Designing the Right Global Supply Chain Network

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Abstract: This paper considers how research in Operations Management can support the development of strategies for the design and management of global supply chains. It includes a model-based statement of the problem and an overview of highlights of past research that is relevant to both theory and practice. The paper identifies opportunities for research that focus on how global supply chain modeling can inform the current debate concerning the reaction of firms to changes in government policy that are relevant to global manufacturing and logistics. This includes policy changes such as tariffs, content requirements, taxes and investment incentives.

1. Introduction and Motivation

The global economy is in the midst of major upheavals that affect global supply chain strategy in every industry. Today, firms are facing enormous pressure to re-structure, re-design and re-think where and how products are produced, inputs are sourced and customer demand is fulfilled. The drivers for this change include all of the usual factors such as market volatility, cost differentials and technology disruption. Additionally, there are unknowns concerning government policies which affect both cross-border trade and local processes. This has led to the current situation where we are experiencing a trade war, with governments looking to optimize the domestic portion of the supply chains that operate in their jurisdiction. At the same time, accompanies are striving to optimize their particular global supply chains which operate in multiple jurisdictions and which generate extensive cross-border flows of goods, money, information and control.

The focus of this paper is on how these forces could guide the research on the design and management of global supply chains, given the past three decades of operations management research and applications. In addition to formulating a model-based statement of the problem

and to providing an overview of highlights of past research, we will consider current challenges and trends which suggest new opportunities for both research and practice. Our particular focus will be on how global supply chain modeling can inform the current debate concerning how firms should modify their global supply chain strategy in response to changes in government policy.

First, let us define the key elements of a global supply chain strategy. The goal, as in all supply chains, is to match supply with demand, but on a *global scale*. This is achieved through a hierarchy of decisions that determine material flows, capacities and capabilities at each manufacturing and stocking location, as well as cash flows and technology investments. These decisions jointly determine the *landed cost* for every product/customer destination combination as well as the total cost of ownership, both of which are keys to customer acceptance and market share. Tradeoffs that must be considered include all fixed and variable costs, revenues that drive global after-tax profit, as well as metrics related to customer satisfaction, service and competitive position. In addition, resource constraints based on the capacity and capabilities of all value-adding processes, at all stages in the product life cycle (i.e. design, produce, fulfill, support), must be satisfied. Finally, there are the constraints imposed by government policies within each country of operation. While many objective functions can be formulated for the global supply chain strategy problem, (e.g. maximize global, after-tax profit, maximize corporate market value, increase growth, etc.,), most major companies also recognize that their global supply chains can act to mitigate the many risks they face as they operate globally. These risks include foreign exchange rate fluctuation, market demand and price volatility, uncertainties in trade policies, and decisions made by their competition. As noted, the focus of this paper will be on the responses associated with government policy changes such as adjustments to tariffs, import and export quotas, investment credits and incentives, cash flow restrictions and foreign ownership limitations.

2 Challenges and Trends

It is instructive to note some of the current challenges associated with the management of global supply chains that firms are facing as we evaluate the relevance of the current state of operations management research. As globalization has become pervasive, suppliers have pursued global markets and most companies source extensively from global suppliers. This has

led to an increase in outsourcing and a corresponding decline in vertical integration. As a result, supply chain networks have become more complex and both first and lower tier suppliers are playing a more important role in many industries. A recent reaction to this re-structuring of supply chains has been increased interest in re-shoring, especially in the US and other developed economies, where there is pressure to re-examine sourcing strategy and to promote "bringing manufacturing back" (or at least closer) to home. As supply chain re-structuring has accelerated, we observe increased volatility of costs and demand. At the same time, more emphasis is now given to product quality and labor relations. Other factors which must be considered include the need to mitigate the impact of supply chain disruptions-caused by both economic and political events, and the rising expectations for end-to-end product support services which has led a movement towards incentive aligned, performance-based contracting. Finally, technology developments now affect product design, production processes and the management of production and service-support supply chains. Some of these technological developments are expected to be highly disruptive (e.g. industry 4.0, Internet of Things, blockchain, and robotics, etc.). This disruption will occur in part due to the possibility for increasing coordination through the leverage of enhanced data sharing and visibility, and through enhanced integration of decision making among supply chain partners. Finally, we note that supply chain strategy has a major impact on a firm's carbon footprint, energy consumption, waste and recycling and end-of-life disposal. Such environmental considerations also must be considered.

