WORKING PAPER
2016-08

REPA

Resource Economics
& Policy Analysis
Research Group

Department of Economics
University of Victoria

Do Countries Shift Their Carbon Dioxide Emissions Offshore? A Time Series Analysis of Emissions Embodied in Trade

Taylor Peiris

August 2016

REPA Research Group
Department of Economics
University of Victoria PO Box 1700 STN CSC Victoria, BC V8W 2Y2 CANADA
repa@uvic.ca
Fax: 250.721.6214
http://web.uvic.ca/~repa/

Do Countries Shift Their Carbon Dioxide Emissions Offshore? A Time Series Analysis of Emissions Embodied in Trade

by

Taylor Peiris

ABSTRACT

This analysis uses a bilateral trade input output model and time series data to estimate the balance of emissions embodied in trade for six major trade economies over a period of 15 years. Results indicate that the United States and the United Kingdom are net importers of emissions, and that the balance of emissions in trade for these countries shifts further towards imports continually over the period. The remaining countries are shown to be net exporters of emissions, with China's embodied emissions in exports rising continuously over time. Canada and Russia display a shift in their trade emissions balance towards imports, evidencing a trend of developed nations outsourcing emissions to developing nations, particularly China.

Key words: Trade and CO_2 emissions; emissions embodied in imports and exports; climate change mitigation

JEL Categories: Q56, F18, F64, D57

I. INTRODUCTION

The rise of globalization over the past 50 years has been a driving force behind changing growth dynamics in economies across the world. Developing countries have benefitted from increased access to international trade which has allowed them to grow by providing goods and resources to developed nations. Rich countries have in turn benefitted from the provision of relatively inexpensive imports from these developing nations. However, the pathways of trade which have developed between nations may also be acting as a means for certain countries to shift the production of harmful emissions out of their borders.

In recent decades there has been an increasing focus on emissions accounting which has been driven largely by concerns over the impact of emissions on human health, as well as the possible anthropogenic impacts on global warming through the release of greenhouse gases, notably carbon dioxide (CO_2). Given the global scope of these issues, coordination across countries is required to enact standards and regulations aimed at addressing the release of harmful emissions. The most significant effort has been from the United Nations, which established the United Nations Framework Convention on Climate Change (UNFCCC), a coalition of member nations that has been responsible for such emissions reduction initiatives as the Montreal Protocol and the Kyoto Protocol. Member nations of the UNFCCC are divided into Annex I (developed) and non-Annex I (developing) nations, and the UNFCCC operates under the direction that Annex I nations must shoulder the economic burden of emissions reduction, given that the majority of historic emissions were produced by these nations during their periods of economic growth.

The restrictions placed on the emissions of Annex I countries under agreements, including the Kyoto Protocol, make emissions-intensive processes, such as manufacturing and resource extraction, relatively more expensive for these countries. Under UNFCCC accounting rules, a country's emissions include only those that are produced within the country's borders and jurisdiction. This system creates an incentive for Annex I countries to reduce their own emissions without reducing consumption by outsourcing emissions-intensive production to non-Annex I countries and importing the end products. The emissions associated with the consumption of goods and services in Annex I countries then become the responsibility of the non-Annex I countries producing those goods and services, a phenomenon which might be termed a carbon leakage.

The UNFCCC framework is emblematic of a fundamental issue with emissions accounting and regulation. While the definition of carbon leakage is linked directly with UNFCCC classifications, the concept has a broader application in that it is clear that any relatively strict emissions regulation in one country creates an incentive for outsourcing emissions-intensive processes to other jurisdictions, given a production-based system of accounting for emissions. The result of this is the "leak" of emissions production out of the accounts of developed countries and into the accounts of developing countries with less strict emissions policy, and from energy importing countries to energy producing countries.

This paper examines the issue of carbon leakage through the concept of net embodied emissions. We quantify the emissions released by a domestic country in producing the goods and services it exports (emissions embodied in exports, or EEE), and balance this value against the emissions associated with that country's import demand (emissions embodied in imports, or EEI). The resulting difference, referred to as the balance of emissions embodied in trade (BEET), gives us an indication of the degree to which carbon leaks into or out of an economy. Developed countries, for which locally produced emissions are relatively costly, are expected to import emissions-intensive goods and thus have a negative BEET. Developing countries with relatively lax emissions standards and countries whose economies rely on emissions-intensive resource extraction and exports are thus expected to have a positive BEET.

In our analysis, we construct a model to determine the BEET for each of six major trade economies: the United States (US), China, the United Kingdom (UK), Russia, India and Canada. This list of countries includes the top emitters in the world, and presents a representative mix of developed, developing, energy exporting and energy importing countries. We create a time series of BEET for each country over a period of 15 years, ranging from 1995 to 2009, in order to identify the trends in the transfer of emissions between countries.

Our results show that the US and UK are both net emissions importers, while the remaining countries are all net exporters to varying degrees. This demonstrates the expected divide between developed, energy importing countries and developing and energy exporting countries. Our results also indicate that developed countries have increasingly shifted towards importing emissions over the period, while the quantity of emissions embodied in the exports of China increased over the period relative to those embodied in its imports. There is a noticeable inflection point in the data in 2002, the first full year of China's membership in the World Trade Organization (WTO), after which the rate of decrease in the BEET of developed countries becomes greater, lending support to the notion that the emissions of developing nations have leaked to China to a degree which appears to be increasing over most of the period.

The remainder of this paper is laid out as follows: Section II provides an overview of the literature; Section III details the methodology employed in our analysis; Section IV provides a description of the data sources used; Section V details our results, both general and country-specific, as well as highlighting possible sources of error in our analysis; Section VI provides concluding statements regarding the results of this analysis and presents possible avenues of further research.

II. LITERATURE REVIEW

There is an extensive literature analyzing emissions embodied in trade between countries, with a large amount of the attention paid to the United States (Weber and Matthews 2007) and China (Pan et al. 2008, Yan and Yang 2010). These are the two largest single economies and emitters in the world (worldbank.org, epa.gov), with each representative of the respective roles of developed and developing countries in facilitating carbon leakage. The dominant methodology employed involves the analysis of input-output modelling, accounting for varying degrees of heterogeneity and granularity in the flow of goods between countries.

Studies focusing on embodied emissions in the trade of developed countries typically focus on the import side of the ledger, while analysis of developing countries tends to highlight the overall imbalance of embodied emissions. Early work by Wyckoff and Roop (1994) establishes significant import of emissions relative to total reported emissions for OECD (Organization for Economic Co-operation and Development) countries. More recently, Weber and Matthews (2007) show that the US's emissions embodied in imports is increasingly sourced away from countries that have ratified the UNFCCC's Kyoto Accord, and that imported emissions from China have grown since 1997 to become the majority of the US's EEI by 2002, while continuing to increase into 2004. Some authors have shown that the United States, Japan and the European Union have negative BEETs and EEI in these countries is sourced primarily from developing countries. In agreement with this result, Pan et al. (2008) find China to be a net exporter of emissions to developed countries, with the United States being the most pronounced example at a net EEI of 165.14 Mt CO_2 sourced from China in 2002. This study also shows China to be a net importer of emissions from Russia, with a net value of 32.35 Mt CO_2. Yan and Yang (2010) conclude that China's BEET grew significantly between 1997 and 2007 owing to a rapid increase in EEE over the period, from roughly 400 Mt CO_2 to more than 1,700 Mt CO_2.

Many studies incorporate a temporal component by studying a handful of discrete years over a period, but there is little by way of continuous time series analysis. This is largely due to the reliance on publicly accessible input-output tables such as those published by the OECD, which are released intermittently. Shui and Harriss (2006) provide a short time series analysis which shows that the degree to which the United States has avoided emissions through trade with China grew continuously from 150 Mt CO_2 in 1997 to 357 Mt CO_2.

We also consider the approximation of time series data provided by Sato (2014), which takes the form of a review that synthesizes the results of studies undertaken for different years, and presents them chronologically so as to create a time series of results. This analysis finds a wide variation in computed embodied emissions across the literature, owing in no small part to differences in methodology. Sato's review shows that the calculated EEI for the US trended upwards, from loosely 600 Mt CO_2 in 1995 to 1,000-1,500 Mt CO_2 by the mid-2000s. The average reported magnitude of the US's BEET over this period appears to increase from a range between -200 and -300 Mt CO_2 in 1995 to a range between -400 and -700 Mt CO_2 by the end of the period.

Likewise, the UK's EEI also appears to increase over this period, but the effect is difficult to isolate due to a more limited number of synthesized studies providing more disparate results. The UK's BEET appears to grow between the mid-1990s and the mid-2000s, from an approximate zero balance in 1995 to a range of -100 to -300 Mt CO_2 by the mid-2000s. Conversely, China's EEE grows from roughly 500 Mt CO_2 in 1995 to between 1,500-2,500 Mt CO_2 by 2006/07, with an associated growth in the average reported BEET from between 200-400 Mt CO_2 to a range of

500-1,000 Mt CO_2 over the same period.

