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An Illustrated User Guide to the World Input–Output Database: the Case of Global Automotive Production

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Abstract

This article provides guidance to prudent use of the World Input–Output Database (WIOD) in analyses of international trade. The WIOD contains annual time-series of world input–output tables and factor requirements covering the period from 1995 to 2011. Underlying concepts, construction methods and data sources are introduced, pointing out particular strengths and weaknesses. We illustrate its usefulness by analyzing the geographical and factorial distribution of value added in global automotive production and show increasing fragmentation, both within and across regions. Possible improvements and extensions to the data are discussed.

1. Introduction

Stimulated by declining coordination and transport costs, production processes increasingly fragment across borders. This fundamentally alters the nature of international trade, away from trade in goods towards trade in tasks and activities, with profound implications for the geographical location of production, the patterns of gains from trade and the functioning of labor markets (Feenstra, 2010). However, current statistical frameworks are not well equipped to provide the necessary data to analyze these phenomena. Grossman and Rossi-Hansberg, for example, state that "the globalization of production processes mandates a new approach to trade data collection, one that records international transactions, much like domestic transactions have

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* Timmer: Groningen Growth and Development Centre, Faculty of Economics and Business, University of Groningen, PO Box 800, 9700 AV, Groningen, The Netherlands. E-mail: m.p.timmer@rug.nl. Dietzenbacher, Los and de Vries: Faculty of Economics and Business, University of Groningen, Groningen, The Netherlands. Stehrer: The Vienna Institute for International Economic Studies (wiiw), Vienna, Austria. The World Input–Output Database (WIOD) is an outcome of a project that was funded by the European Commission, Research Directorate General from 2009 to 2012 as part of the 7th Framework Programme, Theme 8: Socio-Economic Sciences and Humanities, grant Agreement No. 225 281. The project was carried out by a consortium of 12 research institutes headed by the University of Groningen, The Netherlands and including the Institute for Prospective Technological Studies (IPTS), Seville, Spain; The Vienna Institute for International Economic Studies (wiiw), Vienna, Austria; Zentrum für Europäische Wirtschaftsforschung (ZEW), Mannheim, Germany; Österreichisches Institut für Wirtschaftsforschung (Wifo), Vienna, Austria; Hochschule Konstanz, Germany; The Conference Board (TCB) Europe, Brussels, Belgium; CPB Netherlands Bureau for Economic Policy Analysis, The Hague, The Netherlands; Institute of Communication and Computer Systems (ICCS), Athens, Greece; Central Recherche SA, Paris, France and the Organisation for Economic Co-operation and Development (OECD), Paris, France. We are grateful to all participants in the project for their contributions in the construction and validation of preliminary versions of the database. In particular we wish to thank Abdul Azeez Erumban, Umed Temurshoev, Neil Foster-McGregor, Johannes Pöschl and Reitze Gouma for their invaluable research assistance without which the construction of this database would have been impossible. Continued support from the OECD and the World Trade Organization (WTO), in particular Hubert Escaith, is also gratefully acknowledged. Stimulating comments from two reviewers and the editor are gratefully acknowledged.

been recorded for many years" (Grossman and Rossi-Hansberg, 2008, p. 1996). Official trade statistics however, are still collected with no information on the supplying industry nor on the use by the importers. This drove researchers to compile their own databases, typically merging international trade statistics with a collection of input–output tables from the Global Trade Analysis Project (GTAP) project into a world input–output table (see e.g. Trefler and Zhu, 2010; Johnson and Noguera, 2012a,b; Koopman et al., 2014). These efforts are difficult to replicate, however, as GTAP is a proprietary database. It is not grounded in official statistics and only available for certain benchmark years, which precludes analyses of long-term trends.

Given this, we constructed a new alternative, the World Input–Output Database (WIOD) that provides annual time-series of world input–output tables from 1995 onwards. These tables have been constructed in a clear conceptual framework based on the system of national accounts (Intersecretariat Working Group on National Acccounts (ISWGNA), 1993, 2010). They are based on officially published input–output tables merged with national accounts data and international trade statistics. In addition, the WIOD provides data on factor inputs enlarging the scope of potential applications considerably. Since its public inception on April 2012 (at http://www.wiod.org), the WIOD has proved very useful in analyses of international trade. It has been used to describe trends in global supply chain trade and research into the formation of regional production clusters in the world economy (e.g. Baldwin and Lopez-Gonzales, 2013; Timmer et al., 2013; and Los et al., 2015), as well as analyzing the domestic value-added content of gross exports (e.g. Wang et al., 2013; Koopman et al., 2014; Johnson, 2014). The data also proved suitable for calibrating general equilibrium models to evaluate the effects of trade policies (e.g. Costinot and Rodríguez-Clare, 2013; Ottaviano et al., 2014). The cross-section panel dimensions of the data allowed a revisit of the debate on the effects of offshoring on labor demand (e.g. Foster-McGregor et al., 2013; Schwörer, 2013). WIOD also found its way into numerous policy-oriented studies on the effects of globalization (e.g. Greenaway, 2012; Di Mauro et al., 2013; European Commission, 2013; Saito et al., 2013).