We argue that firms today are facing a crisis, created by all of the challenges note above. Firms have found that facing these challenges is unavoidable as they will have a major impact on their competitive success and the welfare of countries in which they do business. The question concerning how companies are responding or should be responding to the current crisis is now hotly debated and has become highly politicized. In particular, there is a debate about re-shoring to the US, Japan, Europe and/or other developed countries. Is it a real phenomenon that will revive domestic manufacturing and service industries or has it yet to occur on a scale that will restore domestic manufacturing employment in the developed economies? The decline in employment in manufacturing industries in the US and other developed economies has been underway for some time and is typically attributed to major cost differences for labor. The potential impact of disruptions due to government policy changes is unknown. Figure 1

illustrates historical employment data (in thousands) for the US which is representative for all developed economies.

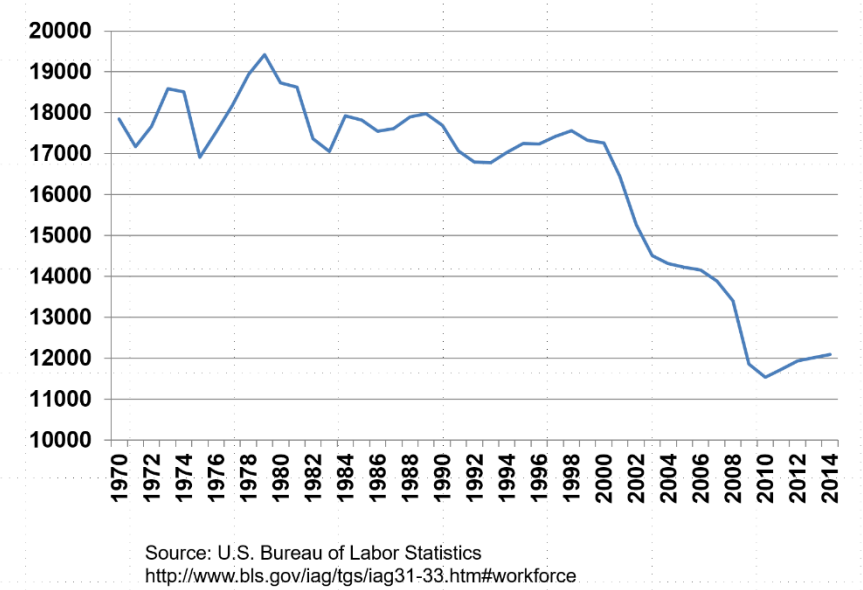

Figure 1: US Employment in Manufacturing Industries

We recently conducted a detailed benchmark survey of manufacturing sourcing decisions (see Cohen et al., 2018). One of its key findings was that many firms were adopting new global supply chain strategies and were re-structuring their supply chains in response to fundamental changes in their environment (costs, markets, suppliers, and technology, etc.). The common wisdom, as reported in the press, tries to explain this restructuring as a response to a dominant factor such as the pursuit of lower labor costs or as a reaction to changes in tariffs or government incentives. Our survey results indicated that companies were re-defining their global supply chain footprint in a manner which considered the complex tradeoffs of multiple factors along with risk factors associated with global supply chains. This is consistent with the operations management modeling literature, which has formulated the global strategy problem in terms of models that capture many of the interactions and tradeoffs that are relevant to the problem.

The survey also noted the following trends in production sourcing decisions.

1. China continued to be the most attractive region for production sourcing. However, cost was not the sole driving force. Market access, quality and supply chain performance have emerged as dominant drivers for increasing production volume in China.

2. In the opposite direction it was primarily labor cost that drove companies out of China to lower cost locations like ASEAN countries.
3. Eastern Europe and Russia was the second most attractive region for offshoring. Especially Western European countries used near-shore cost advantages.
4. Western Europe was the region with the largest outflow of production volume and one out of only two with a negative net-effect on production volume in our sample. Yet, machinery companies still invested in capital-intensive production in Western Europe
5. For North America, a growth in production volume can be observed with more companies investing than divesting.
6. Only Asian firms with a strong commercial focus on Japan and ASEAN countries increased production volume in Japan while even more firms shifted production from Japan in light of the recent natural disaster

These observations suggest that outsourcing to low labor cost countries continues to be a favored strategy in certain industries in spite of government policies and incentives to promote domestic manufacturing and/or restrict outsourcing. Some argue that technology (e.g. robotics, 3-D printing, social networks) will tip the balance between offshoring and reshoring.

The reported multi-dimensional decision drivers and the resulting complex pattern of supply chain sourcing is consistent with the operations management modeling literature. An early formulation of the problem is due to Cohen and Lee (1989), who introduced a constrained optimization model that derived both inbound and outbound material flows as well as customer and supplier sourcing and production capacity utilization. An interesting observation in this paper is the discussion of particular component strategies associated with a firm's overall global supply chain strategy. These component strategies include:

Plant Charter Strategies

- Consolidation at either a regional or global level for the full product line. This strategy has important implications for market, product quality and customer service.
- Product Focus which specializes for a particular class of products and which leverages economies of scale and avoids diseconomies of scope. Distribution costs will increase under this strategy.

