A FRAMEWORK FOR ANALYZING THE EFFECT OF GLOBAL TRADE PATTERNS ON DOMESTIC FREIGHT OPERATIONS

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Introduction

Global trade patterns are continuously changing as economies and trade policies develop and interact. For example, the cross-border trade between the United States (U.S.) and Canada has rapidly increased since the North America Free Trade Agreement (NAFTA) was implemented. In approximately just the last decade, U.S. freight exports to Canada have increased by 60.6% and US freight imports from Canada have risen by 36.0% (*1*). At the same time, the manufacturing cost advantage of China has been gradually weakening, particularly in recent years (*2*), contributing to the growing trend of U.S. manufacturing re-shoring: the transfer of manufacturing investment and production from overseas back to the U.S.

Recent developments suggest changes in global trade patterns are likely to continue. The Canada-European Union Comprehensive Economic and Trade Agreement (CETA) covers a broad scope of trade issues and is expected to have far reaching impacts, affecting numerous sectors of the Canadian economy as well as millions of workers and consumers (*3*). Canada and South Korea are moving closer to a free trade agreement, despite resistance from Canadian-based auto makers, but with the support of Canadian pork producers (*4*). Even internal trade patterns within Canada are likely to change, as the Agreement on Internal Trade (AIT) sees amendments (e.g., in 2009 to support labour mobility) and is supplemented by regional arrangements (e.g., the New West Partnership between British Columbia, Alberta, and Saskatchewan) (*5*).

Global trade patterns ultimately manifest themselves in freight flows on global and domestic transportation systems, but the translation of economic flows into transportation patterns is not straightforward. First, it is important to recognize that the inter-dependencies of the global, national, and regional economies connect global trade patterns to local supply chains and logistics in differential ways. For example, CETA will have direct and indirect effects on the Greater Toronto Area (GTA) and these effects may be different than those experienced by other provinces and regions in Canada, due to each area's unique economy. Second, trade flows as measured by a producer at the origin and a consumer at the destination [i.e., production to consumption (PC) flows] are complicated by supply chains; it would be incorrect to assign PC flows directly to a transportation network because of the indirect transportation movements caused by supply chains [e.g., the use of distribution centers (DCs), consolidation centers (CCs), etc.]. Finally, once a PC flow has been converted into a series of commodity origin-destination (OD) movements within a supply chain, vehicle routing patterns must be considered; it is well known that vehicle flows and commodity flows are not always congruent, not to mention that empty vehicle trips are induced, although avoided where possible.

The purpose of this paper is to introduce a framework for analysing the effects of global trade patterns on domestic freight operations. The remainder of this paper is organized as follows. The next section provides a brief background on two existing input-output (I-O) methodologies, their capabilities, and their potential synergy. The following section addresses the developments necessary to extend these existing approaches to link global trade and domestic freight operations. The next section provides a complete conceptual framework in the Canadian context. Then, an example of U.S. demand shocks in food and paper products from the in-progress Canadian framework is presented, demonstrating the feasibility of the extensions necessary to develop the conceptual framework.

Background

Two important tools exist to help overcome the challenge of modelling the effect of global trade patterns on domestic freight operations. First, global multi-region input-output (GMRIO) tables, models, and analysis are increasingly common, so much so that a special of issue of *Economic Systems Research* was recently devoted to their latest developments (*6*). These models are essentially a quantitative means of representing both the interdependencies between different sectors and different nations of the global economy. Second, random utility based multi-region input-output models (RUBMRIO) are used for freight modelling, generally using national and regional multi-region input-output (MRIO) datasets (i.e., I-O tables and trade flows). The I-O portion of these models handles supply and demand linkages between sectors of the economy, while the random utility maximization (RUM) based trade coefficient model [e.g., multinomial logit (MNL) model] simulates trade choices between regions based on transportation and economic variables. For example, the RUM based trade coefficient model might include: selling prices, transport costs, number of employees by sector, a same zone dummy variable, a common boundary dummy variable, trade agreement specific dummies, and so on (*7*).

