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Evaluating CO_2 Emissions Associated With International Outsourcing in Manufacturing Supply Chains

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Abstract

International outsourcing is a growing phenomenon in manufacturing industries due to the limited resources and the economic benefits of this phenomenon. Although international outsourcing seems to be a cost efficient way of production, the concerns about its CO_2 emissions are rising dramatically. In this research, the impacts of international outsourcing on the CO_2 emissions of all industries have been quantified. Input output analysis and linear programming have been implemented by programming in the Matlab as the research methodology. Australian manufacturing industry (outsourcer) and Chinese manufacturing industry (outsourcee) and their main suppliers that emit high CO_2 levels were selected as a case study. The results of this study depict that international outsourcing of Australian manufacturing industry will reduce not only the CO_2 emissions of that industry but also the CO_2 emissions of the other domestic industries in Australia. In contrast, this international outsourcing will increase the CO_2 emissions of both China and the other countries' industries. This will lead to the growth of global CO_2 emissions. In the worst case scenario, if the Australian manufacturing industry shuts down all its production, China and other countries CO_2 emissions will increase 4.88% and 0.05% respectively. On this occasion, global CO_2 emissions will increase by 0.82%. This paper presents a decision support system that will be useful for policy makers to evaluate the effect of different international outsourcing scenarios on CO_2 emissions before making any real outsourcing decisions.

Keywords: international outsourcing, environmental sustainability, CO_2 emissions, supply chain management, input output analysis, decision support system

1. Introduction

The consumption of imported resources and products is expanding among societies specifically in OECD and EU countries (Falk & Wolfmayr, 2008; Kissinger & Rees, 2010; Bhatti et al., 2011). This is due to the international outsourcing phenomenon that represents the departure abroad of the products or services of a firm or industry that previously produced within the country (Jones, 2005). It was reported that the growth of international outsourcing would be more than 20% annually (Jacques, 2006). Although this growth of international outsourcing has been claimed to have positive impacts such as increasing the GDP and job opportunities in exporting countries, the incremental emitted CO_2 in the outsourcee industries and their supply chains is a major challenge for having a sustainable environment. Environmental sustainability is defined as stakeholder behaviour impacting on the natural environment that meets the needs of the present without compromising the ability of future stakeholders to meet their own needs (Elliot, 2011). For achieving such sustainable environment, a number of scholars focused on the current CO_2 emissions embodied in exporting and importing at the firm and industry levels (Wiedmann, 2009; Li & Hewitt, 2008; Shui & Harriss, 2006; Kara et al., 2010; Muñoz & Steininger, 2010; Chen et al., 2011; Su & Ang, 2010; Moosavi Rad et al., 2013).

The CO_2 emissions embodied in UK's imports and exports were studied by Herrmann and Hauschild (2009). They investigated the carbon footprint of products when production is changed from UK or Denmark to China. They used environmental Input Output Analysis (IOA) for evaluating carbon footprint in the bilateral trade among these countries. They found that carbon footprint will enhance considerably because of the differences between the production technologies of European and Chinese manufacturing (Herrmann & Hauschild, 2009). Li and Hewitt (2008) focused on the emissions embodied in the trade between UK and China in 2004 using extended environmental single-regional IOA. They found that the direct CO_2 emissions of UK consumers can be reduced about 11%, compared to the situation where the same quantity and type of goods are manufactured in the UK instead of being imported from China (Li & Hewitt, 2008). However, the carbon footprint of UK consumers increased about 19% because of the carbon inefficiencies of Chinese technologies relative to those of the UK. Wiedmann et al. (2010) also developed a time series model of national carbon footprints for the UK between 1992 and 2004 by consider UK trade with three world regions including OECD Europe, OECD non-Europe and non-OECD countries. Lenzen et al. (2010) undertook a comprehensive uncertainty analysis for the CO_2 emissions embodied in UK exports (EEE) and those for imports (EEI). They conclude that EEE were lower than EEI in all years between 1992 and 2004. Furthermore, Lenzen et al. (2010) found that the carbon footprint of the UK has been increasing during the mentioned years.

In China, Andersen et al. (2010) investigated the transports' role in creating CO_2 emissions associated with the exports in 2008. They considered sea and air transport data and the CO_2 emissions factors for ships and air transports for their calculations. Results show that the total China's CO_2 emissions associated with import and import transports go beyond 300 Mega tons (Mt) CO_2, with net export of emissions, i.e. the CO_2 emissions embodied in exported goods by China minus the imported goods by China equals to 110 Mt CO_2. Shui and Harriss (2006) investigated the effect of China-United States (US) trade on CO_2 emission form the national and global perspectives using extended environmental single-regional IOA. They found that, in 1997, US avoided 150 Million Metric Tons CO_2 ($MMTCO_2$) that increased to 357 $MMTCO_2$ in 2003 as a result of importing Chinese products (Shui & Harriss, 2006). In another study, Su and Ang (2010) demonstrated energy-related CO_2 emissions embodied in international trade at the different levels of spatial aggregation. Su and Ang (2010) presented a numerical example using the data of China and divided China into eight regions. They used Monte-Carlo simulation for grouping eight regions sequentially and randomly. They concluded that the results are highly dependent on the spatial aggregation and it is meaningful to look into the effect of spatial aggregation for large countries (Su & Ang, 2010).

