# Uncertainties in environmentally extended MRIO tables arising from assumptions made in their construction and the effect on their usefulness in climate policy

Anne Owen[1] and John Barrett[2]

[1]PhD candidate at School of Earth and Environment, University of Leeds, Leeds, LS2 9JT

[2]Professor at School of Earth and Environment, University of Leeds, Leeds, LS2 9JT

a.owen@leeds.ac.uk

## Abstract

The use of environmentally extended multi-regional Input-Output (MRIO) tables has been applied to numerous applications related to accounting for emissions from consumption (Kanemoto et al., 2011a; Peters & Solli, 2010, Minx et al, 2009). However, global MRIO tables are not specifically created for this purpose and have to be approximated using individual country level input-output tables and information on bilateral global trade. Creation of an MRIO table is a significant undertaking requiring many assumptions in its construction (Inomata et al., 2006). Each assumption inherits and passes on error and uncertainty to the system. Using the freely available OECD set of IO tables and UN's ComTrade database, this paper briefly describes the methods for constructing an MRIO and highlights where uncertainties may lie. The paper then classifies the types of assumptions that have to be made in each case and suggests a framework for investigating uncertainty in the model and a methodology for understanding implications of decisions made in model construction. The research aims to parameterise the space each input variable resides in, create input distributions for each model variable and show the differences in model outcome that result from a change in input variable. It is suggested that by gaining further insight into the sensitivities of input variables and the assumptions made in model creation, MRIO analysts can better understand which inputs and decisions, make significant differences to the way emissions are reallocated to consuming countries, which in turn could have great significance in deciding emissions reduction responsibilities. These insights should help focus attention on which data needs most attention, which decisions are significant on the overall results.

## Keywords

MRIO construction, uncertainty, error, bilateral trade, RAS technique, Consumption based accounting

# Contents

# 1 Introduction

Accounting for a country's Greenhouse Gas (GHG) emissions usually takes a territorial perspective in line with UNFCCC guidelines, capturing only those emissions emitted within the territory itself (UNFCCC, 1997). More recently, research has considered GHG emissions occurring in foreign nations to satisfy domestic consumption. This consumption-based accounting approach is gaining policy relevance as nations consider their roles and responsibilities in global emissions reduction. Consumption-based approaches (CBA) can measure the impact of the products consumed by domestic population, taking into account emissions occurring throughout the global supply chain of the product's production. Tracing these global flows of emissions and understanding the complex pattern of production and consumption can also reveal the nature of carbon leakage[1] where production in country A is shifted to a country without emission reduction commitments to satisfy consumption in country A (Peter & Hertwich, 2008; Peters & Solli, 2010). Trade measures, such as Border Carbon Adjustments (BCA) are being considered to address concerns over leakage and competitiveness induced by the introduction of schemes such as the EU Emissions Trading Scheme (EUETS). The calculations involved in multilateral agreements, such as BCA, require a robust global accounting framework, capable of measuring and allocating impacts (Lockwood & Whalley, 2010; de Cendra, 2006). If these measurements are to be trusted, the uncertainties inherent in the calculations also need to be implicit and understood.

Input-Output (IO) techniques have long been used to understand the economic linkages between production and consumption, and their use in reallocation of emissions from the producer to the consumer is well documented (Wiedmann, 2009; Wiedmann et al, 2011). Extending the IO technique to a measure of global interactions can provide a modelling framework - a Multi-regional IO table (MRIO) - from which analysts can start to explore emissions associated with consumption patterns and trade. Model outcomes have been used beyond the academic forum in the creation national emissions inventories, to explore drivers of emissions and to estimate the 'carbon footprint' of products, sectors, individuals and businesses (see Minx et al., 2009 for further applications). Creation of an MRIO table is not trivial, and many assumptions and decisions have to be made in its construction (Inomata et al., 2006). Each assumption made inherits and passes on error and uncertainty to the system. Authors including Peters et al., (2011a) and Wiedmann et al., (2011) call for further research into MRIO comparison and understanding error. This paper describes the process of building a relatively simple MRIO model with the specific aim of understanding the nature of uncertainties in the system. Investigation of assumptions inherent in MRIO construction involves testing the model with each combination of assumption sets to gain insight into the full range of model outputs achievable at regional down to sector level. By testing assumption sets we can understand which decisions are critical and result in widely different model outcomes and which decisions make little difference. An outcome of this research might be establishing that results at an aggregated level can be reviewed with a high level of confidence but that caution needs to be taken when scrutinising each individual element. These findings will be crucial for deciding whether certain policies such as BCA can be modelled to an appropriate degree of accuracy using MRIO techniques. Findings may also aid the research community in this field focus attention on which data needs to be better collected so fewer assumptions are taken.

[1] Peters & Solli (2010) define weak carbon leakage as the shifts that happen over time due to changes in demand and strong carbon leakage as any shifts that can be attributed to a change in policy in country A.

Section 2 of this paper gives a brief overview of MRIO, the data needed to build an MRIO system and models currently available. Section 3 describes the process of building an MRIO and at each stage reveals any decisions and assumptions that have to be made in the construction process. Section 4 explains how analysts can measure variation and uncertainty in MRIO model results. Initial model runs from the MRIO built for this research are revealed in Section 5 and findings are briefly explained. Finally, next steps and future research is discussed in section 6.

# 2 Literature review

The use of IO models (IOM) to measure the value and the emissions embodied in traded goods and services is rapidly becoming one of the major research areas in IO analysis (Ahmed & Wyckoff, 2003; Duchin, 2005; Kanemoto et al., 2011a; Lenzen et al, 2010; Minx et al., 2009; Nakano et al., 2009; Peters & Solli, 2010; Peters & Hertwich, 2008; Su & Ang, 2011; Tukker et al., 2009; Weber & Matthews, 2007; Wiedmann et al, 2011; Wiedmann, 2009; Wiedmann et al., 2007). IO analysis can be used to reallocate emissions from the source production to the products consumed by final demand. Adding a geographic extension to this framework reveals impacts associated with trade. To start to consider the impacts associated with global production systems, we need to be able to calculate impacts of production globally and at the national level and understand how goods and services are traded globally. The literature describes two theoretical approaches to considering expansion of the system to a global scale. **Consumption based emissions** (CBE), referred to as the Carbon Footprint, are the sum of the Global Emissions to satisfy final demand in a particular country or region A, whereas **trade-adjusted emissions inventory** (TAEI) is the territorial emissions in country A minus the balance of emissions embodied in trade[2] (Peters & Solli, 2010).

## 2.1 Data requirements to extend IOMs to consider Global impacts

Both CBE and TAEI require a set of regional IO tables (IOT) alongside additional data to help understand the complex web of international trade interactions that take place between each region. The EU (European Union) member states are required to produce standardized 60 sector supply and use table (SUTs) on an annual basis to comply with ESA95, from which a set of symmetric IO tables (SIOTs) are generated every five years (Tukker et al, 2009). Other major nations produce SUTs and SIOTs but there is no Global standardisation to sector classification (Tukker et al., 2009). In producing country level SIOTs both a domestic table and an imports table is produced. The domestic and imports tables have the same structure; showing for each sector, the amount of goods by sector needed for domestic production processes and the associated final demand for domestic and imported products. The imports table is not broken down by country, so the tables show the sector that is imported, but not the country it is imported from. Additional bilateral trade data (BTD) is required to break down the imports by source country.

In addition to information describing the economic interactions in global supply chains, emissions data by global production sectors is required as model inputs. For the EU member states' 60 sector SIOTs, matching sector emissions data is available from the National Accounting Matrix including Environmental Accounts (NAMEA) (Eurostat, 2005). For a Global system, consistent emissions data is needed for every country in the database. The literature describes two approaches as to assigning an

[2] The territorial emissions minus the emissions in country A that are used for export, plus the emissions from other territories used to make imports to country A (Peters & Solli, 2010).

impact per unit of output to each industrial sector. The International Energy Agency (IEA) produce tables showing energy output by industry by country and authors such as Shimoda et al (2008) explain how IO data is matched to emissions. However this technique is criticised by Tukker (2009) who points out that not all countries are signatories of the IPCC (Intergovernmental Panel on Climate Change) so do not have to report such statistics. An alternative method involves estimating the $CO_2$ emissions associated with an industry based on the reported energy use of each sector. To do this, data is used from the IOTs, to determine how much is spent on fuel that is burnt on site. However, this technique incurs the problem of Global emissions totals not summing to the reported Global totals (Tukker 2009). Clearly there is uncertainty inherent in emissions inventories used by models.

