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Using H-O-V Theorem to Predict the Factor Intensities in Canadian Agricultural Trade

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Abstract: Canada is an open economy that relies heavily on international trade, which contributes approximately 30% to GDP. More specifically, Canada is one of the world largest suppliers of agricultural products. The current study investigated factor intensities and Greenhouse Gas emissions intensity from Canadian agriculture and processed food trade. Capital, labor, and land were included as production factors. Contrary to Leontief's finding for the US trade, it is revealed that Canada's exports were relatively capital-intensive as compared to its imports. GHG emissions from exports were higher than imports, coinciding with previous findings. Moreover, land, representing natural resources, was found to be relatively more intensive in exports as compared to the capital intensity in exports. This finding also reaffirms the assumption of natural resources as being a determinant factor in the structure of Canadian agricultural and processed food trade.
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1 Introduction

Canada is an open economy that relies heavily on international trade. Its exports accounted for about 30% of GDP, and its international trade continues to increase. The United States is Canada's largest trading partner accounting for 75% of exports and 50% of imports in 2010 (Statistics Canada, 2011). As one of the world largest suppliers of agricultural products, Canada's exports of agricultural and agri-food products increased from 6.5% to 7.5% during 1995-2010 (Statistics Canada, 2011). Similar to overall trade, the US is Canada's largest agriculture products export market. In terms of the balance of trade, Canada has run a surplus in agricultural and agri-food products trade even when the total trade in Canada faced a deficit in 2009 (Statistics Canada, 2011). According to Heckscher-Ohlin-Vanek (H-O-V) theorem, assuming equal factor price and technology across countries, a country exports products dependent on its abundant factors and imports products containing scarce factors. However, Leontief (1953) found that the US was an exporter of labor and an importer of capital, contradicting the prediction of the H-O theorem and coined the Leontief paradox. To understand Canadian agriculture and food trade in depth, a comprehensive study of trade and its factor content was undertaken. To date, no literature on factor intensities of Canadian agriculture and food trade has been conducted. This study is beneficial to the understanding of Canadian agricultural and food trade and a test of the H-O-V theorem. Moreover, the paper further reveals the environmental impacts in terms of GHG emissions intensity associated with international trade in Canada. The paper is structured as follows: section 2 provides a literature review. In section 3, the use of the Canadian Input-Output (I-O) model to investigate the factor content of trade using the Leontief and Leamer's approaches are described. The means to assess the GHG emissions from agriculture and processed food trade is also provided. Section 4 outlines the data sources used in the study. Section 5 provides the results and a discussion of their implications. Section 6 concludes the paper.

2 Literature Survey

Factor endowment theory argues that the determinant of international trade is the difference in production factor endowments between countries. The Heckscher-Ohlin(H-O) model (Hecksher and Ohlin 1933) and the further developed Heckscher-Ohlin-Vanek (H-O-V) model represent the essential development in factor endowment theory. The H-O model describes the situation in which a country that is relatively well endowed with capital would export capital intensive products and import labor intensive products. Prior to the 1940's, economists had very little systematic knowledge of the productive structure of any national economy. Therefore, it was difficult to empirically investigate factor endowments and trade patterns of a country. In the early 1940's, Leontief (1941) developed the Input-Output model, which described the structural relationships among industries in the USA. He used the Input-Output model to study factor intensities in US trade as a test of the H-O theorem. He found that the US exports were relatively labor intensive and its imports were relatively capital intensive. This finding was contrary to what was suggested by the H-O theorem. This paradoxical finding is known as the Leontief paradox. Similar empirical approaches have been used to investigate factor endowments and have resulted an inconclusive evidence of whether the Leontief paradox or the H-O theorem holds.

Several studies have investigated the trade direction of production factors. Many of these studies (Baldwin 1971; Brecher and Choudhri 1982; Hufbauer 1970; Vanek 1963; Weiser 1968) have reaffirmed the Leontief paradox and have provided possible explanations for the results. Some researchers (Baldwin 1971; Leontief 1956; Swerling 1954; Vanek 1968; Vanek 1959; Weiser 1968) recognized that trade direction may be determined by production factors other than capital and labor. Natural resources should be included as a production factor when investigating the factor content of trade (Kreinin 1965; Naya 1967). Vanek (1963) was the first to explore the role that natural resources played in US trade. He observed that the US changed its position as an exporter of natural resources to an importer of natural resources after 1900. Using the 1947 Input-Output model of the US and the labor and capital requirement computed by Leontief, Vanek further computed the direct and indirect natural resource requirements of US exports and competitive imports. He confirmed his earlier argument that the US was relatively scarce in natural resources. By comparing the ratio of factor requirements (capital, labor, and natural resources) between exports and import requirements respectively, he observed a strong complementary relationship between natural resources and capital. Even if capital was a relative abundant factor in the US in 1947, it entered productive processes only in conjunction with a relatively small amount of natural resources. This caused the observation of the U.S being an exporter of labor and importer of capital. Therefore, to comprehend trade patterns for a country, natural resources as a production factor must be included together with capital and labor. Vanek (1968) expanded the H-O model to include multiple production factors in his study, and hence developed the H-O-V theorem. This model was widely adopted in studies investigating trade patterns (Casas and Choi 1985; James and Elmslie 1996; Lee et al. 1988; Marshall 2011; Maskus 1985). Other researchers (Baldwin 1971; Branson 1971; Keesing 1965; Kreinin 1965; Lowinger 1971; Travis 1972) proposed that the difference between endowment of skilled and un-skilled labor would determine trade patterns. Several studies attempted to test the validity of the H-O-V theorem and confirmed that factor content of international trade conforms to the H-O-V theorem (Bernhofen and Brown 2011; Leamer 1980; Lee et al 1988; Morrow 2010; Reimer 2006; Trefler and Zhu 2010; Wills and Lee 1990). Leamer (1980) stated that the Leontief paradox was due to a misinterpretation of factor content, thus US trade complied with the prediction of the H-O-V theorem. Others argued that relaxing the assumptions of the H-O-V theorem and a consistent definition of factor content would bring empirical data into line with the theory. The factor content of trade predicted by the H-O-V theorem is more than the empirical evidence between north and south countries which results in the "missing trade puzzle" (Davis and Weinstein 2001; Trefler 1995). Caron et al. (2014) studied international trade from both the supply and the demand sides, and explained that nonhomotheticity and costs of trade affects the openness to trade. Research is continuing to solve the theoretical questions associated with trade that explains the empirical evidence.