Our analysis contributes to the existing literature by establishing a continuous time series of BEET values for major trade economies. We improve upon existing time series by expanding the scope to countries outside of the United States and China, and by applying a consistent methodology that allows direct comparability of results across years.

III. Methodology

This paper seeks to analyze the CO_2 emissions embodied in the trade flows of six major trade economies. We employ a bilateral trade input-output (BTIO) model to estimate the embodied emissions, conducted independently for each of the six countries so as to capture specifically the emissions associated with each country's imports and exports, and to determine the balance of emissions embodied in trade (BEET) for each. We include a temporal component as well; the balance of emissions for each country is calculated for each year over a 15-year period to highlight changing trends and points of inflection.

The BTIO model utilized in this analysis was constructed to incorporate heterogeneity in production efficiency across countries, across sectors and over time. We calculate production emissions intensity ε in each sector *i,* for each of our six domestic countries *C,* as the total associated emissions from that sector divided by the real value of the output in that sector:

$$(1)\quad \varepsilon_{C,i,t} = \frac{e_{C,i,t}}{y_{C,i,t}},$$

where *y* indicates the total output and *e* indicates the total emissions from sector *i* in year *t*. From here, quantifying the emissions embodied in exports (EEE) for a given country and year is a straightforward summation of the real value of exports in each sector multiplied by the associated intensity:

$$(2)\quad EEE_{C,t} = \sum_i \varepsilon_{C,i,t} X_{C,i,t},$$

where *X* denotes the real value of total exports for the given country, sector and year.

Quantifying the emissions embodied in imports (EEI) presents a more complicated problem, since foreign country-specific intensities must be applied to the imports sourced to that country in each sector. Given the comparatively wide scope of this analysis as compared to other BTIO analyses, applying unique emissions intensities for each source country in each sector and year quickly becomes impractical and data intensive. To obtain usable results, we employ a simplification to produce estimates for source country intensities based on the overall intensity of the economy of the source country relative to the domestic country:

$$(3)\ \varepsilon_{S,i,t} = \varepsilon_{C,i,t} \times \frac{\left(\frac{E_{S,t}}{Y_{S,t}}\right)}{\left(\frac{E_{C,t}}{Y_{C,t}}\right)},$$

where the subscript *S* indicates the source country, while *E* denotes total aggregate emissions and *Y* denotes the real value of total output in the economy of the given country. In this way, we employ the comparative intensity of the source country's economy as a scaling factor to the broadly used import substitution assumption (assuming imports were produced with the same technology and intensity as domestic production). This allows us to capture the heterogeneous makeup of import intensities, albeit imperfectly, while at the same time preserving the relative simplicity in execution. Given (3), we can now quantify the total EEI for domestic country *C* in year *t* as:

$$(4)\ EEI_{C,t} = \sum_i \sum_S \varepsilon_{S,i,t} \times M_{S,i,t},$$

where *M* denotes the real value of imports in the given sector for the indicated source country and year.

Putting (2) and (4) together, the BEET for domestic country *C* in year *t* can be easily calculated as the difference between the two values:

$$(5)\ BEET_{C,t} = EEE_{C,t} - EEI_{C,t}.$$

We adopt the conventional approach of expressing BEET in terms of the net export of emissions. Countries that have a positive balance are those which have a higher quantity of domestically-produced CO_2 emissions embedded in their exports than foreign-produced emissions embodied in their imports. Given that our analysis effectively employs consumption-based accounting of each domestic country's total emissions net the balance of emissions embodied in its trade flows, this directionality is somewhat counter intuitive in that a country with a positive BEET has lower net total emissions. However, we preserve this convention in order to facilitate the direct comparison of results between our analysis and those found in the existing literature.

IV. DATA

Data for this analysis are drawn primarily from the World Input Output Database (WIOD) (wiod.org). WIOD compiles nationally produced input-output tables from 40 countries, and also assembles these tables into a singular world input-output table itemizing the trade of goods between domestic and source countries. WIOD also compiles environmental data for each of these same 40 countries, including accounts of CO_2 emissions which we use as our emissions indicator in this analysis. Both the input-output tables and the environmental data are disaggregated into 35 production sectors, which allows us to account for heterogeneity in emissions intensity across sectors when performing our analysis. It also allows us to isolate production-based emissions from consumption-based emissions, improving the accuracy of our estimated emissions intensities, ε. The continuity in the availability of both national and world input-output tables provided by WIOD allows for time series analysis that is not achievable using other intermittently published input-output tables. For this analysis, we are limited to the time period ranging from 1995 to 2009 due to the lack of emissions data provided beyond this point.

While WIOD is the most suitable data source available for undertaking time series analysis with a BIOT model, it is not necessarily ideal. The database project was funded by the European Commission, the executive arm of the European Union, so the countries for which data are available are primarily European.[1] Other significant economies are included as well; however, countries in key regions like the Middle East are only included as a component of the "rest of world" category and for which we do not have unique emissions or output data.

Additionally, the emission data presented in WIOD are derived from the application of emissions intensities to production numbers, rather than nationally reported emissions values. While this approach is not necessarily less accurate than relying on reported values, especially in cases where a source country may be inclined to misreport emissions quantities for political reasons, the emissions intensities employed by WIOD do not appear to be given explicitly (Genty et al. 2012) and the aggregate values produced appear to be consistently below those compiled by other databases of economic and environmental indicators (unfccc.int, wri.org). Owing to this uncertainty regarding the aggregate values of emissions produced by WIOD, we instead rely on the aggregate CO_2 emissions data compiled by the World Resources Institute (wri.org) in its CAIT database when constructing the scaling factor used in (3), used to approximate source country emissions intensities. Likewise, we also use aggregate output (gross domestic product) data compiled by the International Monetary Fund (IMF) (imf.org) in producing this scaling factor.

The output data produced by both WIOD and the IMF give values in nominal US dollars (USD). Since we rely on the application of CO_2 emissions intensities to these output values to quantify emissions, inflation present in our output data would create bias in our results –downward bias in our estimated emissions intensities, and upwards bias in our estimates of embodied emissions. We convert this nominal data to real data, using 2007 as our base year, in order to ensure that the embodied emissions calculated in our analysis reflect the real value, free of inflationary bias. In converting to real output, we multiply our nominal values by a deflator calculated using average annual inflation values reported by the United States Department of Labour (bls.gov).

V. RESULTS

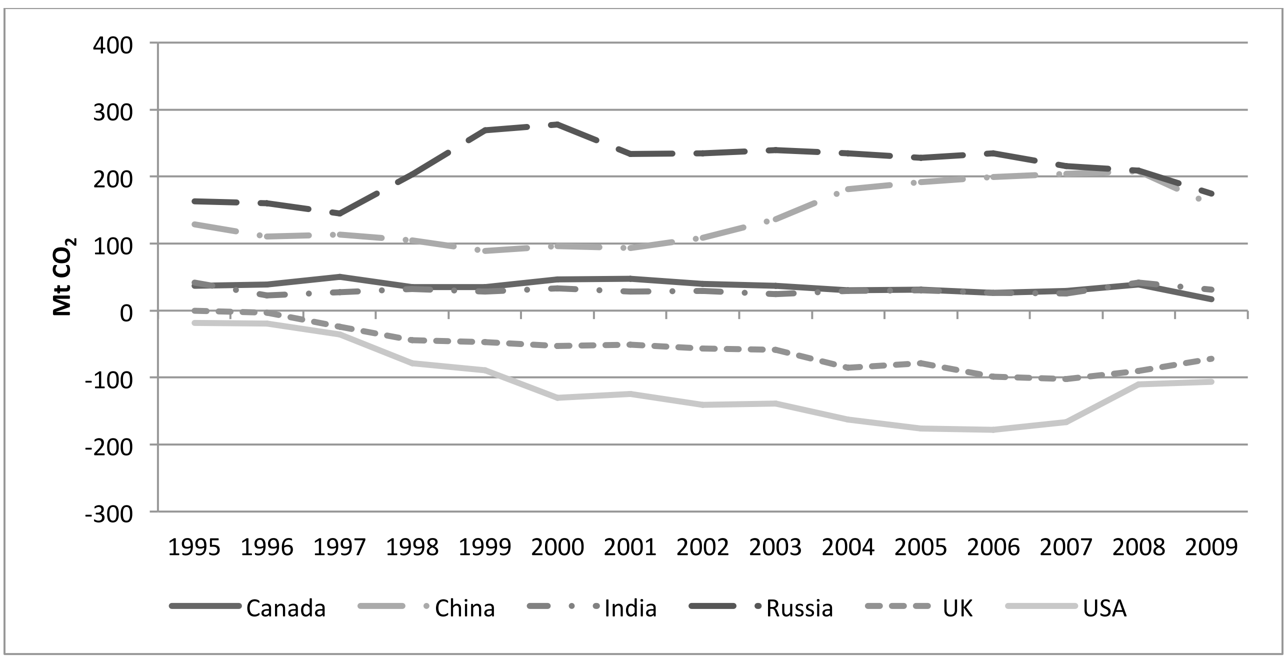
The final results of our estimates of the BEET for our six countries of interest are summarized in Figure 1. More detailed results regarding country and sector specific emissions can be found in the Appendix, and more specific consideration of the results for each country are provided later

[1] For a complete list of source countries included in this analysis see Table A6 in the Appendix.

in this section. It also warrants mentioning that there is a pervasive issue in the underlying emissions intensities used in our analysis which is discussed under the section detailing sources of error and uncertainty which follows this results section; results are presented here as given, with a focus on the resulting balance in emissions which appears unaffected, but it is worth bearing this limitation in mind.