The uptake of the WIOD is still ongoing and many more applications are foreseen. To optimize the benefit of this new database, users need to understand its conceptual and practical underpinnings. The main purpose of this article is therefore to summarize the methodology employed in constructing the database, guiding researchers on appropriate uses. This requires that we also consider the practical limitations of the database and indicate areas for further improvement. We illustrate the strengths and the limitations of the database by analyzing fragmentation and the shifts in regional and factorial distribution of value added in global automotive production. The automotive industry has been particularly affected by the increasing opportunities for offshoring and international fragmentation of production (e.g. Sturgeon et al., 2008). So far, quantitative evidence on this is missing and we will provide trends since 1995 based on times-series information in the WIOD, which might stimulate further research on the causes and consequences of international fragmentation of production.

The remainder of this article is organized as follows. In section 2 we lay out the basic conceptual framework of a world input–output table and briefly discuss its basic data sources and main methodologies. The main challenges in construction are discussed in a non-technical manner, deferring technical details to a companion paper (Dietzenbacher et al., 2013). It also provides a comparison with GTAP and the Organisation for Economic Co-operation and Development (OECD) Trade-in-value-added (TiVA) database. In section 3 we use the WIOD to analyze trends in global automotive production, illustrating its power in analyses of international production fragmentation. Section 4 is more general and considers specific measurement issues that are important for prudent use of the data, and identifies areas that are most in need for improvements. The WIOD is meant to serve as a dynamic resource that will be expanded over time and section 5 considers future developments.

2. WIOD in Comparative Perspective

In this section we first outline the concept of a world input–output table, followed by a brief discussion of the contents of the WIOD compared with other database initiatives. Through a comparison of value-added export measures based on the various databases we conclude that empirical differences are relatively minor.

WIOD Characteristics

Central in the WIOD is a time-series of world input–output tables. A world input–output table (WIOT) can be regarded as a set of national input–output tables that are connected with each other by bilateral international trade flows. This is illustrated by the schematic outline for a WIOT involving three countries in Figure 1. A WIOT provides a comprehensive summary of all transactions in the global economy between industries and final users across countries. The columns in the WIOT contain information on production processes. When expressed as ratios to gross output, the cells in a column provide information on the shares of inputs in total costs. Such a vector of cost shares is often referred to as a production technology. Products can be used as intermediates by other industries, or as final products by households and governments (consumption) or firms (stocks and gross fixed capital formation). The distribution of the output of industries over user categories is indicated in the rows of the table. An important accounting identity in the WIOT is that gross output of each industry (given in the last element of each column) is equal to the sum of all uses of the output from that industry (given in the last element of each row).

In addition to a national input–output table, imports are broken down according to the country and industry of origin in a WIOT. This allows one, for example, to trace the country of origin of the chemicals used in the food industry of country A. The combination of national and international flows of products provides a powerful tool

			Use by country-industries							**Final use by countries**			**Total use**
			Country 1			…	Country M			Country 1	…	Country M	
			Industry 1	…	Industry N	…	Industry 1	…	Industry N		…		
Supply from country-industries	Country 1	Industry 1											
		…											
		Industry N											
	……												
	Country M	Industry 1											
		…											
		Industry N											
Value added by labour and capital													
Gross output													

Figure 1. Schematic Outline of a World Input–Output Table (WIOT)

for analysis of global production networks as will be shown in section 3. While national tables are routinely produced by national statistical institutes, WIOTs are not, as they require integration of national account statistics across countries. It is this gap that the WIOD project aimed to fill.

