Preliminary version: June 2008

The Changing Structures of Greenhouse Gas Emissions and Managerial Applications: Canada and Japan, 1990-2000

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Abstract

According to the Kyoto protocol Japan, for example, must bring down its level of carbon dioxide and other greenhouse gas emissions (referred to collectively in this paper as CO_2 emissions) over the period of 2008-2012 to a level which is 6% below its 1990 level. Our first objective of this paper is to show the importance of taking account of the multi stage and multi sector nature of firms' production processes in implementing the protocol requirements. This is because firms' operations in procurement of raw materials, manufacturing, distribution, usage and disposal involve many economic sectors of domestic and international economies in multiple stages. An Input-Output (I-O) model provides a framework for doing this. Differing amounts of CO_2 emissions are produced in many economic sectors at different stages in production. As an example, consider household behavior. The use of electric power in the household sector generates little or no CO_2, but production of electric power can produce considerable amounts. Under the current Japanese life-style, households' direct CO_2 emissions amount to about 13% of Japan's total emissions, while households' combined direct and indirect CO_2 emissions amount to about half of Japan's total emissions. Our framework allows us to assess how households' direct and indirect CO_2 emissions are affected by Japanese or Canadian households' adoption of a new life-style.

Our second objective is to use I-O analysis to measure the impacts of foreign trade and also foreign direct investment (FDI) on CO_2 emissions over the sample period (1990-2000). Analysis with respect to FDI is particularly relevant for multinational firms, because multinational firms in general can design policies for achieving reductions in CO_2 emissions using various combinations of domestic and overseas production facilities. They need not carry out all of their production activities at the same location. We use a Canada-Japan bilateral trade framework to discuss a number of policy and methodological issues. The differences in the structures of the Canadian and Japanese economies are helpful for illustrating our points. One question of interest is whether multinational firms have indeed changed their CO_2 emission behavior with regard to trade and FDI in recent years.

Keywords: Kyoto protocol, firms, greenhouse gas emissions, Canada, Japan.

1. Introduction

According to the Kyoto protocol developed countries must reduce their carbon dioxide and other greenhouse gas emissions (referred to collectively in this paper as CO_2 emissions) by specified amounts by target dates. Under the terms of the protocol, Canada and Japan, for example, must bring down their CO_2 emissions levels over the period of 2008-2012 to a level which is 6% below their respective 1990 levels. Canada's largest trading partner, the United States, has opted not to sign the protocol. However, Japan has signed, and Japan is also Canada's important trading partner. In many countries that have agreed to the Kyoto protocol, the mechanisms for achieving the target reductions in emissions are still being determined. A main objective of this paper is to show the importance of taking account of the multi stage and multi sector nature of firms' production processes in implementing the protocol requirements. This is because firms' operations in procurement of raw materials, manufacturing, distribution, usage and disposal involve many economic sectors of domestic and international economies in multiple stages. An Input-Output (I-O) model provides a framework for doing this. Differing amounts of CO_2 emissions are produced in many economic sectors at different stages in production. For example, the use of electric power in the household sector generates little or no CO_2, but production of electric power can produce considerable amounts.

We use I-O analysis for tracing the production of CO_2 emissions through the various stages of production.[1] The design of policies for achieving the promised reductions can be facilitated by allowing for the multi stage and multi sector nature of production processes and the fact that companies need not carry out all of production activities at the same location.[2] We use a Canada-Japan bilateral trade and economic cooperation framework to make a number of policy and methodology points. Both these countries have agreed to the Kyoto protocol, and hence have a common reason to be interested in trade arrangements that might ease the burdens of meeting the Kyoto emissions reduction targets. Moreover, the differences in the Canadian and Japanese economies are helpful for illustrating the points of interest.[3]

The Japanese government, like the governments of most developed EU countries, now require corporations to account for CO_2 emissions their corporate operations generate and to try to achieve substantial year-by-year reductions in their CO_2 emissions over time. Such reductions in CO_2 emissions must also be accurately measured. We show that our methodology presented in this paper is an effective tool for measuring CO_2 emissions associated with corporate activities. Precise measurement of CO_2 emissions generated by corporate activities is an important aspect of the government policies in order to achieve the greenhouse gas emission reductions mandated by the Kyoto protocol.

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[1] Leontief (1970, 1986) proposed that input-output (I-O) analysis is a potentially useful tool for analyzing the environmental implications of economic activities. Details of our model are given in Appendices along with a discussion of the limitations of I-O models as a policy tool. Generally speaking, these models assume fixed technologies and relative prices. Hence, policy makers need to proceed with caution when these models are used, for example, to analyze the effects of price changes including price changes that are in response to changes in technologies over the period of analysis.

[2] This is a relevant issue for Japan, since Japan already adopted many energy savings measures since the oil crises of the 1970s and has relatively little slack left for improving energy efficiency in its industrial and household sectors.

[3] Multinational firms from EU and Japan, for example, are often required by their home governments to make sure that their new investment in energy-intensive projects will not add new CO_2 emissions to their nations' total emissions. The firms typically cope with this kind of CO_2 emissions requirement by locating their production facilities outside their home countries and also by buying CO_2 emission rights from developing nations. This paper provides a practical framework in which multinational firms can analyze this kind of global CO_2 emissions problems.

The total amounts of CO_2 emissions have been increasing for both Canada and Japan. Over the period 1985-2000 CO_2 emissions climbed in volume from 403 million tons in 1985 to 429 (in 1990), to 461 (in 1995), and to 530 million tons (in 2000) for Canada; and from 872 million tons in 1985 to 1058 (in 1990), to 1141 (in 1995), and to 1172 million tons (in 2000) for Japan. The business sector generates over 80% of total CO_2 emissions for both Canada and Japan, as in many developed countries.[4] In both countries, electric power generation generates most emissions.[5]

Estimating CO_2 emissions

In this paper we first estimate, using Input-Output (I-O) analysis, CO_2 emissions during the period 1990-2000 that are attributable to Canadian and Japanese firms in various economic sectors. We then use these estimates in our case studies later in the paper. For this reason we explain briefly how we obtain these estimates.

Using Canadian and Japanese I-O tables and emissions data for 1990, 1995 and 2000, we have estimated total CO_2 emissions for each of the I-O table components of the business sectors for Canada and for Japan. (For example, there were 479 and 405 commodity sectors, respectively, for Canada and Japan for 1990.)[6] Our sector specific estimates take account of the emissions from various stages of production processes including the emissions associated with production of the raw materials and intermediate product inputs. For example, whereas auto assembly produces very little in the way of CO_2 emissions, production of the steel that goes into automobiles and transport of automobiles to market produce substantial amounts of CO_2 emissions.

The organization of the rest of the paper is as follows. In the next Section 2 we present our estimates for CO_2 emissions for Years 1990-2000. In Section 3 we show how I-O analysis and their CO_2 emissions can be used to evaluate domestic recycling policies in Japan. In Section 4 we first present two case studies, which require calculating CO_2 emissions arising from bilateral foreign trade explicitly. We present the methodology used in this section and then apply it to two case studies: calculating CO_2 emissions associated with Canada's imports of Japanese passenger cars and Japan's imports of Canadian pulp.[7] These two case studies are of interest because they exploit the two countries' comparative advantages. Such comparative advantages are reflected by the fact that Japan imports large quantities of energy-intensive natural resources from Canada, while Canada buys large quantities of manufactured goods from Japan. Given that CO_2 emissions rights have commercial value and are being traded, these case studies are of potential interest for both profit-maximizing firms and government policy makers. In the second part of Section 4 we show that, using the I-O model incorporating the above methodology, it is possible to evaluate

[4] Since our focus is CO_2 emissions in the business sector, we do not include in our calculations the CO_2 emissions generated, for example, when heating oil, natural gas or auto gas are burned in the household sector. We do include, however, the emissions generated when these fossil fuel products are produced (including production of what the household sector uses). We also include emissions from fossil fuels used to generate electric power.

[5] CO_2 emissions from electric power generation increased in volume from 84 million tons in 1985 to 95 million tons in 1990, to 101 million tons in 1995, and to 122 million tons in 2000 for Canada; and from 275 million tons in 1985 to 340 million tons in 1990, to 365 million tons in 1995, and to 321 million tons in 2000 for Japan.

[6] Our analysis requires extensive sector-specific CO_2 emission data. The emissions data used are described in Statistics Canada (1996a, 2000) for Canada and in Yoshioka et al. (1996) and Hayami et al. (2000) for Japan. (See Appendix B for details.) If our approach is to be used for forecasting purposes, it is important to bear in mind the standard I-O assumption that the input-output matrix (matrix A in Appendix A) is stable over time. For broadly defined sectors there is evidence that matrix A changes very slowly (Carter (1970)), though for narrowly defined commodity sectors such as the ones used in this paper technical change could cause important changes in some elements of A even within a 5-year period. This does not mean that our model cannot be used for forecasting purposes. It is a limitation that must be remembered in interpreting model results. We also note that not all technical change would necessitate adjustments in the results obtained with our approach. For example, there has been rapid technical change in Japan in the electronics and computer industries but these industries have had little impact on Japanese CO_2 emissions.

[7] The Kyoto protocol provides some flexibility for allowing for international substitutions of CO_2 emissions.

numerically the effects on domestic and trading partner's prices of a carbon tax introduced in one country. Section 5 concludes.

2. CO_2 emissions, 1990- 2000

We show in Tables 1 and 2 CO_2 emissions emitted in 2000 in various economic sectors for producing specified amounts of output measured in local currencies (one million Canadian dollars and one million Japanese yen, respectively).[8] For products in some sectors more CO_2 emissions are emitted in the production activities prior to the final production of the products. Such final products include diesel and fuel oil for Canada and crude steel for Japan.

Tables 1 and 2 about here

Using estimated unit CO_2 emissions (CO_2 emission coefficients) we can also make inter-industry comparisons for each country. Figures 1 and 2 show these coefficients by economic sector for Canada and Japan. The width of each bar represents the output of each sector. While these figures may be used for inter-industry comparisons within each of the Canadian and Japanese economies, they are not useful for comparing the two economies.

Figures 1 and 2 about here

We have shown estimated direct and indirect sector-specific CO_2 emissions for the two countries per output measured in their local currencies. In order to facilitate inter-country comparisons we now present CO_2 emissions estimated per output per million US dollars.

In Table 3 we show CO_2 emissions for the 20 commodity sectors which are among the largest contributors of CO_2 emissions. These are estimated per million U.S. dollars worth of output.[9] Next, we show in Table 4 CO_2 emissions per unit volume of output rather than per unit value for selected commodities for which we have output quantity data for both Canada and Japan.[10] These sector-specific emission estimates will be used in our case studies to follow.

