where f procures Q_{ift} ($i \in \mathrm{IM}_f$) amounts of raw materials, uses them in its registered process, produces Q_{jft} ($j \in \mathrm{OM}_f$) amounts of final products, and sells them, all during period t. f has two suppliers for its raw materials, one domestic and the other foreign. We also assume that f has zero inventories of raw materials and finished products at the beginning of period t. Let γ_{ift} be the fraction of material m_i ($i \in \mathrm{IM}_f$) that f imports from the foreign supplier during period t and CIF_{ift} denote the cost, insurance, and freight ($/mass) that f pays for its import. If the import duty rate is ID_{ift} ($/$ of costs, insurance, and freight), then f must pay a total duty of $\gamma_{ift} ID_{ift} CIF_{ift} Q_{ift}$. If the duty refund rate is DR_{if} ($/$ of paid duty) according to the local regulations, then one upper limit for the claim amount MD_f for facility f during period t is

$$MD_f \leq \sum_{i \in \mathrm{IM}_f} \gamma_{ift} ID_{ift} CIF_{ift} Q_{ift} DR_{if} \tag{2}$$

In IDS, the values and amounts of the export products do affect a MD claim. To illustrate this, consider that f produces Q_{jft} amounts of final product m_j during period t. If f exports only a fraction γ_{jft} of this product during t, then the amount of raw material m_i required to produce exported product m_j is $\gamma_{jft} Q_{jft} \sigma_{if} / \sigma_{jf}$. The corresponding import and refundable duty amounts are $\gamma_{jft} ID_{ift} CIF_{ift} Q_{jft} \sigma_{if} / \sigma_{jf}$ and $\gamma_j ID_{ift} CIF_{ift} DR_{if} Q_j \sigma_{if} / \sigma_{jf}$. Because this raw material also contributed concurrently to the production of other final products, we multiply the refund amount by RV_{jft} to identify the claim for the pair of materials m_i–m_j. Thus, an upper limit on the MD claim for import m_i with reference to export m_j is $\gamma_{jft} ID_{ift} CIF_{ift} DR_{itf} RV_{jft} Q_{jft} \sigma_{if} / \sigma_{jf}$. Summing over all exports m_j and then all imports m_i, we get

$$MD_f \leq \sum_{i \in \mathrm{IM}_f} \sum_{j \in \mathrm{OM}_f} \gamma_{jft} ID_{ift} CIF_{ift} Q_{jft} \frac{\sigma_{if}}{\sigma_{jf}} DR_{if} RV_{jft} \tag{3}$$

From Eqs. 2 and 3, we get

$$MD_f = \sum_{i \in \mathrm{IM}_f} ID_{ift} CIF_{ift} DR_{if} \min\left[\gamma_{ift} Q_{ift}, \sum_{j \in \mathrm{OM}_f} \gamma_{jft} Q_{jft} \frac{\sigma_{if}}{\sigma_{jf}} RV_{jft}\right] \tag{4}$$

From the above discussion, it is obvious that for computing MD in a multiproduct manufacturing process, we must consider all pairs of duty-paid raw materials and exported products. We now explain how this basic requirement changes in the presence of two additional factors.

Multiple international suppliers

In practice, a manufacturer may source its raw materials from multiple international suppliers, instead of just one as in the example above. This further complicates the computation of MD because the claim will now depend on the origins of imports, which directly affect the duty rates. The manufacturer must track the duty-paid raw materials from each international supplier and the exports that arise from these specific imports.

Multiperiod planning horizon

In production planning, it is often necessary to use a multiperiod planning model to capture the variations in demands, market prices, costs, insurance, freight, and so forth. In a multiperiod planning model with multiple international suppliers, MD computation becomes more involved because of the need to track three pieces of information in addition to the supplier identity, quantities of duty-paid raw materials, and quantities of exported products. These are:

(1) *The import times of raw materials*: This is because the duty paid by a facility (which in turn affects its MD claim) depends on the time-dependent CIF values of materials.

(2) *The times of consumption of raw materials*: This is because the manufacturing time determines the relative values of the finished products (as in the Code of Federal Regulations).

(3) *The export times of finished products*: This is because the drawback regulations stipulate limits on the duration within which an imported raw material must be consumed to produce export products.

The computation of MD for multiproduct manufacturing processes poses significant modeling challenges in a global multiperiod planning model. We now address this complexity in our new model for DPDP-R.

Problem Statement

A multinational corporation (MNC) owns a set IF of processing facilities ($f \in$ IF) in several countries. We designate these as internal facilities. Each facility houses a manufacturing process that uses raw materials to manufacture some products. In addition to receiving/supplying materials from/to each other, an internal facility ($f \in$ IF) may also interact with some external facilities that do not belong to the MNC. These could be raw material suppliers, customers, and facilities to which internal facilities could outsource their production. We define EF as the set of all external facilities ($g \in$ EF) that could possibly interact with the internal facilities. Finally, we define F = IF $\cup$ EF and assume that the location and the incoming and outgoing materials for each $f \in$ F (whether internal or external) are prefixed and known.

For each $f \in$ F, we group its associated materials (raw materials and products) into two sets as done in the previous section on MD computation. IM_f denotes the set of incoming materials m_i ($i \in \text{IM}_f$) consumed by f, and OM_f denotes the set of outgoing materials m_j ($j \in \text{OM}_f$) produced by f. Note that for an external facility $g \in$ EF, we include only the materials that are relevant to the MNC. For instance, suppose that an external facility g produces C and D from A and B. However, the MNC neither supplies currently or ponders supplying at any time A or B to g nor needs currently or ponders needing at any time D from g at any of its internal facilities. Then, $\text{IM}_f = \varnothing$ and $\text{OM}_f = \{C\}$. For each internal facility f ($f \in$ IF), we designate one material $\pi(f)$ as a primary material, and define the production capacity (X_{ft}^U) of f as the rate at which f uses or produces $\pi(f)$ during a period t. Thus, $\pi(f)$ can be either an incoming or an outgoing material of f.

Every internal facility f ($f \in$ IF) has three options of fulfilling an order placed by a customer c ($c \in$ EF) for a product i ($i \in \text{OM}_f \cap \text{IM}_c$). First, it may manufacture i in-house. Second, it may source i partially or fully from another internal facility g ($i \in \text{OM}_g$, $g \neq f$) that will in turn produce and arrange i to be delivered to c. Third, it may outsource the production to external facilities g ($i \in \text{OM}_g$) that will manufacture i and send it to c. In the last two options, the internal facility f bears the costs of getting the outsourcing facilities to produce and deliver i to customer c. On the front end of the supply chain, each internal facility f has two ways of obtaining its raw materials ($i \in \text{IM}_f$). It can procure directly from other internal facilities g ($i \in \text{OM}_g$) or external suppliers s ($s \in$ EF, $i \in \text{OM}_s$).