Therefore, a compelling way to model the effect of global trade patterns on domestic freight operations is to integrate the strengths of the methodologies described above. Although both approaches are based on I-O techniques, each only focuses on one spatial scale, whether it is global, national, or regional. To conduct an analysis that transcends spatial scales requires a model that includes multiple spatial layers. Creating a multi-scale multi-region input-output (MSMRIO) model, that is an input-output model that includes more than one spatial scale, can be accomplished in at least two different ways. On the one hand, two already existing and possibly conflicting MRIO models that describe different spatial scales could be integrated into one multi-scale model. For example, a GMRIO model could be integrated with an MRIO model of Canada's ten provinces and three territories, creating a model of global trade with a provincial level of detail for Canada. On the other hand, an existing I-O table for a particular region could be disaggregated into sub-regions using disaggregation and estimation techniques. For example, Ontario's I-O table from the Canadian MRIO dataset could be disaggregated into smaller areas such as economic regions (ERs), and used to create a model of Canadian provincial trade with a regional level of detail for Ontario. Note that in Canada, an ER is generally a grouping of complete census divisions (CDs) created by Statistics Canada as a standard geographic unit for analysis of regional economic activity. The aggregation and disaggregation examples from above could be combined to create a three-level MSMRIO model that includes fully integrated trade at the global, national, and regional scales; the next section describes some extensions necessary to construct such a model.

Existing Gaps

There is little precedent for developing a model of integrated production, consumption, and trade flows at the global, national, and regional levels. The only well-known multi-scale I-O table is the Transnational Interregional Input–Output (TIIO) table between China and Japan (*8*). This multi-scale table includes 3 regions (ASEAN5, East Asia, and the USA), 7 sub-regions of China, and 8 sub-regions of Japan; sub-regions were created by disaggregating China's and Japan's national I-O tables using supplementary data. Moreover, there are no I-O tables or models with three levels of scale (e.g., global, national, and regional) as suggested above. Therefore, this section focuses on ways in which a MSMRIO model can be developed in the Canadian context. The envisioned model includes global trade between countries, with provincial detail for Canada, and regional detail for Ontario. In this light, the model would assist in analyzing the effect of global trade patterns on Ontario's freight transportation system.

The linking of spatial scales (e.g., countries of the world to the provinces of Canada) can be established by extending the multi-regional assumption. Recall that the standard I-O assumption for a single region model is that production recipes are fixed and proportionate (i.e., using technical coefficients). In the case of a MRIO model, regions also trade in fixed proportions (i.e., using trade coefficients). To develop a MSMRIO model, it can be assumed that sub-regions (e.g., a province) of a region (e.g., country) contribute to exports in fixed proportions (i.e., using export coefficients). For example, when the United States imports grain from Canada, Ontario's percentage contribution is fixed; if the United States increases its import of grain, Ontario's contribution grows in proportion to Canada's contribution. Therefore, Canada links the United States to its own 13 sub-national regions, using the standard multi-regional assumption.

Linking spatial scales with export (and import) coefficients assumes that the MRIO datasets at different scales use the same industry classification system. However, there are numerous industry and commodity classification systems, adding another layer of complexity to multi-scale modelling. Commonly used systems include: North American Industry Classification System (NAICS); International Standard Industrial Classification of All Economic Activities (ISIC); Central Product Classification (CPC); Standard International Trade Classification (SITC); Standard Industrial Classification (SIC); and many more. Most systems also receive periodic updates known as revisions, changing the format of data from one revision to another (e.g., ISIC Rev. 1, 2, 3, 3.1, 4). Therefore, it is possible (and likely) that the MRIO data available at different spatial scales do not share a common classification system and neither classification system is necessarily an aggregation of the other. Therefore, a sectoral linkage must be developed for the classification systems to interact.

Input-output data are also recorded using different table configurations. Traditionally, IO tables use the industry-by-industry format, such as those produced by the OECD for many countries. However, sometimes a commodity-by-industry format is used with the notion that industries use commodities to make commodities. For example, Statistics Canada has used this framework since the early 1960s. Therefore, it is possible that these alternative approaches may need to be integrated in a multi-scale model.

Finally, MRIO datasets (i.e., I-O tables and trade flows) are rarely available for small areas such as the ERs of Ontario. In this case, the MRIO data need to be estimated and/or disaggregated from their larger "parent" I-O table. There is a long history of estimating MRIO tables and models at the regional scale [e.g., see (*9*) for an introduction]. The approach selected should maximize the data available and be tailored for the particular application at hand.