In the case of the US, Chen, Z. M. and Chen, G. Q. (2011) presented energy consumption of thirty-four countries by tracking both direct and indirect energy usage. Environmental IOA has been applied as a research methodology in their research. They found that the US is the biggest embodied energy importer (683 Megaton oil equivalent (Mtoe)) and surplus receiver (290 Mtoe), in contrast to China as the biggest exporter (534 Mtoe when only the mainland is included, 662 Mtoe when Hong Kong and Taiwan are also included) and deficit receiver (271 Mtoe when only the mainland is included, 274 Mtoe when Hong Kong and Taiwan are also included) (Chen, Z. M., & Chen, G. Q., 2011). For reducing the CO_2 emissions embodied in the US' trade, Weber and Peters (2009) argued that the US carbon tariffs on trade probably did not need to protect industrial competitiveness in the traditional sense. Carbon tariffs could cover only a small proportion of total embodied emissions in trade, and they may be counterproductive at a moment when global cooperation is needed.

As it was discussed, most of these studies focused on the explanation of current CO_2 emissions embedded in exporting and importing. However, there is lack of research to quantify the direct and indirect environmental effects of different international outsourcing ratios at the industry level. The direct CO_2 emissions impacts are related to variation of the outsourcer's CO_2 emissions while the indirect CO_2 emissions impacts are associated with the emitted CO_2 of supporting industries. These quantifications would help decision makers to measure the magnitude impacts of their international outsourcing decisions. In addition, finding these negative impacts would assist decision makers to implement supporting policies for controlling the negative impacts of international outsourcing decisions. Hätönen and Eriksson (2009), Harland et al. (2005) and Moosavirad et al. (2013) also presented this lack of research as a new stream for international outsourcing research. Therefore, the aim of this paper is to quantify the CO_2 emissions of international outsourcing at the industry level.

2. Methodology

Environmental IOA (EIOA) is used widely as a methodology for calculating the global CO_2 emissions by using the equation $\sum_{i=1}^{n}(CO_{2_i} \times X_i)$ where $CO_2 emissions_i = CO_{2_i} \times X_i$ presents the CO_2 emissions of industry i and $X = (I - A)^{-1}Y$. The parameters of these equations are defined in Table 1. However, when international outsourcing occurs, the intermediate demands and final demands of outsourcer and outsourcee industries and their suppliers might change. Consequently, these changes alter the A and Y in EIOA equation. Therefore, the new A and Y need to be specified for calculating the new global CO_2 emissions. In this section, a new research approach is proposed for this objective as follows.

The research methodology for addressing the presented research objective is based on IOA and Linear

Programming (LP). IOA was selected as a main research method in this research in order to deal with the complexity of interactions among and within industries (Ferng, 2009). In this research, at the first step, it is essential to generate a baseline input-output table with the associated CO_2 emissions and CO_2 emissions coefficients based on the case study (baseline scenario). Input-output table demonstrates flows of money or products among sectors (Leontief, 1986). In step 2, first, a new international outsourcing ratio (b) should be introduced for the outsourcer industry (International outsourcing scenario). Then, a set of constraints based on the baseline input-output table, IOA and the international outsourcing assumptions is developed (see Table 1). Table 1 presents these constraints as follow.

Table 1. Model's constraints and objective

Constraints

$$\mathbf{X}_{\mathbf{1}_{\mathbf{new}}} = (\mathbf{1}-\mathbf{b})\mathbf{X}_{\mathbf{1}} \quad (1)$$

$$\begin{bmatrix} \mathbf{x}_{\mathbf{11}_{\mathbf{new}}} \\ \mathbf{x}_{\mathbf{21}_{\mathbf{new}}} \\ \mathbf{x}_{\mathbf{31}_{\mathbf{new}}} \\ \vdots \\ \mathbf{x}_{\mathbf{n1}_{\mathbf{new}}} \end{bmatrix} = (\mathbf{1}-\mathbf{b}) \begin{bmatrix} \mathbf{x}_{\mathbf{11}} \\ \mathbf{x}_{\mathbf{21}} \\ \mathbf{x}_{\mathbf{31}} \\ \vdots \\ \mathbf{x}_{\mathbf{n1}} \end{bmatrix} \quad (2)$$

$$\begin{bmatrix} \mathbf{Y}_{\mathbf{1}_{\mathbf{new}}} \\ \mathbf{Y}_{\mathbf{2}_{\mathbf{new}}} \\ \mathbf{Y}_{\mathbf{3}_{\mathbf{new}}} \\ \vdots \\ \mathbf{Y}_{\mathbf{n}_{\mathbf{new}}} \end{bmatrix} = \begin{bmatrix} \mathbf{Y}_{\mathbf{1}_{\mathbf{new}}} \\ \mathbf{Y}_{\mathbf{2}} \\ \mathbf{Y}_{\mathbf{3}} \\ \vdots \\ \mathbf{Y}_{\mathbf{n}_{\mathbf{new}}} \end{bmatrix} \quad (3)$$

$$\mathbf{a}_{\mathbf{ij}} = \frac{\mathbf{x}_{\mathbf{ij}}}{\mathbf{X}_{\mathbf{j}}} \quad (4)$$

$$\boldsymbol{a}_{\boldsymbol{ij}_{\boldsymbol{new}}} = \boldsymbol{a}_{\boldsymbol{ij}} \ \boldsymbol{if}\ \boldsymbol{i} \neq \mathbf{1}, \boldsymbol{n} \quad \boldsymbol{otherwise}\ \boldsymbol{a}_{\boldsymbol{ij}_{\boldsymbol{new}}} = \frac{\boldsymbol{x}_{\boldsymbol{ij}_{\boldsymbol{new}}}}{\boldsymbol{X}_{\boldsymbol{j}_{\boldsymbol{new}}}} \quad (5)$$