Tables 3 and 4 about here

3. Japanese recycling policy and CO2 emissions (To be updated)

Transport of material inputs to production facilities and transport of products to markets can result in CO_2 emissions that must be counted as part of the full emissions for that product. For example, paper recycling was introduced to begin with for environmental reasons but, as we show below, its environmental effectiveness crucially depends on how much CO_2 emissions are generated in transporting the paper to be recycled.

Japan has been promoting public policy measures to recycle many types of consumer products including paper products. The Japanese Recycling Act of 1997 requires all supermarket stores to collect and sort used paper products (e.g. milk cartons, cereal packages) and recycle them. Significant amounts of both public and private R&D funds have been spent on the development of

[8] Using the average exchange rate for Year 2000, we have: one million Canadian dollars = 72 million Japanese yen.
[9] We used (A5) in Appendix A to derive Tables 1-4.
[10] The results in Table 4 are more suitable for making inter-country comparisons than the results shown in Table 3. Some of the differences between the two countries that are apparent are interpretable in light of recognized inter-country differences in production conditions and methods. (See Hayami and Nakamura (2004).)

technologies that facilitate recycling of these products. Recycling been promoted in Japan for the purpose of reducing the quantity of solid waste. In Japan, many localities face severe limitations on space for solid waste disposal. These laws, however, do not address the issue of the CO_2 emissions that are generated as a consequence.

Japan consumes a large quantity of paper. Indeed, its per capita consumption of paper is world's 7th largest. Japan is also the largest consumer of recycled paper in the world (17.92 million tons).[11] In 2000, Japan recycled 58% of paper products, and 57% of pulp input in its paper production was recycled paper pulp (with the rest being virgin pulp).[12] CO_2 emissions can be reduced by using recycled paper because production of recycled paper does not result in the burning of the byproducts of virgin pulp production (pulp black liquor and waste). However, collecting paper products for recycling from households and business firms at the municipality level results in transportation activities and these activities consume significant amounts of fuel, resulting in CO_2 emissions.

Using the Japanese I-O model and emissions data for 1995, we conducted simulation experiments to assess the impact of the input ratio between new and recycled paper pulp on the total CO_2 emission from paper producing firms (Table 5). Required transportation energy levels were fixed at various plausible levels in the reported simulations. We used the current (industry-average) ratio of new to recycled pulp of 52:48 and specified the required unit transportation energy as 121 Megacalories (Mcalories) per ton for the bench mark case. Increasing the recycled pulp content from the bench mark level to the new to recycled pulp ratio of 28:72 while holding the unit transportation energy level fixed at 242 Mcalories per ton reduces total emissions. We found no improvement in emissions, however, beyond the ratio of 33:67 for new to recycled to pulp. For Japan we estimate that a ton of truckload can be transported for about 360km using 725 Mcalories. Considering the amounts of transportation required to collect and transport recycled paper, we also conducted simulation experiments using alternative unit transportation energy levels while fixing the new to recycled pulp input ratio at 28:72. As the required transportation energy level increases from 242 to 1449, the total emission also increases by 6 million tons.

Table 5 about here

We have also calculated the shadow prices for newsprint quality and high quality paper produced using recycled pulp. Given the low price for recycled newsprint, the shadow price of newsprint paper using recycled pulp does not exceed the bench mark price (1.00) until the required unit transportation energy level exceeds 725 Mcalories/ton. On the other hand, the shadow price of high quality paper is considerably higher than the bench mark level for all unit transportation energy levels. This reflects the high cost of recycling high quality paper.

Japan's paper recycling policy involves 3,246 local governments, but a relatively small number of these separately collect or sort out different types of paper products for recycling. The production of high quality paper requires high quality paper to be recycled separately. Our simulation results suggest that significant governmental subsidies may be needed to expand the paper recycling movement to support the production of high quality paper.[13]

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[11] Japanese local governments collected at most 11 types of wastes separately in 2001. The waste collected for recycling in 2001 included paper packages (49,723 tons), corrugated cardboards (448,855 tons), and paper milk cartons (13,136 tons). (http://www.env.go.jp/recycle/kaden/fuho/index.html)

[12] These figures were: 46% and 24.5% for Canada, 40.1% and 5.2% for Finland, 33.9% and 51% for China, 46.6% and 57.8% for France and 48.7% and 42% for the U.S. (METI (2001)). The new vs. recycled pulp ratio is a standard parameter to measure the degree of environmental friendliness in both company and government policy decision processes.

[13] It is also possible to design simulation experiments using various numerical optimization procedures.

4. Relationships of CO_2 emissions to foreign trade: Canada and Japan

4.1. Location choice and CO_2 emissions

In this section we show our estimates for CO_2 emissions that are generated by foreign trade between Canada and Japan. While two-way merchandize trade flows between Canada and Japan have been generally in balance, the types of goods Canada exports are quite different from the types of goods Japan exports.[14, 15]

Our I-O approach[16] allows us to estimate the potential effects on CO_2 emissions in each country of various forms of production activities in bilateral trade.[17] Tables 6 and 7 show the amounts of exports for 20 representative commodity groups, respectively, from Canada to Japan and from Japan to Canada, together with the associated total sector-specific CO_2 emissions induced in the exporting activities.[18] For example, Table 6 shows that Canadian firms exported U.S. $693 million worth of coal to Japan in 1990. This coal export induced industrial activity in Canada worth U.S. $698 million and generated 599 kilo tons of CO_2 in Canada.

Tables 6 and 7

Table 6 shows, as expected, that Canada's exports contain, for both 1990 and 1995, many resource commodities, production of which generates considerable industrial activity and significant amounts of CO_2 emissions in Canada. These include mined products (e.g. coal, metal ores and primary metals), forest products (e.g. pulp, lumber) and an agricultural product (Canola). We also note that certain production activities induced indirectly by Canada's exports to Japan generate considerable CO_2 emissions in Canada. For example, while Canada does not export (or exports very little) electrical power and crude mineral oils to Japan, other Canadian exports induce considerable demands for these commodities, production of which generates substantial amounts of CO_2. In total, in 1995 (in 1990), Canada's commodity exports to Japan generated economic activity worth U.S. $17.53 billion (U.S. $10.56 billion) and 6.96 million tons (5.44 million tons) of CO_2.

Table 7 reports CO_2 emissions attributable to Japanese firms' exports to Canada. The structure of CO_2 emissions generated by Japanese exports to Canada, as shown in Table 7, is remarkably different from that for Canada. CO_2 emissions generated by Japan's exports to Canada are almost entirely indirectly induced emissions, since Japan's manufacturing assembly processes are almost CO_2 free. On the other hand, CO_2 emissions generated by Canada's exports to Japan consist of both the emissions generated directly by production of the exported commodities

[14] Both imports and exports between Canada and Japan fluctuated between 7 and 9 billion dollars U.S. in the 1990s. There are basically four data sources for Canada-Japan trade. Some of the reported discrepancies in these trade statistics are illustrated using 1990 data in the following. Canada's exports to Japan in 1990 are given as 7.013 (billion dollars U.S.) in the Trade Statistics, and 5.599 in the I-O Tables. Japan's imports from Canada are given as 8.426 in the Trade Statistics (CIF), and 8.876 in the I-O Tables (CIF+tariff+import tax). Canada's imports from Japan are given as 8.161 in the Trade Statistics, and 8.419 in the I-O Tables. Japan's exports to Canada are given as 6.739 in the Trade Statistics (FOB) and 6.398 in the I-O Tables (FOB-transport margin).

[15] Japan buys Canada's natural and agricultural resources while exporting manufactured goods to Canada. Trade between Japan and the U.S. or trade between Canada and the U.S., on the other hand, involves large amounts of exchange of manufactured goods and hence the types of issues discussed here do not necessarily arise.

[16] See Appendices and also Hayami and Nakamura (2004) for further details on how to calculate these quantities and data.

[17] Our approach is sector specific. Antweiler (1996), on the other hand, proposes a macro index for the pollution terms of trade between two countries.

[18] The 20 commodity groups used here generally capture the current patterns of trade-related CO_2 emissions. Results for all commodity groups are available on request from the authors.

themselves and the emissions generated indirectly by the production activities required for producing the commodities Canada exports to Japan.

Using the same I-O framework adopted in this study it is shown[19] that, for 1990, the quantity of CO_2 emissions that would be generated in Japan if Japan's imports from Canada were replaced entirely by domestic production, assuming that such import substitutions were feasible, is 6.55 million tons, and the quantity of CO_2 emissions that would be generated in Canada if Canada's imports from Japan were replaced entirely by domestic production is 5.34 million tons. We note from Tables 6 and 7 that, in 1990 Canada's exports to Japan induced 5.44 million tons of CO_2 in Canada and Japan's exports to Canada induced 2.83 million tons of CO_2 in Japan. Thus, under the scenario of no trade between Canada and Japan, the net change in the total combined amounts of CO_2 emissions for both countries is calculated to be the sum of the net change for Canada, –0.09 (=5.34-5.44) and the net change for Japan, 3.62 (=6.55-2.83). This combined net change is an increase in the total CO_2 emissions of 2.53 (=3.62-0.09) million tons.[20]

Auto and pulp firms' CO_2 emissions

In implementing the Kyoto protocol commitments to reduce CO_2 emissions Japanese government relies primarily on voluntary efforts by industry[21, 22]. At this point it seems unlikely, however, that voluntary measures alone will be enough for Japan to meet its Kyoto target. For this reason the Japanese government began introducing a number of stricter measures for industry

[19] Hayami, Nakamura, Asakura and Yoshioka (1999).

[20] This scenario is based on the assumption of the existing production technologies, competitive imports, consumption (final demand) preferences and abundant production inputs. Under a more realistic scenario we need to specify which countries would replace Canada (Japan) as Japan's (Canada's) trading partner and recompute.

[21] E.g. ISO 14000 certification. Obtaining certifications for internationally acceptable standards for environmental management is often required for manufacturers to enter global markets (e.g. European and Japanese markets). Many Japanese firms have obtained the ISO 14001 certification that attests that they possess ISO-acceptable environmental management systems. The current interest in business certification focuses on ISO 14040-14044 which certify firms that they possess environmental management systems for controlling the environmental impacts of their products over their product life cycles, the stages of which include procurement of raw materials, manufacturing, distribution, usage and disposal. Controlling the amounts of CO_2 emissions throughout the life cycle of a product is an important factor for such certifications. Many of these environment-certified firms are betting that green consumerism is and will continue to be an important component in marketing their products globally. Firms' responses to global warming issues are analyzed, for example, in Nakamura, Takahashi and Vertinsky (2001) for Japan and Takahashi, Nakamura, van Kooten and Vertinsky (2001) for Canada. The latter find, as the Pembina Institute (1995, 1996) did, that Canadian voluntary programs are not effective in reducing firms' CO_2 emissions. See also Kollman and Prakash (2001) and Prakash (2000).