There are numerous data sources that could be used to estimate a MRIO model for the ERs of Ontario. First, Statistics Canada has estimates of population by economic region, sex and age group. Combined with the Survey of Household Spending (SHS) by size of area of residence and by age of reference person, these data can be used to allocate Ontario's final demand (i.e., consumption) to specific ERs. Second, technical coefficients (i.e., the recipes used by industries) can be taken directly from the provincial I-O table, assuming that ERs use the same technology to make and use commodities. Statistics Canada also provides employment by economic region and industry which can be used as a surrogate for industry output. It is generally assumed that value-added is a linear function of industry output, and value-added can be converted to jobs using appropriate factors (e.g., jobs/$ value added). Therefore, employment data gives an indication of the industry output in each ER. Finally, trade coefficients can be estimated using transportation survey data. In particular, the Ministry of Transportation of Ontario (MTO) Commercial Vehicle Survey (CVS) has a Commodity Information Section. However, careful attention must be paid to how an origin and destination are defined in the survey, as the MRIO model uses PC flows. All of these data could be used to estimate a regional MRIO model for the ERs of Ontario; one approach is to estimate the model coefficients through an optimization model that aims to minimize the deviation from each of these data sources while meeting the various MRIO constraints (i.e., "adding-up" constraints).

Conceptual Framework

To address the gaps noted in the previous section, a conceptual framework linking global trade and domestic freight operations was developed. For the sake of space, the complete conceptual framework is broken into two parts: an economic portion and a freight portion.

Figure 1 shows the economic portion of a conceptual framework for analysing the effects of global trade patterns on domestic freight operations; the economy is simulated with a MSMRIO model. The main exogenous inputs that drive the MSMRIO model are final demands by sector/commodity and region, including countries, Canada's provinces and Ontario's economic regions. These data are available from I-O tables of the various regions, and can be scaled for forecasting using population data or gross domestic product (GDP) growth, as well as manipulated individually for scenario analysis (e.g., demand shocks). Note that technical coefficients are also exogenous inputs (not shown), representing the ‘recipes” industries use for production, also available from I-O tables. The last remaining components are the trade coefficients, calculated using a random utility based model based on transportation and economic variables that are calculated endogenously, as well as other exogenous attributes mentioned earlier (as with a typical RUBMRIO model). Note that there are two feedbacks captured within the framework; these are between: 1) the trade coefficient model and the multi-scale I-O model (e.g., growing market share attracts further trade); 2) the trade coefficient model and the traffic simulation model (e.g., increased transportation costs deters trade).

The MSMRIO model in Figure 1 has some additional features compared to a typical RUBMRIO model, to address the gaps described in the previous section. First, import and export coefficients are used to link individual I-O models at different scales (i.e., the global, national and regional I-O models). Second, sector transformation matrices are used where necessary to connect regions using different industry classification schemes at different scales. Third, a conversion is made between industries and commodities using recipes from the commodity-by-industry framework where required. These additions are shown between the GMRIO model and the provincial MRIO model in Figure 1, but are omitted between the provincial MRIO model and the regional MRIO model for the sake of space. These additional components provide the linkages to integrate global, national, and regional trade, and hence the outputs of the MSMRIO model are PC flows at the global, national, and regional scales, including flows between scales (e.g., from a country to an ER in Ontario).

It is important that the framework begins with modelling PC flows because they represent economic relations – the transactions within and between different sectors and regions of the global economy. Starting with PC flows allows changes in final demand, international and interregional trade patterns, and the structure of the economy to be linked to freight modelling at all scales. In any case, data on economic linkages are expressed in PC flows, not in terms of flows