$$\begin{bmatrix} \mathbf{a}_{\mathbf{12}_{\mathbf{new}}} + \mathbf{a}_{\mathbf{n2}_{\mathbf{new}}} \\ \mathbf{a}_{\mathbf{13}_{\mathbf{new}}} + \mathbf{a}_{\mathbf{n3}_{\mathbf{new}}} \\ \vdots \\ \mathbf{a}_{\mathbf{1n}_{\mathbf{new}}} + \mathbf{a}_{\mathbf{nn}_{\mathbf{new}}} \end{bmatrix} = \begin{bmatrix} \mathbf{a}_{\mathbf{12}} + \mathbf{a}_{\mathbf{n2}} \\ \mathbf{a}_{\mathbf{13}} + \mathbf{a}_{\mathbf{n3}} \\ \vdots \\ \mathbf{a}_{\mathbf{1n}} + \mathbf{a}_{\mathbf{nn}} \end{bmatrix} \quad (6)$$

$$X_{i_{new}} = \sum_{j=1}^{n} x_{ij_{new}} + Y_{i_{new}} \quad (7)$$

Objective

$$\mathrm{Min}\ \ Z = \sum_{i=1}^{n} (CO_{2_i} \times X_{i_{new}}) \quad (8)$$

Parameters definitions

X_j: the physical output of sector j

x_{ij}: the amount of products of sector i absorbed–as its inputs-by sector j

a_{ij}: input coefficient of the product of sector I into sector j as a technical coefficient

b: the outsourcing ratio of sector 1 while sector 1 is the outsourcer industry and sector n is the outsourcee industry

Y_j: the final demands of the products of sector I that absorbed by households, government, and other final users

CO_{2i}: the CO_2 emissions coefficient of sector i which means the direct emitted CO_2 for one product of sector i

new subscripts of parameters demonstrate the values of parameters after international outsourcing

Equations (1) and (2) depict the outsourcer sector's production (outputs) and inputs reduction due to international outsourcing respectively. Equation (3) shows that the new final demands of all sectors except outsourcer and outsourcee are equal to what it was before outsourcing. The technical coefficients of all sectors in the baseline scenario and the new international outsourcing scenario are presented in Equations (4) and (5) respectively. The fact that outsourcee sector can support the demands of outsourcer sector is illustrated in Equation (6). The last constraint (Equation (7)) represents the basic concept of IOA that the total production of each sector equals to the intermediate demands and the final demand of that sector.

A solution for this set of constraints is obtained in step 3 by minimising the global CO_2 emissions as an assumption (see Table 1). According to the production-based CO_2 emissions (Boitier, 2012), the global CO_2 emissions can be calculated by the $\sum_{i=1}^{n}(CO_{2_i} \times X_{i_{new}})$.

The linearity of the system's objective function (see Equation (8)) and constraints is due to the linear assumptions of IOA and international outsourcing. Therefore, this system can be modelled as a linear programming model (Taha, 1992). For dealing with this linear programming problem, the simplex algorithm can be used (Taha, 1992). In this paper, the aforementioned steps were implemented by programming in the Matlab. The results of this step configure a new input-output table in a new international outsourcing scenario. The obtained new X_i and CO_2 emissions coefficients (CO_{2_i}), are the inputs of next step. At the step 4, the CO_2 emissions of each sector can be calculated as follows.

$$CO_2 emissions_i = CO_{2_i} \times X_{i_{new}}, \ i = 1,2,\dots,n \quad (9)$$

3. Case Study

Australian manufacturing industry is the second largest contributor to the Australian economy. In 2009, this industry produced 15.7% of total Australian outputs in terms of dollar value (Timmer et al., 2012). From the environmental perspective, manufacturing industry is also responsible for the 32.33% of Australian CO_2 emission in 2009 (see Figure 1). This share puts manufacturing industry as the biggest polluting industry after the sectors of Electricity, Gas and Water Supply (EGWS). The EGWS and manufacturing sectors with 47.70% and 25.26% have the major contributions to the CO_2 emissions of the Australian manufacturing industry's inputs (Timmer et al., 2012).

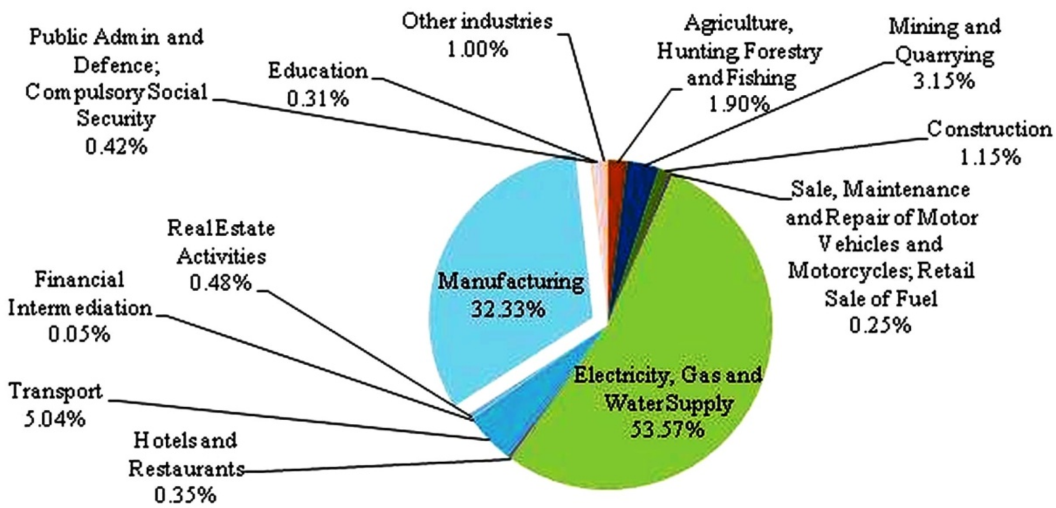

Figure 1. Share of Australia's industries from Australian CO_2 emissions in 2009

While the importance of manufacturing industry is explicit in Australia, the share of Australian manufacturing industry from the total output of Australian economic sectors is decreasing. Considerable amounts of manufacturing products are outsourced and imported from outside of Australia. Furthermore, China has the biggest share (around 23%) of the manufacturing products that are imported back to Australia (Timmer et al., 2012). In this research, the case study that is shown in Figure 2 include Australian manufacturing industry (outsourcer), Australian EGWS industry, other Australian domestic industries, China's manufacturing industry, Chinese EGWS industry, other domestic industries in China (outsourcee) and other international industries in other countries.