There are several empirical studies investigating the factor intensities in trade for other countries. Dasgupta et al. (2011) confirmed the H-O theorem explained trade between India and the rest of the world, but identified the existence of the Leontief paradox for India and North America trade in 2003-2004. Sikdar and Chakraborty (2011) confirmed the Leontief paradox with trade between India and Sri Lanka. Heller (1976), using time-series data, discovered that factor content converged over time for the Japanese economy. Japanese exports were recognized as capital intensive by Drysdale and Song (2001). Lowinger (1971) used trade data to observed a lower endowment of skilled labor in Brazil as compared to the US and North America. The Leontief paradox was detected for Japan in 1951 by Tatemoto and Ichimura (1959). Yokokawa (1994) found that the Leontief paradox did not exist for Japan which contradicts the earlier study. Wahl (1961) investigated the factor content in Canadian-US trade and concluded that the Leontief paradox existed for Canadian trade in 1949. According to the authors' knowledge, an empirical investigation of the factor intensities of agriculture trade for Canada has never been conducted. Such a study will contribute to a better understanding of the agriculture and processed food trade structure and its relationship to the domestic industrial production.

There has been an increased interest in studying the linkages between trade and GHG emissions recently (Su and Ang 2013; Kozul-Wright and Fortunato 2012;

Homma et al. 2012; Su et al. 2013). Kozul-Wright and Fortunato (2012) found that the trade openness of a country is strongly positively correlated with carbon emissions, especially in less industrialized countries. Empirically, Input-Output models were used to estimate the GHG emissions from trade (Su et al. 2013; Su and Ang 2013). Su and Ang (2013) compared the differences between using non-competitive imports and competitive imports to estimate GHG emissions from trade. Su et al. (2013) distinguish between processing exports and normal exports. They concluded that combining these two types of exports resulted in an overestimation of the GHG emissions from processing exports, while underestimates the GHG emissions from normal exports.

Homma et al. (2012) evaluated GHG emissions by sector and region using consumption-based accounting. Their study found that emissions embodied in consumption per capita for developed economies were larger than developing economies. Canada and USA's agriculture exports were found to be medium emission intensive compared to the world average. This study adds to the literatures by focusing on agricultural trade for Canada using an Input-Output model. The estimation of GHG emissions provides insights into the agricultural and processed food trade impacts on the domestic environment.

3 Methods and Procedures

3.1 Canadian Input-Output Framework

Canadian Input-Output accounting tables are based on a rectangular accounting framework where the number of commodities and services exceeds the number of industries. The model is based on the following accounting equations:

$$q = Ui + Fi \tag{1}$$

where q is a vector of total demand for commodities, i.e. intermediate inputs plus final demand by commodity; U is the matrix of intermediate inputs by industrial sectors; F is the Final Demand Matrix, allocating the flow of commodities to final demand categories; i is a column vector whose elements are unity with appropriate row dimensions.

The Canadian Input-Output model assumes industry-based technology. An input coefficient matrix B can be estimated using this assumption as follows:

$$B = U\hat{g}^{-1} \tag{2}$$

where, g is a vector of the total value of industrial output by industrial sector; "^" indicates a diagonal matrix; superscript "$^{-1}$" represents a vector or matrix inverse.

Similarly, the industrial sectors share of the total market for commodities can be represented by a matrix of commodity output proportions, also called the market share matrix, "D". This can be expressed as follows:

$$D = V\hat{q}^{-1} \tag{3}$$

where, V is the Make Matrix, documenting the share of each commodity produced by each industrial sector;

The market share matrix is an industry by commodity matrix. Each cell in a column is the output share of a commodity by industrial sector. Rewriting equation 2 and 3, U and V can be expressed as:

$$U = B\hat{g} \tag{2*}$$

$$V = D\hat{q} \tag{3*}$$

$$q = B(\hat{g}i) + Fi = Bg + Fi \qquad (4)$$
$$g = D\hat{q}i = Dq \qquad (5)$$

Rearranging (4) by replacing g according to (5), (4) can be rewritten as:

$$q = (I - BD)^{-1}Fi \qquad (4^*)$$

where, I is an identity matrix with appropriate dimensions; i.e., industry by industry or commodity by commodity.