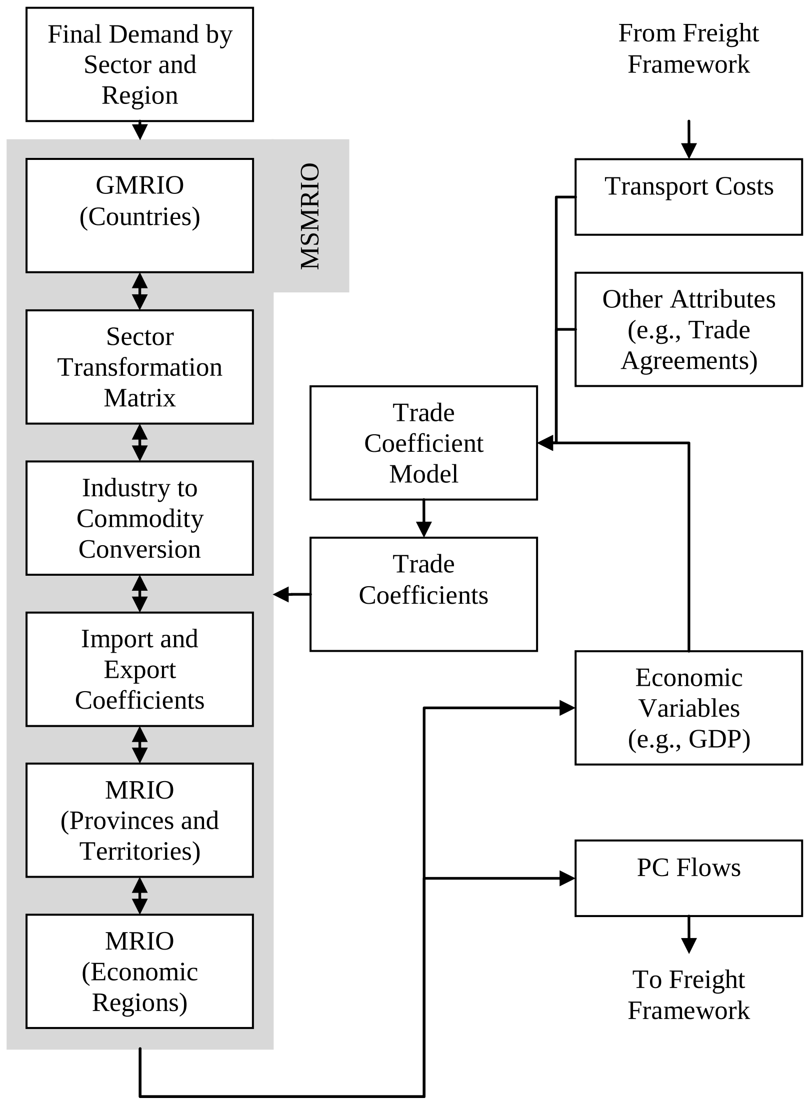

Figure 1 – Conceptual framework (economic portion)

between producers and trans-shipment points, between two trans-shipment points, or between trans-shipment points and consumers. However, the process of translating PC flows, to OD flows, and then to vehicle flows is not straightforward, as already mentioned.

Figure 2 shows a disaggregate freight framework. PC flows enter the framework and are first disaggregated to individual firms in the regions containing the production and consumption activities. This could be done based on observed proportions of firms in local production and consumption data and/or from a registry of business establishments that includes a size metric (e.g., number of employees, square footage, etc.). Then, a model [e.g., (*10*)] or series of models [e.g., (*11*)] are used to simulate the logistics decisions of firms (e.g., shipment size, use of CCs and DCs, modes, and loading units, such as containers). These logistics models are typically derived from RUM based models because they capture behavioural choice theory. The advantage of this framework is that it allows for the logistics decisions to be modelled at the level of the actual decision maker and can include the decision maker's attributes. Finally, assignment can be done by aggregating the shipments between firms to OD flows between regions for network assignment (i.e., a macroscopic) or assignment can be done at the level of individual vehicles (i.e., microscopic, as shown). In either case, these transportation travel costs can be fed back to the trade coefficient model to include congestion effects (if the trade coefficient model was originally estimated to include this attribute).

Figure 3 provides a more aggregate freight framework as an alternative to the disaggregate freight framework in Figure 2. Once again, PC flows enter the framework but are not disaggregated. Rather, the PC flows are translated directly into freight flows using value/quantity (e.g., $/kg) transformation factors. This direct transformation completely ignores the supply chain and logistics, as well as vehicle routing complexities noted earlier. These freight flows are then normally split between modes using a mode choice model resulting in a freight matrix by quantity and mode. In this framework, resulting freight flows can only be assigned to a macroscopic traffic simulation, as the firm level of detail was never established (to feed a microscopic traffic simulation). The results of the traffic simulation can be fed back to the mode choice model to update the free-flow travel times, and again consider congestion feedbacks. Similar to the disaggregate freight framework, the logsum of the mode choice can be fed back to the trade coefficient model (if the trade coefficient model was originally estimated to include this attribute) [e.g., see (*12*)].