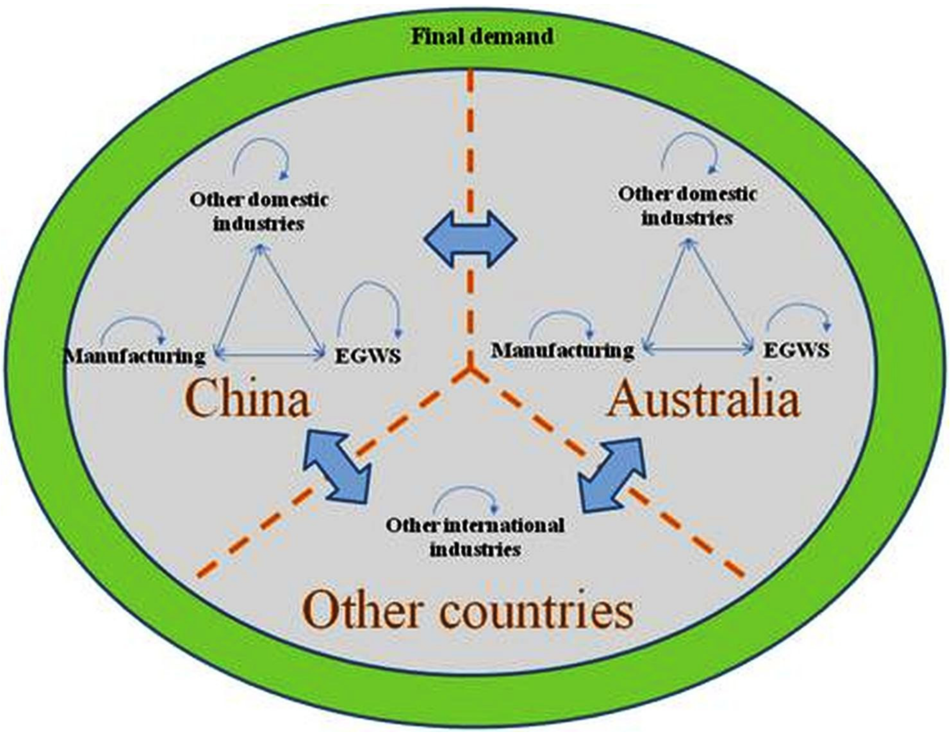

Figure 2. Interactions among and within the industries that have involved in the case study

4. Results

According to the presented research methodology, at the first step, a baseline input-output table is developed for the case study. World Input Output Database (WIOD) has been used to configure the baseline input-output table with the seven sectors of case study. Originally, WIOD presents the transactions of 35 industries in 40 major countries from 1996 to 2009 (Timmer et al., 2012). In this paper, the sectors of WIOD are aggregated into a table with the sectors involved in the case study. Furthermore, it is assumed that physical input-output table is similar to its monetary input output table. A summary of the baseline input-output table in 2009 is illustrated in Table 2.

Table 2. A summary of baseline input-output table in 2009 (US$ millions)

Region	Sector	Intermediate demand	Final demand	Total output
Australia	Manufacturing	203,751.82	118,148.30	321,900.12
	EGWS	26,104.37	19,755.01	45,859.38
	Other domestic industries	837,642.25	839,053.22	1,676,695.47
Other countries	Other international industries	48,843,997.83	52,453,999.43	101,297,997.26
China	Other domestic industries	3,417,841.86	3,250,514.27	6,668,356.13
	EGWS	442,444.94	20,798.60	463,243.54
	Manufacturing	6,353,271.64	1,836,815.46	8,190,087.10

Global CO_2 emissions data can be extracted from the environmental accounts of WIOD (Timmer et al., 2012). This section of WIOD presents the CO_2 emissions of each economic sector based on the consumptions of different kinds of fuels such as hard coal, coke, diesel oil, motor gasoline, natural gases, etc. Table 3 presents the CO_2 emissions of the aggregated sectors in 2009. The global CO_2 emissions based on the fuel consumption was 24,812,101.75 Gigagrams (Gg) in 2009.

For investigating different international outsourcing ratios, 10 new international outsourcing scenarios are studied in this research. These scenarios are varied from 0% to 100% with a 10% interval. Therefore, steps 2 to 4 are implemented for these ten new international outsourcing scenarios. The results are presented in two parts. The first part demonstrates the 90% international outsourcing scenario in details. The second part shows all ten new international outsourcing scenarios.

Table 3. CO_2 emissions of industries in the baseline scenario (before international outsourcing) in 2009 (Gg)

Region	Sector	CO_2 emissions	CO_2 emissions coefficients
Australia	Manufacturing	65,955.77	0.20
	EGWS	206,645.90	4.51
	Other domestic industries	91,723.21	0.05
Other countries	Other international industries	18,238,554.76	0.18
China	Other domestic industries	875,549.17	0.13
	EGWS	3,326,274.88	7.18
	Manufacturing	2,007,398.07	0.25

4.1 90% International Outsourcing Scenario

The 90% scenario is depicted as an example to highlight the results produced by steps 3 and 4. This scenario represents that the Australian manufacturing industry reduces 90% of its outputs/production and the remaining intermediate and final demands of that industry are supplied by the Chinese manufacturing industry. A summary result of step 3 in this scenario is illustrated in Table 4. Comparing Table 4 with Table 2 shows that the reduction of Australian manufacturing industry's outputs by 90% reduces the total outputs of EGWS and other domestic industries in Australia by 14.48% and 10.16% respectively. In contrast, these reductions lead to increase the total outputs of the Chinese manufacturing industry, Chinese EGWS industry, other Chinese domestic industries and other international industries in other countries by 484118.93, 19269.29, 121253.25 and 47051.85 million dollars, respectively.