## 2.2 Emissions in traded goods

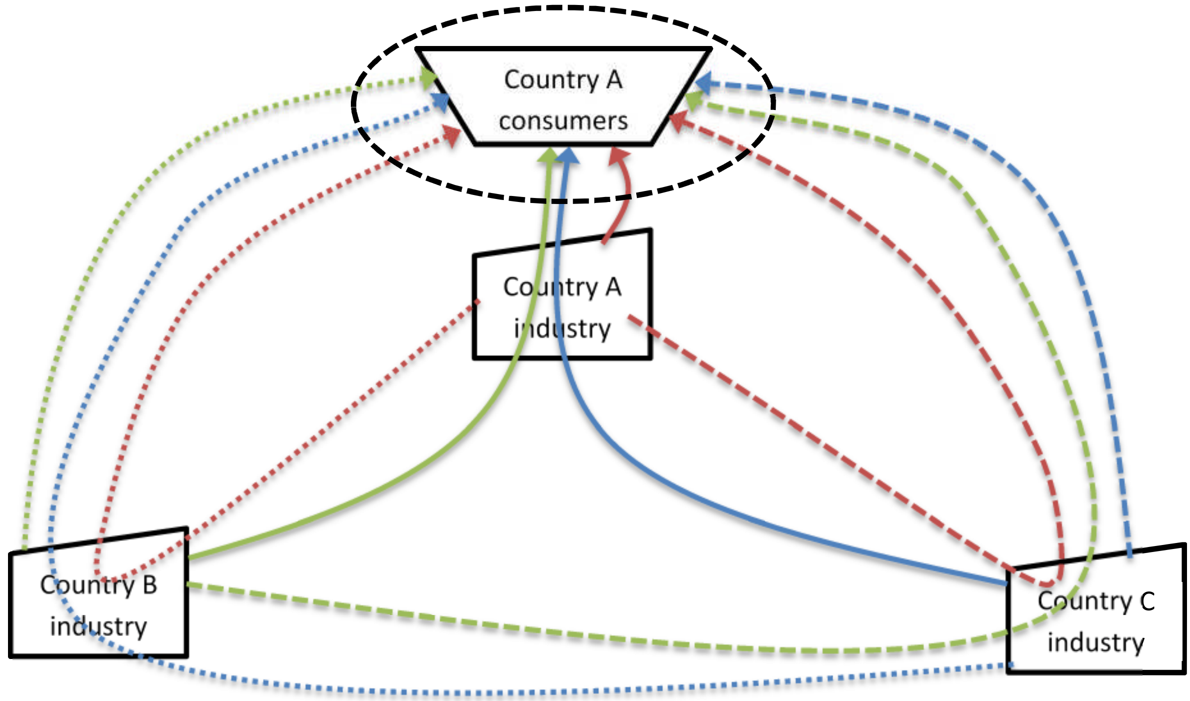
The impacts of trade flows from the rest of the world to country A can occur in two ways. Either a consumer in country A buys an imported finished good as a final demand product, or an industry in country A imports goods from the rest of the world as intermediate demand. Similarly, emissions can leave Country A either in finished goods as final demand imports or as intermediate demands to other countries' industry. Accounting for the size of these flows and hence the size of the emissions is complex and there are two main methods to building and using systems capable of tracing these emissions embodied in trade (Peters, 2008). The Emissions Embodied in Bilateral Trade (EEBT) method is used to determine the TAEI and the Multi-Regional Input Output (MRIO) method is used to measure CBE. This research now focuses on the MRIO methodology.

## 2.3 The MRIO approach

Where the EEBT approach considers a set of national SIOTs linked by measures of imports and exports, an MRIO approach can be considered as one very large single IOT. In the MRIOT each column shows the industry requirements from both domestic sectors and foreign to produce a product from a specific sector in a specific country. This means that if a consumer in country A, buys a domestically produced product, it takes into account any intermediate flows from countries B and C that are used to make products in country A that are consumed by country A consumers.

Figure 1 explains the emissions flows captured by an MRIO in forming the consumption based emissions account for country A. Flows from domestic production are shown as arrows with solid lines. Note that the **blue** and **green** solid arrows represent goods *purchased* from domestic production in country A but originate from industries in countries B and C with some processing in A. This effect is shown by the arrow passing through 'country A's industry'. Also note that a product imported to final demand from country B (dotted arrows) can include not only emissions from industry in countries B and C, but also some domestic territorial emissions from country A. Here the boundary is drawn around Country A's consumers and does not include country A's industry. If the boundary included industry, the red arrows would be double counted. The MRIO system can show the consumption account for country A broken down by the country of final assembly, (or the place shown in the final demand imports), by summing the solid arrows (for country A), the dashed arrows (for country B), and the dotted arrows (for country C). Or, alternatively, the system can show the consumption account broken down by source country by summing the red arrows (for country A), the blue arrows (for country B) and the green arrows (for country C).

Figure 1: Flows included in measuring consumer emissions in country A using MRIO




A full multiregional input output model (MRIO) can isolate and measure each of the explicit flows from every industry, in every country making up the full supply chain of a product (Su and Ang, 2011; Wiedmann et al, 2011; Wiedmann, 2009). Tukker et al. (2009) state MRIO as "the best way of taking trade into account" but again, Peters and Solli (2010) explain that this is very much dependent on the research question. MRIO can help measure the impacts of a country's final consumption, but it does not distinguish final and intermediate demand because the intermediate demand is inherent in the MRIO table. The EEBT approach is the only way to count the exact size of the flows that leave a country as exports (regardless of if they flow back in imported goods). Both EEBT and MRIO account for the same global emissions but the allocation is different depending on the level of trade in intermediate products.

In theory, an MRIO table (MRIOT) for n countries each with m sectors is a super matrix of dimensions 'm x n' rows by 'm x n' columns. Figure 2 shows the MRIOT as being constructed by placing the SIOTs[3] from every region along the diagonal of a large composite matrix and filling in the off diagonal matrices to show the sectoral requirements from non-domestic regions in the production of domestic products (Peters et al., 2011a). This assumes that SIOTs are available for all nations, there is a degree of harmonisation in sectors described and that trade linked data can be determined (Tukker et al., 2009). One of the reasons the EEBT technique has been used to account for emissions from consumption rather than a full MRIO analysis is the difficulties in obtaining suitable data to construct a MRIOT (Peters et al., 2011a). Different countries having matching sectors in SIOTs is rare

[3] An MRIOT can be produced using SUT tables, see Lenzen et al. (2011) but for this research we focus on building an MRIOT from SIOTs

and filling in the off diagonal sections is complex, time consuming and can involve a lot of assumptions.

Figure 2: Diagrammatic representation of an MRIOT

<table>
<tr><td>Country A's SIOT</td><td>Country A's industry used to make Country B's products</td><td>Country A's industry used to make Country C's products</td><td>Country A's industry used to make Country D's products</td><td>A 's Final Demand from A</td><td>B's Final Demand from A</td><td>C's Final Demand from A</td><td>D's Final Demand from A</td><td rowspan="4">Total output</td></tr>
<tr><td>Country B's industry used to make Country A's products</td><td>Country B's SIOT</td><td>Country B's industry used to make Country C's products</td><td>Country B's industry used to make Country D's products</td><td>A's Final Demand from B</td><td>B's Final Demand from B</td><td>C's Final Demand from B</td><td>D's Final Demand from B</td></tr>
<tr><td>Country C's industry used to make Country A's products</td><td>Country C's industry used to make Country B's products</td><td>Country C's SIOT</td><td>Country C's industry used to make Country D's products</td><td>A's Final Demand from C</td><td>B's Final Demand from C</td><td>C's Final Demand from C</td><td>D's Final Demand from C</td></tr>
<tr><td>Country D's industry used to make Country A's products</td><td>Country D's industry used to make Country B's products</td><td>Country D's industry used to make Country C's products</td><td>Country D's SIOT</td><td>A's Final Demand from D</td><td>B's Final Demand from D</td><td>C's Final Demand from D</td><td>D's Final Demand from D</td></tr>
<tr><td>Value Added from A</td><td>Value Added from B</td><td>Value Added from C</td><td>Value Added from D</td><td colspan="4"></td><td></td></tr>
<tr><td colspan="4">Total output</td><td colspan="5"></td></tr>
</table>

## 2.4 MRIO Systems currently available

Despite many countries producing IO tables on an annual basis and also reporting their bilateral trade, the number of fully operational MRIOTs remains low and many systems are unable to be updated regularly due to funding dependencies (Peters et al., 2011a). The latest audits of the main global MRIO initiatives (Peters et al., 2011a; Wiedmann et al., 2011), describe five MRIO systems: Exiopol, GTAP, Eora, AIIOT and WIOD.

### 2.4.1 EXIOPOL

**EXIOPOL** has a large number of consistent sectors (124 sectors from Peters et al., 2011a; 130 sectors from Wiedmann et al., 2011; about 130 from Tukker et al., 2009) and the authors argue that this sector level of detail was their main consideration and the advantage **EXIOPOL** has over other systems (Tukker et al. 2009). The **EXIOPOL** authors state their aim of being as faithful as they could to official, publically available statistics and not manipulating source data too much. The system has 44 world regions with the main focus - the EU27 nations - represented as separate countries, alongside 16 other countries and a rest of world region. Nations were chosen representing important trading partners to the EU, but the authors recognise that many countries that are important in supplying energy resources to Europe, such as countries in the Middle East, are lumped together in the rest of world region. **EXIOPOL** only contains a single year's worth of data (the year 2000) and updates to the system will be funding dependent. Since it has only just been made available, there is limited academic literature on its application.

### 2.4.2 GTAP

For its latest year (2007), the Global Trade Analysis Project (**GTAP8**) initiative has a larger number of regions than **EXIOPOL** (127), and 57 commodity sectors. The **GTAP** system relies largely on voluntary contributions and contributors must enter the data to match specific requirements and fields. Checks are performed on the data but guarantee of its quality is one of the criticisms cited with this system (Peters et al., 2011a). In addition, Peters et al., (2011a) observe that it is difficult to find out exactly how much the original data supplied to **GTAP** is modified by the harmonisation and balancing techniques. **GTAP** was also never intended to be used for, and is not provided as a full MRIOT, but it can be has been converted to a full MRIO system (Peters et al., 2011a). Conventional IOTs use basic prices, but **GTAP** contains data in market prices. Peters et al., (2011a) explain that market prices are close to basic prices and can be used in IOA. In addition, the **GTAP** database is already balanced so conversion to an MRIOT is fairly straight forward (Peters et al., 2011a). Wiedmann, (2009) cites the **GTAP** system as being the MRIO which has been used for the most environmental analyses. Examples include, but are not limited to Peters' (2007) initial study of traded emissions in 87 world regions[4]; Peters et al. (2011b) consideration of the growth in emissions in trade from 1990 to 2008; Davis et al., (2011) work on supply chains of energy consumption. An advantage of the **GTAP** system is that the database is updated at regular intervals, so studies can investigate impact over time (Peters et al., 2011a).