Equation (4*) is used to estimate the commodity output change due to a change in the final demand for commodities. This model is called the Commodity-Demand Driven Model (Miller and Blair 2009). The industrial output changes to satisfy an exogenous shock by final demand can be written as:

$$g = [(I - DB)^{-1}D]Fi \qquad (6)$$

The bracketed quantity $[(I– DB)^{-1}D]$ is an Industry by commodity total requirement matrix. This matrix is the impact matrix and is used to estimate the direct plus indirect impacts in industrial output that are required to satisfy a change in final demand for commodities.

3.1.1 Leakage

Leakages are included in the model in order to provide a better estimate of the impact of a change in final demand. In this model, the leakage is defined as the import share to the domestically available goods and services and is represented by a commodity vector, "a". Using "$\hat{a}$" donates the diagonal matrix of the import share. Equation (6) can be rewritten to incorporate the leakage as follows:

$$g = [(I - D(I - \hat{a})B)^{-1}D]Fi \qquad (7)$$

Equation (7) will be used to estimate the direct plus indirect impacts on industrial sectors that are required to satisfy changes in final demand.

3.2 Factor intensities of Canadian agriculture and processed food trade

This study computes factor intensities (capital, labor, and land) for Canadian agriculture and processed food trade using the Agriculture and Agri-food Canada (AAFC) Input-Output model (Statistics Canada 2010a). This model was an extension of the Statistics Canada Input-Output model, which extended the agriculture sector in the model. Equation (7) was used to compute the direct plus indirect impacts on industrial outputs to satisfy the final demand for commodities.

A factor coefficient matrix, "Z", was used to estimate factor intensities. The approach taken to investigate the production factors for Canada is similar to that suggested by Vanek (1959); i.e. capital, labor, and land. The factor requirements needed to satisfy the change in final demand can be written as:

$$\text{Factor requirements} = Z * [(I - D(I - \hat{a})B)^{-1}D]Fi \qquad (8)$$

Factor intensities between net-exports and consumption were further compared using Leamer's proposition.

3.2.1 Leontief's approach

Leontief computed the factor requirements for a million dollar shock for exports and import replacements respectively, and compared the ratio of factor intensities for US exports and imports to draw his conclusions. A similar approach was taken in this study. It is assumed that the production functions and factor coefficients are identical between Canada and the rest of the world. Therefore, using "X" and "M" to represent a 1 million dollar worth of agriculture and processed food commodity exports and imports respectively, the factor requirements for a 1 million dollar worth of agricultural and processed food exports and import replacements can be estimated using equation (8). Final demand vector "Fi" in equation (8) is replaced by X and M respectively to estimate the factor requirements for a 1 million dollar worth of exports and imports. The factor requirements for a 1 million dollar of agriculture and processed food exports and imports can be rewritten as:

$$Z_X = Z * [(I - D(I - \hat{a})B)^{-1}D]X \tag{8*}$$

$$Z_M = Z * [(I - D(I - \hat{a})B)^{-1}D] \tag{8**}$$

where Zx represents the factor requirement for exports and Z_M represents the factor requirement for import replacements. The ratio of capital (labor and land) embodied in imports versus exports can then be computed. The ratio between capital per working hour of labor (land per working hour) in imports over exports can also be computed. If the ratio of capital and labor absorbed from a 1 million dollar worth of exports is greater than that ratio for the equivalent amount of import replacements, then the country exports capital intensive goods and imports labor intensive goods i.e.

$$\frac{K_X}{L_X} > \frac{K_M}{L_M} \tag{9}$$

Therefore, if capital per working hour of labor in exports is greater than that for import replacements, the Canadian agriculture and processed food exports are relatively capital intensive and its imports are relatively labor intensive. Similarly, if the ratio of land and labor for a 1 million dollar worth of exports is greater than that ratio for the equivalent amount of import replacement, then Canada's exports is relatively more intensive in natural resource than labor.

$$\frac{R_X}{L_X} > \frac{R_M}{L_M} \tag{10}$$

By comparing the ratio of capital and land for exports and import replacements gives more insight into the most intensive factors for Canadian agriculture and processed food trade. If the ratio for exports is greater than import replacements, then Canada's exports are dominated by natural resource intensive goods compared to other factors[i], i.e.:

$$\frac{R_X}{K_X} > \frac{R_M}{K_M} \tag{11}$$

The calculation of capital and labor intensity used in this study were different from those used by Leontief (1956) and Lee (1988). In their studies they estimated capital requirements using capital flows from the US Input-Output model. This study used a stock value for capital requirements. Using a stock value for capital as oppose to a flow value is expected to give a more accurate estimate of capital intensity.