Table 4. Total output of sectors in 90% international outsourcing scenario (US$ millions)

Region	Sector	Intermediate demand	Final demand	Total output
Australia	Manufacturing	5,634.89	26,555.12	32,190.01
	EGWS	19,462.94	19,755.01	39,217.95
	Other domestic industries	667,216.45	839,053.22	1,506,269.67
Other countries	Other international industries	48,891,049.68	52,453,999.43	101,345,049.11
China	Other domestic industries	3,539,095.11	3,250,514.27	6,789,609.38
	EGWS	461,714.23	20,798.60	482,512.83
	Manufacturing	6,745,797.40	1,928,408.63	8,674,206.03

By applying step 4 for this scenario, the CO_2 emissions of industries have been obtained (see Table 5). The results depict that if Australian manufacturing industry outsources 90% of its production, the CO_2 emissions of EGWS and other domestic industries in Australia will decrease 14.48%, and 10.16%, respectively. Consequently, the total CO_2 emissions of Australia will reduce 27.07%. On the other hand, the CO_2 emissions associated with manufacturing, EGWS and other industries in China will grow 5.91%, 4.16% and 1.82%, respectively. Similarly, the CO_2 emissions of other industries in other countries will increase 0.05% in this circumstance. Finally, the global CO_2 emissions rises 0.74% and reach to 24,994,902.97 Gg because of two issues. The first issue is the high CO_2 emissions coefficients of Chinese industries in comparison with Australian industries. The second one is the production dependency of Chinese manufacturing industry on its suppliers which is 16% more than the production dependency of Australian manufacturing industry on its suppliers. This is due to the inefficiency of Chinese industries in comparison with Australian industries.

Table 5. CO_2 emissions of industries in the baseline and 90% international outsourcing scenarios (Gg)

Region	Sector	Baseline scenario	90% international outsourcing scenario	Percentage change
Australia	Manufacturing	65,955.77	6,595.58	-90.00%
	EGWS	206,645.90	176,719.12	-14.48%
	Other domestic industries	91,723.21	82,400.10	-10.16%
	Total	364324.88	265,714.80	-27.07%
Other countries	Other international industries	18,238,554.76	18,247,026.38	0.05%
China	Other domestic industries	875,549.17	891,469.61	1.82%
	EGWS	3,326,274.88	3,464,636.11	4.16%
	Manufacturing	2,007,398.07	2,126,056.08	5.91%
	Total	6,209,222.11	6,482,161.80	4.40%
World		24,812,101.75	24,994,902.97	0.74%

4.2 Ten Alternative International Outsourcing Scenarios

This part of paper presents the percentage changes of countries and industries' CO_2 emissions in other international outsourcing scenarios compare to the baseline scenario. Figure 3 shows that when the international outsourcing ratio of Australian manufacturing industry increases by 10% for each consecutive scenario, the total CO_2 emissions of Australia reduces around 3.1% for each consecutive scenario. Therefore, as expected, there is a negative relationship between the international outsourcing of Australian manufacturing industry and Australia's CO_2 emissions. The results also depict that the CO_2 emissions of other countries and specifically China will increase when the Australian manufacturing industry outsources its production. As a result, there will be a positive relationship between the outsourcing ratio of the Australian manufacturing industry and the other countries' CO_2 emissions. Figure 3 also presents that the global CO_2 emissions will be enhanced if outsourcing of the Australian manufacturing industry occurs. Therefore, international outsourcing of Australian manufacturing industry has a positive relationship with the global CO_2 emissions.