[22] Nippon Keidanren (Japan Business Federation) established its own environment charter and keeps track of and publishes detailed emissions data for its member associations (Nippon Keidanren (2002)). As of now it is not supporting government allocation of CO_2 emission reductions among Japanese firms, nor energy or other types of environmental taxes. Nevertheless these policy measures are under serious consideration by the government and industry.

environment performance.[23] It seems likely that each Japanese firm will be given mandatory CO_2 emissions reduction requirements in the near future.

In anticipating mandatory CO_2 emissions reduction programs Japanese firms are also adopting various other environmental management strategies. For example, Toyota, Nippon Paper and Mitsui & Co. have already jointly invested in tree planting in Australia and other countries in Asia for future offsetting of their CO_2 emissions as is allowed under the terms of the protocol. Another way for firms to reduce CO_2 emissions from their production processes is to use foreign sourcing of the intermediate goods that are energy-intensive.

In this section we present two case studies in which we show how much CO_2 emissions are generated in Canada and Japan for two traded goods, passenger cars and paper pulp.[24] Computing CO_2 emissions generated in every step of their production processes, as shown here, has become an important dimension in management planning for many firms. In particular, such calculations may be used as well by other manufacturers interested in import strategies for shifting CO_2 emissions.

This sort of offsetting strategy is becoming more important for Japanese firms as reducing greenhouse gas emissions has become an importance corporate goal. From the overall public policy perspective, however, emissions reduction strategies need to be considered in conjunction with other public policy concerns and objectives including the potential loss of employment. So far this issue has received only modest attention from the Japanese government.[25]

Canadian imports of Japanese cars and the overall CO_2 emissions[26]

The Canadian demand for one thousand U.S. dollars worth of Japanese passenger cars generates Japanese firms' production activities in many sectors.[27] CO_2 is generated in every stage for each of the production activities. Table 8 shows estimated amounts of Japanese production activities and associated CO_2 emissions resulting from the Canadian demand for one thousand U.S. dollars worth of Japanese cars. They add up to U.S.$3,114 in 1995 (U.S.$3,077 in 1990) worth of commodity output and 297 kg in 1995 (458 kg in 1990) of CO_2 emissions. Assuming the average producer price of an auto to be U.S.$10,000, the amount of CO_2 emissions in Japan per exported vehicle is 2.97 tons in 1995 (4.58 tons in 1990). The corresponding induced production activities and CO_2 emissions in Canada have been calculated and found to be negligible.[28] Table 8 shows that the use of electric power and ocean transport as parts of the production cycle for cars generates significant

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[23] One such measure in the revised energy savings law of April 1999 is termed a "top runner method" which sets a compulsory target for the energy consumption level for a particular line of products at the level attained by the most energy-efficient product currently available in the market. For example, based on 1999 performance, gasoline based passenger cars were given the target of a 22.8% reduction in energy usage over the period 1999 and 2010, while home air conditioners were given the target of 63% over the period 1997 and 2004. The penalty for non-compliance will include public announcement of the violators and a fine. Many large Japanese manufacturers have been preparing to meet these targets for the last few years (Yamaguchi (2000)). The U.S. raised concerns that this law might be used as an invisible barrier against foreign products but Japan argues that it is completely consistent with the WTO rules.
[24] Results reported below were obtained using the method discussed in the previous section and Appendix B.
[25] Since the 1980s, there has been massive global outward foreign direct investment by Japanese firms. Many view this as a significant source of Japanese employment loss. Nevertheless, the Japanese government has not taken any measures to restrict this sort of outward FDI. Since this policy is likely to continue into the future, it is entirely up to individual firms to decide how to meet their respective CO_2 emissions requirements using a mix of domestic and foreign production.
[26] The computational method used for this and next case studies is described in detail in Appendix C.
[27] Cars made in Canada by Japanese transplants are not included in our calculations here.
[28] Car parts, aluminum and pulp are the three largest commodity sectors in Canada whose production is affected by the Canadian purchase of U.S.$1,000 worth of Japanese automobiles. However, numerically the total effects are quite small (U.S.$1.39 per $1,000 or $13.9 per car). The associated CO_2 emissions are 0.77572 kg per $1,000, or 7.7572 kg per car. Further details are available from the authors on request.

portions of the resulting CO_2 emissions in both 1995 and 1990. These sources of emissions in Japan would be curtailed if production were moved to Canada.

Table 8 about here

Japanese imports of Canadian pulp and overall CO_2 emissions

Table 9 shows estimated amounts of Canadian firms' production activities and associated CO_2 emissions resulting from the Japanese demand for one thousand U.S. dollars worth of Canadian pulp: U.S.$2,001 in 1995 (U.S.$2,137 in 1990) worth of commodity output and 1103 kg in 1995 (1721 kg in 1990) of CO_2 emissions. We have also estimated the amounts of Japanese firms' production activities and associated CO_2 emissions resulting from the Japanese demand for one thousand U.S. dollars worth of Canadian pulp and found these to be numerically small.[29] We can also show, for example for 1990, that production of 1,000 tons of pulp generates 444 ton of CO_2 emissions in Canada, whereas the same amount of pulp production generates 755 tons of CO_2 emissions in Japan. This difference (444 tons vs. 755 tons of CO_2 emission) is far less than the amount of CO_2 emissions generated by transporting pulp from Canada to Japan.[30] Thus a reduction in CO_2 emissions could presumably be achieved if Japanese paper mills imported more pulp from Canada.[31]

Table 9 about here

4.2. Carbon tax

One possible policy tool to reduce greenhouse gas emissions is carbon tax which taxes the carbon content of goods and services consumed. Suppose Japan introduces a carbon tax of one U.S. dollar per ton of CO_2 emitted. It is shown in Appendix D that the domestic price increases as a result of this carbon tax are given in Table 3. (That is, figures in Table 3 are also estimated shadow prices.) For example, Japanese domestic cement price would increase by 1.229% ((=12.2864/1000) times 100) because of the carbon tax for 1990; the corresponding figures for 1995 and 2000 are, respectively, 1.016% and 1.243%. [32]

Estimated price increases for some other goods for 1990, 1995 and 2000 (Table 10) are: 1.225%, 0.927% and 0.692%, (self power generation); 0.347%, 0.219% and 0.248% (electric power); 0.610%, 0.623% and 1.026% (pig iron); and 0.542%, 0.751% and 0.745% (coal products). We note that these price increases correspond to the CO_2 emissions of the respective sectors arising from the unit output (US$1 million). Estimated price increases for Canada for 1990, 1995 and 2000 are: 1.153%, 1.376% and 0.424% (cement); 0.544%, 0.488% and 0.602% (electric power); 0.329%, 0.245% and 0.191% (flat iron and steel); and 0.303%, ---, and 0.202% (coke).

Table 10 about here

[29] For example, US $2.26 worth of commodity output and 0.77077 kg of associated CO2 for 1990. The detailed estimated figures are available from the authors on request.
[30] The same conclusion also holds for 1995.
[31] As of now manufacturers who invest in FDI need not worry about their CO_2 emissions that they generate using their FDI plants overseas for their home country regulation purposes so long as they satisfy the host country requirements. (Some may still care about this because of their corporate image.) This is one area where international coordination is clearly needed.
[32] Calculations given in this section are based on estimates given in Table 3.

The introduction of a carbon tax influences the domestic prices of trading partners through trade. Table 11 shows the estimated price increases for Canadian (Japanese) domestic prices when the above carbon tax is introduced in Japan (Canada), assuming that no substitutions take place in the supply of and the demand for these goods in both countries. (See Appendix D for details.) For example, Canada's carbon tax will increase Japanese domestic prices of vegetable oil, coal, copper, paper and nuclear fuels by 0.0100%, 0.0066%, 0.0062%, 0.0044% and 0.0023%, respectively. On the other hand, Japan's carbon tax will have much smaller effects on Canadian domestic price increases. For example, oil and gas pipe prices will increase by 0.0027% while auto prices would increase by 0.0011%. We conclude that Japan's carbon tax will have only a modest impact on the Canadian prices of goods. Such Japanese carbon tax induced price increases in Canada may be mitigated relatively easily by Canada's ability to locate alternative suppliers other than Japan. On the other hand Canada's carbon tax will potentially have a much more significant impact on the Japanese prices of goods which are energy-intensive. Furthermore it may be difficult for Japan to locate alternative exporting countries which could supply Japan with energy-intensive materials in large quantities for prices which are low enough to mitigate the impact of Canada's carbon tax.

Table 11 about here

5. Concluding Remarks

In this study we first computed estimates for CO_2 emissions for over 400 economic sectors of Canadian and Japanese economies.[33] We then used these estimates and our models for analyzing various policy implications of CO_2 emissions as related to recycling, foreign direct investment and also trade between Canada and Japan. In particular detailed case studies were presented for paper recycling, automobile and pulp production, and carbon tax, among other topics. These case studies illustrate some of the common types of tradeoffs that underlie firms' managerial decisions as well as public policy decisions on greenhouse gas emissions. Policy suggestions were also presented for these applications.

This paper shows that, using our method presented in Appendix C, Canada (Japan) can estimate detailed sector-specific CO_2 emissions in Canada (Japan) resulting from its trading activities (both importing and exporting) with Japan (Canada).[34] Using this methodology we show, for example, that the complementary nature of international trade between Canada and Japan adds considerable flexibility to Japan's planning for meeting its CO_2 emission target.[35] Despite their limitations discussed in Appendix A, only I-O based models such as ours can analyze and provide estimates for many sectors required for the types of applications discussed in this paper.

We have also argued that firms can apply our methodology for estimating sector-specific CO_2 emissions which result from their production activities. This measurement issue is becoming an important part of implementation of the Kyoto protocol. Japanese firms, for example, are now required to account for their CO_2 emissions accurately in order for Japan to comply with the Kyoto protocol requirements. As noted above our methodology allows Japanese firms to compute direct and indirect sector-specific CO_2 emissions resulting from their operations not only in Japan but also in Canada. Because greenhouse gas issues are global in nature, this aspect of our method should prove useful when trading CO_2 emissions between countries is at issue. Another application of our method is in the area of life cycle assessment (LCA) in which firms are required to estimate all

[33] To save space this paper does not report CO_2 emissions for all of these sectors. Complete results are available on request from the authors.
[34] Technical details are given in Appendix C.
[35] Potential sources for such flexibility include Japanese firms' foreign direct investment in Canada and more imports from Canada.

greenhouse gas emissions associated with a product over its life cycle (i.e. from its conception to its consumption and disposal).[36]

Finally, even though we have presented our empirical examples using data for Canada and Japan, our methodology and models can be applied to other countries for which relevant data exist.[37]

[36] LCA is an essential part of the ISO 14000 family of environmental management standards, which major manufacturers, for instance, in Japan and EU are trying to get certified for for staying competitiveness in global markets.