### 2.4.3 Eora

Eora is developed by the Integrated Sustainability Analysis (ISA) group at the University of Sydney (Kanemoto et al., 2011b, Lenzen et al., 2011). IO tables are provided for 187 countries for a time series from 1990-2009. The tables can be used at high resolution heterogeneous sector classification or as a 25 sector harmonised system. Eora also features reliability statistics for all results – one of the first systems to recognise the need for uncertainty to be acknowledged and explained. At the time of writing, Eora is only available to a pilot user group and will become more widely available in Summer 2012. Since the database is so new, there is little literature detailing its application.

### 2.4.4 AIIOT

The Asian International Input-Output Table (**AIIOT**) is produced by the Institute of Developing Economies, Japan External Trade Organisation (IDE-JETRO) and is available for 9 Asian countries, the USA and a rest of world (ROW) region. There is a 5 yearly time series of data starting in 1985 and from 1990 onwards, the system is available with 76 sectors (Peters et al., 2011a). The system is presented in balanced SIOTs and detailed documentation as to how this process was calculated is available (Inomata et al., 2006). No environmental extensions are provided with the system so other datasets have to be found and aligned (Peters et al., 2011a). Zhou and Kojima (2009) use the GTAP $CO_2$ environmental extension with the **AIIOT** MRIO to investigate consumer responsibility for emissions and found that for many of the Asian countries consumer emissions are considerably lower than the reported territorial emissions base. Lastly, Su and Ang (2011) compute emissions data based on the described energy consumption data based on the IPCC approach. This means they can keep the full 24 sectors used in the **AIIOT** tables. They compute a ROW region as the aggregation of all the nine Asian economies since it is believed that the ROW behaves in a similar way.

[4] Using GTAP6

### 2.4.5 WIOD

The World Input-Output Database (**WIOD**) is produced by the University of Groningen and covers the 27 EU countries and 13 others for the years 1995 to 2009 (Timmer et al., 2012). The system is built using country level SUT tables covering 35 industries and 59 products, or as a world IOT with 35 industries by 35 industries and an MRIOT with 6 regions and each with 35 industries (Timmer et al., 2012). Like **Eora** and **EXIOPOL**, **WIOD** was released in the last year and papers detailing its application are yet to appear.

### 2.4.6 OECD data

This research aims to construct a MRIOT for the purpose of investigating how differing methods of construction affect the results produced by the model. This 'test base' MRIO is not designed to be a rival to the five systems described above; rather an independent system where all data sources and assumptions can be known and tracked. The **OECD** compiles a set of 44 national IOTs comprising 48 sectors. Most countries tables are for the years 1995, 2000 and 2005 but there are some discrepancies in common years (see appendix 1). Wiedmann et al., (2011) do not count OECD data as an MRIO and to date there are no analyses that use the data in the full MRIO context. Nakano et al., (2009) use **OECD** IOT and BTD for 41 regions and 17 aggregated industries to measure $CO_2$ embodied in trade over time. The authors show countries with net trade deficits and those with trade surplus and warn of the worsening $CO_2$ leakage effects when production shifts to countries with more GHG intensive industry. The authors show that with increases in Global trade, emissions increase and that technology transfers from less carbon intensive countries to more carbon intensive economies reduce global emissions and carbon trade gaps. An EEBT technique is employed with a 'rigorous iterative procedure' to deal with imports rather than producing the off diagonal elements in an MRIOT. Similarly, Ahmad and Wyckoff (2003) use an EEBT type approach looking at consumption impacts of goods but not services.

This **OECD** data forms the cornerstones of the basic MRIOT built for this project and the model is henceforth named OECDMRIO. Details of construction are described in section 3.

# 3 Methodology: Constructing an MRIOTs and classifying assumptions

This section describes the steps taken to construct the OECDMRIOT and discusses the assumptions that had to be made at each stage and the types of error that making each assumption incurs. When building an MRIO a number of conditions need to be met, namely:

- The sum of the columns = sum of the rows
- The sum of value added = sum of final demand
- The sum of imports as intermediate demand to a country's industries should remain close to that reported in the imports SIOT
- The sum of exports from a country's industries to other country's industry and final demand should remain close to that reported in the domestic SIOT

## 3.1 The rest of world region

Sets of SIOTs do not cover every county in the world. For an MRIO to function without losing information, either a 'rest of world' (ROW) region is created to describe the trade flows of countries who have not produced SIOTs or equivalent SIOTs are chosen as proxies for the missing countries. This research initially chooses to create a representative single ROW region. The volume of trade by sector and country can be estimated by looking at the differences between reported Global trade flows and the sum of flows by countries whose data has been captured. The missing element is a generalised structure of the economy for the ROW; a ROW IOT. One approach is to pick a country that is considered representative of the ROW (Peters et al., 2007). The selection of this representative country will depend on which countries you already have data for. For example, some authors studying specific continents, such as Europe might choose China's IOT to represent the ROW (Peters et al., 2007). Nakano et al., (2009) when using the OECD IOTs to consider EEBT, used the emissions factors of Malaysia to represent the ROW. For their work on the AIIOT MRIOT, Su and Ang (2011) argue that the ROW region behaves similarly to the average Asian economy, noting similarities in the per capita GDP of the ROW and Asia and the emissions intensities. The authors aggregated nine Asian economies to simulate the emissions intensities and domestic IOT for the ROW. The final demand structure was also mirrored for ROW final demand (Su & Ang, 2011). Selection of the ROW region is an assumption responding to missing data and this research intends to investigate the effect of choosing a variety of countries as the proxy production and imports structure for the rest of the world.

## 3.2 Adjustment to common base currency

Each country's system of national accounts reflects the differing situation within each country as to how data is collected and what data is available (Inomata et al., 2006). An MRIOT needs to be consistent in the meaning of each category and number collected and as a first consideration, this means that each SIOT needs to be in the same currency. Exchange rates can be used to convert data to one common currency (Bouwmeester & Osterhaven, 2007). Additional changes that might be required to adjust the presentation of the national SIOTs used in an MRIOT include converting data to basic prices; adjusting the import matrices so that they are valued at CIF (cost, insurance and freight) and that they do not include import duties and commodity taxes; dealing with negative entries and representing government subsidies by treating the entity as 'value added' items. For more detail see Inomata et al., (2009). It is recognised that there are no "hard and fast" rules to this procedure and there are 'trade-offs' between a consistent and uniform system and level of original information and detail (Inomata et al., 2009).

For this research, the SIOTs are already in basic prices but are presented in domestic currencies. Another issue is that while most tables are for the year 2005, some represent the economic transactions of a different base year. Tables need to be converted to US dollars (USD) for the year 2005. Rather than use exchange rates to convert tables to USD then apply process of inflating or deflating values to show tables in the correct base year, it was decided to adjust all tables using a multiplying factor so that the sum of the value added (VA) data equals the reported GDP in 2005 USD as reported by the OECD (OECD, 2012). Summing the VA is one method of calculating GDP so multiplying the whole table by the factor will adjust for both currency and base year in one calculation. An obvious disadvantage of this method is that certain commodities may have inflated or deflated at different rates. Investigation into this effect may be one of the future directions of this research. Adjusting the prices in each SIOT to a single base unit will involve making an assumption as to which methodology is most appropriate given the source data.

The OECD IOT's also contained a number of negative values. For simplicity and to get a model running relatively quickly, this research altered all non-positive entries to be zero. Again the implications for making this assumption need investigating and further work into other methods of dealing with negative entries is suggested.

## 3.3 Creating common classification system

Once data in the SIOTs has the same meaning across all tables, each table has to be aggregated or disaggregated to a common set of sectors. Each national economy has its own unique characteristics and the sector classification system used to record data reflects this character. Some economies are heavily agriculture based and these countries will often use sector classification systems very detailed in the agriculture sectors, whilst other might be more biased to industry. Bouwmeester & Oosterhaven, (2007) note that often it is easier to revert to older classification systems when attempting to produce a common set of sectors. The Eora system preserves original sector classification systems, choosing to use concordance matrices to describe the off diagonal intermediate trade from foreign industry (Kanemoto et al., 2011b). However, the team have produced an aggregated table with a consistent set of 24 sectors for easier use. Summing two or more sectors to a single new sector is a simple enough procedure; Inomata et al (2009) note the difficulties that arise when a national IO entry needs to be split between two or more sectors in the new consistent sector system. However, Lenzen (2011) demonstrates that disaggregation is always more preferable to aggregating even when addition data required to disaggregate is of questionable quality.

The OECD data is presented as a consistent set of tables, each with 48 sectors. However, closer inspection reveals that although tables show columns and rows for a particular sector the data can be missing and actually included within another sector. A decision needs to be made as to whether to reduce the number of sectors to a common less detailed, smaller set or whether to use additional data to split categories up. For this research paper, categories were left as reported for ease of table creation. This means that not all sectors have the same meaning between countries[5] - an assumption of homogeneity due to lack of data. Further research will reveal the inaccuracy in this assumption.