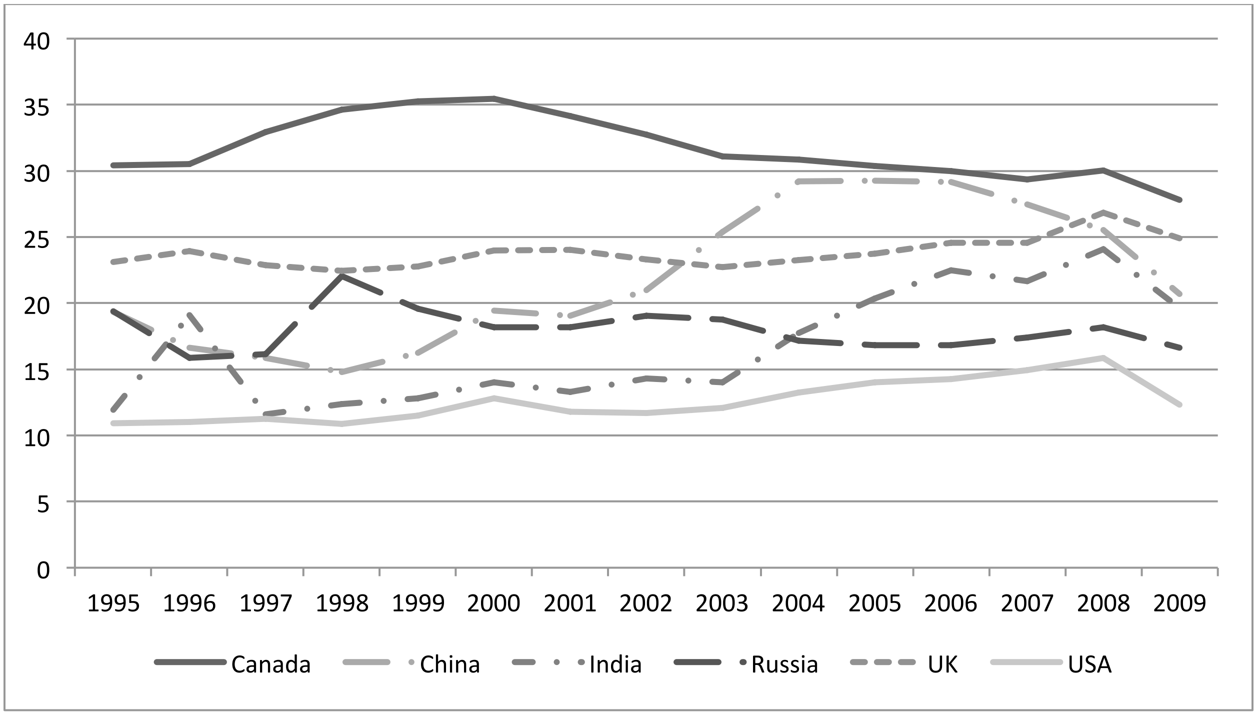
Based on Figure 1, we can see that the US and the UK both carry a negative balance of emissions, meaning that the emissions required to meet these countries' import demands exceeds the emissions embodied in the exports produced by these countries. This result is unsurprising as these are two developed countries which have historically been energy importers. The US has the highest degree of imbalance in favour of EEI in each year of the study period, reaching a maximum quantity of close 200 million tonnes (Mt) of CO_2 in 2006. Both the US and UK exhibit an increasing imbalance in embedded emissions over the majority of the period.

Figure 1: Balance of Emissions Embodied in Trade for Countries of Interest



As a means of further informing our analysis, from Figure 2 we can see that the US actually has the lowest proportion of imports compared to its total output, while the UK has one of the largest proportional quantities of imports. However, over the period, particularly up to the peak in 2008, the share of imports relative to total output in both of these countries is growing. Combined with the results shown in Figure 1, we conclude that the US and UK have increased both the proportional quantity and the emissions content of their imports over the period. Increasing trade with China after its membership in the World Trade Organization (WTO) in late 2001 undoubtedly plays a significant role in this, and the rate of growth in EEI and the share of imports for the US and UK does exhibit a notable increase from 2002 onwards until a sharp decline following the financial crisis in 2008.

Figure 2: Imports as Percentage of Total Output (Real)

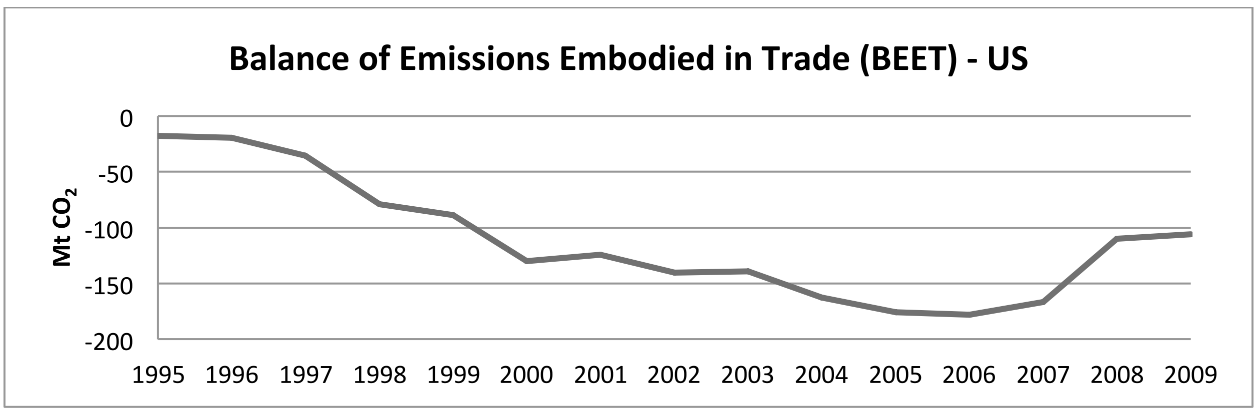


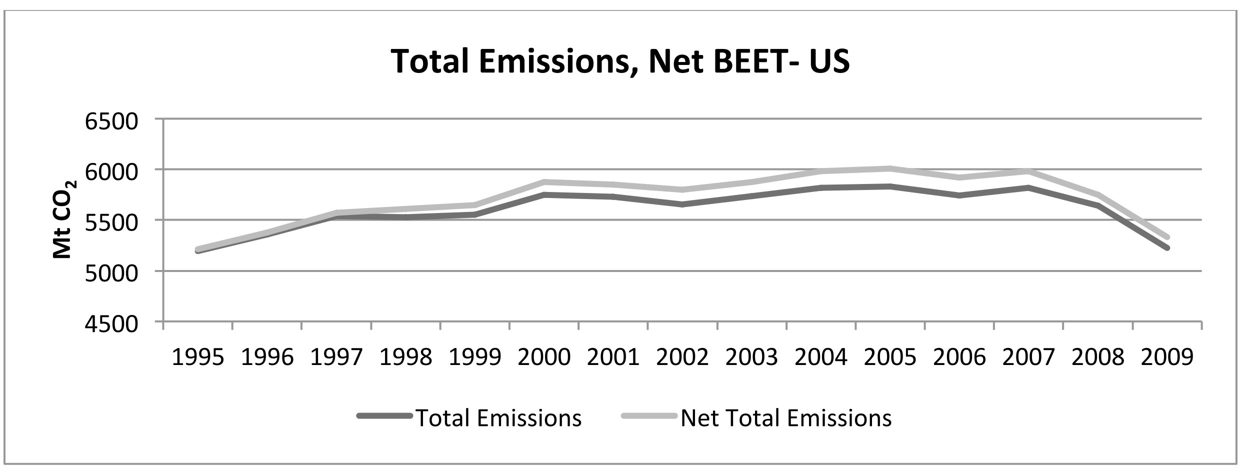
On the opposite side of the ledger, Canada, China, India and Russia all maintain a net positive BEET in each year of the period. This result is intuitive given that China and India are developing economies which saw a period of growth based on providing goods and services to developed countries during this timeframe, and Canada and Russia are largely export economies with significant energy export sectors. Despite dramatic increases in the relative proportion of imports, China is seen to move in an increasing imbalance towards EEE over the period, while India appears to maintain a consistent BEET. On the other hand, Russia's and Canada's balance of emissions appears to decrease modestly over the period, as their quantity of EEI is seen to increase by a larger degree relative to their EEE (see Tables A1.1 and A1.4 in the Appendix), similar to the other developed nations already analyzed.