[37] Our approach can also be used to compute the amounts of CO_2 emissions to be traded using the Clean Development Mechanism (CDM) clause of the Kyoto Protocol. CDM allows multinational firms to buy reductions in CO_2 emissions in return for investing in their CO_2 emissions-saving FDI projects in a developing country. Such FDI projects must be authorized as CDM projects (Hayami, Nakamura and Yoshioka (2003)). The CDM clause provides the current international framework for the commercial market mechanisms by which multinational firms and developing nations trade their CO_2 emissions rights.

Appendix A. Input-Output Analysis and Estimation of CO_2 Emissions

The input-output data used for this study are the 1990 and 1995 Input-Output tables for the Japanese economy (Management and Coordination Agency (1994, 2000)) and the 1990 and 1995 Input-Output tables for Canada (Statistics Canada (1996b, 2000)). These data sets are available for public use. The Japanese I-O table is provided in square matrix form (matrix A below) with additional columns representing various types of final demand (columns d_j below) and additional rows representing various types of value-added (Yoshioka et al. (1996) and Hayami et al. (2000)).

The Canadian I-O matrices are based on the System of National Accounts (SNA) and consist of a use matrix, a make matrix, final demand columns and value-added rows. (See, for example, Statistics Canada (1989), Miller and Blair (1985), Miller, Polenske and Ross (1989) and Polenske (1989).) A detailed derivation of the I-O square matrix (A) for Canada and other information on Japanese and Canadian data are given in Hayami, Nakamura, Asakura and Yoshioka (1999).

Our basic I-O model is as follows. We divide an economy into n broad industrial and other relevant sectors where production of goods and services takes place. We define I-O technical coefficients a_{ij} (i,j = 1,2,...,n) to be the dollar amount of input from sector i per dollar's worth of output of sector j, where the a_{ij} lie between 0 and 1 and their column sums are less than one. We denote by x an nx1 vector in which each component x_j represents the domestic production of sector j (j=1,2,..,n). We denote by d_j, e_j and m_j the final domestic demand, exports and imports for sector j, respectively. We also denote by d, e and m their corresponding nx1 vectors. Then we have the I-O equation

(A1) $$Ax + d + e = x + m.$$

Assuming a competitive imports structure, m is given by

(A2) $$m = M (Ax + d + e)$$

where M is an nxn diagonal matrix with its diagonal element M_{jj} representing the imports coefficient for sector j. The import coefficient matrix M is derived in Hayami, Nakamura, Asakura and Yoshioka (1999). Substituting (A2) into (A1), we get

(A3) $$x = (I- (I-M)A)^{-1} ((I-M) (d + e)).$$

Suppose we have estimates $E1_j$ (j=1,2,..,n) for the amounts (in kilo tons) of CO_2 produced per million U.S. dollars worth of production in each of n sectors. We denote by E1 the corresponding nxn diagonal matrix with $E1_j$ in the j-th diagonal position. Then the amount of CO_2 produced by a unit demand for the output of sector j is given by

(A4) $$E1(I-(I-M)A)^{-1} u_j$$

where u_j is a unit nx1 vector with one in the j-th position.[38] Let *i* be a 1xn vector of ones. Then the total CO_2 co-produced with a unit of output in sector j is given by

(A5) $$E_j = iE1(I-(I-M)A)^{-1} u_j \qquad j=1,2,...,n.$$

[38] The data on CO_2 emissions used were taken from Environment Canada (1992), Jaques (1990), Smith (1993), Statistics Canada (1996a) as well as unpublished data provided by Statistics Canada for Canada; and Yoshioka et.al (1996) and Hayami et al. (2000) for Japan.

(A5) is a standard open I-O model formulation of pollutants. See Miller and Blair (1985,Ch.7) for other types of models. In this paper we focus on CO_2 emissions from industrial production processes only. We should also note the standard limitations of I-O analysis. For example, if policy alternatives of interest involve, in reality, significant changes in the relative prices of production inputs, I-O analysis will not reflect this since, as is typical for I-O models, the technical coefficients are fixed.[39] Another limitation of our approach is the time lags involved in obtaining I-O data. This problem, however, is becoming less severe as national statistical agencies improve their timeliness in providing this data. Despite these potential limitations, I-O analysis is a useful supplement to macro simulation models of the sort used by many government offices, and the only realistic alternative for taking account of the CO_2 emissions generated in many sectors in different stages of production processes.[40]

Appendix B. Data and Model Derivation Details

In Appendices B and C we give detailed description of our methodology and data analyses for Canada and Japan for 1990. The same methodology and data analyses also apply for 1995 and 2000.

Japan

The original 1990 Japanese public use I-O data consists of an I-O matrix representing intermediate transactions with 527 column sectors (based on the Japanese 7-digit classification) and 411 row sectors (based on the 6-digit classification), an 11x411 value-added matrix, a 527x30 final demand matrix and an output (527x1) vector.[41] In order to derive a square I-O table with sectors which are comparable to the Canadian sectors the 527 column sectors were first aggregated into 6-digit classification sectors (i.e. 411 sectors). In this process iron scrap and metal scrap were, respectively, combined with pig iron and other non-ferrous metal sectors. Then 10 sectors in agriculture, fishery and utility industries were aggregated into 4 sectors: vegetables, fishery, inland water culture and power generation.[42] The resulting I-O table for Japan is 405 by 405. The input coefficient matrix $A=(a_{ij})$ is derived from the following balance equation:

(B1) $\Sigma_j\{a_{ij}\, Qj\} + FDi + EXi = Qi + IMi \qquad i,j = 1,2,...,m$

where m=405, FDi, EXi, Qi and IMi denote, respectively, final demand, exports, output and competitive imports for sector i.

Canada

The Canadian System of National Accounts for 1990 provide the I-O matrices: a 478x161 use matrix (Uij), an 161x478 make matrix (Vij), a 478x136 final demand matrix (FDij), and a 7x161 and a 7x136 value-added matrices (VAij and VAFDij).[43] Total industry sector output vector (161x1) is also given (g_i). Because of the privacy requirement of the provisions of the Canadian

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[39] See, for example, Smith (1991, 1993, 1995).

[40] See, for example, Environment Canada (1997) and Natural Resources Canada (1999) for the use of a macro simulation model for obtaining forecasts for Canada's future CO_2 emissions. In this simulation model population and GDP growth, oil prices and other model inputs are assumed given.

[41] The corresponding dimensions of these matrices for 1995 are as follows: I-O matrix (519x403), value-added matrix (10x403), final demand matrix (519x23) and output vector (1x519).

[42] In this process we reduced the number of column (and also row) sectors by 6 from 411 to 405.

[43] The corresponding dimensions of these matrices for 1995 are as follows: 476x167 use matrix (Uij), 167x476 make matrix (Vij), 476x122 final demand matrix (FDij), and 7x167 and 7x122 value-added matrices (VAij and VAFDij).

Statistics Act some cells in both use and make matrices report figures which have been rounded up from thousands of dollars to millions of dollars. (Statistics Canada (1996, 2001).) Such rounding occurs when the sources of reporting units (company establishments) are identifiable because of too few reporting units in particular cells. Such processing implies that the columns of the use and final demand matrices do not sum to the given output vector:

(B2) $\Sigma_{i=1}^{478}$ Uij + $\Sigma_{i=1}^{7}$ VAij $\neq g_j$ j=1,...,161

(B2*) $\Sigma_{i=1}^{478}$ FDij + $\Sigma_{i=1}^{7}$ VAFDij $\neq (g_f)_j$ j=1,..., 136

Similarly the row sums of the make matrix do not equal the output vector:

(B3) $\Sigma_{i=1}^{478}$ Vij $\neq g_i$. j=1,...,161

In order to accommodate these discrepancies we have introduced an adjustment row as the last (479th) row, U_{479j} and FD_{479j}, in the use and final demand matrices. The adjustment rows are set equal to the differences between the right and left sides of (B2) and (B2*) above. Similarly we have introduced an adjustment column vector as the last (479th) column, V_{i479}.

(B2a) $\Sigma_{i=1}^{478}$ Uij + U_{479j} + $\Sigma_{i=1}^{7}$ VAij = g_j j=1,2,..,161

(B2*a) $\Sigma_{i=1}^{478}$ FDij + FD_{479j} + $\Sigma_{i=1}^{7}$ VAFDij = $(g_f)_j$ j=1,2,...,136

(B3a) $\Sigma_{i=1}^{478}$ Vij + V_{i479} = g_i i=1,2,…,161

The resulting I-O input technical coefficient matrix A is 479x479 and is obtained as follows.
We first define a technical coefficient:

u_{ij} = { Uij / g_j } i=1,...,479 j=1,...,161

Let m=479 and n=161.
Then the commodity balance equation is

(B4) $\Sigma_{j=1}^{n} u_{ij} g_j$ + FDi +EXi = Qi + IMi i=1,...,m

We next introduce the industry-based technology assumption which is a standard assumption in input-output modeling. This assumption states that the total output of a commodity is provided by industries in fixed proportions and hence that the following commodity output proportion (market share coefficient) forms a constant matrix:

d_{jk} = { Vjk / Qk } k = 1,2,…,m j = 1,2,…,n

Using (B3a) we get

(B5) $\Sigma_{k=1}^{m} d_{jk} Q_k = g_j$ j=1,2,…,n

Substituting (B5) into (B4) we get

(B6) $\Sigma_{k=1}^{m} \{\Sigma_{j=1}^{n} u_{ij} d_{jk}\} Q_k$ + FDi +EXi = Qi + IMi i = 1,2,…,m

Defining the I-O technical coefficient matrix A,

$A = \{ a_{ij} \}$, $a_{ij} = \Sigma_{k=1}^{n} u_{ik} d_{kj}$ i=1,...,m j=1,...,m

we obtain from (B6) the following balance equation for each commodity

(B7) $\Sigma_{j=1}^{m} \{a_{ij} Q_j\} + FDi + EXi = Qi + IMi$ i = 1,2,...,m

Thus the d_{jk} allocates the u_{ik} across m commodities into a_{ij}.

Derivation of the Imports Coefficients and the Leontief Inverse

The standard definition of the imports coefficient for competitive imports in sector i is
(B8a) $Mi = IMi / (\Sigma_j\{a_{ij} Qj\} + FDi)$ i=1,2,...,m,

where it is assumed that exported commodities do not include imported commodities. In order for the Lentief inverse to exist, however, we require that the imports coefficient is nonnegative and strictly less than 1: $0 \leq Mi < 1$.