- Process Focus - Specialize in a stage of manufacturing. This can lead to reduced productions costs and increase product quality
- Vertical Integration - Define a range of products and process to manage in a integrated fashion

Supply Strategies

- Centralized Control leading to lower costs and enhanced purchasing bargaining power
- Regionalize Control Local supplies and plant coordination along with co-location of suppliers to facilitate JIT
- Consolidation such that the number of vendors will decrease and the level of collaboration and achieved quality will increase
- Diversification multiple sourcing and mitigate risks of currency adjustments and supply chain disruption

Distribution Strategies

- Consolidation – Pooling of demand by consolidating multiple DC sites into a single major DC. This can lead to lower fixed and inventory costs and higher logistics costs.
- Co- Location – This involves adding manufacturing capabilities to DCs to support local market presence and flexibility
- Market Service – Local DCs are placed close to markets to speed up response times and increase the level of customer service

The model introduced by Cohen and Lee (1989) was an early formulation of the global supply chain strategy problem. The model introduced a linear program network representation of the supply chain, with multiple levels for the product and value-adding locations, i.e. components, sub-assemblies and final products, as well as for vendors, sub-assembly plants, final product assembly plants, distribution centers and market regions. The objective of the model was to maximize global, after tax profits computed in the numeraire country currency. After tax profit was defined as before-tax profit – local taxes paid in each country of operation, adjusted for conversion to the numeraire country currency. Before tax profit was generated by sales revenue derived from the material flows from the plants to other plants (transshipments) and to distribution centers as well as from distribution centers to markets minus all fixed and variable costs (production, transportation, facility fixed). Constraints included plant/product specific

production capacity, material requirements generated by the production schedule consistent with the bill of material, and all outbound and internal material flows from vendors, plants and distribution centers. Additional constraints included market region demand for each finished products and supplier capacity. The model also included offset requirements which captured country-specific content based on the percentage of country profits relative to total profits versus country-specific value added relative to total global value added. This constraint was motivated by the need to achieve a balance between sales and production across all regions and when it is satisfied the firm is said to be using a "natural hedging" strategy. The formulation was motivated by a study of personal computer assembly operations for a major US manufacturer with a global footprint.

While the Cohen and Lee (1989) model derived supply network strategies of a firm that captured the effects of government policies, taxes, customs and duties, and incentives, there are important deeper research issues that can be explored. Although the purpose of this paper is not a comprehensive literature review, we discuss some illustrative examples on how such deeper research has expanded our understanding of the complex global supply network design problem.

First, we note that there is an extensive literature on operational decision making once a network has been defined. This is not the focus of the current paper, and we will simply cite Cohen and Lee (1988) as one such example, where a framework was described to coordinate inventory policies and service requirements in a supply network.

Second, there are tactical decisions that are also tied to the supply network. For example, Huchzermeier and Cohen (1989) explored how, with a global supply network, the capacities of the multiple production locations can be used to provide operational flexibilities by switching production in the presence of taxes and exchange rate uncertainties. Another tactical decision is the determination of capacities. Since governments allow tax cross-crediting (where a global company can use excess foreign tax credits to offset the tax liabilities of other divisions), companies can take advantage of this to set manufacturing capacities that can be different from the ones used purely to match supply and demand. A treatment of this problem can be found in Xiao et al. (2015). Next, the exact way in which tax incentives work can potentially require a special network set up. This was the subject of Hsu and Zhu (2011), which focused on the export tax policies of China. Material inputs imported into China, to be made into final products for export, can be exempted from tariffs and value-added taxes. To simplify and reduce the

operational costs in monitoring this process, a separate bonded warehouse for the materials may be needed if the firm also produces for the Chinese domestic market. Hsu and Zhu (2011) studied the optimal structure, with or without the bonded warehouse. Another example of tactical decisions in the presence of complex tax rules is procurement strategies. Xu et al. (2018) studied, again using China as an example, the comparison of consignment versus turnkey procurement strategies when working with a contract manufacturer in China.

In the next section, we will discuss how the dynamic changes in such government policies and incentives, coupled with economic developments globally as well as infrastructural investments could complicate the development of the appropriate global supply network design. This gives rise to a set of interesting and relevant research problems which we will discuss later.

3. Opportunities in Designing the Supply Chain in Turbulent Times

In such turbulent times, the design of the supply chain is much more complex than before. There are certainly more "land mines" that supply chain executives need to be aware of and thus they must navigate their decision process accordingly. At the same time, there are also new opportunities that render more flexibility and potentially new value-creating paths that smart supply chain designs can take advantage of. Both the challenges and the opportunities have implications on operations management research going forward.