The second release of the WIOD in November 2013 provides a time-series of world input–output tables (WIOTs) from 1995 to 2011. It covers 40 countries, including all 27 members of the EU (as of 1 January 2007) and 13 other major economies: Australia, Brazil, Canada, China, India, Indonesia, Japan, Mexico, Russia, South Korea, Taiwan, Turkey and the USA (see Appendix Table A1 for a full list). These countries have been chosen by considering both the requirement of data availability of sufficient quality and the desire to cover a major part of the world economy. Together, the countries cover more than 85% of world gross domestic product (GDP) in 2008 (at current exchange rates). In addition, a model for the remaining non-covered part of the world economy is estimated, called the "rest of the world" (RoW) region. To address several important research questions it is crucial to have a full model of the world economy. The values in WIOTs are expressed in millions of US dollars and market exchange rates were used for currency conversion. All transaction values are in basic prices reflecting all costs borne by the producer, which is the appropriate price concept for most applications. International trade flows are accordingly expressed in "free on board" (fob) prices through estimation of international trade and transport margins.

The WIOTs have an industry by industry format as many applications require such a square matrix reflecting the economic linkages across industries. They provide details for 35 industries mostly at the two-digit ISIC rev. 3 level or groups thereof, covering the overall economy. These include agriculture, mining, construction, utilities, 14 manufacturing industries, telecom, finance, business services, personal services, eight trade and transport services industries and three public services industries (see Appendix Table A2). This level of detail was dictated by the available data, reflecting the lowest common denominator across countries. The WIOTs are built up from published and publicly available statistics from national statistical institutes around the world, plus various international statistical sources such as OECD and UN National Accounts. In the Appendix we discuss how we dealt with four major challenges in data construction: harmonization of basic supply and use tables; derivation of time-series; disaggregation of imports by country of origin and use category, and global closure.

The WIOD has a number of distinguishing characteristics when compared with other data initiatives, most notably the Asian International Input–Output Tables constructed by Institute of Developing Economies–Japan External Trade Organization (IDE-JETRO) (Meng et al., 2013), the OECD–WTO database on TiVA (OECD and WTO, 2013), Eora (Lenzen et al., 2013), and various attempts based on the GTAP database (such as Johnson and Noguera, 2012a).[1] First and above all, the WIOTs from WIOD have been specifically designed to trace developments over time through benchmarking to time-series of output, value added, trade and consumption from national accounts statistics. In contrast, the IDE-JETRO and GTAP data sets have been compiled for particular benchmark years, and cannot be used in analyses over time.

Second, WIOD is based on official and publicly available data from statistical institutes to ensure a high level of data quality. In particular, it is constructed within the framework of the international System of National Accounts and obeys its concepts and accounting identities. This obviously restricted the number of countries that could be covered in WIOD as there is a trade-off between quality and coverage. The WIOD is covering 40 countries and a RoW region. The Asian tables by IDE-JETRO are arguably of a higher statistical quality but only cover a limited number of countries. In contrast, Eora covers all countries in the world, but heavily relies on imputation methods to fill up the many blanks in data for countries with less well-developed statistical systems.

Third, the WIOTs have been constructed on the basis of sets of national supply and use tables (SUTs) that are the core statistical sources from which statistical institutes derive national input–output tables. SUTs provide a more natural starting point for building WIOTs than national input–output tables as which are the basic building blocks in other initiatives. The latter tables contain less information and are typically derived from the former with additional assumptions. Moreover, SUTs can easily be combined with trade statistics that are product-based and employment statistics that are industry-based and allow one to take the multi-product nature of firms into account.

Fourth, apart from the WIOTs themselves, the WIOD also provides tables with underlying data and statistics that have been used to construct the WIOT. Examples are national and international supply and use tables, as well as valuation matrices with product-specific trade and transportation margins and net taxes. In addition, the WIOD provides data on the quantity and prices of input factors, including data on workers and wages by level of educational attainment and capital inputs. These data are provided in the so-called *Socio-economic accounts* and can be used in conjunction with the WIOTs as similar industry classifications are used. This greatly enhances the scope of analysis, as shown in the next section.

Finally, the WIOD is yet the only database that is publicly available and for free (at www.wiod.org). The OECD–WTO database, which comes closest to WIOD in terms of coverage and construction philosophy, currently provides only derived indicators on TiVA and does not share the underlying international input–output tables. The WIOD is also the only database that provides full transparency by providing all the underlying data sources and methodologies. This not only allows for full replication of its construction and results based on it, but also invites users to build alternative datasets based on the same data but with different assumptions.