We have found that imports coefficients calculated by definition (B8a) using the Canadian I-O data exceed one for some sectors. This is because the above assumption for (B8a) is not satisfied. This is explained as follows. Some sectors of the Canadian economy import commodities which are in turn exported while transport margins and storage fees are domestically charged. In these cases domestic production Qi consists of mostly transport margins and storage fees, and domestic production $\Sigma_j\{a_{ij} Qj\}$ is relatively small and exports EXi is close to import IMi. When inventory stock decreases domestic final demand FDi becomes negative and we may have

$\Sigma_j\{a_{ij} Qj\} + FDi < IMi$ ---> $Mi > 1$.

For this reason we define our imports coefficient as follows:

(B8b) $Mi = IMi / (\Sigma_j\{a_{ij} Qj\} + FDi + EXi)$ i=1,2,...,m

Under this definition Mi will always be less than 1.

Data on CO_2 Emissions

We use Japanese emission data provided in the Japanese Environmental I-O Table for 1990 (Yoshioka et al. (1996)) and the revised Japanese Environmental I-O Table for 1995 (Hayami et. al (2000)). These data consist of CO_2 emissions for intermediate production activity and final consumption activity for each sector j. Estimates of CO_2 emissions were obtained based on the amounts of carbon contained in the 50 energy commodities for 1990 (53 energy commodities for 1995) which were consumed in each of the 411 activities for 1990 (403 activities for 1995). Our Canadian emission data consists of emissions for 161 industrial sectors (corresponding to the rows in make matrix) and emissions for 136 final demand sectors. Emissions for 161 industrial sectors are allocated to commodity production sectors using the same type of equations as (B5)-(B7). In calculating CO_2 emissions per million U.S. dollars worth of production activity we use a diagonal conversion matrix U whose j-th diagonal element denotes monetary worth of energy per calorific value used in sector j and a row vector E whose j-th element denotes the amount of CO_2 emitted per calorific value of energy used in sector j as follows. CO_2 emissions per million U.S. dollars worth of consumption and production activities are, respectively, given by E2=EU and E1=EUA, where E1 and E2 are both diagonal matrices.

Aggregation issues

For estimating CO_2 emissions for Canada we allocated CO_2 emissions of about 160 sectors to about 500 commodities. In doing so we used the standard assumption (called the industry-technology assumption) that all products produced by an industry are produced with the same input structure (i.e. the same input coefficients). (E.g. Miller and Blair (1985, p.166).) This assumption is reasonable for some industries but not for some others. For example, the petroleum refinery industry produces four main products (commodities) on a single production line: gasoline, diesel oil, kerosene and heavy oil. These different products are produced only by differing the distilling temperatures of the system. For this industry it is reasonable that the above assumption holds and that the four oil refinery products get assigned the same amounts of CO_2 emission per dollar of production.

On the other hand, this assumption is less likely to hold in an industrial sector in which multiple products are produced, for example, using both product-specific production inputs and processes as well as some production inputs and processes that are common to all the products being produced in the same industry. For example, the precision equipment sector may produce multiple digital electronics products such as printers, photocopiers and cameras in the same factory. For such a sector the above assumption is less likely to hold and hence allocation of CO_2 emission based on the industry-technology assumption may not be reasonable.

This problem can be lessened to some extent by disaggregating industry sectors. For example, by having as many industry sectors as commodity sectors, the problem is somewhat lessened but it cannot be eliminated entirely. This is in part because firms almost always produce multiple products in the same establishments in an industrial sector. Allocation of the common indirect overhead costs and the associated CO_2 emissions incurred by these multiple products over the multiple products requires some subjective judgments and is not done in accordance to the industry-technology assumption.

One potentially confusing issue arises when we try to compare the quantities of the CO_2 emissions from two different products (e.g. apples and pears) produced in the same industry sector (e.g. fruit production). We note that, since I-O analysis is typically done using monetary units, it is generally not possible to distinguish the CO_2 emissions associated with production of one-ton of apples from the CO_2 emissions associated with the production of one-ton of pears. Also, the industry-technology assumption implies that, production of one hundred-dollar worth of apples and production of one hundred-dollar worth of pears each produces the same amounts of CO_2 emissions in the fruit production sector.

For example, at the aggregate industry sector level, a production process uses 100 units (say, 100 dollars worth) of industrial products, which generates 10 tons of CO_2 emissions in total. Suppose there are two industry sectors at the disaggregate sector level, the manufacturing products sector and the mining products sector. Suppose further that the above production process uses 50 units (50 dollars worth) of products from each of these two product sectors. So the total output of the production process measured in the aggregate industry level is 100 dollars and the amount of CO_2 emissions is 10 tons. In this case, can we say that, because of the industry-technology assumption which implies all products produced in the aggregate sector produces the same amounts of CO_2 emissions, the production process generates 5 tons of CO_2 emissions in each of the manufacturing products sector and the mining products sector at the disaggregate sector level? The answer is no, provided that we have CO_2 emissions estimates separately for the manufacturing products sector and the mining products sector at the disaggregated level. Under such a disaggregated situation the activity levels can be different for the two manufacturing sectors and hence the 50-dollar worth of output from each disaggregate sector need not have to generate the same amounts of CO_2 emissions. So CO_2 emissions from the two sectors might be 3.5 and 6.5 tons, 7.0 and 3.0 tons, etc. (They must sum to 10 tons).

Appendix C. Modeling CO_2 Emissions Induced by Trade between Canada and Japan

Japan's demand for Canadian products generates production activities in Canada which in turn produce CO_2. Similarly Canadian demand for Japanese products generates production activities, together with accompanying CO_2 emissions in Japan. If commodity, industrial, final demand, imports and export sectors were all identically defined for both Canada and Japan, it would be straight forward to calculate CO_2 emissions generated by one country's exports, or partner country's demand for such imports. Unfortunately commodity groups for the I-O matrix and trade statistics, for example, are not identical for different countries. We show below how we translate Japan's imports from Canada (Canada's imports from Japan) into Canada's exports to Japan (Japan's exports to Canada). These translation formulas would allow us, for example, to translate Japan's imports from Canada given in Japanese I-O classification into Canada's exports to Japan given in Canadian I-O classification and vice versa. Using these formulas it would be straightforward to calculate the impact, for example, of Canada's imports from Japan on the Japanese economy and CO_2 emissions in Japan.[44]

Conversion formula for translating Japan's imports into Canada's exports

The conversion consists of six steps using the following statistical databases including three different classification systems.[45] The statistical data bases used are (1) Canada's I-O table, (2) Canada's trade data, (3) Japan's I-O table and (4) Japan's trade data. The trade data are based on customs statistics. The three different classification systems are (1) Canada's I-O system with 479 sectors, (2) the Harmonized Commodity Descriptions and Coding System (HS) with 2420 commodities and (3) Japan's I-O system with 405 sectors.

We define the following quantities.

Xm^J:	Japan's imports in Japan's I-O table (405 x 1 vector)
Rm^J:	The ratio between Japan's imports from Canada and Japan's total imports from the world (405 x 405 diagonal matrix)
¡Error!:	Japan's imports from Canada in Japan's I-O table (405 x 1 vector)
${}_{tr}Xm^J{}_{io}$:	Converter matrix from Japan's I-O table to Japan's trade data (405 x 405 diagonal matrix)
¡Error!:	Japan's imports from Canada in Japan's trade data system (405 x 1 vector)
¡Error!:	Allocation matrix from Japan's trade system (405 commodities) into the 8-digit HS system (2420 x 405 matrix)
¡Error!:	Japan's imports from Canada in the 8digit HS system (2420 x 1 vector)
¡Error!:	Aggregation matrix from the 8digit HS system into Canada's 479 trade data system (479 x 2420 matrix)
¡Error!:	Data adjustments matrix from Japan's trade data to Canada's trade data in Canada's trade data system (479 commodities) (479 x 479 diagonal matrix)
¡Error!:	Canada's exports to Japan in Canada's trade data system (479 x 1 vector)
${}_{io}Xe^C{}_{tr}$:	Converter matrix from Canada's trade data system to Canada's I-O system (479 x 479 diagonal matrix)

[44] We follow the steps presented in Hayami and Nakamura (2004, 2007).
[45] Details are available from the authors.

¡Error!: Canada's exports to Japan in Canada's I-O system (479 x 1 vector)

Conversion formula for translating Canada's imports into Japan's exports

As before the conversion consists of six steps using four statistical data bases and three different classification systems.[46] Essentially the same procedure as before can be applied. The only difference to note here is that the Harmonized Commodity Descriptions and Coding System which we use here consists of 3578 (rather than 2420) commodities.

We define the following quantities.

Xm^{C}:	Canada's imports in Canada's I-O table (479 x 1 vector)
Rm^{C}:	The ratio between Canada's imports from Japan and Canada's total imports from the world (479 x 479 diagonal matrix)
¡Error!:	Canada's imports from Japan in Canada's I-O table (479 x 1 vector)
${}_{tr}Xm^{C}{}_{io}$:	Converter matrix from Canada's I-O table to Canada's trade data (479 x 479 diagonal matrix)
¡Error!:	Canada's imports from Japan in Canada's trade data system (479 x 1 vector)
¡Error!:	Converter matrix from Canada's trade system (479 commodities) into the 8digit HS system (3578 times 479 matrix)
¡Error!:	Canada's imports from Japan in the 8digit HS classification system (3578 x 1 vector)
¡Error!:	Converter matrix from the 8digit HS classification into Japan's 405 classification (405 x 3578 matrix)
¡Error!:	Data adjustments from Canada's trade data system to Japan's trade system (405 x 405 diagonal matrix)
¡Error!:	Japan's exports to Canada in Japan's trade system (405 x 1 vector)
${}_{io}Xe^{J}{}_{tr}$:	Converter matrix from Japan's trade data to Japan's I-O system (405 times 405 diagonal matrix)
¡Error!:	Japan's exports to Canada in Japan's I-O table (405 times 1 vector)

Conversion formulas: summary

It is shown that Japan's imports from Canada and Canada's exports to Japan are connected by the following formulas.[47]

(C1) **¡Error!= ¡Error! ¡Error! ¡Error! ¡Error! ¡Error! ¡Error!**

which can be rewritten as

(C2) **¡Error!=¡Error! ¡Error!**
=¡Error! ¡Error! ¡Error!.

where **¡Error!**is the conversion matrix defined by

(C3) **¡Error!=¡Error! ¡Error! ¡Error! ¡Error!· ¡Error!**.

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[46] Details are available from the authors.
[47] Details are available from the authors.

Similarly it is shown[48] that Canada's imports from Japan and Japan's exports to Canada are connected by

(C1a) **¡Error!= ¡Error! ¡Error! ¡Error! ¡Error! ¡Error! ¡Error!**.

which can be rewritten as

(C2a) **¡Error!=¡Error!¡Error!**
=¡Error!¡Error! ¡Error!.