3.2.2 Leamer's computation

In addition to using the Leontief approach to measure factor intensity, the approach used by Leamer to investigate factor intensities was also applied to the Canadian agriculture and processed food trade. A country is capital abundant if one of the following three relationships holds (Leamer 1980):

1. $Kx>0$, $Lx<0$
2. $Kx>0$, $Lx>0$, $Kx/Lx>Kc/Lc$
3. $Kx<0$, $Lx<0$, $Kx/Lx<Kc/Lc$

where, Kc and Lc are the capital and labor used in domestic consumption for agricultural and processed food goods, and can be calculated by rewriting the equation 8:

$$Z_C = Z * [(I - D(I - \hat{a})B)^{-1}D]C \quad (8^{***})$$

where C is the vector of domestic consumption.

The same comparison can be estimated for land (R) and labor (L) by replacing the capital (K) in the above statement with land (R). A country's factor endowments between land and labor can be revealed from the rewritten statement. Lastly, a comparison between capital and land using the above statements would give us a complete understanding of the factor intensities in Canadian agriculture and processed food trade.

3.3 GHG emissions from exports and imports

Factor intensities explain the direction of trade. It is also critical to understand whether Canada's exports are "cleaner" than its imports. In other words, the authors were interested in understanding whether Canada is importing goods that release more GHG emissions if they were produced domestically. Equation 8* and 8** were modified by replacing factor requirement "Z" by the vector of GHG emission factors by industry, namely "E". Hence the total GHG emissions from Canadian agriculture and processed food exports and imports can be estimated using equation 8* and 8**, with emission factors replacing the production factor requirement.

4 Data Sources

4.1 Input-Output tables

This study used the 2006 AAFC Input-Output model that had been extended with detailed agriculture sectors. The extended agriculture Input-Output tables were used to build the agriculture sectors in the modified tables[ii]. There are 84 industrial sectors in the modified Input-Output model. These include 13 agriculture and 12 processed food sectors.

4.2 Production factors

Production factors included in this study included capital, labor, and land. They were collected from different data sources, and aggregated to levels that correspondent to the modified input-output model.

4.2.1 Capital

Capital coefficients were collected and computed based on the KLEMS database (Statistics Canada 2007b) built by the Micro-Economic Analysis Division, Statistics Canada, and the "Canadian Farm Financial database" (Statistics Canada 2010b) for the year 2006. The capital stock defined by Statistics Canada consists of 15 types of equipment, 13 types of structures, and land and inventories adding up to a total of 30 types of assets (Baldwin et al. 2007).

4.2.2 Labor

Labor coefficients for most industrial sectors were derived from the KLEMS database for Canada in 2006 (Statistics Canada 2007b). In this study, working hours were used to measure the labor used in each industrial sector. For agricultural activities, the KLEMS database aggregated the agriculture sectors into 4 sectors; i.e. greenhouse, nursery and floriculture production, crop production, animal aquaculture, and animal production. Labor coefficients for the disaggregated agriculture sectors were estimated using information from the total payment of wages and salaries, and supplementary labor income shares by agricultural activity according to the Input-Output table for the year 2006.

4.2.3 Land

Land coefficients were only estimated for the agriculture activities in the model. Land as a factor of production does not play an important role in most industrial sectors, with the exceptions of agriculture, forestry, and mining. Since the analysis is focused on agriculture and food commodities, only the land coefficients for the agricultural activities were estimated using agricultural activity information from the 2006 Census of Agriculture (Statistics Canada 2007a).

4.2.4 GHG emission factors

Statistics Canada (Statistics Canada 2010c) provided the total GHG emissions by industry for 2006. GHG emission factors for industrial sectors other than agriculture were calculated by dividing the total GHG emissions by the value of total industrial output per industry in 2006. GHG emission factors for the agricultural sectors were estimated using information from the Canada National Inventory Report (Environment Canada 2010) and the 2006 Agricultural Census for Canada (Statistics Canada 2007a). GHG emissions from dairy, beef cattle, and swine production were deduced from the Canada National Inventory Report separately, while emissions from poultry and other animals were aggregated together in the report. The GHG emissions for poultry and other animals were allocated using the share by animal numbers from Statistics Canada (Statistics Canada 2007a). The GHG emissions from the application of synthetic nitrogen fertilizers were allocated using fertilizer expenditures by crop type. GHG emissions from crop residue decomposition and other management practices were allocated across field crop production using the share of farmland area for each crop (Statistics Canada 2007a).

5 Results and Discussions

5.1 The Canadian agriculture and food trade

According to the Input-Output final demand table, Canada exported 33,177 million dollars and imported 25,109 million dollars of agriculture and food commodities in 2006. Canada was a net-exporter of agriculture and processed food products, with a net-exports value of 8,068 million dollars. Agriculture and processed food exports and imports accounted for 6.7% and 5.3% of total trade respectively in 2006. However, the net-exports of agriculture and processed food products were greater than the total net-exports for Canada. This suggests that the large outflow of agriculture and processed food commodities from Canada contributed greatly to the Canadian trade surplus in 2006.

Canada's largest agricultural export was wheat, worth 3,624 million dollars. Pork, fish and seafood products, vegetables other than potatoes were the second to the fifth largest agriculture and process food product exports. In terms of agriculture and processed food imports, Canada imported 1,790 million dollars' worth of vegetables, which was the largest proportion of imports in agriculture and processed food. Wine, fresh fruits, fish and seafood products, and cigarettes were the second to the fifth largest inflow of commodities in 2006. Of the total agriculture and processed food commodities, the share of processed food exports and imports were over 50%. The share of agriculture products in exports was greater than the share in imports. This structural difference between Canadian agriculture and process food commodities exports and imports in 2006 suggests that Canada's exports were dependent more on agriculture products, while its imports were more dependent on processed food products. The different structure of production factors used in agriculture and processed food production would have an impact on the factor intensity in Canada's agriculture and processed food trade.