Given the emissions-intensive process of resource extraction, it is not surprising to see Russia with the highest net BEET over nearly the entire period. Only after a period of growth following its joining the WTO does China approach Russia in this regard. Canada and India remain consistent at a more modest BEET balance, owing to the smaller scale of their respective economies in comparison to the other countries in this grouping. It is noteworthy that India's BEET remains relatively constant in magnitude, while Canada's BEET decreases somewhat over this period.

Narrowing our focus to country-specific dynamics, we see from Figure 3 that the US typifies the expected BEET from a developed country. The US maintains a negative BEET for the duration of the period, which is continually increasing in magnitude up until the financial crisis of 2008. Broadly speaking, there is a break in the trend for every country at this point, as the crisis caused a downscaling of trade, reflected by a decrease in magnitude of the BEET of each country studied in this analysis. It is worth noting that the rate of increase in the magnitude of the US's BEET becomes greater after 2003 relative to the two preceding years, though the change in the overall trend is not as dramatic as we might expect given the significant transfer of emissions from China to the US established in the literature (Weber and Matthews 2007, Pan et al. 2010). Our estimates for the US's BEET are appreciably lower than those reported in other analyses (Sato 2014). Regardless, the results obtained from this analysis are still in line with those found elsewhere; the emissions content of the US's imports has been growing continuously since the mid-1990s, providing evidence of the net transfer to its trading partners of its emissions associated with consumption.

Figure 3: The United States' BEET and Net Total Emissions

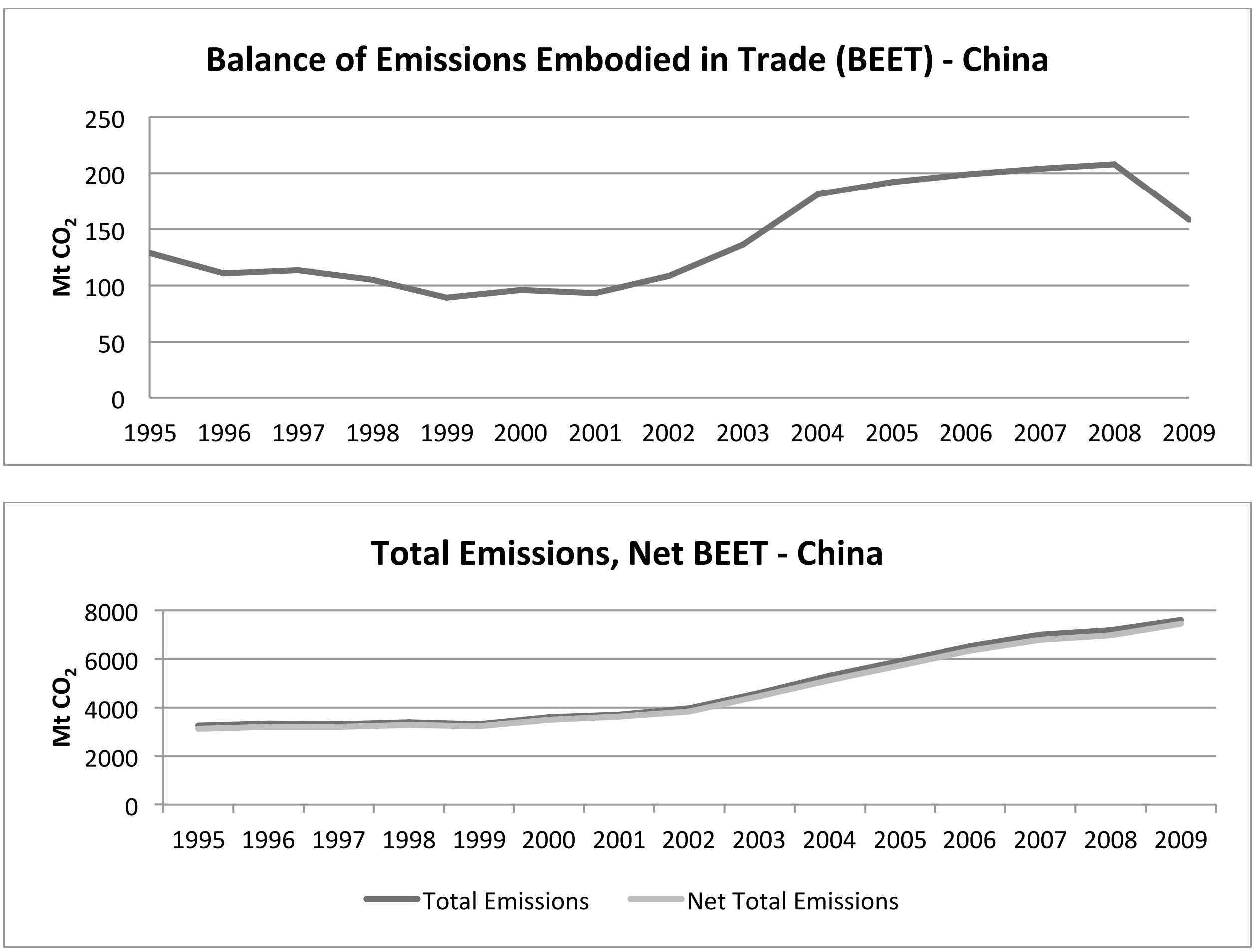




The results for China are provided in Figure 4. The general "shape" of the results is as expected; as a centre for global manufacturing and export, the CO_2 emissions embodied in China's exports outweigh those embedded in the products it imports. We also see a clear inflection point in 2001, the year in which China joined the WTO and gained greater access to overseas markets, especially developed countries. The values we obtain for China's BEET are low compared to the existing literature (Yan and Yang 2010, Sato 2014), though it is worth noting that there is a very wide variance in the reported values between studies.

We see in Figure 2 that the relative share of imports in China's economy increases significantly after its economic boom in 2002. This increase could be decomposed into the general increased consumption of goods from a larger economy and also the intermediate goods imported from foreign countries which are used in the production of goods destined for export. Our model does not allow us to make this decomposition, so we likely have an upward bias in estimate of China's EEI from the perspective of consumption-based accounting. This in turn places a downward bias on the resulting BEET for China's economy.

Figure 4: China's BEET and Net Total Emissions



It is clear from Figure 5 that the UK is a net importer of emissions. While the country's BEET is near zero at the start of the period, the net quantity of emissions embodied in the country's imports grows steadily, reaching a maximum balance of -102 Mt CO_2 before the financial crisis in 2008. This is not a surprising result, given the country's large dependence on imports as evidenced in Figure 2, and it also seems reasonable to assert that the growing trade imbalance in the country after 1995 is due at least in part to the UK joining the WTO in that year. We can see from Figure 7 that, while the UK's total CO_2 emissions remain relatively constant over the period, once we factor in the net balance of the emissions released to produce the goods and services that it imports, the country's net total emissions are in fact increasing over the majority of the time frame before the financial downturn in 2008. This indicates that the UK has shifted an increasingly significant portion of the emissions associated with its consumption outside of its own borders. Other estimates of the UK's BEET appear in line with the quantities produced by our analysis, though our estimates of the country's EEI are low compared to many other studies (Li and Hewitt 2008, Sato 2014).