Considering a global problem, we let the facilities be located in N different nations ($n = 1, 2, \ldots, N$) or countries, and define F_n as the set of facilities situated in nation n ($f \in \text{F}_n$, $\text{F}_1 \cup \text{F}_2 \cup \cdots \cup \text{F}_N = \text{F}$, and $\text{F}_n \cap \text{F}_{n'} = \varnothing$ for $n \neq n'$). The legislation of a host country n normally imposes several restrictions on the ownership, imports, exports, accounts, earnings, and so forth of the facilities located in its jurisdiction ($f \in \text{F}_n$).

Based on the forecasted and confirmed orders from the sales division, the MNC wishes to develop an optimum production–distribution plan over the next fiscal year. We divide this tactically into T equally spaced time periods ($t = 1, 2, \ldots, T$) to form the time basis of planning for the MNC. The production–distribution plan constitutes (1) production rate, (2) raw material sourcing scheme, and (3) finished product distribution strategy for every $f \in$ IF during each period t. The objective of the production–distribution plan is to maximize the total after-tax profit (ATP) of the MNC over the planning horizon.

We make the following assumptions for the above DPDP:

(1) All business intelligence data crucial for generating a reliable production–distribution plan are available. These include the sale orders, raw material requirements, raw material prices, product prices, transportation costs, operating costs, import duties, and corporate taxes of all internal facilities and the capacities of all internal and external supplier facilities over the T periods.

(2) The business intelligence data are adjusted to account for the fluctuations in exchange rates of currencies involved in N nations over the T periods. Thus, we express all expenditures and returns in terms of a numeraire currency.

(3) Although several regulatory factors affect the operation and earnings of the MNC, duty drawbacks, import duties, and corporate taxes are the only dominant regulatory factors. Others have only a negligible impact on the profit of MNC.

(4) The internal facilities of each country n ($f \in \text{IF} \cap \text{F}_n$) pay corporate and other taxes collectively to the country's revenue authorities at the end of each fiscal year.

(5) Every internal facility f pays the duties on all its imports from facilities (internal or external) that are outside its own country. All import duties are based on the CIF costs (cost, insurance, and freight) of imports at f. This refers to the total value of goods including the purchase, insurance, and freight costs incurred in bringing them to the delivery facility.

(6) The international commerce term (Incoterm[30]) governing all international sales contracts is the EX works (EXW). In EXW, the buyer or customer bears all costs and risks involved in taking the goods from the seller's premises.

(7) MD is the only type of drawback relevant to the MNC. The rules governing the MD computations in all nations are similar to the Code of Federal Regulations (Title 19, Part 191). These countries and internal facilities have efficient drawback administrations to manage their duty refund mechanisms.

(8) Every internal facility f needs to satisfy a time limit stipulated in its local drawback laws to claim MD. This time limit, represented by TL_f, defines the upper bound on the facility's holding duration of each manufactured product before its exportation. Thus, if f consumes its raw material for production at τ and exports its finished product at θ ($\theta \geq \tau$), then it can claim for MD only if $(\theta - \tau) \leq TL_f$.

(9) The MNC has an established infrastructure that enables its facilities to claim drawbacks within the same fiscal year of the export of finished products.

(10) The authorized BOM that forms the basis of MD computation for each internal facility f is given by

$$\sum_{i \in \mathrm{IM}_f} \sigma_{if} m_i = \sum_{i \in \mathrm{OM}_f} \sigma_{if} m_i \qquad f \in \mathrm{IF}$$

where the notation is similar to that previously described.

(11) Each internal facility f has constant lower and upper limits on its production rate (denoted by X_f^L and X_f^U, respectively, as measured in terms of the primary material) over the entire planning horizon. It must operate within these limits, and cannot shut down.

(12) The length of each period ($t = 1, 2, \ldots, T$) is adequately small so that the inventory levels of products at period ends provide sufficient granularity to compute the inventory costs and to track the fluctuation in product market prices and CIF values.

(13) The depreciation charge incurred by each internal facility f stemming from its previous capital investments is constant over the planning horizon. Furthermore, there are no upcoming capacity expansion projects during the planning horizon.

(14) Each local supplier s of an internal facility f ($f \in \mathrm{IF} \cap \mathrm{F}_n$, $s \in \mathrm{F}_n$, $f \neq s$) in nation n makes its products ($i \in \mathrm{IM}_f \cap \mathrm{OM}_s$) using only domestic raw materials. Thus, the material sourced from such appliers cannot save any MD for the internal facilities.

In the formulation presented below for the above stated DPDP-R, unless stated otherwise, the indices (f, t, i, etc.) assume their full ranges of values.

Problem Formulation

To model the incoming and outgoing flows of materials at the facilities, we let $F_{isct} \geq 0$ ($i \in \mathrm{OM}_s \cap \mathrm{IM}_c$, $c \neq s$) denote the quantity of material i that a facility $s \in \mathrm{F}$ sells directly to a facility $c \in \mathrm{F}$ during period t. If x_{ift} and X_{ft}, respectively, denote the actual consumption/production levels of materials m_i and $\pi(f)$ at an internal facility f during t, then we must have

$$\sigma_{\pi(f)f} x_{ift} = \sigma_{if} X_{ft} \qquad i \in \mathrm{OM}_f \cup \mathrm{IM}_f$$

We also let G_{ifgct} denote the quantity of material i that an internal facility f outsources to another facility $g \in \mathrm{F}$ to fulfill orders from a facility $c \in \mathrm{F}$ partially or fully during period t, where $i \in \mathrm{OM}_f \cap \mathrm{OM}_g \cap \mathrm{IM}_c$, $f \neq c$, $f \neq g$, and $g \neq c$. Therefore, the inventory level (I_{ift}) of a material i associated with an internal facility f at the end of a period t is

$$I_{ift} = I_{if(t-1)} - X_{ft}[\sigma_{if}/\sigma_{\pi(f)f}] + \sum_{s \ni i \in \mathrm{OM}_s} F_{isft} \qquad f \in \mathrm{IF},\ i \in \mathrm{IM}_f \quad (5)$$

$$I_{ift} = I_{if(t-1)} + X_{ft}[\sigma_{if}/\sigma_{\pi(f)f}] - \sum_{g \in \mathrm{IF} \ni i \in \mathrm{OM}_g} \sum_{c \ni i \in \mathrm{IM}_c} G_{igfct} - \sum_{c \ni i \in \mathrm{IM}_c} F_{ifct} \qquad f \in \mathrm{IF},\ i \in \mathrm{OM}_f \quad (6)$$

Note that I_{if0} denotes the inventory level of i at f at time zero.