5.2 Leontief's Approach

The capital, labor, and land requirements for exports and import replacements for agriculture and processed food commodities are listed in Table 1. These results show that an average million dollar worth of Canadian agriculture and processed food exports use more capital and less labor than an equivalent amount for the import replacements. The ratios between capital and labor for exports and import replacements are 168.2 and 112.2 dollars per working hour respectively. The ratio of capital per working hour between exports and import replacements is 1.5. These results suggest that Canada used international trade in agriculture and processed food commodities to optimize labor and dispose of excess capital. In Leontief's work, the capital per labor year ratio between exports and imports was 0.77. He concluded from this computation that the US exported labor-intensive goods while importing capital-intensive goods. Using Leontief's method, Canadian agriculture and processed food exports are relatively more capital intensive than its import replacements. Similar results are obtained for Canadian international trade including all industries in the economy. The ratios between capital and labor for exports and import replacements are 100.9 and 82.8 dollars per working hour respectively, and the ratio of capital per working hour between exports and import replacements is 1.2. Gu and Rennison (2005) computed the capital intensity of exports relative to imports for Canada as being 1.7 to 1.5 in 1989 and 1997. Their results are in the same range as the results from this study. As a developed economy, Canada is endowed with an abundance of capital, and it faces scarcity of labor. According to the H-O-V theorem, a country should export commodities that use its relative abundant factor and import commodities that use its relatively scarce factor. The estimates for Canadian agriculture and processed food trade and for total trade are consistent with the H-O-V theorem.

(Table 1)

As mentioned earlier, the share of agriculture goods in agriculture and processed food exports is greater than its imports. The capital requirement for exports is greater than the capital requirement for imports. Contrarily, the labor requirement for exports is smaller than the labor requirement for imports. This result may suggest a relatively capital-intensive production technology in the agriculture sector in Canada. Canada as a developed economy has replaced labor with capital in agriculture production as a means of substituting for its lack of labor, which makes agriculture production relatively capital intensive. Evidence of the capital intensity of agriculture production can be observed. The agriculture and processed food industry in Canada accounted for about 8% of GDP, while the labor force primarily employed in agriculture accounted for 1.8% of total labor supply. On one hand, the number of farms in operation has declined while the area dedicated to crop production has increased. On the other hand, there have been changes in the crops grown on Canadian farms. Production of labor intensive crops have declined while crops that grow on low bushes and can be machine harvested have increased. Moreover, greenhouse production has also seen an expansion. For specific crops, wheat remains the major crop in Canadian agriculture production. There has been an increase in canola and soybean production to meet the growing demand.

Apart from capital and labor, land as a natural resource was also included in this analysis. The results indicate that Canadian exported agriculture and processed food goods used more land, and imported goods used less land. The ratio of land use between exports and import replacements is 2.2. This means that for the equivalent amount of exports and import replacements, land use in exports is more than double the land use in import replacements. It was noted that the share of agriculture goods in agriculture and processed food exports is higher than that of imports. In this study, land is considered for agriculture sector only. Higher land requirements for exports are mainly due to the higher share of agriculture goods in exports. This finding agrees with the trade data. The ratio of land by labor was also computed for both exports and import replacements. It is found that the land-labor ratios for exports and import replacements are 0.1 and 0.04 acres per working hour respectively. The land-labor ratio in exports is 2.5 times the ratio for import replacements. These results suggest that Canadian agriculture and food exports require more land per working hour than the imports if they would have been produced domestically. Moreover, the ratio between capital and land for exports was smaller than for import replacements, which indicates that land was the dominant factor in Canadian agriculture and food trade. Natural resources are a source of comparative advantage for Canada (Gu and Rennison 2005). In Gu and Rennison's (2005) study, the ratio of natural resource content in exports relative to imports was found to be 1.5 for agricultural, forestry and fishery products. A similar trend was found for mining, crude petroleum and natural gas industries.

Capital and land requirements were relatively greater in Canadian agriculture and food exports, while the labor requirements were relatively greater in Canadian agriculture and processed food imports in 2006. This result can be interpreted as indicating that Canadian agriculture and food exports are relatively capital- and land-intensive[iii], while its imports are relatively labor intensive. As a developed economy, Canada is expected to be well endowed with capital and have labor scarcity. It is also known that Canada is endowed with a large stock of natural resources. The computed results show that land as a natural resource plays a dominant role in exports. Therefore, the results suggest that the Canadian agriculture and food trade supports the H-O-V theorem.

5.3 Leamer's Approach

Factor content of net-exports of agriculture and processed food trade was computed. The results suggest that Canada was a net-exporter of capital, labor, and land in its agriculture and processed food trade (Table 2). The capital-labor ratio and land-labor ratio were 450.7 and 0.41 respectively. An average 1 million dollar of net-exports of agricultural and processed food products requires 6.48 million dollars of total capital inputs, 14,384 working hours, and 5,946 acres. For total Canadian trade, it is found that Canada requires more labor in import replacements as compared to exports, and Canada is a net-exporter of capital. Therefore, according to Leamer's propositions, Canada is relatively endowed with an abundance of capital, while labor is scarce as compared to the rest of the world.

