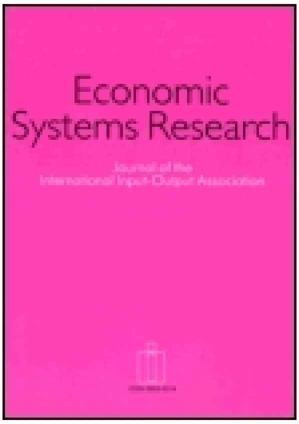

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GLOBAL MULTIREGIONAL INPUT-OUTPUT FRAMEWORKS: AN INTRODUCTION AND OUTLOOK

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INTRODUCTION

GLOBAL MULTIREGIONAL INPUT–OUTPUT FRAMEWORKS: AN INTRODUCTION AND OUTLOOK

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This review is the introduction to a special issue of *Economic Systems Research* on the topic of global multiregional input–output (GMRIO) tables, models, and analysis. It provides a short historical context of GMRIO development and its applications (many of which deal with environmental extensions) and presents the rationale for the major database projects presented in this special issue. Then the six papers are briefly introduced. This is followed by a concluding comparison of the characteristics of the main GMRIO databases developed thus far and an outlook of potential further developments.

Keywords: Multiregional input–output tables; Global analysis; Environmental extensions; Trade; Supply and use tables

1. INTRODUCTION

This special issue brings together examples of the world's most ambitious projects and studies in the field of global multiregional input–output (GMRIO) modeling.[1] It is published just after three new major GMRIO databases were finalized: WIOD (Dietzenbacher et al., 2013), EORA (Lenzen et al., 2012a; 2012b) and EXIOBASE (Tukker et al., 2009; 2013). As will be pointed out in the next section, the construction of these databases was triggered by discussions that have recently taken place in the literature. For quite some time databases did exist with harmonized national input–output tables (IOTs) and bilateral trade information for a large number of countries and for several years. The best known examples are GTAP and OECD. The GTAP database was set up in the 1990s as the result of collaboration among numerous individuals in the GTAP network and recently saw its eighth release (Narayanan et al., 2012). The OECD database was first developed in 1995 and updated several times and has been disseminated freely (see, e.g. Yamano and Ahmad, 2006).[2] Also some (but few) true intercountry IOTs have been constructed some time ago. A noteworthy example covering a long range of time series are the Asian International IOTs (AIIOTs) produced by the Institute of Developing Economies, Japan External Trade Organization (IDE-JETRO),

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[1] The projects discussed in this special issue are also portrayed in Murray and Lenzen (2013), a forthcoming popular-scientific book on MRIO.
[2] See http://www.oecd.org/sti/inputoutput

since 1975.[3] Yet, true GMRIO databases did not exist and individual researchers have used existing databases with national IOTs and trade data for their studies (see, e.g. Ahmad and Wyckoff, 2003; Bruckner et al., 2012; Yamano, 2012, using the OECD database, or Peters and Hertwich, 2008; Peters et al., 2011a, using the GTAP database).

This special issue builds upon two meetings of representatives of these projects at Réunion Island (March 2011) and Tokyo (January 2012), made possible by funding from the University of Sydney's International Program Development Fund and IDE-JETRO.[4] The Réunion meeting was a small-scale workshop mainly focused on an initial exchange, showcasing, and a comparison of approaches for data collection and manipulation, as well as developing some initial suggestions for enhancing efficiency by mutual collaboration. The Tokyo meeting was set up as an extensive conference with around 100 participants. The latter meeting was the source of most of the papers that – in revised form – are presented in this special issue.

Countless practitioners have done case studies using (national) IO databases (see, e.g. Wiedmann, 2009; Hoekstra, 2010, for detailed overviews of environmental applications). In terms of the analytical approach, the case studies presented in this special issue may not always reflect major novelties. The real innovation of the work presented here is twofold. First, constructing GMRIO databases requires an unprecedented integration and harmonization of data from different sources. Most projects had to develop innovative harmonization, transformation, and estimation methods to enable successful database construction, as well as making assessments of what factors would contribute mostly to errors and uncertainties (e.g. Peters et al., 2012; Tukker et al., 2012). Second, for the first time in history the entire global economy is captured in databases of unprecedented detail (EXIOPOL[5] and EORA) and/or with time series in both current and previous year's prices (WIOD). This, in turn, makes a type of case study possible that until now could not be conducted (e.g. Lenzen et al., 2012a; 2012b).

The next section briefly discusses historical developments that have led to the need for setting up the GMRIO databases central in this special issue. We then briefly introduce the contributions to the special issue, followed by a comparative reflection and conclude with an outlook.

2. ORIGINS AND HISTORY OF GMRIO FRAMEWORKS

2.1. The Recent Background of GMRIO Databases

The recent construction of several GMRIO databases was triggered by discussions in two strands of the literature. That is, discussions on appropriately measuring the responsibility

[3] Another example is the series of tables, constructed by researchers from the University of Groningen, for a set of European countries. The full series of intercountry tables in current prices (for the years 1965, 1970, 1975, 1980, and 1985) can be downloaded at http://www.regroningen.nl. The details of the construction method are given in van der Linden (1999), a summary is given by van der Linden and Oosterhaven (1995). For the intercountry tables in constant prices, see Hoen (2002).
[4] The Réunion Project (http://www.isa.org.usyd.edu.au/mrio/mrio.shtml) is aimed at linking the top global institutions involved in the compilation of GMRIO accounts, and at initiating a large-scale research collaboration that will be able to harmonize world-wide activities on GMRIO database compilation. The idea for this collaboration originated from a meeting of the present researchers at the 18th Input–Output Conference held in 2010 at the University of Sydney.
[5] EXIOPOL is the acronym of an EU funded project called 'A new environmentally accounting framework using externality data and input output tools for policy analysis'.

for emissions and on the role of international trade of goods and services. Both issues called for the use of GMRIO tables.