For each external facility $c \in \mathrm{EF}$, we define D_{ict} ($i \in \mathrm{IM}_c$) as the minimum quantity of i, which c has ordered and the MNC must supply during t. We also define S_{ist} ($i \in \mathrm{OM}_s$) as the maximum amount of i, which an external facility s ($s \in \mathrm{EF}$) can supply to the MNC during t as a direct supplier of raw material or as an outsourcing facility. To ensure that delivery equals order and supply does not exceed available capacity, we use

$$\sum_{f \in \mathrm{IF}} \left(F_{ifct} + \sum_{h \in \mathrm{F} \ni i \in \mathrm{OM}_h} G_{ifhct} \right) = D_{ict} \qquad c \in \mathrm{EF},\ i \in \mathrm{IM}_c \cap \mathrm{OM}_f \quad (7)$$

$$\sum_{f \in \mathrm{IF} \ni i \in \mathrm{IM}_f} F_{isft} + \sum_{f \in \mathrm{IF} \ni i \in \mathrm{OM}_f} \sum_{c \in \mathrm{EF} \ni i \in \mathrm{IM}_c} G_{ifsct} \leq S_{ist} \qquad s \in \mathrm{EF},\ i \in \mathrm{OM}_s \quad (8)$$

MD computation requires that we track the materials from import all the way to export and consider separately each pair of imported and exported materials. Thus, let us consider that an internal facility ($f \in \mathrm{IF}$) imports a material i from a supplier s ($i \in \mathrm{OM}_s$) during a period t. It uses some or all of this i to make a material j ($j \in \mathrm{OM}_f$) during period $\tau \geq t$, which it exports to a customer c ($j \in \mathrm{IM}_c$) during a period θ ($T \geq \theta \geq \tau$). Note that this sort of tracking is possible and routine in a batch plant such as a pharmaceutical plant. However, this is neither possible nor does it normally occur in a continuous plant. Thus, for a continuous plant, it merely represents an artificial distribution of materials to compute MD rather than actual physical tracking of the materials. For computing MD for this scenario, we define three variables:

(1) $q_{sfijt\tau}$: The amount of i imported from s during t on which f can claim MD because of its subsequent consumption in τ to make export j. If s is a local supplier, then $q_{sfijt\tau} = 0$.

(2) $q_{sfij0\tau}$: The amount of i imported from s before the start of the planning horizon on which f can claim MD because of its subsequent consumption in τ to make export j. This is to account for i that exists in the inventory at the beginning of the planning horizon and it is eligible for MD. For simplicity, we assume that each $q_{sfij0\tau}$ has a single corresponding import duty rate and CIF value to compute the eligible MD.

(3) $r_{fcj\tau\theta}$: The amount of j that f makes during τ, subsequently exports to c during θ, and on which it can claim MD. If c is a local customer or it is in a nation for which MD is not claimable, then $r_{fcj\tau\theta} = 0$.

Because the total amount of i that f imports from s during t and consumes over periods t to T cannot exceed the quantity of i that f receives from s during t, we have

$$\sum_{\tau=t}^{T} q_{sfijt\tau} \le F_{isft}$$
$$f \in \mathrm{IF} \cap \mathrm{F}_n,\ s \in \mathrm{F}'_n,\ i \in \mathrm{IM}_f \cap \mathrm{OM}_s,\ j \in \mathrm{OM}_f \quad (9)$$

Note that F'_n-F-$\mathrm{F_N}$. Similarly, the total amount of i that f imports from s before the start of the horizon for consumption over the planning horizon cannot exceed the quantity of i that is present in the inventory at the start of the horizon, that is,

$$\sum_{\tau=1}^{T} q_{sfij0\tau} \le \alpha_{isf} I_{if0}$$
$$f \in \mathrm{IF} \cap \mathrm{F}_n,\ s \in \mathrm{F}'_n,\ i \in \mathrm{IM}_f \cap \mathrm{OM}_s,\ j \in \mathrm{OM}_f \quad (10)$$

where α_{isf} is the fraction (known) of i in the inventory of f at the start of the horizon that f procured from s. Note that

$$\sum_{s \in F \ni i \in \mathrm{OM}_s} \alpha_{isf} = 1 \qquad f \in \mathrm{IF},\ i \in \mathrm{IM}_f,$$

Likewise, the total amount of j that f makes until period θ, exports to c during θ, and on which it can claim MD, cannot exceed the amount of j that f delivers to c during θ. Therefore,

$$\sum_{\tau=\max[1,\theta-TL_f]}^{\theta} r_{fcj\tau\theta} \le F_{jfc\theta} + \sum_{g \in \mathrm{IF} \ni j \in \mathrm{OM}_g} G_{jgfc\theta}$$
$$f \in \mathrm{IF} \cap \mathrm{F}_n,\ c \in \mathrm{F}'_n,\ j \in \mathrm{OM}_f \cap \mathrm{IM}_c \quad (11)$$

where TL_f is previously defined as the duration within which f must export a material after its manufacture to be able to claim MD. Considering the fact that every f would try to claim maximum MD each fiscal year, we assume that f has negligible inventory of finished product ($j \in \mathrm{OM}_f$) that is manufactured before the start of planning horizon and that entitles f to MD upon exportation.