Figure 5: The United Kingdom's BEET and Net Total Emissions

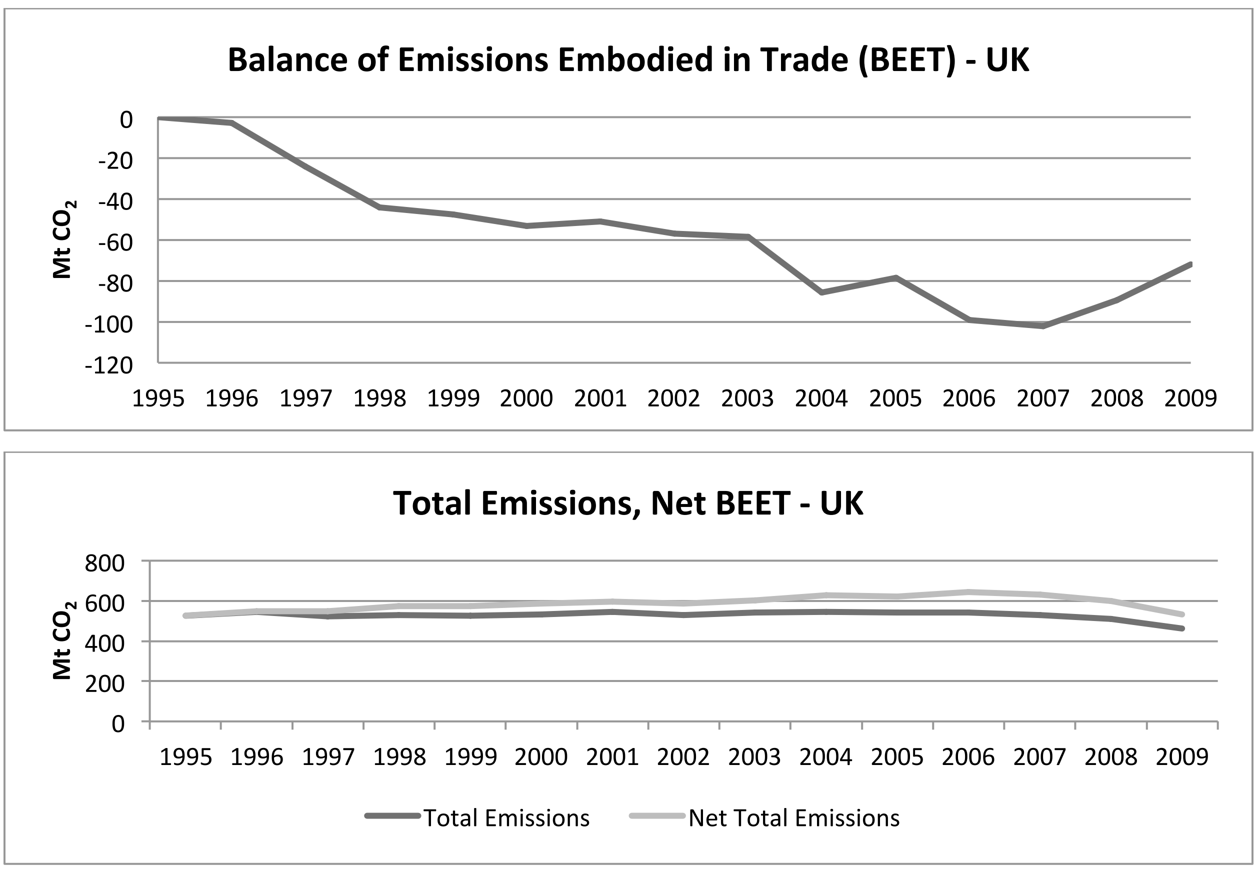
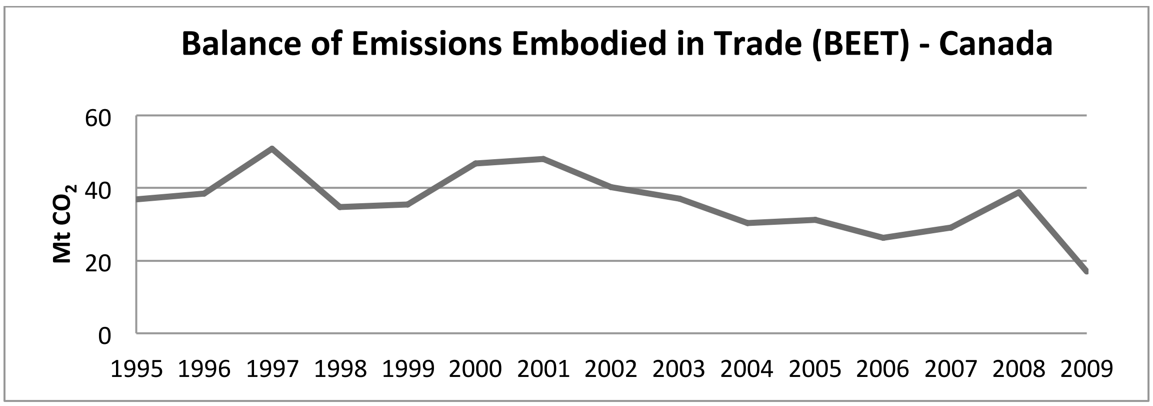


Figure 6 more clearly highlights the trends in Canada's embodied CO_2 emissions which were noted previously. There is a clear downward trend in Canada's BEET over the period, from its highest value of 51 Mt CO_2 in 2001 down to 17 Mt CO_2 in 2008. This last value appears to be a more dramatic break in the overall trend owing to the financial crisis in 2008 softening global markets for exports, especially in the United States, Canada's largest trading partner. This tracks with a sharp decrease in the country's total output and exports in the same year. Table A1.1 shows that the gradual reduction in the magnitude of Canada's BEET is the result of its EEI increasing at a faster rate than its EEE, which, when coupled with the results shown in Figure 2, suggests that, although Canada's imports are declining relative to its total output, the emissions content of its imports is on the rise.

Figure 6: Canada's BEET and Net Total Emissions



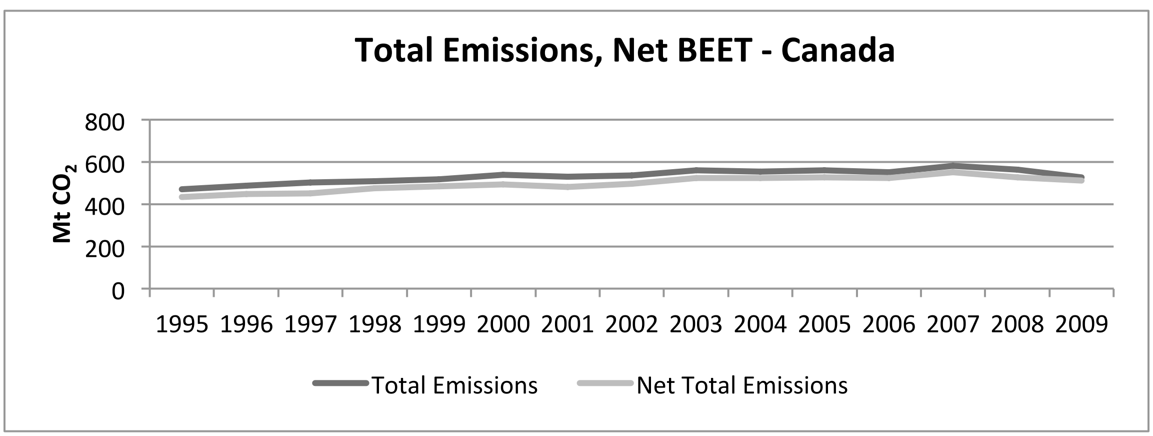
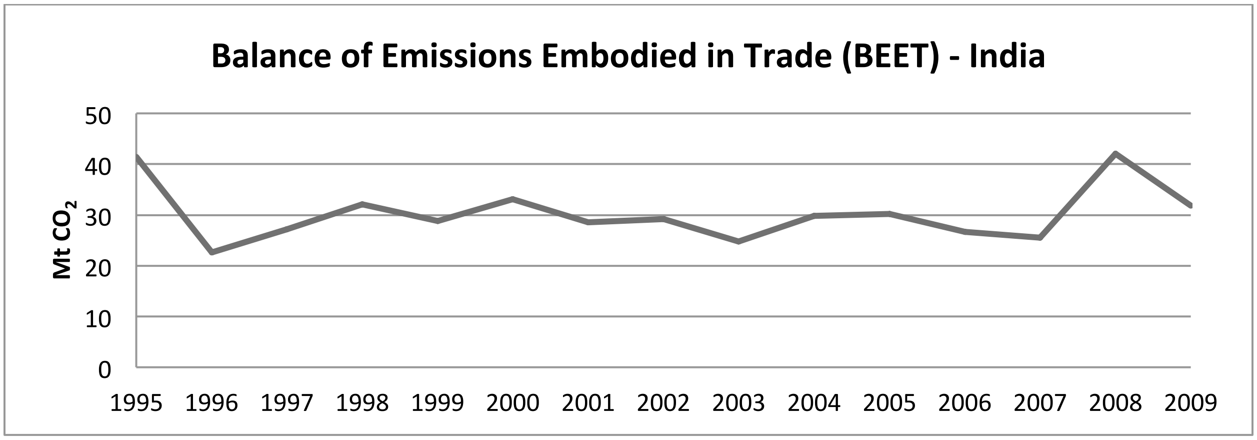
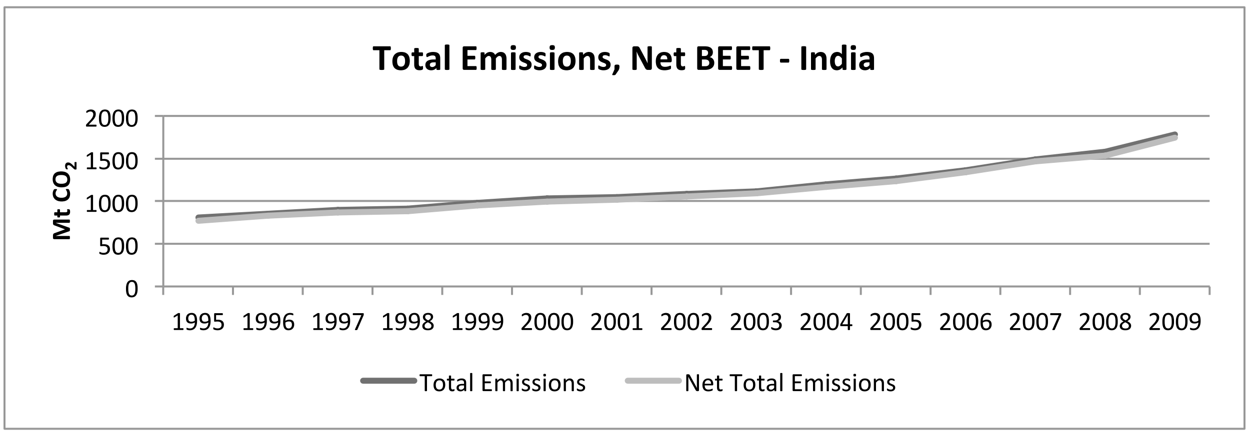