The literature on environmental issues has shown an increased interest in the interactions between trade and the environment since the 1970s (see the surveys by Jayadevappa and Chhatre, 2000; Wiedmann et al., 2007). A policy-relevant discussion centered around the Kyoto protocol, which specifies – for each ratifier country – targets for the reduction in the emission of greenhouse gases (GHG). These national targets, however, are set on a territorial basis and a large part is due to emissions generated by domestic production. That is, it includes the (domestic) emissions embodied in exports and excludes the (foreign) emissions embodied in imports. Given the global character of GHG, this raises questions about the environmental responsibility of a country. This led to the discussion on producer versus consumer responsibility. Under the principle of consumer responsibility, all global emissions that are attributed to the final use of a country and summed, resulting in the national GHG footprint. The producer responsibility reflects the emissions of a country due to its production. Clearly, the difference between consumer and producer responsibility is intimately related to the difference between exports and imports of embodied emissions (see, e.g. Serrano and Dietzenbacher, 2010, for a discussion). Due to a lack of data, early empirical applications focused on single countries, followed by studies that took a small set of countries into consideration. Only recently, individual researchers started to use existing collections of national IOTs and aggregated trade data to estimate GMRIO tables (see Ahmad and Wyckoff, 2003; Wiebe et al., 2012a; 2012b, which are based on the OECD database, and Peters and Hertwich, 2008; Hertwich and Peters, 2009; Wilting and Vringer, 2009; Davis and Caldeira, 2010; Peters et al., 2011a, all of which used the GTAP database).

Similar issues have arisen in the trade literature as succinctly reflected by the titles of some papers, such as "Who produces for whom in the world economy?" (Daudin et al., 2011) or "Give credit where credit is due: tracing value added in global production chains" (Koopman et al., 2010). Production processes have increasingly become sliced up (or fragmented) into ever smaller parts. Many of these parts are outsourced to specialized subcontractors that are more and more located in foreign countries (i.e. offshoring). This has led to an upsurge of trade in intermediate products because the location of the production of intermediate inputs differs from the location of the production of the final products (which corresponds to Baldwin's, 2006, 'second wave of global unbundling'). Today's products and services are no longer produced within a single country. Instead, they are made in global supply chains, or global value chains. That is, countries import intermediate goods and raw materials, to which they add one or more layers of value after which they sell the product (often to a foreign producer who adds the next layer).

Standard trade figures that measure the value of imports and exports do not reflect any more what is really happening because the built-in components in traded products are often counted twice (or more). EU Commissioner for Trade Karel De Gucht gave the following example.[6]

> Imagine a car's wheels are produced in one country and its engine somewhere else. They are all then shipped to a third country for assembly, before the final product is sold to a consumer in a fourth. … [A]s far as global trade statistics are concerned, we

[6] Available at: http://trade.ec.europa.eu/doclib/docs/2012/april/tradoc_149337.pdf.

have produced a car with eight wheels and two engines. … The country that exports the final product is artificially credited with having created all of its value, even if in reality it only assembled ready-made parts. … [T]he export statistics of the third country make it look like the car was built there from scratch. … It doesn't take account of the fact that the final result is the product of a joint effort.

Recently, IDE-JETRO and the World Trade Organisation (WTO) jointly proposed 'trade in value added' as a better approach for the measurement for international trade (see WTO and IDE-JETRO, 2011). The idea gained further momentum by the joint announcement of the WTO and OECD to develop the relevant database and analytical methods (see OECD-WTO, 2012). The approach is very similar to tracing how much emissions in one country are embodied in the use of final products in another country and requires a GMRIO table. Applications only started recently and include Koopman et al. (2010), Bems et al. (2011), Daudin et al. (2011), Johnson and Noguera (2012a; 2012b), and Puzzello (2012).

Two remarks are in place. First, whereas the recent background of and call for *global* MRIO tables comes from the environmental and the trade literature, it should be emphasized that the concept of MRIO tables is anything but new and was developed a long time ago for regions within a nation by Isard (1951). MRIO tables have become a widely discussed topic in the regional science literature and a widely used tool for regional policy. The textbook by Miller and Blair (2009) provides an excellent overview and a thorough introduction to MRIO tables and models. At the same time, it should also be emphasized that the regional science literature makes a sharp disctinction between multiregional and interregional IOTs and models. Interregional models use a_{ij}^{RS}, indicating the input of product i $(= 1, \ldots, n)$ from region R $(= 1, \ldots, N)$ into (and measured per unit output of) industry j in country S. Multiregional models use estimates, i.e. $\tilde{a}_{ij}^{RS} = \lambda_i^{RS} a_{ij}^{\cdot S}$ for all $j = 1, \ldots, n$. Note that $a_{ij}^{\cdot S}$ denotes the regional technical coefficient of region S, which gives the total use (i.e. summed over all origins) of product i in industry j of region S. The scalar λ_i^{RS} shows, for region S, the proportion of the total amount of product i that comes from region R and this proportion applies uniformly to each destination industry j. Theoretically speaking, multiregional IOTs and models are thus a special case of the interregional IOTs and models. In practice, however, interregional IOTs are not compiled but are estimated. Often the assumption of uniform proportionality is adopted, because more detailed information is lacking. In that case, the estimated interregional IOT is a multiregional table. In other cases, the resulting table needs to be balanced implying that the estimate is not a multiregional IOT, but probably still very close.