Comparison of Value Added Exports Statistics

Within the field of international economics, international input–output tables proved to be particularly useful in the analysis of TiVA, starting from the seminal work on vertical specialization by Hummels et al. (2001). The follow-up work by Johnson and Noguera (2012a) and Koopman et al. (2014) on measuring the domestic value content of exports relied heavily on the use of world input–output tables and increased demand for this type of data. Their analyses were based on construction of such tables, combining trade statistics and national input–output tables drawn from the GTAP database. Since then, the OECD–WTO database on TiVA and the WIOD have become available as alternative sources for this type of work. In this section we compare to what extent the choice for a particular database matters for empirical results. Ideally, one would like to directly compare the databases along various dimensions, but as outlined above the WIOD is the only one that provides public access to the underlying data. Therefore the only possibility is to provide a comparison on the basis of derived indicators that have been published in various studies. We will compare the most well-known statistic in this field, namely the value-added exports to gross exports ratio. Value-added exports (VAX) of a country measure the domestic value added embodied in final expenditures abroad (Johnson and Noguera, 2012a). This statistic is available in the OECD TiVA database, as well as in the work of Johnson and Noguera (2012a) and Koopman et al. (2014). The latter studies base their analysis on GTAP data, but have followed somewhat different strategies in database construction. We calculate the VAX ratios on the basis of the WIOD and provide a comparison for all countries in each study, which are also present in the set of 40 countries in the WIOD.

To calculate VAX we follow Johnson and Noguera (2012a) who make use of the decomposition technique introduced by Leontief (1949).[2] Let **Q** denote a vector of output levels in industries, **C** a vector with consumption levels[3] and $\boldsymbol{B}$ a matrix with intermediate input coefficients describing how much intermediates are needed to produce a unit of output in a given industry (as given in the world input–output table). Then $\mathbf{Q} = (\boldsymbol{I} - \boldsymbol{B})^{-1}\mathbf{C}$, where $\boldsymbol{I}$ is the identity matrix. $(\boldsymbol{I} - \boldsymbol{B})^{-1}$ is famously known as the Leontief inverse and represents the gross output values that are generated in all stages of the production process of one unit of consumption.[4] The value added by all factors that are involved in any stage of the production of **C** is then given by a vector **K** that can be derived as follows:

$$\mathbf{K} = \boldsymbol{F}(\boldsymbol{I} - \boldsymbol{B})^{-1}\mathbf{C} \tag{1}$$

where $\boldsymbol{F}$ represents a diagonal matrix of value added to gross output ratios in all industries in all countries.[5] To calculate the value-added exports of a country, **C** should refer to all consumption outside the country of consideration.

Figure 2 provides a comparison of VAX as a percentage of gross exports for 40 countries for the year 2004 across the four studies. Countries are ranked from lowest to highest VAX ratios based on the WIOD. The overriding conclusion is that there is remarkable agreement across alternative data sets about how value-added exports compare with gross exports. This echoes the conclusion of Johnson (2014) in his overview. The overall pairwise correlation between the four datasets ranges from 0.93 to 0.98 (Spearman rank correlation). This is based on 11 observations. When we exclude the results from Koopman et al. (2014) the rank correlations across the other three set of results, based on 39 observations, range from 0.91 to 0.94.

A number of differences stand out though, which have a clear reason and point to important avenues for further research. The ratios for Mexico and China in Koopman et al. (2014) are much lower than in the other databases (except for China in the OECD TiVa database). This is related to the fact that Koopman et al. (2014) relied on additional data on exports from special economic zones for these two countries. When production for exports is more intensive in the use of imported intermediates than production for domestic demand, the use of an input–output table that does not explicitly model the export sector might overestimate the domestic value-added content of exports for countries such as China and Mexico (see Koopman et al., 2012; Yang et al., 2015).[6] Collecting this type of data for more countries, in particular for countries that also have a sizeable domestic market, is therefore highly desirable. The problems in the treatment of processing exports are discussed more in depth in section 4.