3.1. Smart Tax and Incentive-Based Supply Chain Design

As noted earlier, the design of a supply chain has become much more than the standard cost optimization problem where costs have been confined to the traditional fixed and variable costs of operation, and the logistics costs of transporting between operating sites.

The inclusion of additional factors such as local content requirements, customs and duties rates, differential tax rates in different countries, transfer pricing schemes, and incentives provided by local government, however, are complicated by the fact that such factors are dynamic and change rapidly. Take the example of trade agreements. There has been a proliferation of trade agreements in the last decades (see the following figure). These agreements often specified rules that provided incentives for companies in a particular industry to trade with another country on specific products. These incentives could be in the form of duty free rates or a reduction in duties paid on imports. A much publicized example is the North

American Free Trade Agreement (NAFTA), which is currently being revised. Trade agreements aside, governments provide incentives in the form of tax concessions that would encourage companies to set up operations in their countries or locality.

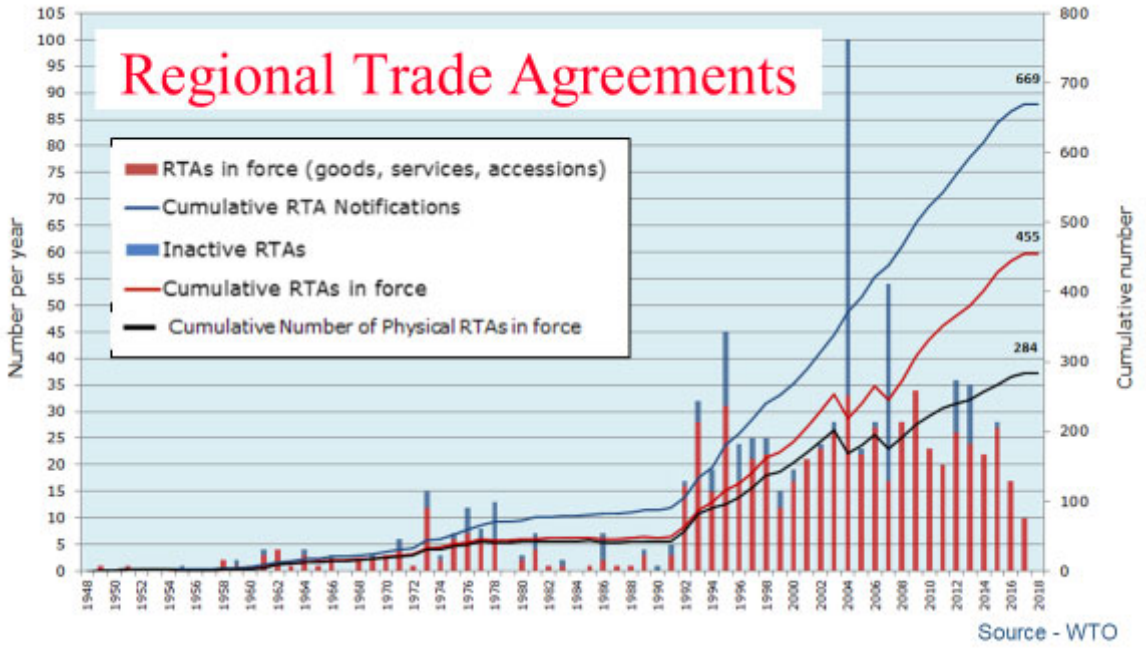

Figure 2: Trends on Regional Trade Agreements

There have been many examples of tax or incentive-based supply chain designs that are strictly based on direct customs reduction or a tax subsidy. Mercedes Benz located the manufacturing site of their SMART car, called Smartville, in Hambach, France, based primarily on the tax subsidy of the French government. For a while, the shoe company Crocs retained its manufacturing plant in Canada to make products to satisfy demands in Israel, taking advantage of the zero duty rate stipulated in the special trade agreement between Canada and Israel (Hoyt, 2007).

But then, as more complex trade agreements are introduced, the design problem needs to take account of the complex interactions of the impacts of such agreements. To illustrate, we use the example of the Logan car of Renault (see Lee and Silverman, 2008). Although intended primarily for the Eastern Europe, Middle East and North Africa, the Logan car became successful in Western Europe as well. This resulted in the need to add capacity as the main Romanian factory for the Logan was not sufficient to meet the demand. Renault took advantage of the complex set of trade agreements between Romania and Morocco, and that between

Morocco and EU, and used the factory in Morocco for the final assembly of Logan. It was too costly to invest in the equipment and tooling in Morocco to build the entire vehicle there, and besides, it would not be easy to get enough skilled labor there. Renault imported the core kit of parts from Romania to Morocco. With the accession of Romania into the EU in 2007, these Romanian parts qualified as European parts, so that the Logan assembled in Morocco could satisfy the rules of origin to achieve a duty-free rate for the finished vehicle shipped to Europe. This was a saving of 10% duty, which was a big boost to the bottom line.