Second, linking industry level information for large groups of countries has a long tradition in economics. Project LINK was initiated in 1968 under the leadership of Nobel laureate Lawrence R. Klein to model the international transmission mechanism of business cycles. In this project, independently developed national econometric models (that distinguish several commodity classes) are linked through trade share matrices into a global econometric model. The project is currently part of the United Nations Development Policy and Analysis Division. According to their website: 'LINK has expanded from a core of … 7 country models in 1969 to … 79 country models, including 45 models of individual developing countries and regions'.[7] A more IO related project is Inforum (which stands

[7] See http://www.un.org/esa/analysis/link, or, e.g. Moriguchi (1973) and Klein (1985).

for INterindustry FORecasting at the University of Maryland, where it is housed) that was founded by Clopper Almon in 1967. Their international system of models includes national models that combine the input–output structure with econometric equations. In this way, the models incorporate economic characteristics of their production structure with estimated country-specific behavior. These national models employ a bottom-up approach so as to yield macro-economic aggregates. Currently, the models for 13 countries plus 2 regions are linked through bilateral trade flows for 120 commodities.[8] The models have been appended with various satellite accounts and have been applied to a wide range of specific research questions and policy issues.

2.2. A Focus on Environmentally Extended IO Frameworks

Given the focus of the applications in this special issue, we shift the attention in this subsection to the environmentally extended (EE) IOTs and models. The review of Hoekstra (2010), although still only available as a conference paper, is arguably the richest historical analysis in the field of EE IO. He tracked close to 360 papers in the refereed literature between 1969 and 2010. Some important conclusions from this meta-review include the following (see Hertwich, 2005, for an earlier review).

- The main scientific production in the EE IO field occurred after 1995; just 50 out of the 360 papers were published before that date.
- Papers published before 1995 focused almost exclusively on energy use (including classics such as Bullard and Herendeen, 1975; Herendeen, 1978).
- About 90% of the papers focused on single countries.
- Issues related to pollution embodied in trade have been discussed in only a few papers before 1995 (e.g. Wyckoff and Roop, 1994), whereas the number of papers increased significantly between 2005 and 2010 (20% of the 100 publications).
- Just six publications took a global perspective, usually expanding on the GTAP database (e.g. Peters and Hertwich, 2008).

Hoekstra concluded that ‘my impression is that the IO literature is still held back by data availability. Very many of the studies in our database are case studies of a single environmental pressure for a single (rich) country for a single year’.

Hoekstra’s concern reflects various issues. The first is the problem that many countries are open economies, importing goods from abroad. The foreign environmental and socio-economic impacts (such as emissions, resource use, jobs, or value added) that are embedded in imports do not appear in a single country’s IOT. Practitioners initially tried to estimate impacts embodied in trade with the so-called domestic technology assumption (Huppes et al., 2006; Palm et al., 2006). That is, foreign countries are assumed to have the same production structure as the country under study. Many authors, however, have demonstrated that multipliers and embodiments can differ substantially between countries, implying that differentiation of imports to country of origin is essential (e.g. Lenzen et al., 2004;

[8] The countries covered in the international systems are Austria, Belgium, Canada, China, France, Germany, Italy, Japan, Mexico, South Korea, Spain, the United Kingdom, and the United States. The two regions cover the rest of Europe and the rest of the world. See http://inforum.umd.edu, or, e.g. Almon (1991) and Nyhus (1991).

Peters and Hertwich, 2006; Andrew et al., 2009). This can be done by including unidirectional trade (i.e. between the focal country and the countries from which it imports; see, e.g. Nijdam et al., 2005, for the Netherlands; Weber and Matthews, 2007, for the USA; Druckman and Jackson, 2009, for the UK; and Gavrilova and Vilu, 2012, for Estonia) or, alternatively, by building a GMRIO database. The main difference between GMRIO and the unidirectional trade approach is that also the embodiments in trade between the trade partners are estimated. This gives additional reliability when compared with the unidirectional trade model (e.g. Su and Ang, 2011), but requires a lot of additional data. For example, in a comparison of the calculations with a full GMRIO model and unidirectional trade models, Lenzen et al. (2004), Andrews et al. (2009), and Wilting (2012) found that the difference in carbon footprints of nations is limited (in the range of 1–4%), but also that it becomes larger when carbon footprints of specific product groups are analyzed. This suggests that GMRIO is probably the best tool to understand how consumption of specific product groups drives environmental and socio-economic impacts (e.g. global emissions and job creation) elsewhere in the world, or the trade-offs therein.

Another data limitation reflected by Hoekstra's concern relates to sector detail, country coverage, and the number of environmental extensions. Even if based on a small amount of proxy information, additional geographical and sector detail improves the reliability of EE GMRIO analyses (e.g. Lenzen, 2011). This is particularly relevant for scenario analyses in the environmental field. An IOT (or the underlying supply and use table or SUT) is a tool for national bookkeeping that is used to calculate Gross Domestic Product (GDP). IOTs thus reflect the production structure using a sectoral breakdown that is in line with the economic importance of the sectors. Consequently, it happens that IOTs for typical service economies may contain just a single sector for agriculture, or for mining and energy production. This implies that calculations with such IOTs will include aggregation errors. For many economic scenario analyses, however, these aggregation errors are likely to be relatively small. This is because the contribution of an aggregate sector to GDP is limited and because the differences in added value or job intensities in the sub-sectors are usually not large. For most environmental scenario analyses, however, the aggregation errors may become very large. This is because the environmental impact intensity of sub-sectors varies highly (e.g. compare meat versus cereal production; iron ore versus gold mining; electricity production by coal or by wind power). For static and dynamic analyses of the environmental impacts, sectoral detail in EE GMRIO tables is essential (see, e.g. Tukker et al., 2011, for a study on the effects of diet changes).