## 3.4 Creating the import and export vectors

Once the domestic SIOTs are placed along the diagonal of the MRIOT's the import SIOTs need to be 'stretched' to fill the off diagonal parts of the MRIOT (see figure 2). The off diagonal matrices represent intermediate demand to industry from non-domestic sectors. Consider a set of n regions and m sectors in an MRIO system. A specific region k, will sell to and buy from 'n-1' other regions. This means that within the column that representing who region k's m industrial sectors buy from, a stack of 'n-1' additional trade matrices is needed along with region k's SIOT. The import SIOTs reveal the imports to region k by which of the m sectors is being imported and which of m sectors the imports going to (Tukker 2009). However, the tables do not reveal the country of origin, i.e. which of the n-1 regions is the import flow from.

A simple method is to evenly share each of the flows reported in k's import matrix across each of the n-1 other regions – so effectively each country supplies 1/(n-1)$^{th}$ of the imports of a particular commodity to each industry from each country. This means the import matrix is repeated and multiplied by a factor of 1/(n-1) in each of the 'n-1' off diagonal spaces in a column. This will preserve the MRIO condition that the sum of imports by destination industry should be preserved but it is unlikely that the row sums of the off diagonals will be close to the reported exports in the SIOTs. Also, assuming imports are evenly spread is a massive assumption.

Other techniques involve bringing in BTD data to disaggregate the flows (Bouwmeester & Oosterhaven, 2007). For example, the UN's ComTrade data shows imports by sector and source country to each country in the OECDMRIOT. For each sector, we calculate the share of total imports of this sector each region of origin supplies, then share the import matrix of region k by these import shares to produce the 'n-1' off diagonal import matrixes for region k (Bouwmeester & Oosterhaven, 2007). Like the equal share technique described above, using BTD will preserve the sum of imports MRIO condition but again it is unlikely that the row sums of the off diagonals will be close to the reported exports. Another limitation of this technique for disaggregating country of origin based on total global averages is that each industry j in region k buys the same percentage of products from industry i in region l (Bouwmeester & Oosterhaven, 2007). In other words, if UK industries are importing steel and Mexico is the country of origin for 60% of all of the steel that is imported by the UK, then for every industry in the UK, 60% of steel imported to domestic production will always come from Mexico regardless of the destination industry. This assumption is likely to introduce greater error when assessing the impacts of products from places whose domestic production is heavily reliant on imported components.

When describing the procedure for creating the GTAP MRIO, Peters et al., (2011a) constructed the off diagonal matrices by considering the exports from a country first. This means working along the row of off diagonal matrices. The authors distribute the bilateral exports (in producing country prices) from country k according to the import structure of each of the other n-1 countries. This means that the export balance consideration of MRIO is preserved (Peters et al., 2011a). Due to the fact that that the tables in the GTAP database are already balanced, the import structure – the sum

[5] For example, in one country pharmaceuticals and chemical products are separate sectors whereas in another, pharmaceuticals are contained within chemical products.

of the off diagonal columns - is also preserved and no additional balancing is required. Unlike GTAP, the OECD SIOT tables are not balanced (Nakano et al., 2009), the reported exports do not correspond to the reported imports, and since the tables are originally presented in domestic currency, the only method producing a 'matching sum' for the off diagonals is to consider spreading the imports across the columns rather than the exports across the rows. The table will then have to be subjected to balancing procedures to ensure that total row sums and total column sums are in agreement.

For this research, I attempt to assess the contribution that different methods of 'stretching' the off diagonal matrices has on the end result. The effect that evenly distributing imports between source countries has in comparison to using ComTrade to share goods product imports in different proportions is investigated. Further work will investigate splitting the ComTrade data into goods products for intermediate and final demand use and assessing whether using data of 'exports from' rather than 'imports to' gives a more accurate picture for some countries. In addition, datasets need to be sourced to disaggregate services data.

## 3.5 Balancing the MRIOT

Inomata et al., (2009) describe the table, at this stage, as being balanced with respect to input composition, but that demand and supply for each country are not consistent. The sum of flows of particular sector from a particular country to all countries of destination should equal the reported export by that country of origin in the BTD, however as Tukker (2009), Inomata et al (2009) and (Bouwmeester & Oosterhaven, 2007) note, this is rarely the case. Reasons for inconsistencies include but are not limited to:

- Valuating or recording imports and exports differently (Gou et al., 2009; Lenzen et al., 2004)
- Different definitions as to what constitutes a trade partner (Gou et al., 2009)
- Time lags between exports being shipped and imports received (Gou et al., 2009; Lenzen et al., 2004)
- Different classifications systems for goods and services (Gou et al., 2009; Lenzen et al., 2004)
- Losses due to accidents in transit (Gou et al., 2009)
- Smuggling (Lenzen et al., 2004)
- Unallocated trade of confidential goods (Gou et al., 2009)
- Trade in second-hand goods which have nor required recent manufacturing or scrap and waste products for recycling or disposal (Gou et al., 2009)
- Re-exports where goods pass through a country without any transformation and some countries record the goods' origin as the importing partner whereas others record the port the goods passed through leading to mismatches in import and export totals (Gou et al., 2009)

Gou et al., (2009) describe re-exports as an increasingly problematic issue with trade data, effecting records for China, Belgium, Hong Kong, the Netherlands, Singapore and Germany. These countries tend to be countries with large ports. In addition the sum of each column, including VA must equal the sum of each row including final demand (FD). The table needs to be bi-proportionally adjusted, using a method known as RAS, to ensure that it balances. This technique uses an iterative process to alter individual cell values using the known export columns and import rows of the original IO tables as constraints (Bouwmeester & Oosterhaven, 2007). Basically, the table is proportioned horizontally to ensure that the row sums total the correct value, and then re-proportioned vertically to the correct column sums. This procedure is repeated until both the row and column sums are to within an acceptable degree of error to what they 'should' be. For this research, another benefit of the RAS procedure will be to distribute the assumed 'even shared off diagonal imports' to a distribution that mathematically, as least, is a valid solution MRIOT. Because the domestic SIOTs and domestic final demand are treated as 'known data', before applying the RAS technique to the MRIO, these tables can be removed and replaced with zeros (Miller & Blair, 2009). However this technique can be shown to sometimes produce 'worse estimates' (Miller & Blair, 2009). The effect of 'fixing' and not fixing the diagonal SIOTs will be investigated as one of the methodological assumptions in this research. It is recognised that at present the OECDMRIO only satisfies the first three of the conditions for MRIO stated at the start of section 3. Further improvements to the model will attempt to satisfy condition four.

## 3.6 Environmental extension data

In order to use the MRIO to redistribute global emissions from the production of goods to the consumption of products, environmental extension data concerning emissions per industrial sector is required. In an MRIO of n countries each with m sectors, the dimensions of $F$, the extensions matrix which holds data on emissions, are 'm x n' by 'f', where f is the number of additional impact variables. An MRIOT of n countries each with m sectors requires the same amount of data for $F$ as n individual SIOTs meaning there are no additional information needs. If each SIOT has matching environmental extension data, the MRIOT is complete. This paper focuses on economic data and the method of assign environmental extension data to industrial sectors will be considered as future research.

## 3.7 Construction assumptions overview

| Assumption | Description | Method used and tests investigated for this paper | Further research required |
|---|---|---|---|
| **The rest of world region** | Need to choose a representative country for the production structure of the rest of the world region<br>Error type – lack of data | Test what happens if we use every one of the 44 SIOTs used in the database | Try aggregation of groups of typical regions to represent the rest of world. |
| **Adjustment to common base currency** | Need to ensure that all SIOTs are in 2005 USD basic prices<br><br>Error type – multiple calculation methods | Multiply the tables by a conversion factor so that the sum of VA/FD is equal to reported GDP in 2005 USD | Investigate the effect of using currency exchange rates and different sectors inflating and deflating at different rates. |
| **Creating common classification system** | All the SIOTs have 48 sectors but some contain zeros where data is unavailable<br><br>Error type – lack of data | None | Investigate methods for aggregating to common number of sectors or disaggregating combined sectors so that there are 48 sectors with data in for all regions. |
| **Creating the import and export vectors** | Need to produce vectors showing the structure of imports from all other countries and sectors to help disaggregate 'off diagonal' data<br><br>Error type – multiple calculation methods & lack of data | Investigate the impact of evenly distributing by import country versus disaggregation using UN's ComTrade data for goods products | Look into ComTrade's difference in final demand and intermediate demand disaggregations. Find data on services. Look into producing export vectors too. Try alternate methods for creating off diagonals – work along rows rather than cols (GTAP method) |
| **Balancing the MRIOT** | MRIOT needs to balance such that sum VA = sum FD and sum columns = sum rows.<br>Error type – multiple calculation methods | Adjust FD so that the sum equals sum of VA. Use basic RAS technique to balance table. | Look at how much the imports structure changes after RAS procedure. Try to limit this. |
| **Env. extension data** | Need to assign emissions per unit of output data to each sector<br>Error type – multiple calculation methods & lack of data | This paper only considers VA | Try using IEA emissions data by sector then try creating emissions by considering the energy use per sector |

# 4 Methodology: How to measure variation and uncertainty in MRIO model results?

This section aims to briefly discuss methods for understanding error and uncertainties in MRIO Global Trade models. The types of known error can be categorised as either there is uncertainty in the quality of the input data or uncertainty in the methods of reallocating emissions from producers to consumers. Because a perfect MRIOT is not in existence, analysts will always struggle to compare output results from MRIO models with a 'correct' value. One reasonable solution to this issue is to make comparisons with other models and note the variation in model outcomes or compare varying outcomes from a single model with different build assumptions.