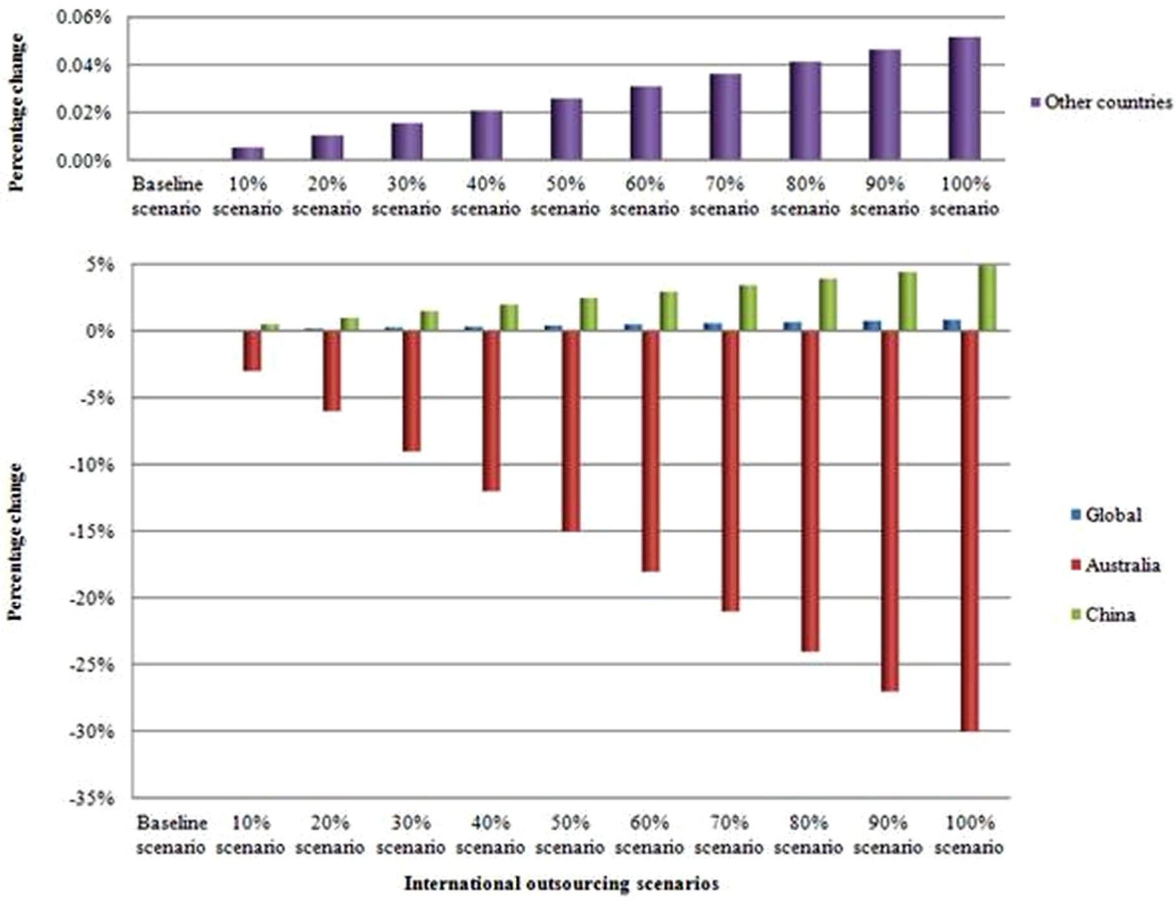

Figure 3. Percentage changes of countries' CO_2 emissions in ten new international outsourcing scenarios

Figure 4 demonstrates that while the CO_2 emissions of Australian manufacturing industry decrease with a consistent ratio (around 10% for each consecutive scenario), the CO_2 emissions of all Australian industries will also be reduced. However, the percentage reduction of CO_2 emissions for each consecutive scenario in the Australia industries including EGWS, and other domestic industries are 1.61% and 1.13%, respectively. On the other hand, the CO_2 emissions of Chinees industries will increase in this circumstance. For example, the Chinese manufacturing's CO_2 emissions increase by 0.66% (13184.22 Gg) due to 10% production reduction of Australian manufacturing industry. Finally, other international industries except Australian and Chinese industries need to produce more products that lead to the creation of more CO_2 emissions by about 0.01% for each 10% rise in the international outsourcing ratio of Australian manufacturing industry.

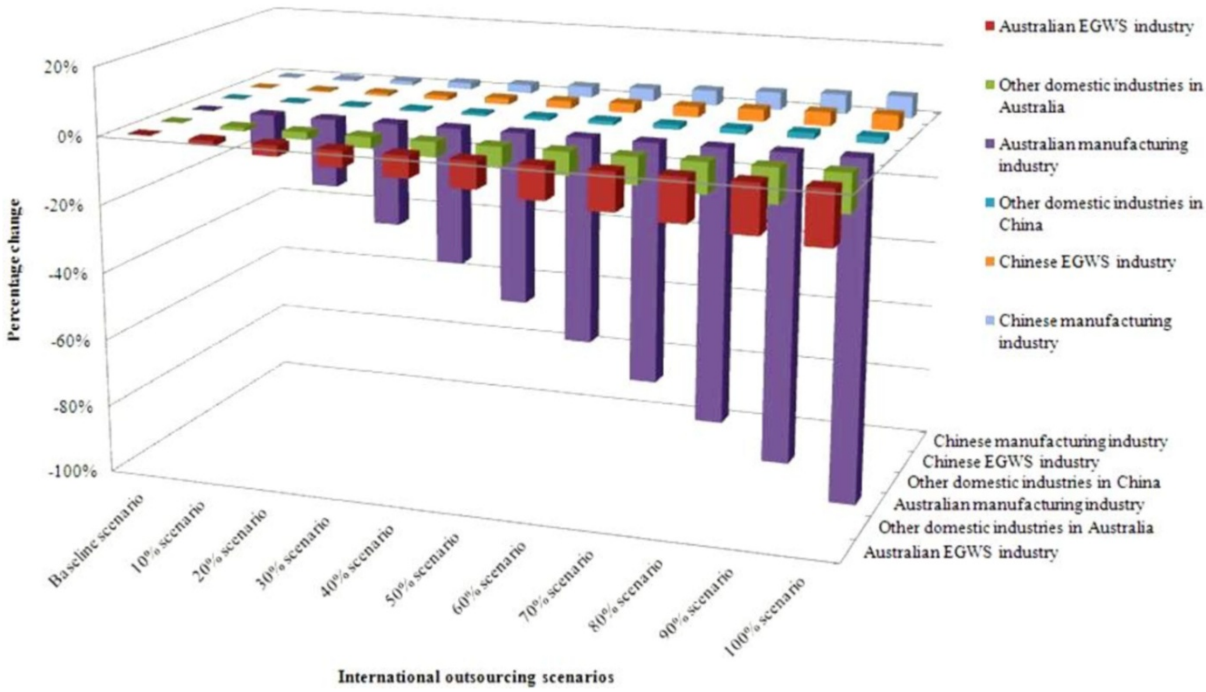

Figure 4. Percentage changes of Australian and Chinese industries' CO_2 emissions in ten new international outsourcing scenarios

Therefore, this paper reveals not only the direct effect of international outsourcing of outsourcer industry on the global CO_2 emissions but also the hidden (indirect) environmental impacts through the suppliers and outsourcee industries. Figure 5 demonstrates the levels of global CO_2 emissions in the new international outsourcing scenarios in two occasions. In the first occasion, both direct and indirect CO_2 emissions impacts of international outsourcing are considered. In the second occasion, the global CO_2 emissions are computed by considering only the direct CO_2 emissions impacts on the outsourcer industry. In the first occasion, the global CO_2 emissions are growing up while the international outsourcing ratio is increasing in each consecutive scenario. According to the second occasion, the global CO_2 emissions are reducing continuously because of ignoring the indirect effect of international outsourcing. The differences between the global CO_2 emissions in these two occasions show the hidden (indirect) CO_2 emissions impacts of international outsourcing. As a result, the hidden (indirect) CO_2 emissions are increased in each consecutive scenario. For instance, in the worst international outsourcing scenario (100% scenario), the hidden (indirect) CO_2 emissions is 269068.2406 Gg.