¡Error! *is the conversion matrix defined by*

(C3a) **¡Error!= ¡Error! ¡Error! ¡Error! ¡Error! ¡Error!**

Our model of bilateral trade interactions

There are alternative ways to model trade interactions. As an example, consider meeting country A's final demand. The final demand itself will generate demands for imports from country B and the rest of the world (ROW). A's production activities to meet its final demand also generate demand for imports from A and the ROW. The demand for B's output from the export sector will induce intermediate production activities in country B, which in turn will generate demands for imports from A and the ROW. These interactions will continue indefinitely. (Alternatively we can consider the above process triggered by country A's exports to country B. A's exports to B in turn generates demands for imports from B and the ROW, and so on.)

Suppose the trade interactions begin with meeting A's final demand. We have the following sequence of events.

Step 1

A's final demand induces A's production in country A:

$$X^A = (I-(I-M^A)\, A^A\,)^{-1}\, Fd^A$$
$$=B^A\, Fd^A.$$

A's total imports from the world is derived by considering A's intermediate production and A's final demand

$$Xm^A = M^A\ \ (A^A\ \ B^A\, (I-M^A) Fd^A + Fd^A)$$
$$= M^A\ \ (I + A^A\ \ B^A\, (I-M^A))\ \ Fd^A\ .$$

A's imports from B is equal to B's exports to A

¡Error!= ¡Error! ¡Error! ¡Error!

B's exports induce B's production

[48] Details are available from the authors.

¡Error!= **¡Error!** ·**¡Error!**.

B generates CO_2 emissions in the production **¡Error!**.

Step 2

B's production activities induces A's production activities through trade

¡Error!=**¡Error!** **¡Error!** $A^B X^{B,A}$

¡Error!=**¡Error!** **¡Error!**

¡Error! =**¡Error!** **¡Error!**

Step 3

A's production induced by its exports to B, in turn, induces B's production in the second round of the trade interactions between A and B.

¡Error!=**¡Error!** **¡Error!** **¡Error!**

¡Error!=**¡Error!** **¡Error!** **¡Error!**

¡Error!= **¡Error!** **¡Error!**

B emits CO_2 from the production **¡Error!**.

Steps 2 and 3 can be summarized as follows:

(C4) **¡Error!**= **¡Error!** **¡Error!¡Error!** **¡Error!¡Error!** **¡Error!** **¡Error!¡Error!** **¡Error!** **¡Error!**

or

(C5) **¡Error!**=**¡Error!** **¡Error!**

where

(C6) **¡Error!**=**¡Error!** **¡Error!** **¡Error!**·**¡Error!¡Error!¡Error!¡Error!¡Error!** **¡Error!¡Error!**
.

If we iterate the above trade interaction process, we obtain the following for the n-th iteration:

(C7) **¡Error!**= **¡Error!** **¡Error!**.

If we add up (B12) over all iterations (n=0,1,2,3,...), the sum converges to:

(C8) **¡Error!** = **¡Error!** **¡Error!**.

¡Error!*is the total amount of production in country* B that is induced by country A's final demand.[49]

Appendix D. *Domestic and Foreign Price Increases due to Domestic Carbon Tax*

Domestic carbon tax

The prices in our I-O model satisfy the following price equation

(D1) $p^d = [I-A'(I-M)']^{-1} (A'M' p^m + v)$.

where p^d and p^m are domestic and imports price vectors, respectively. Suppose a domestic carbon tax of T_j dollars per unit output of the j-th sector is introduced. We let T a diagonal matrix with T_j as the j-th diagonal. Then the domestic price change induced by the carbon tax is given by

(D2) $\Delta p^d = p^d \text{ (after)} - p^d \text{ (before)}$

where p^d (after) and p^d (before) denote, respectively the prices before and after the introduction of the carbon tax. It is easy to see that p^d (before) is a vector of ones. Since the j-th component of v(after) - v(before) = T_j, it follows that

(D3) $\Delta p^d = [I-A'(I-M)']^{-1} T$

$= (T' [I-(I-M)A]^{-1})'$

$= (i \text{ diag}(T) B)'$,

where $B = [I-(I-M)A]^{-1}$ is a Leontief inverse and i is a vector of ones.

If the carbon tax rate θ is proportional to the CO2 emission, Tj = θ E1j for all j, then we have

(D4) $\Delta p^d = \theta (i \text{ E1 B })'$,

where E1j is defined in this paper to be the amount of CO_2 in kilo tons generated for every million U.S. dollars worth of sector j's output.

Numerical values for Δp^d are presented in Tables 1 and 2 for both Canada and Japan.

Foreign carbon tax

Suppose country *A* introduces a carbon tax which results in a domestic price change given by $\Delta p^d(A)$. Denoting by Zp{*A*,*B*} the price converter matrix which transforms prices in country *A* into prices in country *B*, the price changes for the goods imported by country *B* are given by a vector

(D5) $\Delta p^m(B) = Zp\{A,B\}\Delta p^d(A)$.

The change in domestic prices for country B is given by

[49] Our model presented here may be viewed as an extension of the two-country competitive international I-O table to the case where the two countries have different numbers of commodity sectors.

(D6) $\Delta p^d(B) = [I\text{-}A'(I\text{-}M)']^{-1}\ A'M'M_A\,\Delta p^m(B)$
$= (\Delta p^m(B)'\ M_A\ MAB)'$

where M_A is a diagonal matrix with the j-th diagonal representing the proportion of country *B*'s imports of sector j from country *A*. Table 17 presents our estimation results for the effects of the Canadian (Japanese) carbon tax on the Japanese (Canadian) domestic prices for the most highly affected goods.

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Table 1. Direct and indirect emissions for Canada, 2000

	CO2 emission coefficient (emissions per C$million worth of output, in kilo-tons))			**Total direct emissions (kilo-tons)**	**Total output (C$million)**
	direct emissions	indirect emissions	total emissions		
Cement	2.0398	0.8156	2.8554	2686.4	1317
Electric power	3.851	0.2034	4.0544	122040.48	31691
Pipeline transport.	1.8316	0.1834	2.015	10962.05	5985
Diesel and fuel oil	0.6101	1.0998	1.7099	8410.91	13787
Motor gasoline	0.6048	1.0888	1.6937	8660.09	14318
Lime	0.9137	0.5751	1.4888	191.88	210
Natural stone prod.	0.8908	0.5705	1.4613	284.16	319
Mineral wool build.	0.9137	0.5751	1.4888	136.14	149
Ready-mix concrete	2.0112	0.81	2.8211	4261.63	2119
Asphalt compound	0.599	1.0838	1.6828	927.85	1549
Lubricating oils	0.5614	1.0514	1.6128	673.65	1200
Iron ores and con.	0.3521	0.3941	0.7462	570.11	1619
Flat iron and steel	0.5724	0.7114	1.2838	4467.93	7806
Crude mineral oils	1.0117	0.1868	1.1985	31925.46	31556
Natural gas	1.0119	0.1864	1.1983	28163.46	27833
Air transport					
Liquid petroleum gas	0.9468	0.3318	1.2785	6045.24	6385
Petrochemical feed	0.6104	1.102	1.7123	1344.65	2203
Chlorine	0.6884	0.981	1.6694	68.84	100
Oxygen	0.6884	0.981	1.6694	97.75	142

Table 2. Direct and indirect emissions for Japan, 2000

	CO2 emission coefficient (emissions per million Japanese yen worth of output, in tons))			**Total direct emissions (tons)**	**Total output (million Japanese yen)**
	direct emissions	indirect emissions	total emissions		
Cement	104.2946	11.0248	115.3195	52271121.5	501187
Self-Power gener.	57.8359	6.3631	64.199	69536163.7	1202301
Coal products	0.4647	6.317	6.7818	16964.78	36504
Pig iron	79.7826	15.4075	95.1901	100223764	1256211
Ammonia					
Crude steel	4.3698	55.8511	60.2208	9321057.52	2133081
Salt	15.6923	4.908	20.6003	846300.14	53931
Ferro alloy	11.0249	11.9294	22.9543	1243090.63	112753
Ready-mix concrete	0.3406	22.42	22.7606	622719.52	1828559
Electric power					
Hot rolled steel	1.5568	33.3204	34.8773	7065565.68	4538447
Industrial soda chem.	5.8165	17.2202	23.0367	3219123.9	553444
Other sanitary serv.					
Cast and forged mat.	0.8108	6.3345	7.1453	399344.25	492537
Miscellaneous ceramics	2.454	3.6695	6.1235	2062537.83	840472
Crude steel (elec. furnace)	1.0477	18.5965	19.6442	1060330.07	1012055
Pulp	7.543	8.1904	15.7334	5177756.9	686430
Air transport	8.2309	1.309	9.5399	21697510.2	2636102
Foreign and Japanese paper	7.8071	10.4744	18.2815	18326322.2	2347386
Paperboard	0.1978	9.6778	9.8755	127134.03	642820

Table 3. Business sectors with large amounts of CO_2 emissions: Canada and Japan, 1990 - 2000[a]

Canada	**1990**	**1995**	**2000**		**Japan**	**1990**	**1995**	**2000**
Cement	11.53	13.76	4.24		Cement	12.29	10.16	12.43
Electric power	5.44	4.88	6.02		Self-Power gener.	12.24	9.27	6.92
Pipeline transport.	2.71	3.74	2.99		Coal products	5.42	7.51	7.45
Diesel and fuel oil	2.79	3.31	2.54		Pig iron	6.10	6.23	10.26
Motor gasoline	2.79	3.29	2.51		Ammonia	2.30	3.57	---
Lime	2.50	3.14	2.21		Crude steel	4.04	3.39	6.49
Natural stone prod.	2.50	3.14	2.17		Salt	4.15	2.25	2.22
Mineral wool build.	2.50	3.14	2.21		Ferro alloy	4.10	2.23	2.47
Ready-mix concrete	3.80	2.94	4.19		Ready-mix concrete	3.14	2.20	2.45
Asphalt compound	2.74	2.86	2.50		Electric power	3.47	2.19	6.02
Lubricating oils	2.78	2.58	2.39		Hot rolled steel	2.83	2.08	3.76
Iron ores and con.	2.95	2.54	1.11		Industrial soda chem.	2.90	1.94	2.48
Flat iron and steel	3.29	2.45	1.91		Other sanitary serv.	3.06	1.85	---
Crude mineral oils	2.21	2.38	1.78		Cast and forged mat.	2.06	1.81	1.51
Natural gas	2.21	2.38	1.78		Miscellaneous ceramics	3.37	1.75	3.35
Air transport	2.09	2.31	2.21		Crude steel (elec. furnace)	2.87	1.65	2.12
Liquid petroleum gas	2.20	2.31	1.90		Pulp	1.31	1.56	1.70
Petrochemical feed	2.79	2.25	2.54		Air transport	1.30	1.41	1.03
Chlorine	2.34	2.24	2.48		Foreign and Japanese paper	2.19	1.40	1.97
Oxygen	2.34	2.24	2.48		Paperboard	1.66	1.35	1.74

[a] Numbers are estimated amounts of emissions of CO_2 in kilo tons generated per million U.S. dollars worth of production. The exchange rates used are: 144.79, 99.68 and 107.82 yen per U.S. dollar for 1990, 1995 and 2000, respectively; and 1.1668, 1.32724 and 1.48520 Canadian dollars per U.S. dollar for 1990, 1995 and 2000, respectively.