## 4.1 Effect of missing data

Peters and Solli (2010) explain that criticisms levelled at the input data quality are not necessarily due to a lack of data. There is abundant data collected by national statistics agencies but little coordination in devising a common accounting system and a single repository for the data to be housed. The authors call for a system that is not only common to all nations but also expands the representation of the service sectors (Peters and Solli, 2010).

The nature of MRIO systems is that data is required showing the flows from every production sector in every country to every production sector in every country. It is only in recent years that academics have had access to detailed MRIO systems. Early studies that tried to determine the consumption impact of a single country, when data on the production structure of foreign economies was unavailable, sometimes relied on the 'Domestic Technology Assumption' (DTA). This assumes that foreign countries have the same 'A matrix' as the domestic country of focus. This approach not only assumes that goods imported have the same impact per unit of output as those sourced domestically, but also that inputs from foreign goods to domestic production are also at domestic technology levels. To estimate the magnitude of error using the DTA assumption compared to an approach which can take into account the production structure of goods sourced from abroad, a comparable figure is needed to calculate deviation from. Both Andrew et al., (2009) and Peters and Solli (2010) make calculate consumption based accounts for countries using the GTAP MRIO[6] then using the same data, run the analysis again using the DTA. Both studies find that the largest differences in the consumption account occur in those countries, like Switzerland, whose economies are small and domestic production contributes to a small proportion of domestic consumption meaning that the country is reliant on imports. Peters and Solli (2010), describe large differences in economies that are highly specialised or have very clean domestic energy supply. Andrew et al., (2009) also determine the sectors which are most over or underestimated using the DTA assumption and conclude that energy sectors (gas extraction; oil extraction; coal mining; and petroleum and coal products) tend to be overestimated in imports and energy intensive manufacturing sectors are underestimated using DTA assumptions (Andrew et al., 2009).

In this study, 'simpler' model constructions are compared with the results generated by the fuller more complex GTAP system. We must, however, question whether the comparison value can be confidently described as being closer to an actual truth. This research will initially use GTAP7 to benchmark results but further work is necessary to improve the methods of reliability testing.

[6] Andrew et al., (2009) use GTAP 6 with 87 regions and Peters and Solli, (2010) use GTAP 7.1 with 112 regions

## 4.2 Aggregation vs. disaggregation

It is noted that often there is a compromise between MRIO systems having detailed sectors and few countries or many countries and fewer numbers of sectors (Wiedmann et al., 2011). Peters and Solli (2010) attempt to quantify the difference in Nordic consumption based emissions using the GTAP data with eight aggregated sectors and the full 57 sectors. The authors find that the effect of changing the number of sectors is small in the Nordic countries with the results lying between a reduction of -1%, or an increase of 3%. When they extended this experiment to the full 112 countries in the GTAP 7.1 database, Peters and Solli, (2010) found that the maximum error was 17% in Cambodia. Andrew et al., (2009) investigate the effect of using two, to three and up to 87 trading regions within an analysis for a specific country. They conclude that if the 'correct set' of countries is grouped, just five to ten trading regions can adequately describe the consumption based emissions of a country. Again this work benchmarks a less complex system against the full system to understand the influence of assumptions.

## 4.3 Reliability statistics

Due to the fact that tables do not exist with true values held in them, statistics for comparing observed model outcomes with the expected result will be problematic to calculate (Wiedmann et al., 2011). One technique that can be used to test assumptions is to create a dummy model that adheres to MRIO properties but uses random numbers. Analysts can then make assumptions about missing data and test techniques for disaggregating and aggregating in an attempt to get close to the results generated by the 'true' model.

Using this technique, Lenzen (2011) shows that the relative standard errors (RSE) associated with the individual elements a the matrix used to aggregate data from a detailed classification set to a less detailed one are larger than the errors associated with a matrix used to disaggregate to the larger classification. This statement can be shown to be true because the RSE of the sum of a set of numbers is always smaller than the average RSEs of each of the sets of numbers being summed (the summands). In addition, Lenzen (2011) uses Monte Carlo simulation to test the uncertainties that result upon aggregation and disaggregation. The simulation repeatedly creates a certain sized model from random numbers then disaggregates the data to a system with a larger number of sectors with the aim of discovering under what circumstances disaggregation produces closer results than aggregation. One conclusion drawn is that if the sectors are dissimilar in character and are aggregated together, a worse representation of 'reality' is achieved. This research does not yet investigate the effects of disaggregation on the OECDMRIO but I hope to draw from some of the techniques described in Lenzen (2011).

When constructing Eora, the authors indicate standard deviations for both the data used in the MRIO construction and the resulting modelled MRIO table entries (Kanemoto et al., 2011). The standard deviations of the construction data are sourced from "literature and interviews with data providers" and these are then used to estimate standard deviations within the MRIOT using a modified RAS method to spread the errors throughout the table. For this study, I assume the construction data is error free and only measure the size of variation that exists as a result of the decisions made in building the table.

Since we are trying to build a model that produces values that can be used for climate policy we need to have as close to real data as possible. The tests of robustness and reliability that can be applied to the OECDMRIO model will involve assessing variation in model runs and measuring how close model runs are to other MRIO systems currently available. For this paper, I use the coefficient of variance as a measure of robustness. The coefficient of variance is the ratio of the standard deviation to the mean (Hendricks & Robey, 1936). This measure has been chosen because being normalised means that we can compare the variation present in model runs of very large numbers (for example the total consumption impact of the UK) with more granular outcomes (for example the impact of Chinese metal in the supply chain of UK cars purchased domestically). We can discover if the model is more or less reliable at differing scales.

# 5 Case study results

This paper provides an example set of results from the first test iteration of the OECDMRIO model. The findings are merely a snap-shot of what will be a much longer and more comprehensive study in the future. The model has been constructed with a number of simplifications and the results should be viewed as an indication of how uncertainty can be communicated rather than a finished outcome or a challenge to results from existing models. To date, the OECDMRIO model has been constructed to investigate the effect of 3 decisions:

- Using alternative production structures for the rest of world SIOT
- Disaggregating the 'off diagonal' matrices using UN ComTrade data on trade in goods and using an even distribution technique
- Using a RAS procedure which 'fixes' the domestic 'diagonal' SIOTs compared to letting these matrices be altered in the RAS procedure

These decision pathways result in a total of 44 x 2 x 2 = 176 model runs meaning there is a multitude of ways of cutting and comparing outcomes. The initial findings are presented as scatter graphs showing the variation in particular outcomes with each model run. The x axis represents each of the 44 countries used as a proxy for the ROW production structure and the y shows the impact of the outcome being measured. The four choices of:

- 'BASIC' (no diagonal fixing, no ComTrade),
- 'BASIC-diag' (diagonal fixing, no ComTrade),
- 'COMTRADE' (no diagonal fixing, ComTrade)
- 'COMTRADE-diag' (diagonal fixing, ComTrade)

are represented by four sets of coloured points. In addition, the equivalent result from GTAP 7 is included as an indication of how the OECDMRIO model performs against a peer reviewed model. In describing the outcome and variation of these runs, this study takes data at a top level and delves to further and further levels of detail to give insight into whether the system is robust throughout.

First we consider results at a national level by looking at both the proportion of the value added that can be traced back to a domestic production source and the proportion where the source is a specific non domestic region. Next we consider the value added that is assigned to the consumption by a specific region of a specific commodity – this in effect is looking at column sums within the MRIOT. We then break down the impact of this product by looking in detail at the supply chain until we reach the most granular of results representing the value that is assigned to a single cell within the MRIOT. At each stage, we discuss why this type of outcome has meaning in climate change policy and assess the reliability of using data from the model runs for this policy purpose.

## 5.1 Percentage of UK value added where the source is domestic

At a top level, we can use MRIO to assign the proportion of global emissions associated with regional consumption. OECDMRIOT does not yet have the environmental extension data to perform this analysis. The equivalent calculation in value added would simply show GDP. To examine variation in results we step one level further down and test the portion of value added that is from domestic production. Figure 3 shows the percentage of UK VA where the source is UK production. Results are shown as percentages to allow comparison with GTAP7 which uses a different base year[7].