Supply chain design and the strategies outlined in Cohen and Lee (1989) must fully capture the existence of such trade agreements and tax incentives. The challenge is that some of these agreements have a fixed time duration, and sometimes they could change or be superseded by new ones.

3.2. Product and Process Restructuring

High technology products with a modular product structure can postpone some of the assembly processes to multiple global distribution points instead of integrating the complete product at the factory. Distribution points typically are much closer to the customers, and so by allowing them to perform some of the final assembly processes, the point of differentiation of the product into multiple end-products can be deferred. Postponement is an important operations strategy for companies to allow flexibility in face of increasing product variety.

But postponement has an important added dimension in times of rising tariffs. Components usually have much lower duty rates than finished products. Hence, by postponing the finished assembly step in the market, significant duties could be saved. Supply chain executives now have to decide how to redesign their product structure, to determine what part to be built in each country. The implication is that this could generate big customs differences. In addition, countries have, in some cases, redefined what constitute the country of origin of the product. It used to be the final assembly site, but now sometimes the location where the core of the product is built, is defined as the country of origin where import duties are assessed. The result is that, how an importing country assesses duty rates of a product is not purely based on where the final assembly is done. Again, this implies that the supply chain design decision is more complex, and the design of the product and process structure must be part of that decision process.

In the days before China entered WTO, when the apparel quota was still strictly enforced for Chinese products entering the US, manufacturers were able to negotiate an arrangement with the US government known as an OPA (Outward Processing Arrangement). Since Hong Kong's quota was not as tight as the Chinese quota, the Chinese manufacturer could produce all the key panels that made up a finished garment, ship them to Hong Kong for sortation and matching, and then ship back to China for the labor-intensive sewing and finishing. By claiming that the sortation and matching was a very core step in the manufacturing of garments, these manufacturers were able to get Hong Kong as the country of origin for such garments, thereby using the Hong Kong quota instead of the highly competitive and tight Chinese quota.

When HP was still manufacturing workstations in house, it faced the challenge of deciding which key parts of the workstation should be added to the product at their two manufacturing sites in the US and Germany, and which parts should be added at the distribution network. Operations at the factory would give greater scale economies, and leverage the manufacturing efficiency of the factory. Operations at the distribution network would provide postponement values, but at the expense of higher overheads and reduced scale economies. There were also some quality concerns, as the distribution network quality control might not match that of the factory. It turns out that another major driver in the product structuring decision was customs and duties. Workstations as finished products faced very high tariffs. A workstation without a processor usually received much lower duty rates. And a workstation without a processor and without memory and storage often paid zero duty. Hence, the product structuring decision must take account of the customs and duty implications.

In the operations management literature, a commonly cited example of postponement is the HP Deskjet. HP changed the site of localizing the products into country-specific versions from the factory to distribution center in the market. This change enabled more flexibility to localize the products based on demands from the different countries, thereby reducing the imbalance of supply and demand matching. When the product became more mature and demand uncertainties in the product-mix of different countries were reduced, and when HP had offshored production of the printer to China, HP actually reversed the postponement strategy. The company simply localized the country versions in China, as the need for flexibility had gone down with more stable demands. However, in recent years, the rise of tariffs of the product entering Europe had necessitated change again. Freight cost, at the same time, has gone up

significantly so that shipping the printers in finished product packaging was bulky and could be expensive. The revised strategy is to make the core product in China to take advantage of high productivity of the Chinese factory and the proximity of the supply network there. The core product is then shipped to Budapest without the finished product packaging so as to lower freight cost. In Budapest, the product is customized to the final product to meet the different countries' demand. Since Hungary is part of the EU, this revised postponement strategy avoided heavy tariffs as well.

In today's turbulent world, the restructuring of the product and process can add to the degree of freedom to optimize the supply chain design. This is one of the key issues which Cohen and Lee (1989) labelled as "plant charter."

3.3. Expanding the Supply Sources

Closely related to the supply chain design issue of where to locate the factories or distribution centers is the problem of where to source your products or inputs if you are not manufacturing them yourself. Again, with the advent of tariffs and in some cases, incentives, the choice set of supply sourcing has to change. It may also lead to an acceleration of the diversification supply strategy of Cohen and Lee (1989).

Trade tariffs such as what the US may impose on products from China, or trade agreement changes pending on how the arrangement of Brexit turns out, require companies to rethink about where their supply sources are. Countries not affected by trade tariffs directly, or countries that may be deemed as US-customs friendly, can enter in the choice set of supply sources, even though they may not be as attractive prior to the tariff changes.