Whether we compute MD based on the amount of imported material i or on the amount of exported material j, we must get the same MD. In other words, these two computational bases must be consistent with each other, or

$$\sigma_{jf} \sum_{s \in \mathrm{F}'_n \ni i \in \mathrm{OM}_s} \sum_{t=0}^{\tau} q_{sfijt\tau} = \sigma_{if} \sum_{c \in \mathrm{F}'_n \ni j \in \mathrm{IM}_c} \sum_{\theta=\tau}^{\min[\tau+TL_f,T]} r_{fcj\tau\theta}$$
$$f \in \mathrm{IF} \cap \mathrm{F}_n,\ i \in \mathrm{IM}_f,\ j \in \mathrm{OM}_f \quad (12)$$

Finally, the total amount of i that f imports from s before τ and on which f can claim MD cannot exceed the amount of i used to produce j during τ, and thus

$$\sigma_{\pi(f)f} \sum_{s \in \mathrm{F}'_n \ni i \in \mathrm{OM}_s} \sum_{t=0}^{\tau} q_{sfijt\tau} \le \sigma_{if} X_{f\tau}$$
$$f \in \mathrm{IF} \cap \mathrm{F}_n,\ i \in \mathrm{IM}_f,\ j \in \mathrm{OM}_f \quad (13)$$

Note that Eqs. 12 and 13 ensure that the total amount of j that f makes during τ, exports later, and on which it can claim MD does not exceed the amount of j that f makes during τ.

Based on the Code of Federal Regulations, we now require a duty refund rate DR_{if} ($/$ of duty paid) on i for f and relative value $RV_{jf\tau}$ of j among all finished products of f during τ. Then, the MD claim for f over the planning horizon is

$$MD_f = \sum_t \left[\sum_{i \in \mathrm{IM}_f} \sum_{s \ni i \in \mathrm{OM}_s} \sum_{j \in \mathrm{OM}_f} DR_{if} RV_{jft} CIF_{isf0} ID_{isf0} q_{sfij0t} + \sum_{i \in \mathrm{IM}_f} \sum_{s \ni i \in \mathrm{OM}_s} \sum_{j \in \mathrm{OM}_f} \sum_{\tau \ge t} DR_{if} RV_{jf\tau} CIF_{isft} ID_{isft} q_{sfijt\tau} \right]$$

Now, to compute the MNC's collective corporate taxes in a host nation n, we need the taxable incomes of its facilities in that nation. The taxable income is gross income minus depreciation and gross income is the sum of sales and duty drawback credits less operating expense. The operating expense is the sum of procurement, inventory, outsourcing, and manufacturing (or variable production) costs. To this end, let P_{isct}, CIF_{isct}, and ID_{isct} denote, respectively, the purchase price ($/kg), CIF cost ($/kg), and import duty ($/$ of CIF cost) of material i ($i \in \mathrm{OM}_s \cap \mathrm{IM}_c$) sold by $s \in \mathrm{F}$ to $c \in \mathrm{F}$ during t. Note that P_{isct} refers to the intercompany transfer price of the MNC when both s and c ($c \ne s$) are internal facilities. Let IC_{ift} denote the inventory cost ($/kg per period) of material m_i at f during t, and OC_{ifhct} denote the cost ($/kg) incurred by f for every unit of i ($i \in \mathrm{OM}_f$) that it outsources to facility h ($h \in \mathrm{F}$, $i \in \mathrm{OM}_h$) to meet an order of customer c ($c \in \mathrm{EF}$, $i \in \mathrm{IM}_c$) during t, where $f \ne c$, $f \ne g$, and $g \ne c$. Then, the gross income GI_f of $f \in \mathrm{IF}$ over the planning horizon is

$$GI_f = \sum_t \Bigg\{ \sum_{i \in \mathrm{OM}_f} \sum_{c \ni i \in \mathrm{IM}_c} P_{ifct} F_{ifct} + \sum_{g \in \mathrm{IF} \ni i \in \mathrm{OM}_g} \sum_{c \ni i \in \mathrm{IM}_c} P_{ifgt} G_{igfct} + \sum_{h \in \mathrm{F} \ni i \in \mathrm{OM}_h} \sum_{c \ni i \in \mathrm{IM}_c} P_{ifct} G_{ifhct}$$
$$+ \sum_{i \in \mathrm{IM}_f} \sum_{s \ni i \in \mathrm{OM}_s} \sum_{j \in \mathrm{OM}_f} DR_{if} RV_{jft} CIF_{isf0} ID_{isf0} q_{sfij0t} + \sum_{i \in \mathrm{IM}_f} \sum_{s \ni i \in \mathrm{OM}_s} \sum_{j \in \mathrm{OM}_f} \sum_{\tau \ge t} DR_{if} RV_{jf\tau} CIF_{isft} ID_{isft} q_{sfijt\tau} - \sum_{h \in \mathrm{F} \ni i \in \mathrm{OM}_h} \sum_{c \ni i \in \mathrm{IM}_c} OC_{ifhct} G_{ifhct}$$
$$- MC_{ft} X_{ft} - \sum_{i \in \mathrm{IM}_f} \sum_{s \ni i \in \mathrm{OM}_s} (1 + ID_{isft}) CIF_{isft} F_{isft} - \sum_{i \in \mathrm{IM}_f \cup \mathrm{OM}_f} 0.5 IC_{ift} [I_{if(t-1)} + I_{ift}] \Bigg\} \quad (14)$$

where MC_{ft} is the manufacturing cost [\$/kg of $\pi(f)$] of f during t. Note that we use CIF_{isf0}, and ID_{isf0} to denote the corresponding CIF values and import duties for i, existing in the inventory of f at time zero, and was imported from s before the start of the planning horizon. The first three summation terms on the right side of Eq. 14 represent the following three sales components, respectively:

(1) Direct sales of products by f to customers

(2) Sales for internal facilities that have outsourced their production to f

(3) Sales of products that f has outsourced to other facilities

The fourth and fifth summation terms denote the MD savings of f over the planning horizon, whereas the remaining terms represent f's outsourcing costs, manufacturing costs, CIF and import duty expenses, and inventory costs, respectively.

Thus, the taxable income TI_n of the MNC in nation n over the planning horizon becomes as follows:

$$TI_n \geq \sum_{f\in \mathrm{IF}\cap \mathrm{F}_n} \sum_t \Bigg\{ \sum_{i\in \mathrm{OM}_f} \sum_{c\ni i\in \mathrm{IM}_c} P_{ifct}F_{ifct} + \sum_{g\in \mathrm{IF}\ni i\in \mathrm{OM}_g} \sum_{c\ni i\in \mathrm{IM}_c} P_{ifgt}G_{igfct} + \sum_{h\in \mathrm{F}\ni i\in \mathrm{OM}_h} \sum_{c\ni i\in \mathrm{IM}_c} P_{ifct}G_{ifhct}$$
$$+ \sum_{i\in \mathrm{IM}_f} \sum_{s\ni i\in \mathrm{OM}_s} \sum_{j\in \mathrm{OM}_f} DR_{ij}RV_{jft}CIF_{isf0}ID_{isf0}q_{sfij0t} + \sum_{i\in \mathrm{IM}_f} \sum_{s\ni i\in \mathrm{OM}_s} \sum_{j\in \mathrm{OM}_f} \sum_{\tau\geq t} DR_{ij}RV_{jf\tau}CIF_{isft}ID_{isft}q_{sfijt\tau} - \sum_{h\in \mathrm{F}\ni i\in \mathrm{OM}_h} \sum_{c\ni i\in \mathrm{IM}_c} OC_{ifhct}G_{ifhct}$$
$$- \sum_{i\in \mathrm{IM}_f\cup \mathrm{OM}_f} 0.5IC_{ift}[I_{if(t-1)} + I_{ift}] - \sum_{i\in \mathrm{IM}_f} \sum_{s\ni i\in \mathrm{OM}_s} (1 + ID_{isft})CIF_{isft}F_{isft} - MC_{ft}X_{ft} \Bigg\} - DC_f \quad (15)$$