(Table 2)

Factor requirements in net-exports are compared with the factor requirements in domestic consumption to reveal factor endowment for a country. It was defined in Leamer's work that production equals domestic consumption plus net exports. For the Canadian economy in 2006, the total production, domestic consumption, and the net exports for agriculture and processed food commodities were 121,872, 113,804, and 8,068 million dollars respectively. The factor requirements in net-exports and domestic consumption were estimated using equation (8), and are given in Table 3.

(Table 3)

The Capital-labor ratios in net-exports and production are 5 and 1.4 times that of the ratio for consumption. This suggests that net-exports and production of agricultural and processed food goods require relatively more capital, while consumption requires relatively more labor. Similarly, the land-labor ratio in net-exports is higher than in consumption also suggesting that agriculture and processed food trade are relatively land-intensive. The results suggest that Canada's agriculture and processed food is relatively abundant in capital and land as compared to labor. The land-capital ratio for net-exports is higher than consumption and production. This suggests net-exports are more land intensive than capital intensive. Natural resources are therefore the dominant factor for the Canadian agriculture and process food trade.

In summary, Canada was observed to export relatively capital and land intensive products as compared to labor intensive products. This result is supported by Leamer's approach.

5.4 Environmental impacts from agricultural and processed food trade

GHG emissions from agricultural and processed food trade were assessed for the total and 1 million dollar of exports and import replacements respectively. Details are provided in Table 4. It was found that total GHG emissions from 1 million dollar of agricultural and processed food products exports and imports were 1,088.34 and 617.59 tonnes respectively. The GHG emissions from exports were 1.76 times larger than the equivalent value of import replacements. This result suggests that a relatively higher GHG emission was associated with the agricultural and processed food exports compared to the import replacements. The higher CO_2eq emissions from exports also coincides with the earlier finding that Canada's agricultural and processed food exports were relatively capital intensive, since it was expected that capital intensive industries were more likely be more pollution intensive. The total GHG emissions to satisfy the exports and import replacements included the direct plus indirect GHG emissions from

backward linkages in the production of traded agricultural goods. The direct GHG emissions from agricultural and processed food production were also illustrated. The results imply that Canada exported agriculture and processed food commodities with relatively higher GHG emissions as compared to its import replacements. There is a trade-off between environmental and economic interests for agriculture and processed food trade in Canada.
(Table 4)

6 Conclusion

This study shows that Canadian agriculture exports were relatively capital- and land- intensive and its imports were relatively labor intensive. The capital and land intensity in net-exports was greater than that in domestic consumption, which suggests that Canada was relatively endowed with capital and land as compared to labor. This result is in contrast with the Leontief paradox. Furthermore, results from the computation of GHG emissions from agriculture and processed food trade suggests that Canada's exports were associated with higher GHG emissions. The higher GHG emissions from exports coincided with the factor intensities for Canadian agriculture and processed food trade. However, this also raises an issue that net-exports of agriculture and processed food products increased environmental loads in Canada.

Empirically, Canada as a developed country is endowed with a relative abundance of capital and natural resources. The observed capital intensities in agriculture and food trade are consistent with this fact. Canada's exports of agricultural products such as wheat are a large proportion of Canada's agriculture and processed food trade. Land use in wheat and other crop production is large. This can explain the abundant land use in total agriculture and processed food trade.

The results found in this study have the same conclusion of those by Lee et al. (1988) who investigated the Leontief paradox for US agricultural and processed food commodities. Lee et al. (1988) suggested that US agriculture and processed food exports were relatively capital- and land- intensive compared to labor in 1982. Factor intensities in US agriculture and food trade were similar to that in Canada.

In this study the evidence of the Leontief paradox was not found. It cannot be generalized that the Leontief paradox does not exists in Canadian trade. It should be noted that the Canadian trade balance went into deficit for the first time in decades in 2008-2009. This shift from surplus to deficit may be accompanied by a shift in factor intensity in trade as well. It would be interesting to investigate how the change in the direction of trade impacts the factor content of trade by using time-series data.

Endnotes

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i, Other factors: K_i, L_i, R_i represent the capital, labor, and land embodied in trade, and the subscript "i" can be replaced by M or X, denoting imports and exports respectively.
ii. The current study is based on an expanded version of the thesis by Wu (2011). It has used the available 2006 Input-output table with extended agriculture and processed food sectors. The 2008 AAFC Input-Output model (2014) with extended agriculture and processed food sectors is currently available for researchers after the authors completed this study. It is observed that there are no major changes in production technology between 2006 and 2008.

iii. Capital- and land- intensive: A complementary relationship between capital and land was assumed in the study

References

Baldwin, J. W., W. Gu, and B. Yan. 2007. User Guide for Statistics Canada's Annual Multifactor Productivity Program. Statistics Canada, Ottawa, Canada

Baldwin, R. E. 1971. "Determinants of The Commodity Structure of U.S. Trade," *American Economic Review*, 61 (1), 126-146.