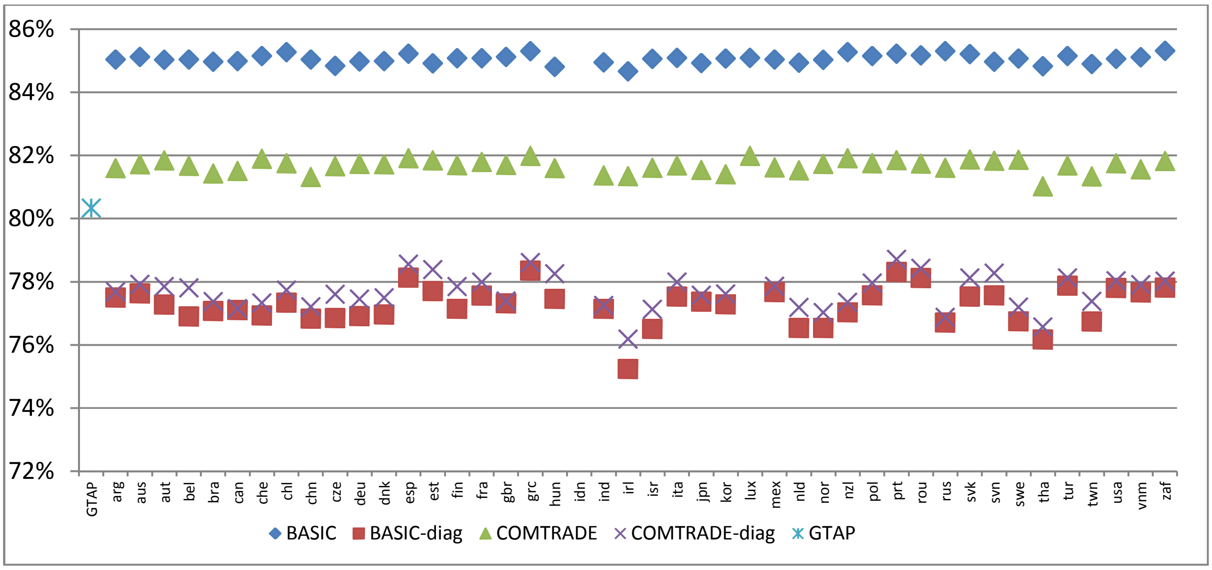



Figure 3 Model runs showing percentage of UK VA where source is domestic

| | BASIC | BASIC-diag | COMTRADE | COMTRADE-diag | All results |
|---|---|---|---|---|---|
| **Max (million USD)** | 1,857,797 | 1,678,475 | 1,777,428 | 1,679,492 | 1,857,797 |
| **Min (million USD)** | 1,805,782 | 1,509,319 | 1,733,100 | 1,508,913 | 1,508,913 |
| **Mean (million USD)** | 1,826,873 | 1,651,770 | 1,747,558 | 1,655,778 | 1,720,495 |
| **Standard deviation (million USD)** | 10,123 | 23,107 | 9,827 | 23,754 | 74,594 |
| **Coefficient of variation (%)** | 0.55% | 1.40% | 0.56% | 1.43% | 4.34% |

Model runs, where the diagonal SIOTs are not fixed, produce less variation when the ROW proxy region is altered. This may be explained by remembering that the majority of global impact is through domestic production and if one was to view a 'heat map' of the MRIOT you would see the largest values along the diagonal. Taking out this diagonal from the RAS procedure may allow greater fluctuation in the numbers. Another finding is that using ComTrade to disaggregate the off diagonal has the effect of increasing the proportion of UK impact that is in trade. For this data snap shot, the OECDMRIO performs similarly to GTAP7. Taking all the results together gives model runs that are similar enough to describe the system as being robust and appropriate for producing high

[7] We also recognise that the production structure in GTAP7's 2004 data will also differ

level results for policy. Understanding the how much of a country's production is consumed domestically is a key result in consumption based accounting. If countries know the proportion of their consumption emissions that are domestically produced they can start to consider how policies designed to lessen impacts from production, have an effect on consumption based emissions (Barrett et al., 2011). The next stage is to run results for every consuming country and test the variation in OECDMRIO results and the degree of alignment with systems such as GTAP. Another interesting finding would be if the countries where results were more variable were the same import reliant countries as those reported by Andrew et al.,(2009) and Peters and Solli (2010) where the DTA produced a poor approximation of impact.

## 5.2 Percentage of ROW value added where the source is domestic

Whereas the results in section 5.1 show that data for the proportion of VA sourced domestically for the UK is reasonably stable, greater variability is anticipated in the data for the rest of the world. The reason for this is that the rest of the world region is one of the areas where data is missing and a proxy is used. In fact, the percentages shown below in figure 4 represent the entire range of domestically sourced VA from each country in the dataset since each county is trialled as a proxy.

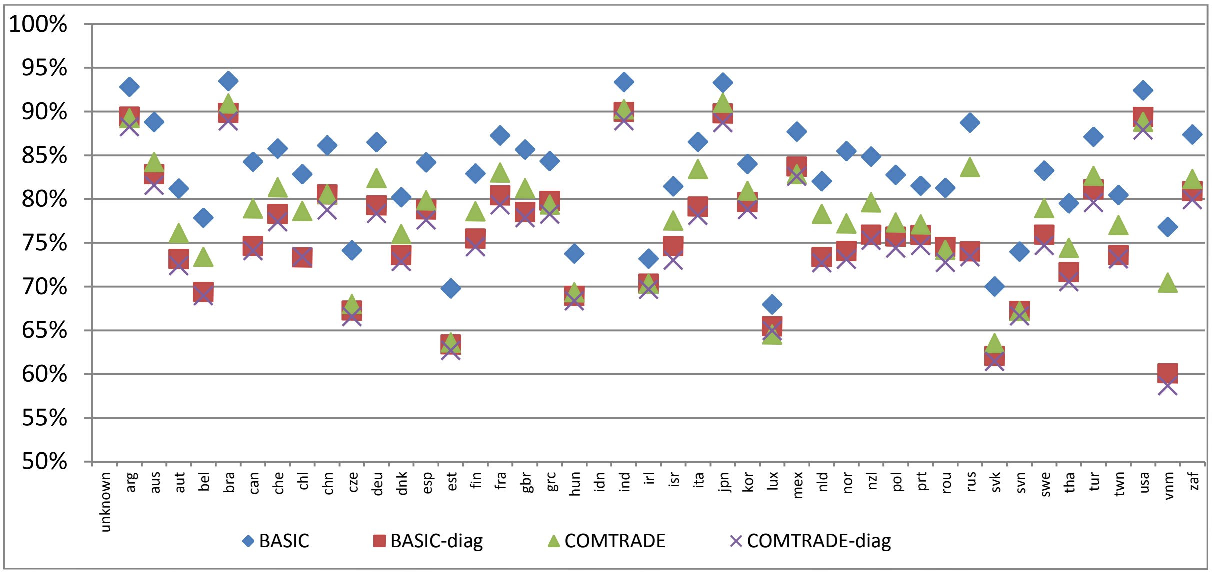



Figure 4 Model runs showing percentage of ROW VA where source is domestic

| | BASIC | BASIC-diag | COMTRADE | COMTRADE-diag | All results |
|---|---|---|---|---|---|
| **Max (million USD)** | 3,766,068 | 3,587,317 | 3,591,976 | 3,547,759 | 3,766,068 |
| **Min (million USD)** | 2,173,357 | 2,118,662 | 2,059,190 | 2,101,456 | 2,059,190 |
| **Mean (million USD)** | 3,190,093 | 2,925,516 | 3,009,851 | 2,887,746 | 3,003,302 |
| **Standard deviation (million USD)** | 335,572 | 364,010 | 338,764 | 354,583 | 367,403 |
| **Coefficient of variation (%)** | 10.52% | 12.44% | 11.26% | 12.38% | 12.23% |

The coefficient of variation for this level of data is considerably higher than found when considering similar data about the UK above. On average, taking all model runs together, a data point can be around 12.23% deviated from the mean. Based on these findings I suggest further research into which country's production structure is most suitable to use as a proxy for the rest of the world particularly when considering data calculated about the rest of the world region. At present this type of data from the OECDMRIO model cannot be used with confidence as it varies too much. In this section comparison with GTAP7 is not sensible as the ROW regions in each MRIO represent different country groupings.

### 5.3 Percentage of UK VA where the source is China

Considering the proportion of VA that is domestically sourced tests the robustness of the results found along the diagonal of the OECDMRIOT. Considering the proportion of value added where the source is different to the domestic country, will identify variation in the off diagonal portion of the matrix. Here the model tests the proportion of value added that can be traced to China as the source.

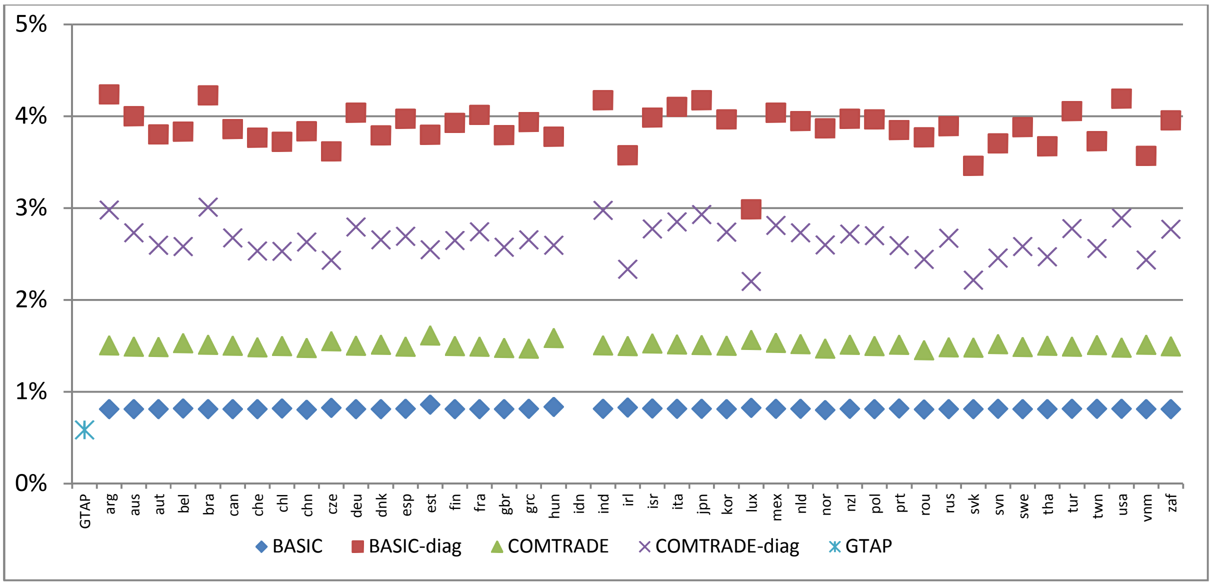



Figure 5 Model runs showing percentage of UK VA where source is China

| | BASIC | BASIC-diag | COMTRADE | COMTRADE-diag | All results |
|---|---|---|---|---|---|
| **Max (million USD)** | 18,220 | 90,837 | 34,145 | 64,492 | 90,837 |
| **Min (million USD)** | 17,170 | 65,149 | 30,755 | 47,110 | 17,170 |
| **Mean (million USD)** | 17,466 | 82,911 | 32,180 | 56,533 | 47,272 |
| **Standard deviation (million USD)** | 191 | 4,660 | 650 | 3,827 | 25,044 |
| **Coefficient of variation (%)** | 1.09% | 5.62% | 2.02% | 6.77% | 52.98% |

As observed in section 5.1, there is less variation in the results where the diagonals are not fixed. China's proportion as the source of UK VA is also greatest when diagonals are fixed. The individual variations are slightly larger than when considering the diagonal data – a hypothesis that can be testing by looking at further countries as a source, but combining the four sets together yields a very large coefficient of variation. Here the OECDMRIOT data does not match well with GTAP7. Whether this is due to China becoming a more dominant trade partner between 2004 and 2005 or gross differences in the model structures should be investigated further.