3. An Analysis of Global Automotive Production

In this section we will illustrate the usefulness of the WIOD by providing an analysis of the deep changes in the global production of automotives. The automotive

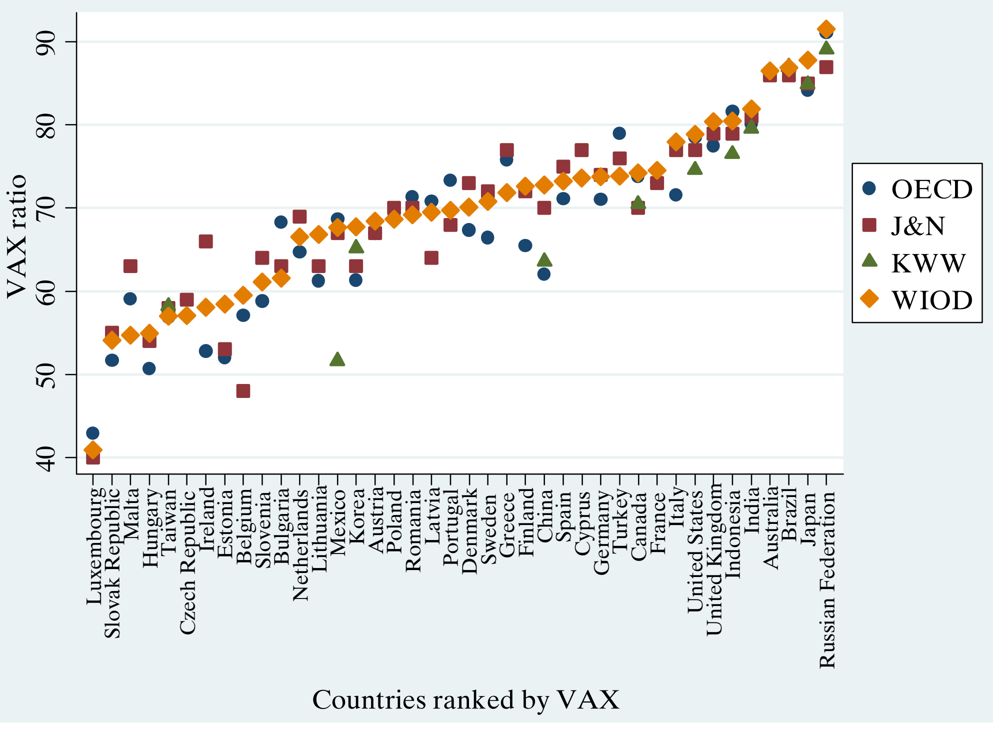

Figure 2. Value Added Exports Ratios in 2004

Source: OECD refers to numbers taken from OECD *Trade-in-value-added* (TiVA) database, July 2013 version. J&N refers to numbers in Johnson and Noguera (2012a) and KWW to Koopman et al. (2014). WIOD are authors' calculations based on the World Input–Output Database, November 2013 version.

industry has been particularly affected by the increasing opportunities for offshoring and international fragmentation of production. For example, Gereffi et al. (2008) suggest that automotive production is characterized by trends towards regionalization as well as globalization of activities at the same time. Using the method developed in Los et al. (2015), we provide empirical evidence for this hypothesis and analyze regional distributions of value added in second subsection below. We also show that the financial crisis in 2008 led to major restructuring, but not to domestic consolidation of production chains. In the third subsection, we analyze the competitiveness of countries in global automotive production based on the concept of global value chain (GVC) income introduced by Timmer et al. (2013) and show that Europe still has a strong position, even after the financial crisis. Finally, in the fourth subsection we provide trends in the factor contents of global automotive production, exploiting the factor requirement data available in the WIOD. It is shown that income shares of capital and high-skilled workers are rapidly increasing, while medium- and low-skilled shares are declining. However, before embarking on a global study, we start with an analysis of the deep changes in the production of German transport equipment since 1995. This value chain, apart from being interesting in itself, allows us to introduce the main methods and concepts to be used in the remainder of the section.

The Global Value Chain of German Automotives

We define a GVC of a final good as the set of all value-adding activities needed in its production. It is identified by the country–industry in which the last stage of production takes place, which we call the country–industry-of-completion (such as the transport equipment manufacturing industry in Germany). A GVC includes the value added in this last industry, as well as in all other industries in the same country or abroad where previous stages of production take place. To decompose value added in production, we make use of Leontief's decomposition method outlined in section 2. In contrast to studies of TiVA we do not trace a country's contribution to its exports, but its contribution to the output value of a particular consumption good. This is done by appropriately choosing the final demand vector **C** in equation (1). So when **C** refers to the consumption of products delivered by the German automotive industry, then this decomposition provides the value added by all labor and capital that was needed in any stage of production of these automotives. Note that in contrast to the TiVA studies, this consumption can be either domestic or foreign, as we are interested in analyzing the production process of the automotives, irrespective of where they are ultimately consumed.[7]