Bernhofen, D. M. and J. C. Brown. 2011. "Testing the General Validity of the Heckscher-Ohlin Theorem: The Natural Experiment of Japan," (No. 3586). *CESifo working paper: Empirical and Theoretical Methods.*

Branson, W. H. 1971. "U.S. Comparative Advantage: Some Further Results," *Brookings Papers on Economic Activity*, 1971 (3), 754-759.

Brecher, R. A. and E. U. Choudhri. 1982. "The Leontief Paradox, Continued," *Journal of Political Economy*, 90 (4), 820-823.

Caron, J., T Fally, and J. R. Markusen. 2014 "International trade puzzles: a solution linking production and preferences," *The Quarterly Journal of Economics*, 2014, qju010.

Casas, F. R. and E.K. Choi. 1985. "The Leontief Paradox: Continued or Resolved?" *Journal of Political Economy*, 93 (3), 610-615.

Dasgupta, P., A. Ghosh, D. Chakraborty. 2011. "Derterminants of India's Foreign Trade during Reforms," Paper presented at the The 19th International Input-Output Conference of the International Input-Output Association, Alexandria VA, USA, 13th June to 17th June, 2011.

Davis D. R. and D. E. Weinstein. 2001. "The Factor Content of Trade," *NEBR Working Paper Series*, National Bureau of Economic Research, Cambridge, MA

Drysdale, P. D. and L. Song. 2001. "Evidence of Shifts in the Determinants of Japanese Manufacturing Trade 1970-95," *Asia Pacific Economic Papers.* Australia-Japan Research Centre, Crawford School, Australian National University

Environment Canada. 2010. National Inventory Report 1990-2008, Environment Canada, Ottawa.

Gu, W. and L. W. Rennison. 2005. "The effect of trade on productivity growth and the demand for skilled workers in Canada," *Economic Systems Research*, 17 (3), 279-296.

Hecksher, E. and B. Ohlin. 1933. *Interreginal and International Trade.*

Heller, P. S. 1976. "Factor Endowment Change and Comparative Advantage: the Case of Japan, 1956-69," *The Review of Economics and Statistics*, 58 (1), 283-292.

Homma, T., K. Akimoto, and T. Tomoda. 2012. "Quantitative Evaluation of Time-Series GHG Emissions by Sector and Region Using Consumption-Based Accounting," *Energ Policy*, 51, 816-827.

Hufbauer, G. 1970. "The Impact of National Characteristics & Technology on the Commodity Composition of Trade in Manufactured Goods," *The Technology Factor in International Trade*, NBER, 145-231.

James, A. M. and B. T. Elmslie. 1996. "Testing Heckscher-Ohlin-Vanek in the G-7," *Review of World Economics*, 132 (1), 139-159.

Keesing, D. B. 1965. "Labor Skills and International Trade: Evaluating Many Trade Flows with a Single Measuring Device," *The Review of Economics and Statistics*, 47 (3):287-294.

Kozul-Wright, R. and P. Fortunato. 2012. "International Trade and Carbon Emissions," *European Journal of Development Research*, 24 (4), 509-529.

Kreinin, M. E. 1965. "Comparative Labor Effectiveness and the Leontief Scarce-Factor Paradox," *American Economic Review*, 55 (1/2), 131-140.

Leamer, E. E. 1980. "The Leontief Paradox, Reconsidered," *Journal of Political Economy,* 88 (3), 495-503.

Lee, C., D. Wills, and G. Schluter. 1988. "Examining the Leontief Paradox in US Agricultural Trade," *Agricultural Economics,* 2 (3), 259-272.

Leontief, W. 1941. *The Structure of the American Econom*y, *1919-1939.* New York, NY: Oxford University Press, (1o ed.: 1941.

Leontief, W. 1953. "Domestic Production and Foreign Trade; The American Capital Position Re-Examined," *Proceedings of the American Philosophical Society,* 97 (4), 332-349.

Leontief, W. 1956. "Factor Proportions and Structure of American Trade: Further theoretical and Empirical Analysis," *Review of Economics and Statistics,* 38 (4), 386-407.

Lowinger, T. C. 1971. "The Neo-Factor Proportions Theory of International Trade: An Empirical Investigation," *American Economic Review*, 61 (4), 675-681.

Maskus, K. E. 1985. "A Test of the Heckscher-Ohlin-Vanek Theorem: The Leontief Commonplace," *Journal of International Economics,* 19 (3-4), 201-212.

Miller, R. E and P. D. Blair. 2009. *Input-Output Analysis Foundations and Extensions,* Second Edition edn. Cambridge University Press, New York, USA.

Morrow, P. M. 2010. "Ricardian-Heckscher-Ohlin Comparative Advantage: Theory and Evidence," *Journal of International Economics*, 82 (2), 137-151.

Naya, S. 1967. "Natural Resources, Factor Mix, and Factor Reversal in International Trade," *American Economic Review*, 57 (2), 561-570.

Reimer, J. J. 2006. "Global Production Sharing and Trade in the Services of Factors," *Journal of International Economics*, 68 (2), 384-408.

Sikdar, C and D. Chakraborty. 2011. "The Factor Content of Bilateral Trade between India & Sri Lanka," Paper presented at the The 19th International Input-Output Conference of International Input-Output Association, Alexandria VA, USA, 13th to 17th June, 2011.