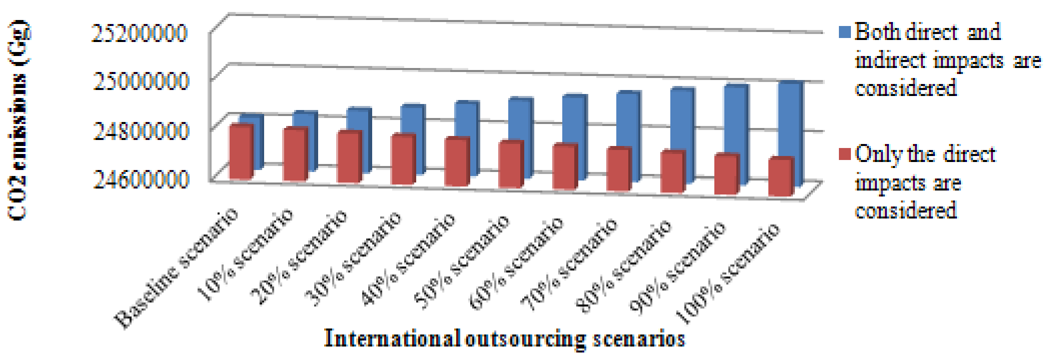

Figure 5. Global CO_2 emissions in two occasions (Gg)

5. Uncertainties

The presented input-output tables have common uncertainties such as the method of data collection, aggregation, the trade flow and currency exchange rate (Wiedmann, 2009). On the other hand, uncertainties of greenhouse gas inventories are associated with the science of greenhouse gases, mathematical calculations and the input data, emission factors and assumptions (Sharma, 2010). It was assumed that aggregated industries have a similar production technology. For evaluating the impacts of these uncertainties on the obtained global CO_2 emissions after international outsourcing, the sensitivity analysis of technical coefficients and CO_2 emissions coefficients can be applied (Wilting, 2012). Similar to Wilting (2012) research, a change of +10% and -10% was assumed for these coefficients in this research.

5.1 Sensitivity Analysis of Technical Coefficients

Technical coefficients can be interpreted as the production technology and efficiency of industries in an economy (Christ, 1955; Miller & Blair, 2009). In this paper, two kinds of sensitivity analysis have been investigated on the technical coefficients associated with the input-output table in 90% international outsourcing scenario. The first one relates to the changes +10% and -10% of all technical coefficients that belong to each block at the country level simultaneously (see Figure 6). The second explored the results of variation -10% and +10% in each technical coefficient of input-output table.

Results of variations on the technical coefficients can be found by following steps: (1) creating a new technical coefficient matrix A^n, (2) obtaining the new Leontief inverse matrix $L^n = (I - A^n)^{-1}$, (3) accounting the total outputs $X^n = (I - A^n)^{-1}Y$, and (4) calculating the global CO_2 emission by $\sum_{i=1}^{n}(CO_{2_i} \times X_i^n)$.

According to the first kind of sensitivity analysis, the group of technical coefficients inside 6 blocks of the input-output table at the country level are changed by +10% and -10% (see Figure 6). The values in Figure 6 without brackets and with brackets show the percentage changes of global CO_2 emissions by altering the associated technical coefficients by +10% and -10% respectively. Results depict that changing +10% and -10% in the technical coefficients related to other countries with other countries has the most impact on the variation of global CO_2 emissions by 7.60% and -6.36% respectively.

	Australia	Other countries	China
Australia	0.12%, (-0.11%)	0.01%, (-0.01%)	0.01%, (-0.01%)
Other countries	0.01%, (-0.01%)	7.60%, (-6.36%)	0.18%, (-0.18%)
China	0.05%, (-0.05%)	0.52%, (-0.52%)	7.47%, (-5.27%)

| | < 0.1%
0.1-0.5%
0.5-1.0%
| | > 1.0%

Figure 6. Effect of +10% and (-10%) variations in all technical coefficients of each block on global CO_2 emissions

Based on the second kind of sensitivity analysis, the values in Figure 7 present the variation of global CO_2 emissions by changing each technical coefficient +10% (values without brackets) and -10% (values with brackets). For example, the percentage change of global CO_2 emissions by +10% change of a_{77} would be 2.73%. The results also reveal the ranking of most effective technical coefficients which have major impacts on the global CO_2 emissions as follows:

$$a_{44} > a_{77} > a_{75} > a_{67} > a_{65} > a_{57} > a_{55} > a_{65} > a_{74} > a_{47}$$

		Australia			Other countries	China		
		Manufacturing	EGWS	Other domestic industries	Other international industries	Other domestic industries	EGWS	Manufacturing
Australia	Manufacturing	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	EGWS	0.00%	0.01% (-0.01%)	0.03% (-0.03%)	0.00%	0.00%	0.00%	0.00%
	Other domestic industries	0.00%	0.00%	0.07% (-0.07%)	0.01% (-0.01%)	0.00%	0.00%	0.00%
Other countries	Other international industries	0.00%	0.00%	0.01% (-0.01%)	7.60% (-6.63%)	0.04% (-0.04%)	0.00%	0.13% (-0.13%)
China	Other domestic industries	0.00%	0.00%	0.00%	0.10% (-0.10%)	0.51% (-0.48%)	0.04% (-0.04%)	0.57% (-0.55%)
	EGWS	0.00%	0.00%	0.00%	0.01% (-0.01%)	0.47% (-0.47%)	0.64% (-0.59%)	0.90% (-0.90%)
	Manufacturing	0.00%	0.00%	0.05% (-0.05%)	0.41% (-0.41%)	0.94% (-0.92%)	0.03% (-0.03%)	2.37% (-1.94%)

| |< 0.1%
0.1-0.5%
0.5-1.0%
| | > 1.0%

Figure 7. Percentage changes of global CO_2 emissions by +10% and (-10%) change of each technical coefficient