2.3. The Need for Improved GMRIO Databases

From the above, it is obvious what the ideal 'Mother of all GMRIO databases' would look like. That is, as detailed as possible in terms of sectors and products, with a set of socio-economic and environmental extensions as extensive as possible, covering the globe and discerning as many as possible countries and regions, including long time series, and cost-effective to build. Unfortunately, compiling such an ideal database encounters a number of complexities. First, compiling such a GMRIO database demands a high level of harmonization and consolidation of different (and frequently conflicting) data sources. Particularly when constructed for the first time this is a laborious job. Second and equally important, GMRIO tables usually rely on (significant) adaptation of statistical data and other estimates.[9] This need for significant transformation of data originally validated in national statistical systems makes it difficult for the National Statistical Institutes to build GMRIO tables themselves or even participate in their building. With the exception of the OECD, until now supra-national organizations did not embark on constructing GMRIO tables either.[10]

As a result, such harmonization of national IOTs has usually been done by individual groups in the research community. As already indicated, IDE-JETRO did so for a number of Asian countries and their tables go back to 1975. The GTAP teams at Purdue University were pioneers with their global collection of IOTs and corresponding aggregate trade statistics since the 1990s. Being a database built primarily for economic modeling purposes, it initially was not suited for environmental analyses. This changed around 2005 when practitioners started to add emissions as extensions and adapted GTAP in such a way that true EE GMRIO analysis became possible (see, e.g. Peters and Hertwich, 2008; Hertwich and Peters, 2009; Davis and Caldeira, 2010; Peters et al., 2011a). Such analyses are typically confined to one or two emissions of substances, most notably CO_2, and use the 57 sector detail of GTAP. Somewhat earlier, the OECD combined their harmonized IOTs and bilateral trade database with estimated CO_2 emissions (using International Energy Agency (IEA) statistics) to perform one of the first global assessments of carbon embodied in trade (Ahmad and Wyckoff, 2003). The Sustainable Europe Research Institute (SERI) and the Gesellschaft für wirtschaftliche Strukturforschung (GWS) used the OECD data sets for creating their Global Resource Accounting Model (GRAM) (Bruckner et al., 2012). It is probably fair to say that these efforts created EE GMRIO tables and models through efficient and pragmatic adaptations of readily available building blocks. They, however, still faced the drawbacks such as limited sector/product detail, lack of consistent time series, or inclusion of just a limited number of extensions.

It is with the aim of tackling the latter problems that projects resulting in databases by WIOD, EXIOPOL and EORA were set up with funding of the EU (WIOD and EXIOPOL) and the Australian Research Council (EORA). The approaches chosen in the set-up of the different (EE) GMRIO projects are discussed in the next section when we summarize the contributions to this special issue.

3. CONTRIBUTIONS TO THIS SPECIAL ISSUE

This section briefly introduces the contributions to this special issue. We start with the three new database projects (i.e. EORA, EXIOPOL, and WIOD), after which the work on already

[9] Examples are emission data in most countries (which, if available at all, do usually not adopt the same sector classification as applied in the SUTs or IOTs), the countries of origin of imports (which are usually not given in national SUTs/IOTs), differences between trade data in SUTs/IOTs and in the trade statistics, imbalances in trade data (i.e. imports from country X reported by country Y do not equal the reported exports by country X to country Y), differences between countries in the type of SUT/IOT that they compile (e.g. some publish SUTs, other IOTs, which can be of the industry-by-industry or the product-by-product type), valuation differences (e.g. producer's, purchaser's and basic prices), differences in sector and product classifications.

[10] For instance, Wiedmann et al. (2011) express the hope that the so-called 'Group of Four' in the EU (EU DG ENV, Eurostat, EEA, and DG JRC) could be a vehicle for GMRIO development initiated by Europe. For practical purposes, it is in the meantime unclear whether the Go4 will remain active in the future. Another experience is that in a project for Eurostat it proved to be impossible to create even an MRIO table for the EU27 countries due to confidentiality problems, so that eventually an aggregated EU27 EE IOT was constructed (e.g. Eurostat, 2011; Tukker et al., 2012).

existing databases follows (i.e. a full GMRIO on the basis of GTAP and the work on AIIOTs by IDE-JETRO). The last paper focuses on the policy relevance of EE GMRIO tables.

Manfred Lenzen, Daniel Moran, Keiichiro Kanemoto, and *Arne Geschke* discuss the construction of the EORA database with GMRIO tables at high country and sector resolution. A guiding principle that makes EORA differ from all other databases in this special issue is that changes to the structure of the original raw data are avoided as much as possible for the sake of transparency. Consequently, EORA's MRIO includes original SUTs for one country, next to industry-by-industry IOTs for another country and product-by-product IOTs for a third country. The project is characterized by a high level of procedural standardization, automation, and data organization, leading to a result that allows for keeping the database up-to-date (with a time lag of 2 years) and an annual time input of two person years. The United Nations Main Aggregates and Official Country databases form the backbone of EORA's domestic country blocks. For 74 countries specific SUTs or IOTs were obtained. EORA separates from the basic price sheet three margins (trade, transport, and other), and one sheet containing taxes and subsidies on products. In addition, trade transactions are often valued 'free on board' (f.o.b.) and 'cost, insurance, freight' (c.i.f.). The EORA tables as published at the time of publication were estimated via a complex automated harmonization and optimization procedure that handled all raw data in one go. The reliability of the raw data is included by means of estimated standard deviations and the resulting MRIO table depends on the choice of reliability settings. It was assumed that national SUTs and IOTs were most reliable, followed by UN Main Aggregates and Official Country data, and then followed by the UN Commodity Trade Statistics Database (UN COMTRADE). The EORA tables currently exist as a time series spanning the period 1990–2010, distinguishing 187 countries represented at a detail of 20–500 sectors, or more than 15,000 sectors in the full MRIO. A small rest of the world region contains any remaining residuals in the event that the compiled table is not 100% balanced. The table is constructed in current US$.