China, as the "factory of the world," has seen itself at risk as the primary supply source for many companies. Labor cost in China has been on the rise. The country has been promoting the movement to manufacture higher value-add and technology-based products, leaving a potential shortage of labor willing to work on low skilled factory work. In addition, the movement by many governments towards protectionism, often achieved through the imposition of border taxes on China-made products, has led to an assault on value chain design with China as the center of manufacturing hub. Supply chain executives have begun expanding the set of supply sources for consideration. In the last decade, we have already seen the gradual expansion of the supply bases in countries like Vietnam, Indonesia and Bangladesh in apparel and footwear

manufacturing. The threat of new tariffs has expanded that choice set to countries that, not long ago, would not have been serious contenders of supply sources.

Ethiopia is a good example here. Located in East Africa, the country has a population of 100 million, most of whom are of young working age, are relatively well educated, and English-speaking. The working wage there was only 1/10 of that in China. The political situation of the country has improved in recent years, so that the country has enjoyed peace and stability. The Ethiopian Government has identified the textile and apparel industry as a focal industry to grow, and has invested in providing training and skill improvements for workers. Ethiopia has some natural advantages. The country has low cost of energy due to the abundance of hydro-electric power dams. It also has good potential for raw materials like cotton and livestock.

Most importantly, Ethiopian apparel and shoe exporters have duty-free access to the US market thanks to AGOA, the African Growth and Opportunity Act, which was renewed by the American government in 2015 for another decade. In addition, the country also enjoys duty-free access to EU as well as preferential treatment to Japan. As such, some leading manufacturers like H&M and PVH have started to source from the country. Besides Western brands, Chinese manufacturers such as Huajian has also started manufacturing shoes in Ethiopia.

In developing new sources of supply, one important consideration which has research implications is the clustering effect. When one company performs the cost-benefit analysis of using a new source of supply, the cost-benefit picture can change drastically if more than one company is considering that same source at the same time. This is what happened to Renault when it considered setting up a new assembly plant of the Logan in South Africa. That consideration was complicated by the news that Toyota was going to open a factory there as well. On the one hand, the entry of Toyota might help in a joint force to negotiate better customs terms with the government, accelerate the development of a more mature input material supply base, and provide a scale effect for the training of skilled workers. On the other hand, it might result in a more competitive labor and input markets in the short run.

In the case of Ethiopia, that effect turns out to be more positive. The government was able to induce China to build a big industrial park, the Hawassa Industrial Park, dedicated solely to apparel and textiles. The park now hosts 18 companies from 11 countries. The park boasts a zero-emission water treatment plant. With the park, global brands, such as Calvin Klein and

Tommy Hilfiger, also added Ethiopia as one of their supply sources, providing the necessary scale effect for manufacturing in Ethiopia.

A direct implication as companies expand their supply sources to include more and more developing economies is the need to uphold supply chain responsibility for the ethical treatment of workers in those locations. Many of these new supply sources have a sustainability record that may be even poorer than that of China, which already has been a concern to many.

3.4. Process Improvement

Border crossing is tedious and difficult, and if one needs to expand to new territories or restructure product/process, then there will be more border crossings which create inefficiencies and bottlenecks. The time and cost of global cross-border trade processes affect the total landed costs, which affect companies' sourcing decisions. Based on data of cross-border container trade flows of apparel and some commodity products like Coffee, tea and cocoa, etc., across 80 countries, Hausman et al. (2013) found that cross-border logistics frictions could significantly impact trade negatively. Such frictions relate to the variations of times to clear customs.

Advances in technology could change the logistics frictions significantly, resulting in a new landscape for the potential values of the candidates in the expanded set of supply sources. Hausman et al. (2010) identified all the detailed steps in cross-border trade flows between China and the US, and developed a corresponding process model to capture the times and costs for the trade flows. Based on data collected from the apparel industry, the authors were able to estimate that, with the latest set of information technologies and software solutions, dubbed Information Technology-Enabled Global Trade Management (IT-GTM), key metrics such as the Manufacture to Invoice Cycle and Days Sales Outstanding for exporters, and the Order to Receipt Cycle for importers can be drastically improved. Under reasonably conservative scenarios the gross savings from IT-GTM amount to 1.7% and 0.6% of annual sales for exporters and importers, respectively.