## 5.4 Percentage of UK VA associated with spend on vehicles

Another way of slicing the data is to consider the columns of the MRIOT associated with spend on a particular product. In this case we investigate spend on motor vehicle products by UK consumers – taking into account the entire motor vehicle production supply chain.

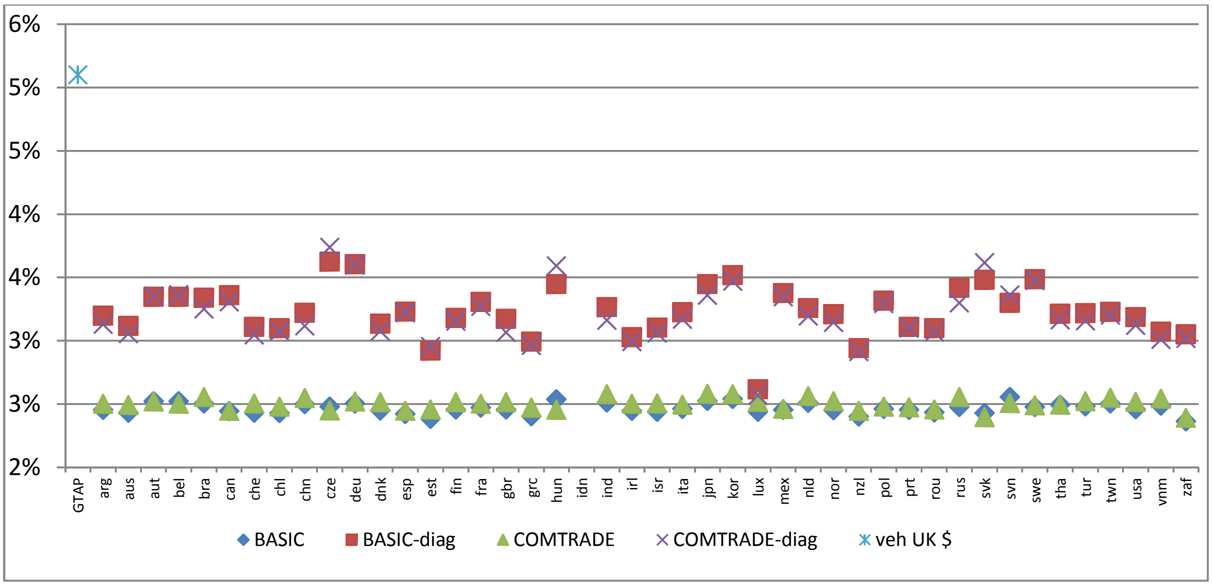



Figure 6 Model runs showing percentage of UKVA on motor vehicles

| | BASIC | BASIC-diag | COMTRADE | COMTRADE-diag | All results |
|---|---|---|---|---|---|
| **Max (million USD)** | 54,660 | 77,907 | 55,490 | 80,117 | 80,117 |
| **Min (million USD)** | 50,669 | 57,133 | 51,038 | 55,930 | 50,669 |
| **Mean (million USD)** | 53,006 | 69,277 | 53,534 | 68,420 | 61,059 |
| **Standard deviation (million USD)** | 1,017 | 4,172 | 1,095 | 4,612 | 8,428 |
| **Coefficient of variation (%)** | 1.92% | 6.02% | 2.05% | 6.74% | 13.80% |

Again observe that the diagonally fixed set of results shows greater variation when comparing results using different rest of world production structures. When the diagonals are removed, spend related to motor vehicles is higher but and further tests with other products are needed in order to make any generalisations. Once environmental extension data is added, this type of model run will show the emissions associated with a product's entire supply chain. This level of analysis is very often the most detail given in consumption based accounts of country emissions. See Roelich et al., (2011) for an example of this type of breakdown for European countries. The OECDMRIO performs badly against GTAP in this case.

## 5.5 Percentage of UK VA associated with spend on UK vehicles where the source is China

A further level of granularity is to look at UK spend on vehicles where the country of final assembly is the UK (e.g. a 'UK' car) but look at the fraction of the supply chain that can be traced back to China. This requires considering the column in the MRIO representing spend on UK cars and looking at the cells that fall into the off diagonal matrix of imports to UK industry from China.

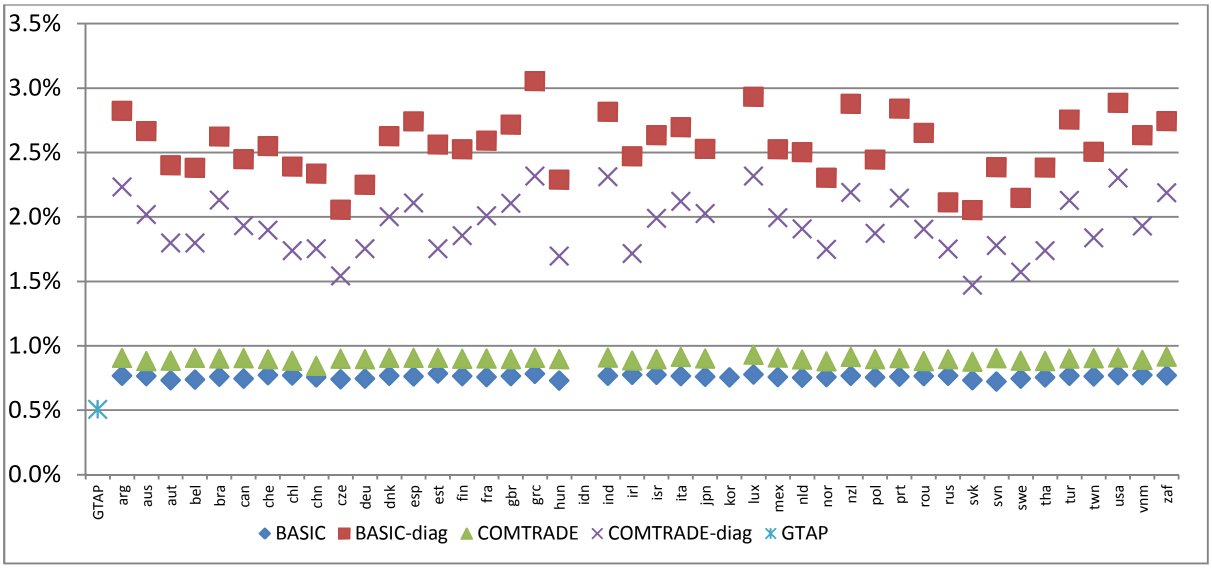



Figure 7 Model runs showing percentage of UK VA on motor vehicles from the UK where source can be traced to China

| | BASIC | BASIC-diag | COMTRADE | COMTRADE-diag | All results |
|---|---|---|---|---|---|
| **Max (million USD)** | 1,619 | 4,314 | 1,467 | 4,186 | 4,314 |
| **Min (million USD)** | 1,422 | 2,949 | 1,147 | 2,071 | 1,147 |
| **Mean (million USD)** | 1,479 | 3,824 | 1,233 | 2,831 | 2,342 |
| **Standard deviation (million USD)** | 35 | 305 | 60 | 481 | 1,089 |
| **Coefficient of variation (%)** | 2.34% | 7.98% | 4.87% | 16.99% | 46.49% |

The pattern shown in the graph is familiar. One point of note is that the coefficient of variation does appear to be increasing as the level of detail increases. But again, this hypothesis needs further investigation with tests of other products and considering final assembly points that are not domestic. Data modelled here does not match the GTAP7 reported value particularly well with some model runs outcomes at 5 to 6 times the proportion found in GTAP7. Models need to be able to distinguish the source production countries associated with domestic consumption and this level of detail was requested in a recent report to the UK Government's Department for Food and Rural Affairs (Barrett et al., 2011). Minx et al., (2009) also reveal the emitting sectors that contribute to the UK's meat consumption footprint and discuss how a consideration of the supply chain can start to make the link between consumption impact and deforestation. The OECDMRIO model is clearly not robust at this level and further work is needed to identify which model runs can be deemed and reduce the variation in outcomes.

## 5.6 Percentage of UK VA associated with UK spend on UK vehicles where the source is Chinese metal

At the greatest level of granularity we consider data that is modelled at the level of a single cell within the MRIO structure. Identifying the amount of impact associated with metal from China in vehicles that are assembled in the UK is an example of this level of detail.