Table 4. Firms' CO_2 emissions (in kilo tons) per unit volume of output, 1990-2000[a]

Canada	1990	1995	2000	Japan	1990	1995	2000
Coal (1000 t)	0.03	0.04		Coal (1000 t)	0.10	0.10	
Natural gas (million m^3)	0.10	0.18		Natural gas (million m^3)	0.10	0.18	
Gasoline (1000 kl)	0.55	0.64		Gasoline (1000 kl)	0.29	0.34	
Wheat unmilled (1000 t)	0.12	0.14		Wheat and barley (1000 t)	0.29	0.34	
Eggs in the shell (1000 t)	1.62	0.93		Hen eggs (1000 t)	0.45	0.35	
Hogs (1000 head)	0.21	0.13		Hogs (1000 head)	0.09	0.71	
Cattle and calves (1000 head)	0.36	0.22		Beef cattle (1000 head)	----	1.93	
Logs, poles, pilings (1000 m^3)	0.03	0.02		Logs (1000 m^3)	0.03	0.04	
Fish and seafood (1000 t)	0.14	0.14		Coast. & dist. fishing (1000t)	1.70	2.15	
Salt (1000 t)	0.02	0.02		Salt (1000 t)	0.71	0.90	
Beer, incl. coolers (100 kl)	0.04	0.07		Beer (100 kl)	0.05	0.06	
Pulp (1000 t)	0.44	0.41		Pulp (1000 t)	0.75	1.18	
Newsprint paper (1000 t)	0.82	0.77		Newsprint paper (1000t)	1.99	1.92	
Cement (1000 t)	1.32	0.95		Cement (1000 t)	0.76	0.84	
crude steel (1000 t)	----	0.86		Crude steel (1000t)	1.14	1.26	
crude steel (elec. furn., 1000t)	----	----		crude steel (elec.furn., 1000t)	1.13	0.71	
Aluminum (primary forms,1000t)	2.00	1.73		Aluminum (regenerated,1000 t)	1.32	2.54	
Electric power generation (gwh)	0.20	0.16		Electric power generation (gwh)	0.42	0.38	

[a] Numbers for CO_2 / volume are estimated amounts in kilo tons of emission per unit volume of production.

Table 5. Japanese firms' use of recycled paper pulp: simulation results (million tons)

New vs. recycled pulp ratio	52:48 (bench mark)	42:58	33:67	24:76	28:72	28:72	28:72	28:72
Unit transport energy parameter for recycling (Mcal cal per ton)	121	242	242	242	242	725	966	1449
1. CO_2 emission due to fossil fuels	991	992	994	996	995	997	998	1001
2. CO_2 emission due to pulp black liquor and discards	14	13	9	7	8	8	8	8
3.[a] Total emission	1005	1005	1003	1003	1003	1005	1006	1009
Recycled newsprint replaces new pulp as a raw material								
Newsprint shadow price[b]	1.00	---	---	---	0.98	1.00	1.02	1.05
Recycled high quality paper with whiter than newsprint color replaces new pulp as a raw material								
High quality paper shadow price[b]	1.00	---	---	---	1.08	1.105	1.12	1.145

[a] These figures are the sums of the figures in rows 1 and 2.
[b] The paper price for the benchmark case is set equal to one.

Table 6. Canadian firms' CO_2 emissions generated by their exports to Japan, 1990-2000[a]

Sector	1990			1995			2000		
	Exports (US$million)	Induced Output (US$million)	CO_2 (kilo tons)	Exports (US$million)	Induced Output (US$million)	CO_2 (kilo tons)	Exports (US$million)	Induced Output (US$million)	CO_2 (kilo tons)
Coal	693.163	697.728	599.020	583.480	597.358	396.735			
Pulp	531.567	577.067	495.392	1164.529	1259.311	633.151			
Canola and other oil seeds	444.349	461.466	256.132	629.445	650.989	362.140			
Cement	0.000	1.411	15.350	0.000	6.676	65.226			
Other metal ores and concentrates	805.170	899.378	204.87	562.674	669.429	134.980			
Aluminum in primary forms	255.885	263.226	161.37	358.223	374.882	147.947			
Flat iron&steel, incl. galv. Tinplate	0.027	17.363	38.865	1.340	85.698	136.289			
Electric power	0.000	193.575	994.221	0.000	281.243	1144.535			
Iron and steel ingots, billets, etc.	4.116	7.667	17.251	0.000	11.636	4.012			
Iron ores and concentrates	25.959	28.238	59.259	15.027	24.553	40.129			
Natural stone building products	1.033	1.1124	2.043	0.955	2.534	5.496			
Fertilizers, excl. nitrogenous	43.348	72.995	88.072	54.870	110.290	87.743			
Lumber and treated wood	750.408	787.112	90.258	2113.437	2190.640	264.114			
Methyl alcohol	43.685	44.098	55.810	69.685	73.523	22.131			
Asbestos, crude and milled	27.950	27.976	27.823	30.115	30.388	25.326			
Flat iron and steel, alloy	0.476	3.218	7.179	1.340	85.698	136.289			
Antifreezing preparations	0.004	1.070	1.630	0.000	0.888	0.268			
Crude mineral oils	11.786	97.562	191.215	0.000	100.338	184.013			
Gypsum	0.000	0.0000	0.000	0.000	0.734	0.612			
Lime	0.000	5.018	9.123	0.000	2.591	5.620			
Total	5599.331	10560.259	5439.621	8483.731	17535.239	6960.079			

[a]Figures reported in this Table are based on the authors' calculations. (See the text for details.)

CO_2 emissions reported here arise from the production for each commodity sector resulting from Canadian exports to Japan.

Table 7. Japanese firms' CO_2 emissions generated by their exports to Canada, 1990-2000[a]

Sector	1990			1995			2000		
	Exports (US$million)	Induced Output (US$million)	CO_2 (kilo tons)	Exports (US$million)	Induced Output (US$million)	CO_2 (kilo tons)	Exports (US$million)	Induced Output (US$million)	CO_2 (kilo tons)
Salt	0.001	0.539	1.642	0.000	0.367	0.673			
Cement	0.742	1.278	14.479	0.013	0.485	4.576			
Pig iron	0.015	80.434	314.655	0.032	48.240	204.165			
Self power generation	0.000	15.100	176.549	0.000	15.371	123.540			
Industrial soda chemicals	1.856	17.200	19.161	0.685	11.200	6.364			
Miscellaneous ceramics	2.512	18.016	51.043	2.222	13.686	19.213			
Coal products	0.000	54.973	254.188	0.000	26.442	172.798			
Ocean transport	0.000	0.050	0.068	0.000	0.041	0.043			
Oil and fat industrial chemicals	0.000	2.926	0.927	0.005	1.857	0.187			
Ferro-alloys	0.000	8.582	23.200	0.000	5.632	5.797			
Self-freight transport by private	0.000	20.530	29.297	0.000	27.428	23.434			
Petroleum refinery production	0.305	99.170	39.215	0.296	69.743	16.503			
Coastal and inland water transport	0.000	18.074	29.063	0.000	15.150	12.181			
Other structural clay products	0.013	0.287	0.183	0.007	0.326	0.128			
Other sanitary service (public)	0.000	0.596	1.721	0.000	0.688	1.169			
Electric power	0.000	211.760	700.745	0.000	195.465	359.651			
Zinc incl. regenerated zinc	0.000	9.603	9.816	0.000	7.018	3.984			
Western and Japanese paper	4.880	43.476	52.459	2.070	31.589	20.557			
Tires and inner tubes	109.460	154.448	22.089	2.127	7.164	0.530			
Passenger cars	2227.676	2222.676	21.215	814.677	814.677	3.315			
Total	6398.270	16564.405	2832.382	6130.153	14153.685	1562.451			

[a]Figures reported in this Table are based on the authors' calculations. (See the text for details.)
CO_2 emissions reported here arise from the production for each commodity sector resulting from Japanese exports to Canada.

Table 8. Japanese firms' sector-by-sector output and CO_2 emissions from all stages of production resulting from Canadian imports of U.S.$1,000 worth of Japanese automobiles, 1990-2000

Sector output (U.S.$1,000)				**Sector CO_2 emissions (kg)**			
	1990	**1995**	**2000**		**1990**	**1995**	**2000**
Passenger cars	1.00000	1.00000		Electric power	106.17770	63.60278	
Motor vehicle parts and access	0.53466	0.61076		Ocean transport	83.93054	57.16338	
Internal combustion engine for	0.22152	0.24520		Pig iron	31.65077	23.20254	
Wholesale trade	0.11748	0.10184		Coal products	29.35207	24.11604	
Electrical equipment for inter	0.08209	0.08424		Self-Power generation	19.63334	15.94432	
Research and development	0.06740	0.07630		Cast and forged materials	15.14578	17.27735	
Motor vehicle bodies	0.06725	0.07676		Motor vehicle parts and access	11.57419	7.52644	
Ocean transport	0.06257	0.05481		Road freight transport	10.28545	7.78989	
Plastic products	0.06100	0.06289		Passenger cars	9.52356	4.06859	
Financial service	0.04054	0.04788		Petroleum refinery products	7.01917	3.18253	
Electric power	0.03209	0.03457		Self-Passenger transport	6.47464	4.50340	
Hot rolled steel	0.02638	0.02140		Sheet glass and safety glass	5.64517	4.01217	
Goods renting and leasing	0.02409	0.02481		Coastal and inland water trans	5.58544	2.90249	
Other business services	0.02405	0.02302		Hot rolled steel	5.48003	2.63502	
Machine repairing	0.02356	0.01937		Crude steel (converters)	5.31962	3.24736	
Other rubber products	0.02321	0.02378		Miscellaneous ceramic, stone etc	5.24723	2.49456	
Cast and forged	0.02088	0.02117		Foreign paper and Japanese	5.01293	2.23811	

materials				paper			
Road freight transport	0.02062	0.01937		Internal combustion engine	4.91431	3.74894	
Cold-finished steel	0.02016	0.01795		Research and development	4.52891	2.23419	
Petroleum refinery products	0.01775	0.01345		Thermoplastics resin	4.50226	2.11478	
Real estate rent	0.01763	0.01482		Petrochemical basic products	4.31515	0.96413	
Transport service in harbor	0.01614	0.01477		Cold-finished steel	4.30387	2.17044	
Non-ferrous metal castings	0.01608	0.01681		Self-freight transport by priv	4.22287	2.50564	
Sheet glass and safety glass	0.01507	0.01592		Synthetic rubber	2.99657	1.66303	
Printings, engraving and book ndings	0.01469	0.01287		Crude steel (electric furnaces)	2.90390	-----	
Tires and inner tubes	0.01448	-----		Air transport	2.49041	2.00997	
Advertising agencies	0.01408	0.01601		Activities not elsewhere class	2.37526		
Electric audio equipment	0.01384	0.01345		Other sanitary services	2.35077	1.87519	
Information service	0.01325	-----		Ferro alloy	2.31446	-----	
Batteries	0.01251	-----		Aliphatic intermediates	2.26295	1.94590	
Others	0.44208	0.38847		Others	50.44436	25.55578	
Total	3.07715	3.11432		Total	457.98368	296.69086	

Notes: Figures reported in this Table are based on the authors' calculations. (See the text for details.)