The preceding freight frameworks (Figures 2 and 3) demonstrate two possible ways to link PC flows to freight flows. The difference between the frameworks is how PC flows are translated into vehicle trips. On the one hand, logistics decisions are micro-simulated by firms to capture the complex nature of supply chains, and on the other hand, PC flows are directly converted to freight flows using conversion factors and ignoring any indirect movements resulting from supply chains. In general, adding logistics models that convert PC flows into vehicle trips allows for a more accurate assignment. For example, consider a hypothetical PC flow that includes a truck from the producer to a distribution center, and another truck from a distribution center to the consumer; even in this relatively simply supply chain, the individual vehicle trips would not be captured by assigning a single PC flow to the network. In this light, the spatial scale at which the framework is applied becomes relevant: at an international scale, freight flows may be more congruent with their commodity flows (e.g., shipments between China and the U.S., although even these might pass through Hong Kong and become re-exports), while at the regional scale, commodities flows are less likely to match vehicle flows due to supply chains and vehicle tours. Of course, there is a myriad of possibilities between these freight frameworks to include varying levels of detail based on the application at hand.

Application

The MSMRIO model described in the preceding conceptual framework is still under development, and currently includes a fully integrated global and national layer (i.e., the regional layer is incomplete). The global layer models multilateral commodity trade between forty-seven countries and Canada. The national layer further models commodity trade in greater detail for Canada by specifically modelling its ten provinces and three territories. The forty-seven countries use the thirty-seven industrial classification system specified by the Organisation for Economic Co-operation and Development (OECD), and the ten provinces and three territories of Canada use the twenty-five industries and fifty commodities specified by Statistics Canada. The model reflects the year 2005 as this is the most recent set of I-O tables available from the OECD. Further details of the model are available by the authors upon request.

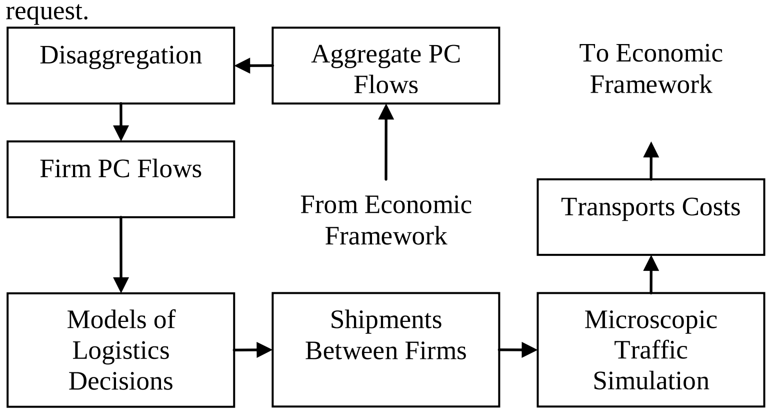

Figure 2 – Conceptual framework (disaggregate freight portion)

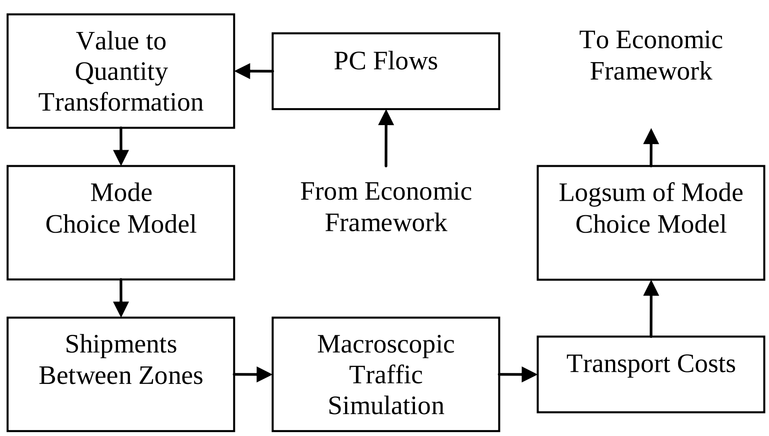

Figure 3 – Conceptual framework (aggregate freight portion)