Arnold Tukker and colleagues describe the construction of the EXIOPOL database (in short: EXIOBASE) and provide an illustrative case study. The EXIOPOL project chose to use SUTs as a basis. The EXIOBASE covers the 27 EU member states next to 16 non-EU countries with a rest of the world. Its main aim was to provide environmentally relevant information and, hence, had as ambition to have detail in sectors such as agriculture, energy, mining, and transport, where impact intensities can differ quite a lot. Next to the problems due to trade-linking, this project thus also faced a different challenge. That was how to arrive at the desired detail of 129 products and sectors? In essence, EXIOPOL used more detailed sector and product accounts to split up product and industry totals in the SUT. Then additional information about, e.g. supply and use coefficients per industry was used from countries with a detailed SUT. A non-linear programming approach balanced the estimated data at the detailed level, ensuring that the given original (and less detailed) table could still be reproduced by aggregation. The use table was split into a domestic and import use table – with primary information if available, otherwise via a proportionality assumption. UN COMTRADE-based trade shares were used to allocate imports to country of origin (without the differentiation in intermediate use, consumption, and investments made in WIOD). The information regarding exports was used to bi-proportionally adjust all import matrices to ensure consistency among imports, exports, and international valuation layers. Extensions were added by using databases (such as the United States Geological Survey (USGS) and United Nations Food and Agricultural Organisation Statistics (FAOSTAT) and the SERI database) for land, water, resource extraction, and biotic resource use, next to using the IEA database to estimate emissions per sector per country. The case study shows that consumption-based impacts for carbon emissions in the EU27 are just 5–10% higher than the territorial ones, whereas for water, land, and resources the EU27 consumption-based impacts include 30–60% resources extracted abroad.

Erik Dietzenbacher, Bart Los, Robert Stehrer, Marcel Timmer, and *Gaaitzen de Vries* discuss the compilation of the World Input–Output Tables (WIOTs) from the WIOD project. This database covers the 27 EU countries, 13 major other economies and a rest of world, provides annual data for the period 1995 to 2007 (and estimates for 2008 and 2009), and distinguishes 35 industries and 59 products. An important point of departure was that WIOD uses only data that are publicly available. Another feature is that WIOD relied on SUTs rather than IOTs. The idea is that SUTs can be linked to trade data (which are at the product level) and to socio-economic and environmental data (which are at the industry level) in a more consistent way. A third feature is that the WIOTs are fully benchmarked on National Accounts Statistics (NAS), because NAS are, e.g. revised whereas SUTs are not. Therefore, using information from NAS (such as gross output and value added by industry) available SUTs have been adapted. The same information from NAS (which is available annually) was used in the construction of a time series. In particular for non-EU countries, this required a time-consuming process of harmonization (e.g. making Chinese price concepts compatible with those used by other countries and making sure that US re-exports were recorded in the same way as for other countries). A fourth aspect is that a lot of attention has been paid in WIOD to constructing a bilateral trade database. For the trade in goods, an improved allocation has been developed. That is, the imports of each of the approximately 5000 products in UN COMTRADE were allocated to three end-use categories (intermediates, final consumption, and investments) and after that aggregated to the 59 WIOT products. This information was used to distinguish domestically produced goods from imported goods in the use table (and to distinguish between the countries of origin). Given the focus of the WIOD project (namely to include detailed socio-economic and environmental satellite accounts) it was important to include a number of service industries. A bilateral database for trade in services was created by combining the existing information from various sources. A final feature in the WIOD project is that tables are available in current prices and in previous year's prices.

Robbie Andrew and *Glen Peters* describe how they transformed the GTAP8 database (Narayanan et al., 2012) to a true multiregional IOT. The construction of the GTAP-MRIOT occurs in two phases involving different institutes. First, the GTAP constructs a harmonized database of IOTs (domestic and import) for 109 individual countries and 20 regions making up the world covering 57 sectors, balanced and harmonized bilateral trade data, macroeconomic data, transport data, and protection data. Second, the already harmonized GTAP database is then converted into the GTAP-MRIOT by distributing the import IOTs over the country of exports using the GTAP trade data (Peters et al., 2011b). Their goal with the GTAP-MRIOT is to perform timely and policy-relevant research, and they are less concerned with methodologies for constructing the GTAP database. Nevertheless, they invested quite some time in checking and understanding the robustness of the results derived from the GTAP-MRIOT. Some aspects they cover in their paper are the following. First, the relevance of spatial detail in the MRIOT was assessed. They found that for GHG, additional regional detail (129 regions in GTAP versus 40 countries plus a Rest of World (RoW) in, e.g. WIOD and EXIOPOL) gives little numerical difference in carbon footprints, though the RoW was found to have a significant share in the carbon footprint of most countries with implications for regional attribution. Additionally, they warn this can be quite different for impacts such as land use or biodiversity that mainly take place in developing countries (e.g. Lenzen et al., 2012b), which are not well covered in WIOD and EXIOPOL. Second, the relevance of sector detail was assessed. Adding sector detail increases the relative uncertainty at the sector level, but the overall result is usually more certain (cf. Lenzen, 2011). In the case of the GTAP database, a test where the 57 GTAP sectors were aggregated to 8 sectors showed that higher detail is more robust, but had little effect on the aggregated results in large countries. Third, differences between studies were analyzed. Important reasons for different outcomes in different studies are: different source data for environmental extensions; and different definitions or methods (e.g. using 'emissions embodied in bilateral trade' or a GMRIO). They made a comparison between different GTAP versions which showed a limited difference, but the differences would be expected to be larger comparing independent databases.