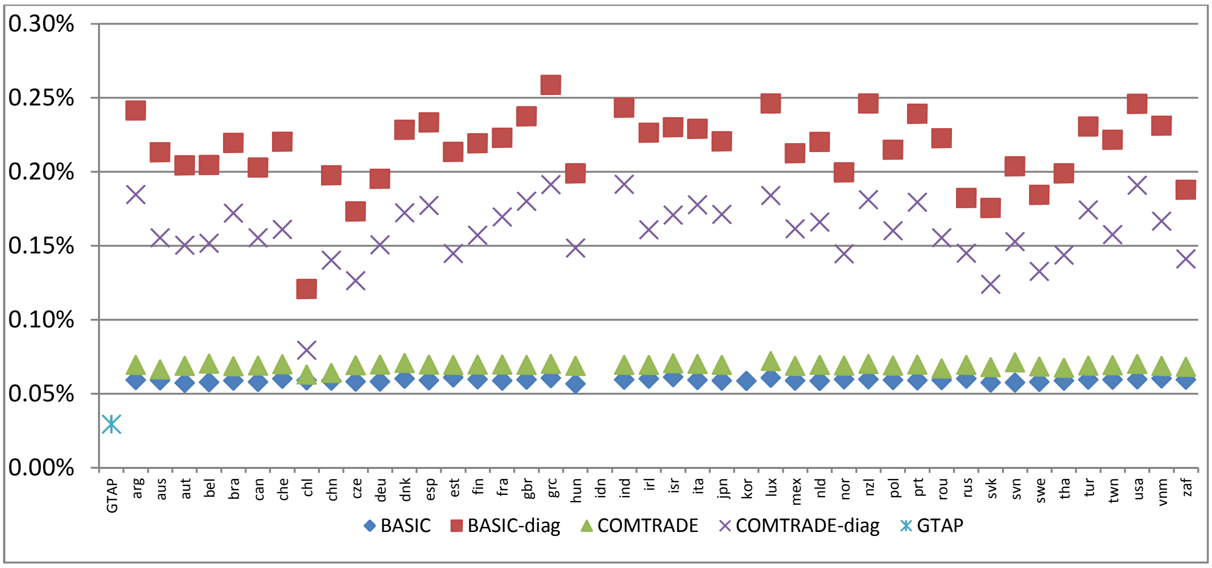



Figure 8 Model runs showing percentage of UK VA on motor vehicles from the UK where source can be traced to Chinese metal

| | BASIC | BASIC-diag | COMTRADE | COMTRADE-diag | All results |
|---|---|---|---|---|---|
| **Max (million USD)** | 34.47 | 169.75 | 39.34 | 129.15 | 169.75 |
| **Min (million USD)** | 29.98 | 80.38 | 33.48 | 52.33 | 29.98 |
| **Mean (million USD)** | 31.41 | 147.96 | 36.98 | 108.57 | 80.94 |
| **Standard deviation (million USD)** | 0.58 | 14.81 | 1.19 | 12.90 | 50.07 |
| **Coefficient of variation (%)** | 1.84% | 10.01% | 3.23% | 11.88% | 61.86% |

Again similar patterns are found which show high variation in results that fix the diagonal. The data is not close to GTAP but the coefficients of variation are reasonable within each set of data. This level of granularity is not regularly commented on in studies of consumption based emissions accounts. However, as countries consider approaches such as border carbon agreements as a response to emissions trading schemes this level of detail may need to be reported accurately. Consider a policy that requires accounting for the steel that is imported to the UK. The steel embedded within imported cars may need to be captured (Barrett et al, 2012). At present, different model runs calculate the value of this steel to be between 30 million USD and 170 million USD – a 5 factor difference. Clearly this particular model is not robust enough to be used for this type of calculation and further work need is needed to identify the model runs that are most trustworthy. In addition, further research is needed into

## 5.7 Brief overview of results

- The greater the level of detail of model outcome required, the more variation is seen in model runs
- Results close to the diagonal matrices seem to be most reliable
- The RAS technique which fixes the diagonal matrices gives more variable model runs across the varying ROW SIOT tests

# 6 Discussion

This research uses the example of the OECD SIOTs and UK ComTrade data to explain how a MRIOT is constructed. The paper also reveals the types of decisions and assumptions encountered in the process. An attempt has been made to characterise both the stages in which error enters the model and the types of error that are met. As authors including Peters el al., (2011a) point out, there is a need for research comparing and investigating different results from different MRIO systems. In addition, Wiedmann et al., (2011) call for further investigation in reliability and uncertainty within MRIO research stating that the literature is lacking in studies that investigate error in environmental Such uncertainties include "source (survey) data, imputation and balancing, allocation, assuming proportionality and homogeneity, aggregation, temporal discrepancies, model inputs and multipliers" (Wiedmann, 2009). This paper lays the foundation for further research into the robustness of MRIO for use within climate policy. Initial findings start to suggest at what level analysts can have confidence in results yielded from the model and how data at the most granular of levels is subject to the greatest uncertainty.

Whether decisions are appropriate within MRIO models is very dependent on the application. A model cannot be described as useful without identifying the application. For example, if the requirement of a MRIO model was to give a broad indication of shifting in embodied emissions between countries then cruder assumptions may be appropriate. However, if MRIO are used to establish carbon intensity factors for the use of border carbon adjustments then a significantly different level of accuracy, precision and transparency would be required. The research will establish the appropriateness of MRIO models to answer pressing policy questions related to consumption, trade and efficiency. The various assumptions will be considered in terms of their ability to deliver robust data for these various policy assessments.

The future research will also investigate further assumptions in MRIO model creation as described in table 1 and then start to use the findings to parameterise the space in which table values exist. This will generate further insights into the creation of MRIO models to critically assess some of the other MRIOTs in existence. Findings from this research can be used to verify results from other models. If the assumptions made in the creation of these models are documented and known, the findings from this study may be able to suggest areas of concern in terms of reliability and recommend the types of policy question results should and should not be used for. Another outcome of future work will be a consideration of more interesting and exciting ways of communicating variation and uncertainty in results; an area of research requiring urgent attention in the field of climate science communication.

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## Appendix 1: Availability of IO tables and BTD from OECD

| | | Country | 1995 | 2000 | 2005 | Imports to | Exports from |
|---|---|---|---|---|---|---|---|
| **1** | ARG | Argentina | 1997 | 1997 | 1997 | | |
| **2** | AUS | Australia | 94/95 | 01/02 | 04/05 | YES | YES |
| **3** | AUT | Austria | YES | YES | YES | YES | YES |
| **4** | BEL | Belgium | YES | YES | YES | BLX | BLX |
| **5** | BRA | Brazil | YES | YES | YES | | |
| **6** | CAN | Canada | YES | YES | YES | YES | YES |
| **7** | CHE | Switzerland | 2001 | 2001 | 2001 | YES | YES |
| **8** | CHL | Chile | 1996 | 2003 | 2003 | YES | YES |
| **9** | CHN | China | YES | YES | YES | | |
| **10** | CZE | Czech Republic | 2000 | YES | YES | YES | YES |
| **11** | DEU | Germany | YES | YES | YES | YES | YES |
| **12** | DNK | Denmark | YES | YES | YES | YES | YES |
| **13** | ESP | Spain | YES | YES | YES | YES | YES |
| **14** | EST | Estonia | 1997 | YES | YES | YES | YES |
| **15** | FIN | Finland | YES | YES | YES | YES | YES |
| **16** | FRA | France | YES | YES | YES | YES | YES |
| **17** | GBR | United Kingdom | YES | YES | YES | YES | YES |
| **18** | GRC | Greece | YES | YES | YES | YES | YES |
| **19** | HUN | Hungary | 1998 | YES | YES | YES | YES |
| **20** | IDN | Indonesia | YES | YES | YES | | |
| **21** | IND | India | 93/94 | 98/99 | 03/04 | | |
| **22** | IRL | Ireland | 1998 | YES | YES | YES | YES |
| **23** | ISR | Israel | YES | 2004 | 2004 | | |
| **24** | ITA | Italy | YES | YES | YES | YES | YES |
| **25** | JPN | Japan | YES | YES | YES | YES | YES |
| **26** | KOR | South Korea | 2000 | YES | YES | YES | YES |
| **27** | LUX | Luxemburg | YES | YES | YES | YES | YES |
| **28** | MEX | Mexico | 2003 | 2003 | 2003 | YES | YES |
| **29** | NLD | Netherlands | YES | YES | YES | YES | YES |
| **30** | NOR | Norway | YES | YES | YES | YES | YES |
| **31** | NZL | New Zealand | 95/96 | 02/03 | 02/03 | YES | YES |
| **32** | POL | Poland | YES | YES | YES | YES | YES |
| **33** | PRT | Portugal | YES | YES | YES | YES | YES |
| **34** | ROU | Romania | 2000 | YES | YES | | |
| **35** | RUS | Russia | YES | YES | 2000 | | |
| **36** | SVK | Slovakia | YES | YES | YES | YES | YES |
| **37** | SVN | Slovenia | 1996 | YES | YES | YES | YES |
| **38** | SWE | Sweden | YES | YES | YES | YES | YES |
| **39** | THA | Thailand | 2005 | 2005 | 2005 | | |
| **40** | TUR | Turkey | 1996 | 1998 | 2002 | YES | YES |
| **41** | TWN | Taiwan | 1996 | 2001 | 2006 | YES | YES |
| **42** | USA | United States | YES | YES | YES | YES | YES |
| **43** | VNM | Vietnam | 2000 | 2000 | 2000 | | |
| **44** | ZAF | South Africa | 1993 | YES | YES | | |
| **45** | ROW | Rest of World | | | | | |