Figure 7 shows India maintaining a positive BEET of roughly 30 Mt CO_2 for most of the period. Significant growth in the country's economy over the period is reflected in an increase in both imports and exports, and considering the relatively unchanging quantity of India's BEET there does not appear to be evidence of carbon leakage from the economy. This result appears consistent with the findings of other research papers (Sato 2014), although as with China our estimates of India's EEE and EEI are consistently below the lower bounds of existing estimates. The difference in estimates is not as pronounced as with China, and there is also a much smaller body of work studying India's emissions balance so we draw no definitive conclusions from this.

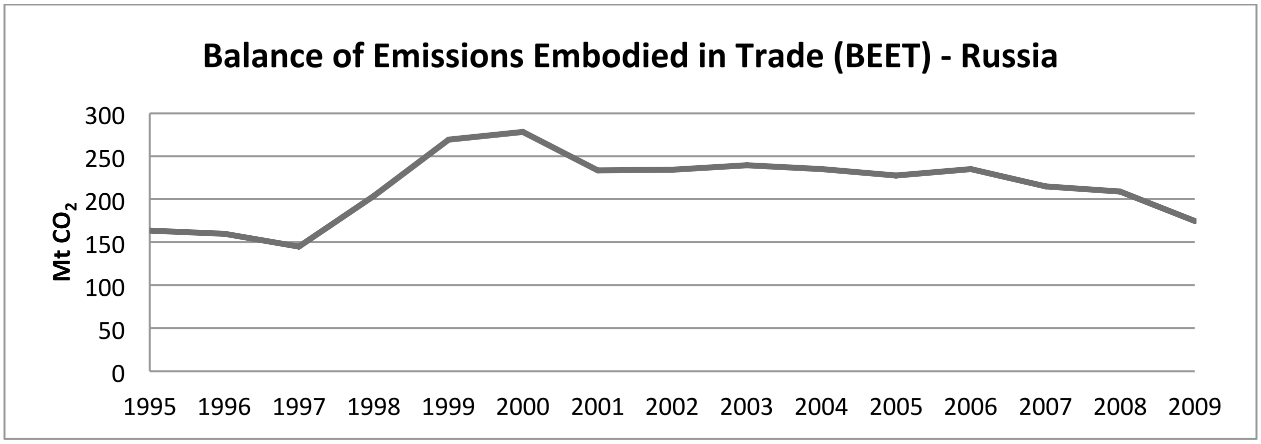
Figure 7: India's BEET and Net Total Emissions

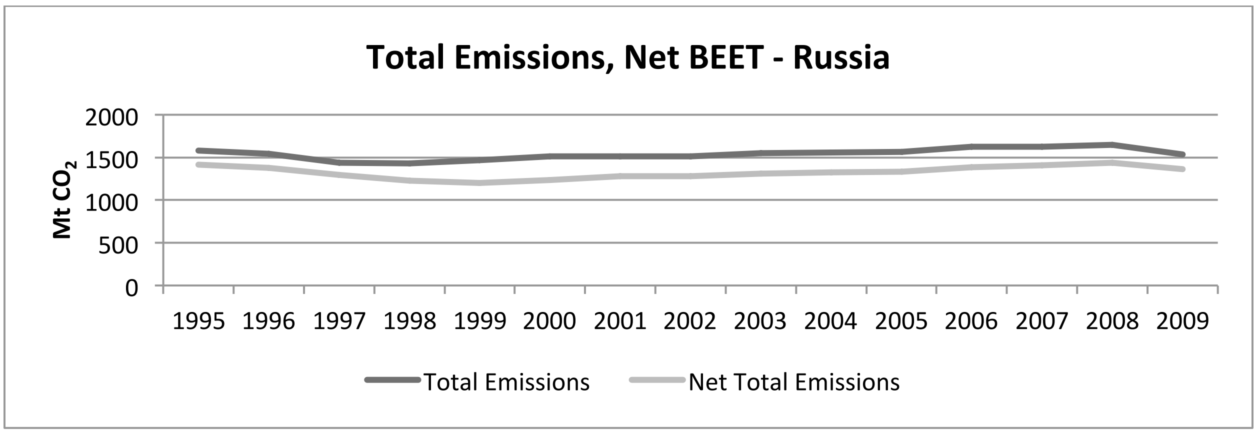




Finally, our estimates show Russia as having the highest BEET in each year of the time period, though this is likely in part due to the unusual estimates obtained for China's BEET. Figure 6 shows a significant jump in the magnitude of Russia's BEET in the first half of the period, owing to a large increase in exports after 1997. This growth in exports is likely explained by Russia capitalizing on high oil prices in the late 1990s, particularly in response to the Russian financial crisis of 1998. Past this point we see a period of growth, and then the general downward trend in BEET, which appears to be common across developed economies. As with Canada, we see a decrease in the proportion of imports relative to total output in Russia, with an accompanying decrease in BEET that suggests an increase in the emissions intensity of imports.

Figure 8: Russia's BEET and Net Total Emissions





Sources of Error and Uncertainty

Reliability of Data

As is particularly noticeable in the EEI and EEE estimates for China (Table A1.2), there is a large degree of inconsistency in the accuracy of the emissions intensities derived from the WIOD data. It is evident in our underlying data that the estimated emissions intensities across all sectors in China decrease over the time period, often dramatically. On average, emissions intensity drops by 61% across all sectors in China, as compared to an average 18% reduction in intensity in the United States over the same period. In many cases, this drastic reduction puts China's emissions intensities at or below the levels of developed countries, and, given the high share of coal in China's energy mix and comparatively lax environmental regulation, this seems to be a highly improbable outcome. The problem does not appear to be exclusive to China, but it is most prominent due to China's high total emissions relative to those calculated to be embedded in its trade flows and the dramatic growth rate of its economy over the period.

Our method for obtaining these intensities, outlined in equation (1), was a straightforward calculation of the tonnes of CO_2 produced per real dollar of output in each sector based on the total sectorial emissions and output reported in the WIOD data. Given that WIOD calculates emissions in each sector as the total output of production in each sector multiplied by an emissions intensity factor based on energy input data, the intensities estimated for this analysis should match those used by WIOD on average, which casts doubt on the reliability of the underlying data. It is clear that there is an error somewhere in the chain, whether it be in WIOD's calculations of emissions intensity or some aspect of our own methodology that has escaped scrutiny.

Approximations Employed in Methodology

The choice to employ a simple scaling factor to import emissions intensities based on the relative emissions intensity of the source country to the domestic country introduces a degree of imprecision in our estimates. Firstly, in doing this we assume that foreign production has the same general relative intensity between sectors as domestic production, which has an ambiguous impact on our results depending on the degree to which this is true and the direction in which we have possibly over- or underestimated the country-specific intensities. Secondly, in utilizing aggregate values of total emissions and gross domestic product when computing this value, we do not make a distinction between production and consumption. This possibly skews our results in an ambiguous direction, depending on the level of agreement between the emissions intensities of production and consumption. Based on a shallow examination of the disaggregated production and consumption data found in WIOD, this impact is expected to be negligible.

Purchasing Power Parity (PPP)

Owing to the fact that WIOD expresses the values of its data in USD for all countries, it is impractical to test the sensitivity of our results to the expression of value in terms of PPP as opposed to only real dollars. There is evidence that results can be highly sensitive to PPP for certain countries (Sato 2014).