Table 9. Canadian firms' sector-by-sector output and CO_2 emissions from all stages of production resulting from Japanese imports of U.S.$1,000 worth of Canadian pulp, 1990-2000

Sector output (U.S.$1,000)				**Sector CO_2 emissions (kg)**			
	1990	**1995**	**2000**		**1990**	**1995**	**2000**
Pulp	1.07209	1.05823		Pulp	920.36371	532.05383	
Wood chips	0.09446	0.10854		Electric power	388.16776	287.09669	
Pulpwood	0.08865	0.05312		Truck transportation	31.58195	49.30222	
Spare artsandmaint.suppl.machandequip	0.08840	0.10294		Water transportation	30.09386	14.51580	
Electric power	0.07558	0.07055		Crude mineral oils	29.33568	14.86494	
Wholesaling margins	0.05563	0.06461		Pulpwood	29.18842	17.76706	
Transportation margins	0.05070	0.05869		Diesel and fuel oil, aviation fuel	26.89690	20.39584	
Truck transportation	0.04606	0.04486		Natural gas	21.03574	4.66758	
Logs, poles, pilings, bolts, etc	0.03762	0.03723		Railway transportation	17.04658	16.11019	
Custom forestry	0.03709	0.02195		Pipeline transportation	15.66706	20.06214	
Repair service for mach and equip	0.02216	0.01524		Caustic soda	13.52631	-----	
Water transportation	0.02177	0.01285		Logs, poles, pilings, bolts, etc	12.94343	12.88909	
Diesel and fuel oil, aviation fuel	0.02069	0.01231		Custom forestry	12.25323	7.48064	
Govt. royalties on nat. resources	0.01785			Wholesaling margins	11.71371	12.39139	
Other finance and real estate serv	0.01780	0.02348		Wood chips	11.69195	16.81328	
Repair construction	0.01763	0.01248		Sodium chlorate	11.07504	1.84928	
Crude mineral oils	0.01497	-----		Water, waste disp. and other utilities	10.03095	-----	
Railway transportation	0.01357	-----		Serv incidental to water	6.90354	-----	

				transport			
Other rent	0.01193	0.01077		Chlorine	5.86235	-----	
Professional service to business management	0.01108	-----		Other industrial chemical prep.	5.76928	-----	
Natural gas	0.01074	-----		Air transportation	4.91669	4.95776	
Caustic soda	0.01069	-----		Other inorganic chemicals	4.85746	-----	
Travelling and entertainment	0.01035	0.01095		Other liquid petroleum gases	4.14150	-----	
Advertising and promotion	0.01034	0.00943		Repair service for mach and equip	3.98385	2.19088	
Felt	0.00911	-----		Travelling and entertainment	3.86320	-----	
Sodium chlorate	0.00875	0.00811		Gasoline	3.77340	2.25890	
Rental, oth mach and equip incl onst.	0.00875	0.00671		Petrochemical feed stock	3.49398	-----	
Telephone and other telecommunications	0.00794	0.00769		Rental, oth mach and equip ncl const.	3.45924	-----	
Other services to business and rsons	0.00765	0.00943		Other metallic salts and roxysalts	3.16642	-----	
Retailing margins	0.00753	0.00728		Ethylene	3.05921	-----	
Others	0.22919	0.16803		Others	71.13803	36.00855	
Total	2.13677	2.00075		Total	1721.00043	1103.62576	

Notes: Figures reported in this Table are based on the authors' calculations. (See the text for details.)

Table 10. Estimated price increases arising from a carbon tax of one U.S. dollar per ton of CO_2 emitted

	Japan			Canada		
	1990	1995	2000	1990	1995	2000
cement	1.229%	1.016%	1.243%	1.153%	1.376%	0.424%
(self)electric power (J)	1.225	0.927	0.692			
electric power	0.347	0.219	0.248	0.544	0.488	0.602
pig iron (J)	0.610	0.623	1.026			
crude steel (J) (converters)	0.404	0.339	0.649			
(electric furn.)	0.287	0.165	0.212			
hot rolled steel (J)	0.283	0.208	0.376			
flat iron and steel (C)				0.329	0.245	0.191
coal products (J)	0.542	0.751	0.745			
coke (C)				0.303	---	0.202

Table 11. Carbon tax and price increases in Canada and Japan[a]

Price Increases in Canada induced by Japan's Carbon Tax ($1US tax per ton of CO_2 generated)		**Price Increases in Japan induced by Canada's Carbon Tax ($1US tax per ton of CO_2 generated)**	
Oil and gas line pipe	0.000027032	Other edible crops	0.000100682
Oil and gas casing and drill pipe	0.000025761	Vegetable oil and meal	0.000100537
Other iron and steel pipes and tubes	0.000025055	Coal products	0.000066015
Iron and steel wire and cable	0.000015048	Copper	0.000062660
Chain, excl motor vehicle and power trans.	0.000015048	Other non-ferrous metals	0.000046911
Welding rods and wire electrodes	0.000015048	western paper and Japanese paper	0.000044035
Railway and telecommunications const.	0.000014651	Zinc (inc. regenerated zinc)	0.000043965
Iron and steel wire fencing and screen	0.000013574	Lead (inc. regenerated lead)	0.000042876
Automobiles, incl vans	0.000011504	Coal-tar products	0.000032106
Trucks, tractors and chassis	0.000011504	Pig iron	0.000030651
Buses and chassis	0.000011408	Paperboard	0.000028384
Hardware	0.000010241	Aluminum (inc. regenerated alum.)	0.000027964
Iron and steel forgings	0.000009915	Rolled aluminum products	0.000026602
Spare parts and maint. suppl. mach and equip	0.000009881	Ferro alloy	0.000024513
Valves	0.000009793	Nuclear fuels	0.000023542
Kitchen utensils and wire products	0.000009496	Flour and other grain milled prod.	0.000023323
Gas and oil facility construction	0.000008628	Organic fertilizers	0.000022546
Commercial cooking equipment	0.000008587	Non-ferrous metal castings	0.000019905
Bulldozers, farm and garden tractors	0.000008587	Rolled and drawn copper	0.000019149
Pumps, compressors and blowers	0.000008587	Rayon ,acetate	0.000018497
Industrial furnaces, kilns and ovens	0.000008587	Corrugated cardboard	0.000018006
Pkg., air pur. and other gen. purp.	0.000008490	Crude steel(converters)	0.000017921

Mach			
Bearings&power trans. eq.	0.000008445	Animal oil and fat	0.000017667
Ind. trucks and mat. handling equip	0.000008392	Other non-ferrous metal prod.	0.000015747
Corrugated metal culvert pipe	0.000008268	Feeds	0.000015510
Iron and steel stampings	0.000008241	Oil and fat industrial chemicals	0.000013436
Metal containers and closures	0.000008192	Crude steel (electric furnaces)	0.000012415
Household equip. excl range.microw.refrig.	0.000008151	Coated paper and paper convert	0.000012277
Conveyors, elevators and hoist. Mach	0.000008093	Electric wires and cables	0.000012095
Fire fight. and traffic contr. Equip	0.000008062	Sulfuric acid	0.000012055
Radio, TV, stereo, VCR and unrec. Tape	0.000007996	Hot rolled steel	0.000011433
Other metal end products	0.000007975	Other pulp, paper and converted	0.000011066
Industry specific machinery	0.000007380	Cement	0.000010924
Iron and steel pipe fittings	0.000007352	Newspapers	0.000010256
Other agricult. machinery	0.000007196	Pulp	0.000010248

Notes: figures reported in this Table are based on the authors' calculations using 1990 estimates given in Table 3. Estimates for 1995 and 2000 (TO BE DONE) are similarly obtained. (See the text for details.)

Figure 1. Unit CO_2 emissions by economic sector output, Canada

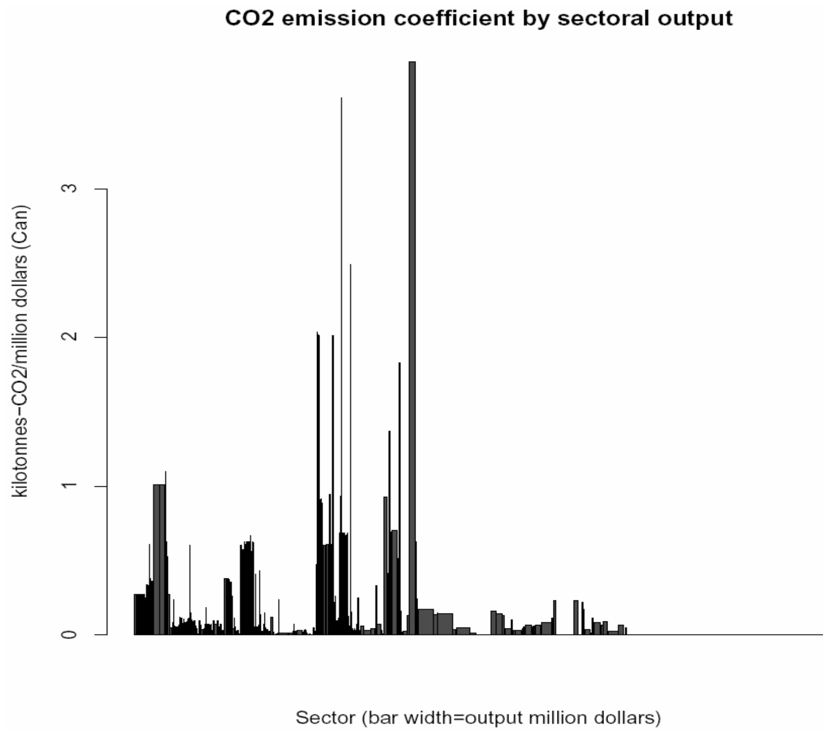

Figure 2. Unit CO_2 emissions by economic sector output, Japan