Hence, supply chain design can be greatly impacted by such technological advances. One of such advances that show promise, but whose values are still not totally proven, is blockchain. Ganne (2018), in his WTO report, estimated that the business value of the blockchain technology in international trade could reach more than $3 trillion by 2030 on a world-wide basis. This value could come from four areas: (1) the creation of paper-less trade, (2) improvement of trade in services, (3) the strengthening of intellectual property ("IP") rights,

and (4) enhancement of government procurement processes. Specifically, the report outlines such potentials:

- automating key trade finance functions such as letter of credit transactions;
- streamlining border procedures through smart contracts, including customs clearance of goods and collection of customs duties;
- launching global trade platforms;
- improving trade-in services efficiencies such as cross-border payments and insurance schemes, particularly marine insurance, by:
    - eliminating costly intermediaries of the international financial system;
    - reducing costs related to policy verification, contract validity, handling claims as well as generating more informed pricing decisions; and
    - decreasing fraudulent behavior and counterfeit goods in e-commerce transactions through increased transparency and automatic payment transfers;
- simplifying ways to establish proof of ownership and streamline patent registration, thereby creating more efficient ways to monitor IP rights and, perhaps, opening the door for managing IP rights globally; and
- improving the government procurement process by increasing transparency and automating procedures related to the bidding process.

Of course, while the potential value of transparency and the reduction of cross-border logistics frictions can be huge, the obstacles and challenges are also significant. The WTO report highlighted a few: it is a daunting task to think about the scalability needed to handle the astronomical volume of transactions needed; the amount of energy that blockchain technology consumes; and, despite the promise that the blockchain technology is highly resilient because of its use of cryptographic techniques, the technology is not totally immune to data security concerns. In a recent paper, Babich and Hilary (2018) outlined some research potentials as well as key challenges for operations management associated with blockchain technology. The challenges include infrastructure failures, companies' reluctance to provide total transparency or participation, and the failure of the security promise due to the network not being totally integrated.

Another technological advance that could give rise to process improvement is automation. Manufacturers have been investing heavily on robotic automation and Industry 4.0

innovations many of which include AI and IoT applications to make the robots smarter or the production processes more efficient and more flexible. These investments improve productivity and, in some cases, were answers to the labor shortage or rising labor cost challenges. It also has the direct implication in changing the key parameters in the supply chain design equation. A site that used to be expensive due to its heavy labor component may become attractive with the application of automation. The setting up of a Foxconn factory in Wisconsin was supposed to be cost-effective only if such automation investments were made. Whether Foxconn would ultimately keep up with those investment promises such that the factory would be a reality remains questionable (Carr, 2019). Still, advances in automation are certainly changing the chess board of the supply chain design game.

With the advances of technologies, the strategies for consolidation, vertical integration, regionalization or co-location described in Cohen and Lee (1989) could be quite different.

3.5. Leveraging Mega-Infrastructure Investments

While protectionism-based border taxes added frictions to global trade, there have been initiatives to reduce the frictions through heavy investments in logistics and financial flow improvements. For example, China's Belt and Road Initiative is supposed to create lubricants to ease the trade frictions. As a result, countries that were not attractive places to be a part of the value chain, either as a potential supply source of a market demand point, can have an opportunity to become integral parts of the global value chain. Of course, skeptics are there to point out that significant portions of the investments in infrastructures for such friction reduction efforts have been wasted, or that they were just political propaganda. It is not easy for operations management researchers to assess the full and true political and economic implications of such initiatives. But we should be aware of cases where such frictions have indeed changed, which can have it respective implications on how we design the supply chain.

Under Belt and Road, it was easier for capital flows to invest in capacity and capability building in countries along the belt and road. One of the key opportunities of the Belt and Road Initiative is that it opens up many new alternatives for trade routes and modal choices for companies doing business between China and the Belt and Road countries. Earlier, we discussed Ethiopia as a rising supply source for apparel and footwear. But a major logistics challenge for the country is that it is land-locked without a sea port. The only way to get its products out through ocean freight is to get the products trucked to the nearest seaport in Djibouti. The road to

Djibouti is already highly congested, and the capacity limit of Djibouti in handling cargoes is already reaching its maximum. This made logistics flows out of Ethiopia highly unreliable. As part of the Belt and Road Initiative, investments have been made to build a new national road network as well as an electrified railway line that connect Ethiopia to the port in Djibouti. This would enable Ethiopia to be an attractive member in the expanded supply source described earlier.

Another example is how HP shipped its laptop computers and accessories out of the manufacturing site of Chongqing (inland China), to the market in Western Europe (Bradsher, 2013). Bringing finished goods to the market involved a long journey of trucking plus rail to go from factory to the ports of Shenzhen or Shanghai, and shipping through the Indian Ocean and Suez Canal to get to the European port. The lead time of such a long journey averaged 5 weeks, with often added delays due to bad weather and other problems. For high technology products, such a long lead time could mean high inventory investment, lack of responsiveness to customers, and potentially increased product obsolescence. To shorten the lead time, the alternative was to air freight the product from Chongqing to the market, which was undesirable due to the high freight cost and the negative environmental impact of air freight. The Belt and Road Initiative created the potential of having the products to take the land route from Chongqing to the main markets in Europe such as Germany. The key is to invest to overcome the obstacles of the land route: many disconnected rail routes, mountain blockages that required the route to be much longer to circumvent these mountains, and the potential for border delays since the route transacts multiple countries.