Bo Meng, Yaxiong Zhang, and *Satoshi Inomata* discuss in their paper the compilation and application of IDE-JETRO's international IOTs. The examples provided are the AIIOTs and the Transnational Interregional IOT between China and Japan. In this summary we will focus on the AIIOTs because they cover an important part of the global economy. Their history goes back to the mid-1970s and a very interesting feature is that IDE-JETRO compiled them with close support from official governmental institutes (such as the National Statistical Institutes) in the countries they cover. For the harmonization, IDE-JETRO carried out an in-depth cross-country survey to understand the differences in statistical treatment and presentation format of individual IOTs of the US and Asian countries. This provided an insight in the transformations that were required even before sector harmonization. Differences were at stake with regard to, e.g. valuation, dummy sectors (such as office supplies and scraps/by-products), the occurrence of negative entries, the treatment of Financial Intermediation Services Indirectly Measured (FISIM), all of which had to be reconciled. Sector concordance then yields national, harmonized IOTs that subsequently had to be trade-linked. For this, each country had to provide detailed information on imports/exports by product and origin/destination, import duties, domestic trade margins, and international freight and insurance margins. Where these data were not available, a gravity model was used to estimate missing information. To uncover the destination of imports (import matrices), a special survey on the use of imported commodities was done. The final step was linking all IOTs via trade, in which a problem occurred that was faced in virtually all database projects discussed here. That is, when imports in the IOT of each country are split up by country of origin, it usually appears that the total exports by a country of a certain product (or a sector) differs from summing – in the MRIOT – the imports of this product over the destination countries. IDE-JETRO tries to reconcile such differences by finding rational reasons for this, such as misclassification of imports or that erroneous reporting of entrepot trade. Such problems were iteratively corrected until the difference is below a threshold level and the difference is reported as statistical discrepancy.

Finally, *Thomas Wiedmann* and *John Barrett* describe to what extent analyses based on EE MRIO databases have contributed to policy decision-making and policy formulation. Analyses undertaken based on an EE MRIO database can deliver relevant information for the design of environmental policies that cannot be obtained from other models. An account of the extent to which policy-makers are aware of this, and whether the results of EE MRIO are reflected in the design of new policies, is relevant. The authors review the most important EE MRIO projects of the last years (an element of their paper summarized in the next section), and then concentrate on the policy relevance. They review various examples such as the WWF (World Wide Fund for Nature) using EE MRIO to analyze the global GHG emissions caused by consumption in the EU or the UK Carbon Trust using EE MRIO for a similar exercise on trade-embedded carbon flows, and other studies using EE MRIO for water and other 'footprint' calculations. They provide evidence that such work is picked up in policy debates and by some policy-makers. For instance, the UK government (through the UK Department for Environment, Food and Rural Affairs, DEFRA) now include consumption-based GHG accounts in their official statistics.

4. REFLECTION AND COMPARISON

To conclude, there are currently around five main GMRIO databases available. Their main characteristics are summarized in Table 1 (compare also the paper of Wiedmann and Barrett, 2013).[11] It concerns:

(1) EORA (Lenzen et al., 2012a; 2012b; 2013).
(2) EXIOBASE (the database from EXIOPOL, Tukker et al., 2009; 2013).
(3) WIOD (Dietzenbacher et al., 2013).
(4) GTAP-MRIOT (Peters et al., 2011b).
(5) GRAM (EE GMRIO tables on the basis of OECD IOTs, Bruckner et al., 2012, Wiebe et al., 2012a; 2012b).
(6) IDE-JETRO's AIIOTs (Meng et al., 2013; currently focusing on the Asian Pacific only, but to be expanded with other main economies in the future, including BRICs economies).

A common problem for virtually all projects was that they lacked the full information to create their desired GMRIO. This is not new, of course. In particular, regional IO practitioners often lacked full survey data and have developed procedures to overcome this problem (at least to some extent). This has led to a rich literature on, for example, how to best combine the available official statistics with non-survey data, how to deal with resulting imbalances, or how to estimate missing data (e.g. Isard, 1951; Lahr, 1993; van der Linden and Oosterhaven, 1995, Oosterhaven et al., 2008). Strategies followed by the projects above are as follows.

- GTAP-MRIOT and GRAM rely heavily on existing databases.
  - GTAP emphasizes an initial reconciliation of bilateral trade data first. The country IOTs are submitted by voluntary contributors following guidelines on definitions and sector classification. The trade data and IOTs are then combined with macro-economic, energy, transport, and protection data sets leading to a balanced database. The GTAP does not construct an MRIOT, but this can be constructed independently without balancing (see Peters et al., 2011b).
  - GRAM uses the OECD trade database that already has been harmonized with the IOTs from the OECD. Further reconciliation is thus not necessary. The GRAM tables, however, focus on production structures and estimate the outputs and values added of the industries (which, therefore, do not match the OECD data, see Wiebe et al., 2012a, Section 4.3).

[11] This special issue has papers on all databases in Table 1, with the exception of GRAM.

TABLE 1. Review of the main GMRIO databases.