Tables 1 and 2 show selected results from the current MSMRIO model under the scenarios that the 2005 levels of US final demand satisfied by international imports in food and paper products is doubled respectively (as it did previously between the years 1995 and 2000, and again between the years 2000 and 2005). Some desirable model properties can be observed from these demand shocks and brief selection of results. First, the mix of commodities produced as a result of the demand shocks differs based on regional particularities. For example, with the food products shock, Ontario's largest shift in production occurs in fruits and vegetables, while Alberta's largest shift in production occurs in meat and fish. Similarly, with the paper products shock, Ontario and Alberta's 3rd largest shift in commodity production occurs in manufacturing, while British Columbia's 3rd largest shift in commodity production occurs in forestry products. These mixes of commodities reflect the market specialties of these

Table 1 - First, second, and third largest commodity production effects in Ontario, Alberta, and British Columbia, due to doubling of US imported final demand in food products.[i]

	Shock: Food products, beverages and tobacco (OECD #3) = $\$47,574\times10^6$ (2005 US Import Final Demand) ×2 (double) = $\$95,148\times10^6$		
	Ontario	**Alberta**	**British Columbia**
1st % ($\$x10^6$)	Fruit, vegetables…[ii]	Meat, fish…[iii]	Meat, fish…
	13.9% (1,724.1)	21.2% (966.7)	15.1% (360.3)
2nd % ($\$x10^6$)	Soft drinks…[iv]	Fruit, vegetables…	Fruit, vegetables…
	9.3% (575.8)	11.1% (209.5)	11.1% (182.4)
3rd % ($\$x10^6$)	Meat, fish…	Soft drinks…	Soft drinks…
	7.4% (727.1)	4.9% (62.4)	5.5% (97.3)

Table 2 - First, second, and third largest commodity production effects in Ontario, Alberta, and British Columbia, due to doubling of US imported final demand in paper products.[v]

	Shock: Pulp, paper, printing and publishing (OECD #6) = $\$8{,}205\times10^6$ (2005 US Import Final Demand) ×2 (double) = $\$16{,}411\times10^6$		
	Ontario	**Alberta**	**British Columbia**
1st % ($\$x10^6$)	Wood pulp, paper…[vi]	Wood pulp, paper…	Wood pulp, paper…
	7.4% (629.7)	10.3% (141.5)	12.2% (497.5)
2nd % ($\$x10^6$)	Printing and publishing[vii]	Printing and publishing	Printing and publishing
	6.5% (748.5)	1.0% (15.8)	3.8% (71.8)
3rd % ($\$x10^6$)	Miscellaneous manufactured…[viii]	Miscellaneous manufactured…	Forestry products[ix]
	0.8% (39.6)	0.5% (3.9)	1.6% (79.9)

provinces. Second, both the relative and absolute value of the production shifts differ across provinces. For example, the three provinces see increases in meat and fish production of 7.4%, 21.2%, and 15.1%, due to the food products shock. Moreover, although Ontario often sees the largest effects in absolute terms, other provinces sometimes see greater relative changes. For example, Ontario has the greatest absolute increase in wood pulp and paper due to the paper products shock, but Alberta has a greater relative increase in wood pulp and paper. Third, the two scenarios show how the industry shocked determines which provinces are most affected. For example, although Ontario is affected the most in both cases, Alberta is affected more than British Columbia by a food products shock, and vice-versa for a paper products shock; this is true for the top three commodities affected and also for the total impact on the provinces. Overall, these results show that a global trade shock can have differential impacts on provinces (and presumably regions), ultimately translating to differences in domestic freight operations.

Conclusions

This paper presents a framework for analysing the effect of global trade patterns on domestic freight operations. The direction of this research recognizes that it is convenient but unrealistic to draw a geographic boundary around the economy and freight transportation system. This framework is uniquely positioned to answer many research questions that are otherwise lacking a sufficient method of analysis. In general, it will be possible to test the effects of policy scenarios related to economic development, growth trends in various industry sectors, and government regulation related to global trade and global supply chains, on domestic transportation systems.

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[i] Part of Table 3 in (*13*)
[ii] Fruit, vegetables and other food products, feeds (Statistics Canada Commodity #10)
[iii] Meat, fish and dairy products (Statistics Canada Commodity #9)
[iv] Soft drinks and alcoholic beverages (Statistics Canada Commodity #11)
[v] Part of Table 3 in (*13*)
[vi] Wood pulp, paper and paper products (Statistics Canada Commodity #18)
[vii] Printing and publishing (Statistics Canada Commodity #19)
[viii]Miscellaneous manufactured products (Statistics Canada Commodity #28)
[ix] Forestry products (Statistics Canada Commodity #28)