Note that TI_n is a nonnegative variable, whereas DC_f refers to the constant depreciation charge that MNC incurs at f over the planning horizon. If the tax rate (\$/\$ of taxable income) is TR_n (nonnegative) for nation n, then the corporate tax for the MNC during t is TR_nTI_n. With this, ATP for the MNC for the planning horizon is

$$\mathrm{ATP} = \sum_{f\in \mathrm{IF}} \sum_t \sum_{i\in \mathrm{OM}_f} \sum_{c\ni i\in \mathrm{IM}_c} P_{ifct}F_{ifct} + \sum_{f\in \mathrm{IF}} \sum_t \sum_{g\in \mathrm{IF}\ni i\in \mathrm{OM}_g} \sum_{c\ni i\in \mathrm{IM}_c} P_{ifgt}G_{igfct} + \sum_{f\in \mathrm{IF}} \sum_t \sum_{h\in \mathrm{F}\ni i\in \mathrm{OM}_h} \sum_{c\ni i\in \mathrm{IM}_c} P_{ifct}G_{ifhct}$$
$$+ \sum_{f\in \mathrm{IF}} \sum_t \sum_{i\in \mathrm{IM}_f} \sum_{s\ni i\in \mathrm{OM}_s} \sum_{j\in \mathrm{OM}_f} DR_{ij}RV_{jft}CIF_{isf0}ID_{isf0}q_{sfij0t} + \sum_{f\in \mathrm{IF}} \sum_t \sum_{i\in \mathrm{IM}_f} \sum_{s\ni i\in \mathrm{OM}_s} \sum_{j\in \mathrm{OM}_f} \sum_{\tau\geq t} DR_{ij}RV_{jf\tau}CIF_{isft}ID_{isft}q_{sfijt\tau}$$
$$- \sum_{f\in \mathrm{IF}} \sum_t \sum_{h\in \mathrm{F}\ni i\in \mathrm{OM}_h} \sum_{c\ni i\in \mathrm{IM}_c} OC_{ifhct}G_{ifhct} - \sum_{f\in \mathrm{IF}} \sum_t \sum_{i\in \mathrm{IM}_f} \sum_{s\ni i\in \mathrm{OM}_s} (1 + ID_{isft})CIF_{isft}F_{isft} - \sum_{f\in \mathrm{IF}} \sum_t \sum_{i\in \mathrm{IM}_f\cup \mathrm{OM}_f} 0.5IC_{ift}[I_{if(t-1)} + I_{ift}]$$
$$- \sum_{f\in \mathrm{IF}} \sum_t MC_{ft}X_{ft} - \sum_{f\in \mathrm{IF}} DC_f - \sum_n TR_nTI_n \quad (16)$$

Finally, the variables in our formulation should satisfy certain bounds. For instance, as a result of the limited storage space availability and the requirement to maintain a minimum stock level for each material, we have

$$I_{if}^L \leq I_{ift} \leq I_{if}^U \qquad f \in \mathrm{IF}, i \in \mathrm{OM}_f \cup \mathrm{IM}_f \quad (17)$$

where I_{if}^L and I_{if}^U, respectively, are the lower and upper limits on the inventory level of i at f over the planning horizon.

Similarly, the production rate of each f has some lower and upper limits:

$$X_f^L \leq X_{ft} \leq X_f^U \qquad f \in \mathrm{IF} \quad (18)$$

where X_f^L and X_f^U are the lower and upper production limits of f over the horizon, respectively. Recall that X_{ft} is the actual consumption/production level of $\pi(f)$ at f during t.

This completes our formulation for the PDP in the presence of corporate taxes, import duties, and duty drawbacks as the regulatory factors. It constitutes maximizing ATP (Eq. 16) subject to Eqs. 5–13, 15, 17, and 18. We now illustrate our model with a realistic example and demonstrate the significant impact of regulatory factors in production–distribution planning.

Case Study

An MNC owns 12 facilities (IF = {F1–F12}) that are classified into two main categories: the primary and secondary plants. The primary plants are the upstream processing facilities that supply raw materials to the downstream secondary plants. In this study, the MNC needs a tactical biweekly production–distribution plan for the next fiscal year. In other words, the planning horizon has 26 equal time periods ($t = 1, 2, \ldots, T = 26$). The key external business partners that deal extensively with the MNC are 10 customers (C1–C10), eight suppliers (S1–S8), and eight outsourcing facilities (O1–O8).

Figure 3. Geographical spread of the nations hosting the facilities in the case study.

This means EF = {C1–C10, S1–S8, O1–O8}. The internal facilities of the MNC sell their products to these customers, procure raw materials from the suppliers, and outsource their production to the outsourcing facilities. The 12 internal facilities (IF = {F1–F12}) and the 26 external facilities (customers, suppliers, and outsourcing facilities) are geographically spread in 10 nations (n = N1–N10) around the globe as illustrated in Figure 3.

Because of the sheer size of the entire case study data (such as operating costs, limits, prices, locations, demands, BOMs, details of regulatory factors, etc.), we are unable to present them all fully in tabular formats. The readers may obtain the full data for our case study by contacting the corresponding author.