VI. CONCLUSION

In our analysis, we estimated the net balance of emissions embodied in trade for six significant trade economies. We employed a bilateral input-output model that incorporated sectorial disaggregation of goods and services, as well as a measure of heterogeneity in production intensity, across sectors and across countries. Our results indicate that the United States and the United Kingdom are net importers of emissions over the entire period, and that the magnitude of the imbalance in their embodied emissions increases significantly over time. This suggests an increasing preference by those countries to reduce domestic emissions of CO_2 by importing products that require emissions-intensive processing. While China, India, Canada and Russia were found to be net exporters of emissions, there is a distinct difference in the growth rates of their respective BEETs. China's BEET grew steadily over the period, suggesting that there is increased foreign demand for the emissions-intensive goods it produces, while India's BEET remained consistent over time. Conversely, Canada and Russia's BEET decreased over the period, which, when coupled with decreasing imports, suggests that these developed countries also increased the emissions-intensity of the goods they import. Notable inflection points occur across all series in 2002, the first full year of China's membership in the WTO, and 2008 when the financial crisis caused a reduction in global trade and thereby a downturn in the magnitude of each country's BEET. It is noted, however, that our results appear to suffer from issues underlying the data set on which they are based.

Several avenues of further study follow from the results of our analysis. Most prominently, a similar analysis using an alternate data set would provide a good measure of the extent to which our findings do or do not suffer from issues in the emissions data used. The lack of alternative time series data makes this currently unapproachable, but should data become available it would be a worthwhile exercise. More substantively, it would be informative to conduct a similar analysis of BEET dynamics between these same countries once data for more recent years becomes available, considering the probable impacts of the dramatic fall in oil prices over the past few years, as well as China's increasing commitment to reduce its release of harmful emissions and move towards cleaner energy sources.

VII. LITERATURE CITED

Genty, Aurelien (ed), Inaki Arto and Frederik Neuwahl. "Final Database of Environmental Satellite Accounts: Technical Report on their Compilation." World Input-Output Database. April 2012.

International Monetary Fund. World Economic Outlook Database, April 2016. *http://www.imf.org.*

Li, You and C.N. Hewitt. "The effect of trade between China and the UK on national and global carbon dioxide emissions." *Energy Policy* 36.6 (2008): 1907-1914.

Pan, Jiahua, Jonathan Phillips and Ying Chen. "China's balance of emissions embodied in trade: approaches to measurement and allocating international responsibility." *Oxford Review of Economic Policy* 24.2 (2008): 354-376.

Sato, Misato. "Embodied Carbon in Trade: A Survey of the Empirical Literature." *Journal of Economic Surveys* 28.5 (2014): 831-861.

Shui, Bin and Robert C. Harriss. "The role of CO_2 embodiment in US-China trade." *Energy Policy* 34.18 (2006): 4063-4068.

United Nations Framework Convention on Climate Change. "National greenhouse gas inventory data for the period 1990-2013." UNFCCC. November 18, 2015. *http://unfccc.int.*

United States Department of Labor, Bureau of Labor Statistics. 2016. CPI Inflation Calculator. *http://www.bls.gov.*

United States Environmental Protection Agency. Global Greenhouse Gas Emissions Data. 2014. *http://www3.epa.gov.*

Weber, Christopher L. and H. Scott Matthews. "Embodied Environmental Emissions in U.S. International Trade, 1997-2004." *Environmental Science Technology* 41.14 (2007): 4875-4881.

World Bank. Gross Domestic Product Ranking Table. July 22, 2016. *http://data.worldbank.org.*

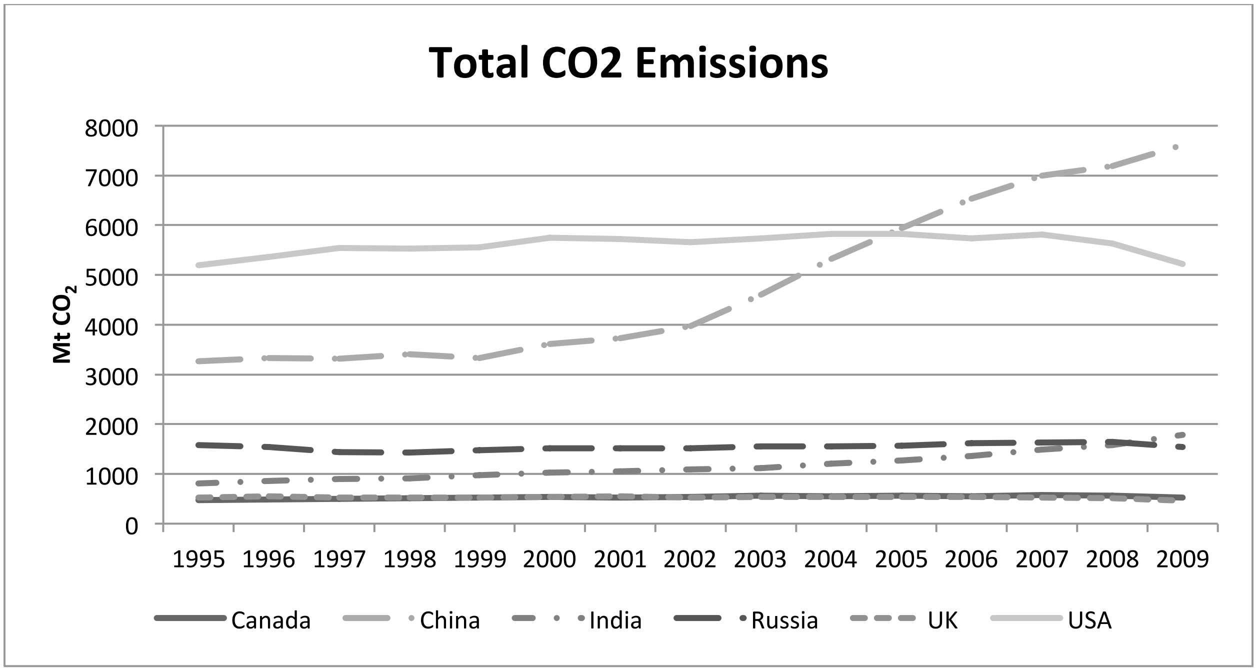
World Resources Institute, CAIT. 2014. Country Greenhouse Gas Emissions Data: CAIT Climate Data Explorer. Washington, DC: World Resources Institute. *http://www.wri.org.*

Wyckoff, Andrew W. and Joseph M. Roop. "The embodiment of carbon in imports of manufactured products: Implications for international agreements on greenhouse gas emissions." *Energy Policy* 22.3 (1994): 187-194.

Yan, Yunfeng and Laike Yang. "China's foreign trade and climate change: a case study of CO2 emissions." *Energy Policy* 38.1 (2010): 350–356.

APPENDIX

Figure A1: Total Emissions and Total Emissions, Net BEET


Total CO2 Emissions
8000
7000
6000
5000
4000
3000
2000
1000
0
Mt CO2
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009
Canada
China
India
Russia
UK
USA

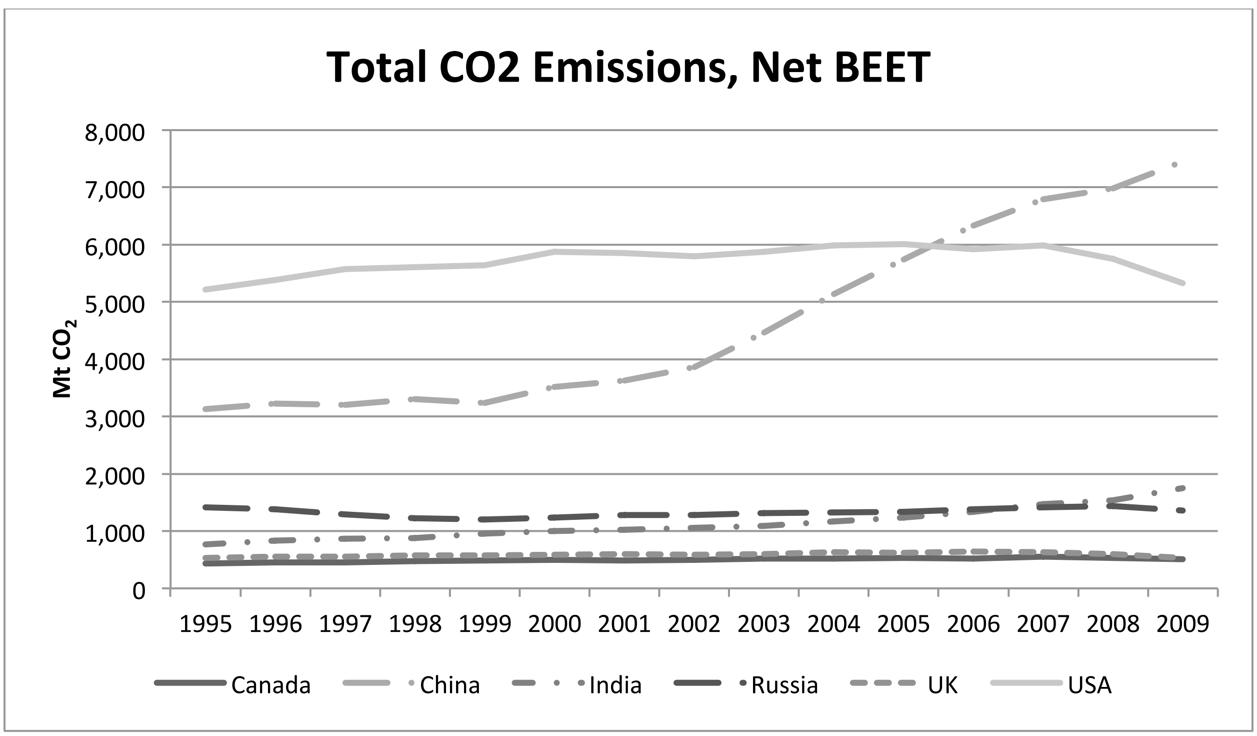

Total CO2 Emissions, Net BEET
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Mt CO2
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009
Canada
China
India
Russia
UK
USA