5.2 Sensitivity Analysis of CO_2 Emissions Coefficients

The sensitivity analysis of CO_2 emissions coefficients can be also implemented in two approaches. The first approach is associated with changing all CO_2 emissions coefficients simultaneously by +10% and -10%; and the second approach relates to the variation of each CO_2 emissions coefficient by +10% and -10%.

Based on the 90% international outsourcing scenario, it was found that changing all CO_2 emissions coefficients simultaneously (first approach) with a same ratio will lead to the same percentage variation in global CO_2 emissions. In contrast, the variations in each CO_2 emissions coefficient (second approach) lead to different levels of global CO_2 emissions (see Table 6). Table 6 demonstrates the percentage changes of global CO_2 emissions by changing each CO_2 emissions coefficient +10% (values without brackets) and -10% (values with brackets). Results depict that the most effective CO_2 emissions coefficients for changing the global CO_2 emissions associated with other international industries in other countries, Chinese EGWS industry, Chinese manufacturing industry, other domestic industries in China, Australian EGWS industry, other domestic industries in Australia and Australian manufacturing industry, respectively.

Table 6. Percentage changes of global CO_2 emissions by +10% and (-10%) variations in each sector's CO_2 emissions coefficient

Region	Sector	Percentage change of global CO_2 emissions
Australia	Manufacturing	0.0026%, (-0.0026%)
	EGWS	0.0707%, (-0.0707%)
	Other domestic industries	0.0330% (-0.0330%)
Other countries	Other international industries	7.3003%, (-7.3003%)
China	Other domestic industries	0.3567%, (-0.3567%)
	EGWS	1.3861%, (-1.3861%)
	Manufacturing	0.8506%, (-0.8506%)

6. Conclusion

This study extended the current research on international outsourcing and environmental sustainability by undertaking a comprehensive analysis of the significant effect of international outsourcing on the CO_2 emissions of Australia, China and the other countries. The baseline international outsourcing scenario and ten new scenarios have been investigated in this research. The results of this paper depict that international outsourcing of the Australian manufacturing industry to China reduces not only the CO_2 emissions by the outsourcer industry in Australia, but also the CO_2 emissions by the other domestic industries in Australia. On this occasion, the international outsourcing increases the CO_2 emissions of Chinese industries and other international industries in other countries. As a result, international outsourcing increases the global CO_2 emissions because of two issues. First, the CO_2 emissions coefficients of Chinese industries are higher than the Australian industries. Second, the production dependency of Chinese manufacturing industry on its suppliers is more than the production dependency of Australian manufacturing industry on its suppliers. In the worst international outsourcing scenario (100% scenario) while the emitted CO_2 of the Australian manufacturing industry (outsourcer) becomes to be zero (100% reduction), the CO_2 emissions of the Australian EGWS industry and other domestic industries in Australia are reduced by 16.09% and 11.29% respectively. However, in this scenario, the CO_2 emissions associated with China and world increase by 4.88% and 0.82% respectively. Although currently manufacturing one product in China emits more CO_2 emissions than manufacturing in Australia, this fact might change in future. This is due to the fast acceleration of technology development in Chinese industries for reducing their CO_2 emissions coefficients in comparison with Australian industries (Timmer et al., 2012).

The implications of this research for decision makers at the macro level are as follow. First, this paper provides a decision support system for industrial managers in order to evaluate the effect of different international outsourcing policies on CO_2 emissions before implementing any real outsourcing decisions. Second, the ranking of most effective technical coefficients and CO_2 emissions coefficients can help Australian government by presenting the investment opportunities and priorities for reducing the global CO_2 emissions.

This study also has several limitations. Input-output tables and GHG inventory databases have common uncertainties including the method of data collection, imputation and balancing, allocation, assuming proportionality and homogeneity and aggregation. In this paper, 1400 industries were aggregated to 7 huge sectors. In addition, some parts of the production technology of industries are considered to be fixed. The assumption that physical input output table is the same as monetary input output table is another limitation. The presented limitations provide additional insight into further research on international outsourcing literature.

For future research, other tangible and intangible impacts of international outsourcing need to be investigated. From the economic perspective, outsourcing can have effect on the industries' value adding, the employees' salaries and government's expenses and revenues. Therefore, investigating both the economic and environmental costs and benefits of outsourcing would be interesting subjects for managers and scholars. Furthermore, the other environmental costs of outsourcing decisions, in terms of carbon tax and carbon tariffs, are hot topics among the policy makers at the macro and micro levels. Other environmental indices such as water footprint or toxic materials can be also evaluated. The loss of manufacturing knowledge because of long term of manufacturing outsourcing is a serious issue for the all outsourced manufacturing industries. In other words, when skilled labours loss their jobs because of outsourcing, the tacit knowledge of related manufacturing activities will disappear gradually. In addition, the dynamic behaviour of systems needs to be investigated over time for determining the real environmental and economic costs and benefits of outsourcing. Finally, further research can apply data envelopment analysis as a tool (Heidari et al., 2011; MoosaviRad et al., 2010) for selecting the efficient strategies for reducing the global CO_2 emissions associated with international outsourcing.

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