Based on the aforementioned problem data, we solved our model for two scenarios. In scenario 1, we included the three regulatory factors (corporate taxes, import duties, and duty drawbacks). Scenario 2 is similar to scenario 1 except that we ignore duty drawbacks. Thus, in scenario 2, we omitted Eqs. 9–13, all $q_{sfijt\tau}$ variables, and set $DR_{if} = 0$. The resulting model determines X_{ft}, F_{ifct}, and G_{ifgct} values that maximize the MNC's ATP without accounting for duty drawbacks. To have a meaningful comparison of the solutions in these two scenarios, we computed the corresponding ATP of the MNC after considering duty drawbacks in an after-the-fact manner for the solution in scenario 2. To do so, we used X_{ft}, F_{ifct}, and G_{ifgct} from scenario 2 to compute the corresponding $q_{sfijt\tau}$, $r_{fcj\tau\theta}$, and thus the MDs, TI_{nt}, and ATP by solving an LP model. This LP model is similar to the model for scenario 1 except that Eqs. 5–8, 17, and 18 are omitted and X_{ft}, F_{ifct}, G_{ifgct} are constant model parameters.

We used CPLEX 9.0 solver within GAMS (distribution 21.4) running on a Windows XP workstation with a Pentium 4 Xeon (2.8 GHz, 2 GB RAM) processor. Scenario 1 involved 209,920 continuous variables, 16,453 constraints, and 703,316 nonzeros, whereas scenario 2 involved 52,347 continuous variables, 4,272 constraints, and 217,337 nonzeros. CPLEX solved scenario 1 in 34.5 s and gave the maximum ATP of $279.0 million. It solved scenario 2 in 5.1 s and gave a maximum ATP (without accounting for duty drawbacks) of $218.6 million. After accounting for the duty drawbacks, the corresponding ATP rose to $260.9 million for the MNC in scenario 2. Note that this required solving another LP model with 155,788 continuous variables, 12,189 constraints, and 453,911 nonzeros, for which CPLEX took 4.5 s to solve.

The omission of the duty drawbacks in scenario 2 resulted in a very different production–distribution plan from scenario 1. The differences include the raw material sourcing strategies, production allocation among internal facilities, outsourcing strategies, and allocation of customer demands among the MNC's internal facilities. Tables 3 to 6 list some of these differences. Instead of discussing in detail how the omission of duty drawbacks in scenario 2 contributes to all these differences in the optimal production–distribution plans, we focus on two key differences to explain the effect of duty drawbacks and to illustrate the importance of modeling duty drawbacks in PDP problems.

First, the import and export profiles of the internal facilities change in the presence or absence of duty drawbacks. Although there is only a small difference (1%) in the total export sales by the internal facilities in the two scenarios (see Table 7), material sourcing strategies of these facilities differ significantly. As shown in Table 8, the consumption of imported raw materials by each internal facility in scenario 1 is greater than or equal to that in scenario 2. This is primarily because imported materials are generally more expensive than domestic materials based on their CIF values and import duties. Therefore, it is not surprising that the optimal solution in scenario 2 sources as much of the cheaper domestic products as possible. Conversely, the accounting of duty drawbacks in scenario 1 means that the material sourcing strategy in an optimal PDP is no longer dependent only on the materials' CIF values and import duties. Now, an optimal solution also entails a coordination of import and export activities of the internal facilities so that the MNC can harness drawback savings, which may help lower the costs of imported materials. Only in cases where these drawback savings make the imported materials more competitive, relative to the domestic goods, would it make financial sense for an

Table 3. Material Sourcing Plans of the MNC's Facilities over the Planning Horizon in the Case Study

Facility f	Material m_i (i)	Scenario 1: Total Procured (ktons)	Scenario 1: Supplier (Composition, %)	Scenario 2: Total Procured (ktons)	Scenario 2: Supplier (Composition, %)
F1	1	423.7	S2 (38.4), S3 (15.6), S4 (18.5), S6 (7.9), S7 (0.7), S8 (19.0)	514.9	S2 (53.5), S3 (11.0), S4 (15.0), S6 (5.4), S7 (0.7), S8 (14.5)
F2	1	492.4	S1 (17.0), S2 (10.2), S3 (2.7), S4 (34.6), S5 (11.1), S6 (4.6), S7 (17.8), S8 (2.0)	383.3	S1 (6.3), S2 (7.6), S4 (71.5), S5 (7.5), S6 (1.7), S7 (5.3)
F3	1	412.9	S6 (100)	430.7	S6 (100)
F4	2	103.4	F1 (63.6), F2 (24.8), F3 (11.6)	110.4	F1 (91.6), F3 (8.4)
F5	2	107.1	F1 (6.8), F2 (42.3), F3 (50.9)	100.2	F2 (92.6), F3 (7.4)
F6	2	44.0	F1 (2.4), F2 (47.1), F3 (50.4)	44.0	F3 (100)
F7	3	58.3	F1 (57.7), F2 (42.3)	63.5	F1 (72.3), F2 (27.7)
F8	3	119.6	F1 (3.6), F2 (18.9), F3 (77.5)	117.5	F1 (1.9), F2 (3.2), F3 (94.9)
F9	3	63.6	F1 (33.2), F2 (62.5), F3 (4.3)	60.6	F1 (51.3), F2 (46.2), F3 (2.5)
F10	4	47.5	F1 (59.6), F2 (34.7), F3 (5.7)	48.1	F1 (72.5), F2 (21.7), F3 (5.8)
F11	4	146.6	F1 (31.1), F2 (54.8), F3 (14.1)	142.3	F1 (48.4), F2 (37.7), F3 (13.9)
F12	4	81.8	F1 (6.3), F3 (93.7)	85.6	F1 (1.4), F3 (98.6)

internal facility to consume more imported materials as illustrated in this case study.

The second key difference in the optimal solutions of the two scenarios lies in the MNC's earnings. Essentially, the omission of duty drawbacks has an adverse impact on the ATP of the MNC. In scenario 1, the optimal PDP enables the MNC to earn an ATP of $279 million. This is $28 million more than that in scenario 2 when duty drawbacks are accounted for accordingly based on its optimal PDP (see Table 9). In effect, the omission of duty drawbacks in scenario 2 slashes the MNC's ATP by 6.5%. Also, note that the duty drawbacks eligible to the MNC in scenarios 1 and 2 amount to $94.6 million and $45.8 million, respectively. These correspond to about 60 and 44% of the import duties that MNC has to pay over the horizon in scenarios 1 and 2, respectively. Clearly, the substantial drawback savings in these scenarios demonstrates the significant financial benefit that companies can reap if they operate in an environment similar to the one in this case study.

Discussion

At this stage, it is worthwhile highlighting four distinguishing features of our model relative to the only existing model of Arntzen et al.[14] that incorporates duty drawbacks.