Database name	Countries	Type	Detail ($i \times p$)*	Time	Extensions	Approach
EORA	World (around 150)	MR SUT/IOT	Variable (20–500)	1990–2009	Various	Create initial estimate; gather all data in original formats; formulate constraints; detect and judge inconsistencies; let routine calculate global MR SUT/IOT
EXIOPOL	World (43 + RoW)	MR SUT	129 × 129	2000**	30 emissions, 60 IEA energy carriers, water, land, 80 resources	Create SUTs; split use into domestic and imported use; detail and harmonize SUTs; use trade shares to estimate implicit exports; confront with exports in SUT; RAS out differences; add extensions
WIOD	World (40 + RoW)	MR SUT	35 × 59	1995–2009, annually	Detailed socio-economic and environmental satellite accounts	Harmonize SUTs; create bilateral trade database for goods and services; adopt import shares to split use into domestic and imported use; trade information for RoW is used to reconcile bilateral trade shares; add extensions
GTAP-MRIO	World (129)	MR IOT	57 × 57	1990, 1992, 1995, 1997, 2001, 2004, 2007	5 (GWP), Land use (18 AEZ), energy volumes, migration	Harmonize trade; use IOTs to link trade sets; IOT balanced with trade and macro-economic data
GRAM	World (40)	MR IOT	48 × 48	2000, 2004	Various	Use harmonized OECD IOTs; neglect differences like ixi and pxp; use OECD bilateral trade database to trade link
IDE-JETRO	Asia-Pacific (8: 1975) (10: 1985–2005)	MR IOT	56 × 56 (1975) 78 × 78 (1985–1995), 76 × 76 (2000, 2005)	1975–2005	Employment matrices (2000, 2005)	Harmonize IOTs based on cross-country survey information; link via trade, manual balancing to reduce discrepancies within a certain bounds

*i = number of industries, p = number of products, **The follow-up project CREEA constructs the EE GMRIO for 2007.

- WIOD, EXIOPOL (and its follow-up Compiling and Refining Economic and Environmental Accounts (CREEA)), and IDE-JETRO all rely on harmonizing the available country SUTs and/or IOTs to a common format. In this, EXIOPOL sets out to create a high level of detail requiring the use of auxiliary data, sometimes from outside the statistical system. The other approaches tend to look for a classification forming the best common denominator across countries covered usually leading to a reduced sector resolution. In this first stage, WIOD also constructs its time series of national SUTs on the basis of the National Accounts. After this, all projects use trade share information to identify the source countries of imports. Reconciliation with export data is done via different approaches.
    - EXIOPOL uses an automated approach that rebalances and scales trade differences after having estimated international trade margins.
    - WIOD uses information for the trade with the rest of the world and adapts its bilateral trade shares, given import and export totals at the product level from the national SUTs.
    - IDE-JETRO relies mainly on a manual, iterative process that tries to understand the underlying reasons for imbalances and to correct them, often with the help of supplementary (unpublished) information provided by collaborating National Statistical Institutes of the countries covered.
- EORA adopts a different approach, using SUTs and IOTs in their original format, and avoids the step-wise optimization and harmonization of the former projects. All raw data (SUTs/IOTs, the countries' main aggregates, trade statistics) are stored and, given an estimated uncertainty range, are processed together in one single balancing and optimization procedure.

All these databases have their own specific strengths and weaknesses. The GRAM project could be perceived as having the advantage that it uses data compiled by a supra-national organization. EXIOPOL has the highest level of sector detail (of 129 sectors and product groups) applied to all countries covered in its database. This can be advantageous, e.g. when analyzing the impacts for agriculture or resource extraction when consumption patterns change. Its drawback, however, is that it has no time series (planned to be developed in the just started EU FP7 project Development of Indicators for a Resource Efficient Europe (DESIRE). IDE-JETRO's AIIOTs, in contrast, offer tables that go back the furthest (1975), with a relatively detailed product classification (76 sectors). Also, non-mechanical, manual handling of data transformation enables a high level of harmonization among constituent national tables. The weakness, however, is explicit in its small country coverage. EORA and GTAP discern considerably more countries specifically than WIOD, EXIOPOL, IDE's AIIOT or GRAM. This has important advantages in assessing impacts of final consumption that take place in relatively poor countries with a low GDP not covered in other databases (Lenzen et al., 2012b) and is also important to attribute impacts to individual countries (as opposed to a large aggregated RoW). Overall, with its broad coverage of countries and varying sector detail per country, EORA seems to split up the global economy in most products and sectors and it is the only database that provides uncertainty information for its estimates. WIOD has a rather aggregated industry classification, in particular for the agriculture and the energy-producing sector where detail is important when is comes to analyzing issues on land use, water use, or resource use. On the other hand, WIOD is the only database with a consistent annual time series in both current and previous year's prices, which is highly relevant for analyses (e.g. applications indicate the substantial and instantaneous effect in 2001 of

China's accession to the WTO). Also, WIOD is fully consistent with the NAS which is important when a link is required to other (socio-)economic data (e.g. for productivity analyses).

5. OUTLOOK FOR FURTHER DEVELOPMENT

In sum, various (EE) GMRIO databases are currently available, developed via different philosophies. One question that obviously lies on the table is with respect to understanding their reliability. The first in-depth cross-comparison still needs to be done. Some initial analyses, however, show that even for carbon footprints of nations (one of the most studied environmental impacts) quite different values can be calculated with different EE MRIO databases (Peters et al., 2012; Tukker et al., 2012). As indicated in the contribution of Andrew and Peters (2013) in this issue, some of these differences are rather trivial and can and should be avoided by additional harmonization. We explicitly mention three of them. First, use similar definitions and avoid comparing results that are – in fact – based on different definitions for the trade in embodied extensions (EEBT versus GMRIO).[12] Second, use similar and consistent system boundaries. For example, avoid using energy data and emission figures that reflect the territorial principle, where economic data in SUTs/IOTs follow the resident principle. Particularly the allocation of (emissions from) international bunkers can lead to major discrepancies, especially for small countries with large shipping fleets. Third, use a harmonized data set for extensions, most notably emissions.[13]