The Belt and Road Initiative invested heavily in physical infrastructure improvements - upgrades of existing rail tracks and new tunnels in Kazakhstan. The transport conveyances have also been improved – using temperature-controlled rail cars to protect the sophisticated and delicate technology products in a journey in which the difference between the highest and lowest daily temperature can exceed 100-degree F. Border crossing frictions have been reduced through locked containers as the products go through Kazakhstan, Russia and Belarus without cross-border checks there. Finally, to ensure product integrity, the countries agreed to allow armed security guards to be stationed on rail cars to safeguard the products. With these measures in place, the new route can be viable, leading to cost and time savings for manufacturers. For the return journey, German electronics, construction machinery, vehicles, auto-parts and medical

equipment were shipped to China. Currently, this rail freight is also subsidized by the Chinese government making it attractive for HP to use the route.

The mega-infrastructure initiatives can therefore change significantly the tradeoffs in the supply and distribution strategies as outlined in Cohen and Lee (1989).

4. Research Opportunities

As we have discussed, the standard approach to the supply chain design problem has to be greatly enriched. The key parameters used, and the constraints faced, in developing the optimal design have to be significantly updated. There is also a need to recognize that changes are dynamic as well as uncertain. Such changes also give rise to new research opportunities for operations management researchers. Here, we discuss some potential ones.

The traditional approach in supply chain management research is to capture the key uncertainties in demand. Most of the literature focuses on demand uncertainties. Supply uncertainties are sometimes captured in the form of uncertain yield or lead time. As described earlier, we have begun to look at how other sources of uncertainties need to be captured. In particular, the inclusion of exchange rate fluctuations has led to new research frontier in the form of operational hedging. Now, we also have to deal with the uncertainties of customs duties and tax, government incentives, trade agreements and political climate. Even in the case of mega-infrastructure projects such as the Belt and Road Initiative, there can be huge uncertainty as to when some of the projects would be completed, and also the extent to which the project would be accomplished (such as the final realized capacity of a new port facility). Another source of uncertainty is the possibility of supply chain disruptions due to natural or man-made events.

A key research question is to understand and guide how companies should best respond to the changing and dynamic environment which we know have occurred, as well as in light of the uncertainties in the trade regimes that might be forthcoming. Actions like reshoring involve significant fixed costs. For every action, there is also the potential future cost to undo that action. Setting up a new factory or supply chain link requires initiation costs, while closing an existing factory or shutting off an existing supply chain link could incur significant exit costs of severance, environmental cleanups, write-downs of assets, and in some cases, financial penalties such as reverting the tax subsidies provided by government when that factory was first set up. Developing best response strategies for companies is a fruitful area of research.

But how can we conduct empirical research on how executives are responding to the turbulent climate? The challenge is that most studies are based on opinions or intent, and we know "talk is cheap." This made it difficult to get to the bottom of truth in real intentions or real potential actions. The Cohen et al. (2108) study tried to address this problem by asking respondents to focus on actual decisions that they have made instead of just intentions. This was more meaningful, but then it suffered from a smaller sample of responses. How can we conduct large scale empirical studies on supply chain redesign decisions? This remains as a significant challenge.

As companies expand their supply sources in response to the tariffs or other new impediments to existing sources, or to the new opportunities in developing economies, they will be confronted with the problem of how to manage sustainability in these new sources. Note that, even if companies plan to reshore and bring manufacturing back to the more developed economies, we have to deal with this problem as the sustainability standards of the developed economies are probably much higher than those in current manufacturing sources. Research on innovations to monitor and improve sustainability would be highly desirable. It is also an opportunity for us to conduct empirical or field-based research on sustainability challenges and improvement opportunities in developing economies, which is not well understood.

As we observed in our discussion of trends, also confirmed in the survey from Cohen et al. (2018), the expanded sources of supply from emerging markets and technology developments are both important considerations in reshoring decisions. On the one hand, expanded sources allowed the use of cheap labor to be available, circumventing the escalated tariffs on Chinese products. On the other, the advances in automation technologies can potentially make it possible to reshore to the developed economies of the market. How can we integrate these two factors in the optimal design model formulation in research?

Finally, even though we often view the design of the global supply chain as a decision problem for a single company, there are interactive effects when you consider the collective decisions of others. For example, for HP to use the rail route to go from Western China to Europe, the rail cost could be quite high, requiring a Chinese government subsidy to make it cost-effective to do so. But if many other companies make similar decisions, rail costs could go down as a result of the economies of scale. We have described this as the "clustering" effect in Section 3.3. An interesting new way to look at the global supply chain design problem is to

examine the market equilibrium effects when we consider the interactive effects of all other companies making such a design decision.

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