Statistics Canada. 2007a. 2006 Census of Agriculture, http://www.statcan.gc.ca/ca-ra2006/index-eng.htm. Accessed April, 2013.

Statistics Canada. 2007b. 2006 KLEMS Database. Statistics Canada, Ottawa, Canada.

Statistics Canada. 2010a. 2006 Agriculture and Agri-food Canada Input-Output Model. Ottawa, Canada.

Statistics Canada. 2010b. 2009 Canadian Farm Financial Database, http://www5.statcan.gc.ca/bsolc/olc-cel/olc-cel?catno=21F0001XBB&lang=eng. Accessed May, 2013.

Statistics Canada. 2010c. Greenhouse Gas Emissions (carbon Dioxide Equivalents) by Sector, 1990 - 2007. Statistics Canda, Ottawa.

Statistics Canada. 2014. 2008 Agriculture and Agri-food Canada Input-Output Model. Ottawa, Canada.

Su, B. and B. W. Ang. 2013. "Input-Output Analysis of CO2 Emissions Embodied in Trade: Competitive Versus Non-Competitive Imports," *Energ Policy*, 56, 83-87.

Su, B., B. W. Ang, and M. Low. 2013. "Input-Output Analysis of CO_2 Emissions Embodied in Trade and the Driving Forces: Processing and Normal Exports," *Ecological Economics,* 88:119-125.

Swerling, B. C. 1954. "Capital Shortage and Labor Surplus in the United States?" *Review of Economics and Statistics,* 36 (3), 286-289.

Tatemoto, M. and S. Ichimura. 1959. "Factor Proportions and Foreign Trade: The Case of Japan," *Review of Economics and Statistics*, 41 (4), 442-446.

Trefler, D. 1995. "The Case of Missing Trade and Other Mysteries," American Economic Review, 85 (5), 1029-1046.
Travis, W. P. 1972. "Production, Trade, and Protection When There are Many Commodities and Two Factors," *American Economic Review*, 62 (1/2), 87-106.
Trefler, D. and S. C. Zhu. 2010. "The Structure of Factor Content Predictions," Journal of International Economics, 82 (2),195-207.
Vanek, J. 1959. "The Natural Resource Content of Foreign Trade, 1870-1955, and the Relative Abundance of Natural Resources in the United States," *Review of Economics and Statistics*, 41 (2), 146-153.
Vanek, J. 1968. "The Factor Proportions Theory: The N-Factor Case," *Kyklos*, 21 (4), 749-754.
Wahl, D. F. 1961. "Capital and Labor Requirements for Canada's Foreign Trade," *Canadian Journal of Economics and Political Science*, 27 (3), 349-358.
Weiser, L. A. 1968. "Changing Factor Requirements of United States Foreign Trade," *Review of Economics and Statistics,* 50 (3), 356-360.
Wills, D. S. and C. Lee. 1990. "Factor Intensity of US agricultural trade," *Agricultural Economic Report-Economic Research Service*, US Department of Agriculture, 637.
Wu, T. 2011. "An Investigation of the Leontief Paradox using Canadian Agriculture and Food Trade: an Input-Output Approach" Masters Thesis, McGill University.
Yokokawa, K. 1994. "Factor Content of International Trade in Post-WW II Japan," Keizai Sushi, 64 (3), 407-418.

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Table 1. Domestic capital, labor and land requirements per million dollars of Canadian agriculture and processed food exports and import replacements

	Exports	Import Replacements
Capital (dollars)	3,542,800	2,572,600
Labor (working hours)	21,063.7	22,937.1
Land (acres)	2,210.1	994.7
Capital-Labor ratio	168.2	112.2
Land-Labor ratio	0.1	0.04
Land-Capital ratio	0.0006	0.0003

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Table 2. Factor requirements for total agriculture and processed food trade

	Exports	Imports	Net-exports
Capital (thousand dollars)	117,910,000	65,601,000	52,309,000
Labor (thousand working hours)	700,494.9	584,440.5	116,054.4
Land (thousand acres)	73,677	25,704	47,973
Capital-labor ratio	168.2	112.2	450.7
Land-labor ratio	0.11	0.04	0.41

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Table 3. Factor content in total agriculture and processed food production, consumption and net-exports in 2006

	Capital (thousand dollars)	Labor (thousand working-hours)	Land (thousand acres)	Capital/ Labor ratio	Land/ Labor ratio	Land/ Capital ratio
Net-exports	52,309,000	116,054.4	47,973	450.72	0.41	0.0009
Consumption	212,010,000	2,352,300	57,563	90.12	0.02	0.0003
Production	328,760,000	2,623,500	146,280	125.31	0.06	0.0004

Table 4. GHG emissions from agricultural and processed food trade in 2006 (tonnes)

	GHG emissions per million dollar exports	GHG emissions per million dollar imports	GHG emissions from total exports	GHG emissions from total imports	Ratio of GHG emissions from 1 million dollar of exports to 1 million dollar of import s
Direct Impact	809.71	401.50	26,993,825.71	10,396,184.96	2.02
Total Impact	1,088.34	617.59	36,397,954.75	15,456,108.56	1.76