First, it is the first PDP model that (1) incorporates the effects of three key regulatory factors (corporate taxes, import duties, and duty drawbacks) and (2) computes duty drawbacks for multiproduct manufacturing processes that abound in the chemical industry. As mentioned previously, the model of Arntzen et al.[14] computes duty drawbacks for single-product manufacturing operations only. In addition, Arntzen et al.[14] conspicuously omitted corporate taxes in their formulation, even though corporate taxes usually constitute a significant portion of a company's annual expenditure. For example, in countries such as Croatia, Peru, Belgium, Italy, and Singapore, companies must set aside 20 to 40% of their before-tax profits for corporate taxes.

Second, in contrast to the model of Arntzen et al.,[14] the solution of our model offers direct traceability from imported materials to exported products. Such traceability (based on the values of $q_{sfijt\tau}$ and $r_{fci\tau\theta}$) is necessary for computing MD accurately in a multiproduct manufacturing environment, especially when the market and CIF values of products are functions of time over the given planning horizon. It also offers information that is necessary for allocating drawbacks among products or effectively managing inventory so that all eligible MDs are duly claimed according to the drawback regulations. For instance, if product substitution (see Table 2) is not permitted by the relevant duty drawback regulations, then the production–distribution plan needs to have details of the utilization path of every batch of imported material to ensure that all eligible MDs are duly claimed. These details include the origins, batch identities, delivery times, and utilization or con-

Table 4. Average Production Rates (Tons/Day) of the MNC's Facilities in the Case Study

Facility f	Average Production Rate (Tons/Day): Scenario 1	Scenario 2
F1	351.1	426.3
F2	406.6	316.7
F3	341.1	355.8
F4	137.4	146.9
F5	138.2	128.6
F6	55.0	55.0
F7	88.5	99.7
F8	191.2	187.7
F9	104.1	96.5
F10	39.3	39.9
F11	121.1	117.5
F12	67.8	70.8

Table 5. Outsourcing Amounts (ktons) and Their Allocation (%) to Facilities for Material m_6 over the Horizon in the Case Study*

Facility f	ktons Outsourced	Outsourced Facility (Outsourced Amount in %)
F4	4.2	O1 (54.3), O4 (18.7), O7 (26.9)
	3.6	O1 (47.1), O4 (21.7), S7 (31.2)
F5	4.7	F6 (19.8), O1 (23.5), O7 (56.7)
	5.6	F6 (29.5), O1 (28.5), O7 (42.0)
F6	23.7	O1 (48.4), O4 (33.2), O7 (18.4)
	24.1	O1 (49.2), O4 (33.3), O7 (17.4)

*First row is the outsourcing data in scenario 1, whereas the second is in scenario 2.

Table 6. Allocation of Customer Demands of Material m_6 over the Horizon in the Case Study

Customer (c)	Supplied (ktons)	Demand Allocation (%) among Internal Facilities*		
		F4	F5	F6
C1	10.1	24.8	50.7	24.5
		27.3	51.5	21.2
C2	10.7	36.4	55.0	8.6
		36.4	52.6	11.0
C3	11.2	13.9	50.3	35.8
		23.7	40.4	35.8
C4	12.9	41.8	30.1	28.1
		43.2	30.1	26.8
C5	7.4	7.1	66.3	26.7
		10.5	66.3	23.2
C6	11.6	37.3	37.2	25.6
		41.8	37.2	21.1
C7	13.5	38.3	28.5	33.2
		39.9	23.3	36.8
C8	13.4	28.8	29.8	41.4
		28.8	28.5	42.7
C9	26.7	43.4	18.3	38.3
		41.2	20.4	38.4
C10	10.8	51.4	23.5	25.1
		53.8	21.1	25.1

*First row is the demand allocation percentage in scenario 1, whereas the second is in scenario 2.

sumption times of imported materials and the export times of merchandise made from them. In our model, $q_{sfijt\tau}$ offers such details, given that it reflects the amount of i imported from s to f at t and used to produce j at τ.

Third, even though our model is developed primarily for production–distribution planning in a multiproduct manufacturing environment, it works equally well for the single-product manufacturing operations.

Finally, and most importantly, our model can also handle uncertainty in problem parameters with only a few straightforward modifications. For example, if a given PDP has uncertain market prices, demands, CIF values, and so forth, and one can represent the uncertainties by a set of probabilistic scenarios with known probabilities of occurrence, then one can easily use our model in such a scenario-based approach that can mimic models described by Tsiakis et al.[21] and Oh and Karimi.[3] For this, the main modifications in our model will be as follows:

(1) Add one additional index to each decision variable to signify its scenario.

Table 7. Export Sales (M$) of Internal Facilities

f	Scenario 1	Scenario 2	Difference* (%)
F1	217,502	228,890	−5.2
F2	216,754	180,201	16.9
F3	112,762	133,176	−18.1
F4	340,231	365,228	−7.3
F5	328,041	305,647	6.8
F6	119,014	109,965	7.6
F7	164,854	179,608	−8.9
F8	370,726	366,187	1.2
F9	158,111	132,535	16.2
F10	170,267	173,164	−1.7
F11	540,093	523,190	3.1
F12	273,946	285,593	−4.3
Total	3,012,301	2,983,384	1.0

*The differences are percentages of the sales in scenario 1.

Table 8. Sourcing Strategies of the Internal Facilities in the Case Study

f	Material m_i (i)	Duty-Payable Sources (%)*	
		Scenario 1	Scenario 2
F1	1	61.6	46.5
F2	1	65.4	28.6
F3	1	0	Same
F4	2	36.4	8.4
F5	2	57.7	7.4
F6	2	100	Same
F7	3	100	Same
F8	3	22.5	5.1
F9	3	100	Same
F10	4	100	Same
F11	4	100	Same
F12	4	6.3	1.4

*The percentage is computed based on the total material flow over the entire planning horizon.

(2) Replicate all constraints for each scenario with specific realizations of uncertain parameters.

(3) Maximize the expected ATP over all scenarios instead of one single deterministic ATP.