Table A1: Total and Embodied Emissions – Canada

Year	Emissions in Imports (Mt CO2)	Emissions in Exports (Mt CO2)	Net Import Emissions (Mt CO2)	Total Emissions (Mt CO2)	Net Total Emissions (Mt CO2)
1995	55.51	92.35	36.84	470.54	**433.71**
1996	57.32	95.85	38.53	486.20	**447.67**
1997	48.20	99.02	50.82	503.24	**452.42**
1998	70.04	104.76	34.72	509.17	**474.45**
1999	68.77	104.20	35.42	518.62	**483.19**
2000	65.12	111.90	46.78	539.23	**492.46**
2001	65.65	113.64	47.99	530.51	**482.51**
2002	66.13	106.42	40.29	537.06	**496.77**
2003	68.73	105.79	37.06	559.44	**522.38**
2004	73.44	103.77	30.33	553.75	**523.41**
2005	75.46	106.67	31.21	559.62	**528.40**
2006	76.16	102.50	26.35	551.30	**524.95**
2007	84.13	113.29	29.15	580.33	**551.18**
2008	84.42	123.18	38.76	564.29	**525.53**
2009	77.63	94.64	17.01	528.26	**511.25**

Table A2: Total and Embodied Emissions – China

Year	Emissions in Imports (Mt CO2)	Emissions in Exports (Mt CO2)	Net Import Emissions (Mt CO2)	Total Emissions (Mt CO2)	Net Total Emissions (Mt CO2)
1995	16.22	145.29	129.07	3258.78	3,129.71
1996	16.97	127.85	110.88	3335.32	3,224.44
1997	19.10	132.78	113.68	3317.75	3,204.07
1998	23.43	128.30	104.87	3406.19	3,301.32
1999	22.25	111.37	89.12	3325.52	3,236.40
2000	23.88	119.92	96.05	3607.56	3,511.51
2001	24.41	117.46	93.05	3725.55	3,632.50
2002	28.10	136.36	108.26	3966.66	3,858.40
2003	30.55	167.02	136.47	4606.21	4,469.74
2004	34.13	215.21	181.09	5320.63	5,139.55
2005	33.35	225.65	192.30	5935.70	5,743.40
2006	31.48	230.54	199.06	6529.78	6,330.72
2007	35.20	239.23	204.03	6994.72	6,790.69
2008	44.50	252.56	208.06	7187.61	6,979.55
2009	44.87	203.16	158.29	7612.15	7,453.86

Table A3: Total and Embodied Emissions – India

Year	Emissions in Imports (Mt CO2)	Emissions in Exports (Mt CO2)	Net Import Emissions (Mt CO2)	Total Emissions (Mt CO2)	Net Total Emissions (Mt CO2)
1995	18.40	59.83	41.43	808.68	767.25
1996	13.73	36.33	22.61	853.04	830.43
1997	12.12	39.25	27.13	897.92	870.79
1998	15.02	47.12	32.10	913.36	881.27
1999	16.40	45.23	28.82	981.02	952.19
2000	15.71	48.76	33.05	1,029.81	996.76
2001	14.35	42.93	28.58	1,048.17	1,019.59
2002	14.22	43.38	29.16	1,084.52	1,055.36
2003	13.70	38.51	24.81	1,115.43	1,090.63
2004	19.31	49.18	29.87	1,200.20	1,170.33
2005	23.95	54.20	30.25	1,265.24	1,235.00
2006	33.69	60.32	26.62	1,364.54	1,337.91
2007	38.44	64.02	25.58	1,490.47	1,464.89
2008	32.24	74.26	42.02	1,577.46	1,535.44
2009	33.54	65.31	31.77	1,779.43	1,747.66

Table A4: Total and Embodied Emissions – Russia

Year	Emissions in Imports (Mt CO2)	Emissions in Exports (Mt CO2)	Net Import Emissions (Mt CO2)	Total Emissions (Mt CO2)	Net Total Emissions (Mt CO2)
1995	8.08	171.65	163.58	1576.92	1,413.34
1996	9.08	169.33	160.25	1540.65	1,380.40
1997	11.00	155.99	145.00	1439.72	1,294.73
1998	8.04	211.66	203.62	1429.51	1,225.89
1999	6.39	275.86	269.47	1470.36	1,200.89
2000	9.37	287.45	278.08	1512.86	1,234.78
2001	9.75	243.46	233.71	1515.69	1,281.98
2002	10.01	244.48	234.47	1514.78	1,280.31
2003	11.42	251.02	239.59	1547.96	1,308.37
2004	12.31	247.43	235.12	1557.00	1,321.87
2005	13.77	241.79	228.02	1562.67	1,334.65
2006	17.60	252.80	235.20	1621.66	1,386.46
2007	19.30	234.63	215.33	1626.37	1,411.04
2008	21.58	230.99	209.41	1647.70	1,438.29
2009	20.84	195.42	174.59	1535.18	1,360.59

Table A5: Total and Embodied Emissions – United Kingdom

Year	Emissions in Imports (Mt CO2)	Emissions in Exports (Mt CO2)	Net Import Emissions (Mt CO2)	Total Emissions (Mt CO2)	Net Total Emissions (Mt CO2)
1995	79.32	79.21	-0.11	526.67	526.79
1996	89.19	86.33	-2.86	546.02	548.87
1997	109.73	85.72	-24.02	524.24	548.25
1998	123.95	79.72	-44.22	528.84	573.07
1999	126.48	79.05	-47.43	526.13	573.56
2000	139.42	86.38	-53.04	533.82	586.86
2001	141.29	90.40	-50.89	546.15	597.04
2002	145.77	88.94	-56.82	530.66	587.48
2003	151.02	92.44	-58.58	542.68	601.26
2004	179.92	94.34	-85.59	543.62	629.21
2005	178.17	99.60	-78.56	541.55	620.12
2006	188.65	89.57	-99.08	543.27	642.35
2007	192.29	90.16	-102.13	530.02	632.15
2008	189.89	100.33	-89.56	509.82	599.38
2009	164.63	92.81	-71.81	461.84	533.65

Table A6: Total and Embodied Emissions – United States

Year	Emissions in Imports (Mt CO2)	Emissions in Exports (Mt CO2)	Net Import Emissions (Mt CO2)	Total Emissions (Mt CO2)	Net Total Emissions (Mt CO2)
1995	209.40	191.47	-17.93	5193.70	5,211.63
1996	211.42	192.10	-19.33	5359.27	5,378.60
1997	238.23	202.70	-35.52	5538.45	5,573.98
1998	265.74	186.84	-78.90	5527.87	5,606.77
1999	279.17	190.23	-88.94	5555.72	5,644.65
2000	332.72	202.59	-130.13	5747.85	5,877.98
2001	317.21	192.85	-124.36	5728.18	5,852.54
2002	321.93	181.49	-140.45	5656.23	5,796.68
2003	317.50	178.60	-138.90	5733.57	5,872.47
2004	351.98	189.65	-162.33	5820.30	5,982.62
2005	368.01	192.44	-175.57	5830.48	6,006.06
2006	380.23	202.29	-177.94	5741.38	5,919.32
2007	393.72	227.11	-166.61	5818.19	5,984.80
2008	327.13	217.41	-109.71	5638.27	5,747.98
2009	298.02	191.98	-106.05	5224.06	5,330.10

Table A7: Countries Included in WIOD World Input-Output Tables		
Australia	Greece	Poland
Austria	Hungary	Portugal
Belgium	India	Romania
Brazil	Indonesia	Russia
Bulgaria	Ireland	Slovak Republic
Canada	Italy	Slovenia
China	Japan	Spain
Cyprus	Korea	Sweden
Czech Republic	Latvia	Taiwan
Denmark	Lithuania	Turkey
Estonia	Luxembourg	United Kingdom
Finland	Malta	United States
France	Mexico	
Germany	Netherlands	