Having said this, Lenzen et al. (2013) state rightly that creating a GMRIO table is an underdetermined problem. The amount of available and validated data is simply not sufficient to create a single GMRIO table that can claim as the most 'correct'. Another problem is that some basic underlying data sets show plain conflicts that can only be solved by choice. Depending on choices, assumptions and perceptions of which data seem most reliable, one will arrive – within certain limits – at different, but equally plausible 'mappings of the global economy'. The policy science literature calls such situations 'trans-scientific'. That is, a problem that can be framed as a scientific question, but that cannot be solved entirely scientifically (Weinberg, 1972; Funtowicz and Ravetz, 1990; Wynne, 1992). Brutally forcing one standard could create an unproductive scientific monoculture in a field that is characterized by complexity (Wynne and Mayer, 1993; Tukker, 1998). In such trans-scientific cases, wisdom in policy support is probably better guaranteed by providing insights from

[12] Indeed, we would claim that the 'extensions embodied in trade' (EEBT) approach is inferior. It uses national EE IOTs to calculate, for example, the pollution in country A as embodied in its exports to country B (and country C, and so forth). In the same fashion, country A also imports pollution embodied in its imports from country B (and country C, and so forth). The answers from this EEBT approach will differ from those obtained from applying a GMRIO table. A simple example suffices to show why. It may be the case that countries A and B do not trade with each other (in which case the EEBT approach will report no pollution embodied in their trade). However, it may happen that all trade between A and B goes through a third country C. Using a GMRIO model will in that case report positive imports and exports of pollution between countries A and B.

[13] Although this appears to be obvious, it is less simple than it seems. SUTs and IOTs reflect sales and use of fossil fuels. Many EE MRIO databases use the IEA database, where energy is allocated to the sector of use, and emission factors to calculate emissions. If such 'IEA-based' emissions are replaced by emissions of external databases like EDGAR, one may end up in a situation where, e.g. CO_2 emissions do not match, e.g. the IEA fuel use for an industry. The databases that use IEA energy flow data to calculate emissions, may use physical energy uses that are not consistent with the economic data in the SUT/IOT.

different perspectives (Lindblom, 1959; Thompson et al., 1990; Schön and Rein, 1994). Or, as pitched by Schwarz and Thompson (1990): ‘Divided we stand’. Having a few different (EE) GMRIO databases around, where each meets basic quality standards, is probably a good thing.

The continued maintenance and update of the databases is a concern. Solely relying on researchers that are successful in applying for grants or that have managed to create a not for profit business model (like GTAP), could pose limits to exploit the potential of GMRIO databases. Formal institutional support of one (or more) of the supra-national organizations (e.g. UN, OECD, WTO) is highly desirable. A promising development therefore is the initiative taken by the OECD to compile GMRIO tables. In this maintenance and updating process, automating the construction of (EE) GMRIO databases is the key to affordability. This is shown by the GTAP project and the construction of EORA. Another example is that TNO was able to produce – with an input of just three person-months – a 2007 GMRIO version of EXIOBASE. This was achieved drastically improving initial, automated procedures from the EXIOPOL project and the experience built up with data mining in EXIOPOL.

What other developments do we expect in the next 5 to 10 years? It is likely that the quest for more sector, product, country and even intra-country regional detail will continue.[14] The integration of economic, energy, and material databases into an integrated global Monetary, Energy, and Material MR EE SUT is already ongoing in the EU FP7 project CREEA[15] Various detailed global transport databases exist, which can help to make more precise estimates of international valuation layers and that may even be used to improve bilateral trade estimates (e.g. Tavasszy et al., 2011). It may be important to have more precise estimates of which sectors use which imports instead of using proportionality assumptions. It may become important to differentiate sectors in firms mainly producing for exports and firms that mainly produce for domestic use, if their impact intensities and value added differ (see Koopman et al., 2012; Dietzenbacher et al., 2012b). There is likely to be a further convergence with life cycle inventory databases. In essence, these are also supply use tables, albeit still mainly in physical terms but at a much finer resolution as regular SUTs.[16] We also expect that there will be developments to add information of significant spatial or product detail. Probably this will come as extension, related to water and land use by sector, in support of impact assessment methods that rely on such spatial and/or product information (e.g. Pfister et al., 2011; Ewing et al., 2012). A new EU-funded FP7 project (SmartSpec) on smart specialization will start in 2013. Using the WIOTs from the WIOD project as the point of departure, the EU will no longer be represented by 27 countries but by more than 200 NUTS2 regions. And in all this, it is indispensable to conduct scientific assessments of what improvements are most crucial and cost-effective for providing more reliable answers to policy questions (Lenzen, 2011; Peters et al., 2012). An expert network such as brought

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[14] Current work in progress on incorporating sub-national regions into a GMRIO includes Cherubini and Los (2012) on Italy, Dietzenbacher et al. (2012a) on Brazil, and Inomata and Meng (2013) on China-Japan-Korea.

[15] See www.creea.eu, accessed 12 August 2012.

[16] For instance, Eco-invent, one of the dominant LCI databases, is currently organizing its data as a supply use system. Personal communication with Eco-invent staff also suggests they may want to move to using product and sector codes usually applied in economic statistics, as well as encouraging data providers to supply (next to the traditional physical information) also price information on inputs and outputs. See, e.g. http://www.ecoinvent.org/df-lca-ecoinvent-v3/, accessed 12 August 2012.

together via the 'Réunion project' as mentioned in the introduction of this editorial can be instrumental in this.

We have only just begun. An exciting future lies ahead for the field of GMRIO.

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