We point out that the LP nature of our formulation is a great advantage, when extending it to the above scenario-based approach. Of course, the scenario-based approach will significantly increase the model size, although that poses no problem for the state-of-the-art LP algorithms. We must point out, however, that the five-index and six-index variables ($r_{fci\tau\theta}$ and $q_{sfijt\tau}$, respectively) in our deterministic model do pose a problem, when one uses a commercial algebraic modeling software such as GAMS. GAMS required considerable RAM resources to generate our model. For scenario 1 of our case study, GAMS needed >1.7 GB RAM and real time of about 11 min to generate our model before it took only another 34.5 s to solve the LP. However, we should point out that this problem is specific to GAMS. It is not mandatory to use GAMS for model generation; we can write special-purpose programs that are more efficient. In addition to the parameter uncertainty, several possible extensions of our model include the accounting of nonlinear relationship between raw material consumption and merchandise production or economies of scale in freight expenses and the like. These extensions are clearly relevant to the manufacturing world because they reflect real operational constraints and modeling/solution challenges. Therefore, improving the formulation and model generation methodology constitute significant future research opportunities for this problem. This would be an essential goal for increasing our model's applicability in the real, uncertain industrial environment.

Conclusion

Duty drawback laws have legislated in many countries with the primary goal of helping domestic manufacturers to compete in foreign markets, some of which have been in existence for as long as three centuries. Despite the long history and prevalence of duty drawback incentives in the global community, it is ironic that hefty sums of drawbacks remain unclaimed annually. This is even more baffling when one considers the fact that many companies are constantly seeking cost-saving opportunities to help them battle in the current fiercely competitive business environment. On the academic front, it is also

Table 9. MNC's ATPs and Percentage Differences in the Case Study

Component	Scenario 1 (M$)	Scenario 2 (M$)	Difference (M$)	Difference* (%)
Sales	4,515	4,512	2,249	0.0
Manufacturing drawback	95	46	49	51.6
Outsourcing costs	1,481	1,483	−2	−0.1
CIF costs	2,225	2,240	−15	−0.7
Import duties	156	105	52	33.0
Production costs	322	323	−1	−0.4
Depreciation costs	13	13	0	0.0
Inventory costs	102	104	−2	−1.6
Corporate taxes	32	31	1	3.3
ATP	279	261	18	6.5

*The differences are percentages of the component in scenario 1.

surprising to note that only one existing production–distribution model accounts for the effects of duty drawbacks in its formulation. Nevertheless, it has limited application in the industry as a result of nongeneric representation of duty drawbacks.

This article makes some primal and significant contributions toward research on production–distribution planning. To the best of our knowledge, this is the first contribution to

(1) Present a concise introduction and overview of duty drawback regulations for multiproduct manufacturing processes typical in the chemical and other industries.

(2) Highlight the tremendous importance of duty drawbacks in supply chain research and practice, which both industry practitioners and academicians have totally overlooked.

(3) Report a new LP model for deterministic production–distribution planning in global multiproduct manufacturing in the presence of three key regulatory factors: corporate taxes, import duties, and duty drawbacks.

The generic representation of duty drawbacks in our new model offers flexibility to accommodate stringent regulations pertinent to duty drawbacks, which previous work has overlooked. For instance, it takes into account the time limit that may be imposed in drawback regulations on the interval between manufacturing and export of a product. Moreover, it also provides a unique traceability feature that may be required by the duty drawback regulations of countries concerned. With the aforementioned features, our model is far superior to the only existing model of Arntzen et al.[14] for industrial applications.

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Notation

ATP = after-tax profits
BOM = bill of materials
CIF = cost, insurance, and freight
CIF_{isf} = cost + insurance + freight charges of shipping a unit of material m_i from s to f at t
D_{ict} = demand of material m_i from by customer c during t
DC_f = depreciation charge of f over planning horizon
DR_{if} = duty refund rate ($/$ of duty paid) to f for its import of i
EF = set of external facilities from which the MNC sources raw materials or to which it sells finished products
EIF = set of existing facilities that the MNC owns
F_n = set of facilities located in nation n
F'_n = set of facilities located outside nation n
F_{ifct} = units of material m_i shipped from f to c during t
F_{isft} = units of material m_i shipped from s to f during t
FTA = free trade agreement
G_{ifgct} = production units of i that is outsourced by f to g to fulfill the order of c during t
GI_f = gross income of f
I_{if}^L = lower limit on the inventory level of i at f
I_{if}^U = upper limit on the inventory level of i at f
I_{ift} = inventory level of a material i associated with an internal facility f at the end of a period t
IC_{ift} = inventory cost of unit material m_i per unit time period during t
ID_{isf} = import duty imposed on material m_i that going from s to f during t
IF = set of facilities owned by the MNC
IM_f = set of incoming materials consumed by f
LP = linear programming
MC_{ft} = variable production cost of manufacturing one unit of $\pi(f)$ by f at t
MD = manufacturing drawback
MILP = mixed-integer linear programming
MINLP = mixed-integer nonlinear programming
MNC = multinational company
MP_{jt} = open market value of j during t
N = number of countries
OM_f = set of outgoing materials produced by f
OC_{ifgct} = cost incurred by f for every unit of m_i that is outsourced to g to fulfill the order of c at t
P_{ifgt} = unit selling price (exclusive of insurance and freight) of material m_i charged by f to g during t
PDP = production–distribution problem
$q_{sfijt\tau}$ = units of i that an internal facility f imports from supplier s at t and it subsequently consumes to manufacture j at τ
$q_{sfij0\tau}$ = units of i that an internal facility f imports from supplier s before the start of horizon and it subsequently consumes to manufacture j at τ
$r_{fci\tau\theta}$ = units of i that is manufactured by f using imported materials at τ and that is subsequently exported to c at θ
R_{jft} = market value of j relative to those of all finished products of f during t
RMD = rejected merchandise drawback
$RV_{jf\tau}$ = relative value of j among all finished products of f during τ
S_{ist} = amount of material m_i that supplier s can supply to the MNC during t
T = number of time periods in the planning horizon
TI_n = taxable income of the MNC in nation n
TR_n = corporate tax rate in nation n
UMD = unused merchandise drawback
WTO = World Trade Organization
X_f^L = lower limit on the units of $\pi(f)$ consumed or produced by f at every t
X_f^U = upper limit on the units of $\pi(f)$ consumed or produced by f at every t
X_f = units of $\pi(f)$ consumed or produced by f during t

Subscripts

c, s = customer and supplier facility, respectively

f, g = internal or external facility (supplier, producer, or customer)
i, j = material
n = nation or country
t, τ, θ = time period

Greek letters

α_{isf} = fraction of i in the inventory of f at the start of the horizon that f procured from s
$\pi(f)$ = primary product associated with f
σ_{if} = coefficient of material m_i in the mass balance equation of f
γ_{ift} = fraction of material m_i that f imports from the foreign supplier during period t

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