The accounting scheme is illustrated in Figure 3 where global value chains are represented by the columns. There is one column for each final product, characterized by the country–industry-of-completion, with cells showing the origin of the value added. Note that the delivering industries are domestic as well as foreign. The sum across all participating industries in a GVC makes up the gross output value of the final product, given in the bottom row. As all final products are consumed somewhere in the world, final output values will equal global expenditure on the product. Thus the summation of final output across all columns equals world GDP, which is measured from the expenditure side. A particular row in Figure 3 provides information on the value added from a particular country–industry to all global value chains in the world. Obviously, this includes value added in the production of its own final products, but also value added to production in other GVCs, by means of delivering intermediate inputs. Note however, that in contrast to a row in the world input–output table (Figure

<table>
<tr><td colspan="3" rowspan="3"></td><td colspan="7">Final products of a global value chain, identified by country-industry of completion</td><td rowspan="3">Value added</td></tr>
<tr><td colspan="3">Country 1</td><td rowspan="2">…</td><td colspan="3">Country M</td></tr>
<tr><td>Industry 1</td><td>…</td><td>Industry N</td><td>Industry 1</td><td>…</td><td>Industry N</td></tr>
<tr><td rowspan="7">Value added from country-industries participating in global value chains</td><td rowspan="3">Country 1</td><td>Industry 1</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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<tr><td rowspan="3">Country M</td><td>Industry 1</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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<tr><td>Industry N</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="3">Total final output value</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>World GDP</td></tr>
</table>

Figure 3. An Accounting Framework for Global Value Chains

Note: Cell values represent the value added generated in the country–industry given in the row, within the global value chain corresponding to the country–industry of completion given by the column.

1) this row indicates the flow of value added, and not the value of intermediate inputs. Moreover, it includes value added delivered directly to the industry-of-completion, but also indirectly through other industries. An element in the final column provides the summation across the row and is equal to the value added in an industry. Summed across all industries, this equals world GDP as measured from the production side. Note that this accounting framework for GVCs thus obeys an important accounting convention: both the columns and the rows add up to world GDP as global final expenditure must be equal to global value added.

In Table 1, we provide the decomposition for the final output of the transport equipment manufacturing industry in Germany, in short "German cars". The table indicates the geographical origin of the final output of German cars in 1995 and in 2008 and reveals striking developments. Between 1995 and 2008, the share of domestic value added decreased rapidly from 79% to 66% of the value of a German car. Value added from Eastern Europe increased. This is well documented in case studies: with the new availability of cheap and relatively skilled labor, firms from Germany relocated parts of the production process to Eastern Europe (Marin, 2011). Perhaps surprisingly, value added from other countries in Europe increased by nearly the same amount. At the same time, the industry quickly globalized by sourcing more and more from outside Europe. Countries outside Europe actually accounted for more than half of the increase in foreign value added.

The WIOD also provides data on the factor inputs used in production (see the fourth subsection), and similar decompositions can be made by appropriately choosing the production requirement matrix $\boldsymbol{F}$ in equation (1). We redo the analysis, but now for each production factor separately: low-, medium- and high-skilled workers and capital. As we define capital income as a residual, the sum of value added by these four factors is equal to the overall value added in an industry. Table 2 provides the factorial decomposition separately for production factors in Germany (left-hand side) and abroad (right-hand side). The decline in domestic value added as shown in Table 1 appears to reflect declining contributions from less-skilled domestic labor, in particularly medium-skilled workers. The value added by domestic capital and high-skilled

Table 1. Value-added Shares in Final Output of Automotives from Germany (%)

Generated in	*1995*	*2008*	*Change*
Germany	78.9	66.0	–12.8
Eastern Europe	1.3	4.3	3.0
Other European Union	11.9	14.3	2.4
NAFTA	2.5	3.1	0.6
East Asia	2.1	4.3	2.2
Other	3.3	8.0	4.7
Total	100.0	100.0	

Notes: Decomposition of final output of the transport equipment manufacturing industry in Germany (ISIC rev. 3 industries 34 and 35) based on equation (1). Eastern Europe refers to countries that joined the EU as of 1 January 2004. East Asia refers to China, Japan, South Korea and Taiwan. Numbers may not sum as a result of rounding.
Source: Authors' calculations based on the World Input–Output Database, November 2013 release.

Table 2. Factor Shares in Final Output of Automotives from Germany (%)

	Factors in Germany			*Factors abroad*		
	1995	*2008*	*change*	*1995*	*2008*	*change*
Workers, of which	58.1	46.5	–11.6	12.9	18.6	5.8
Low-skilled	7.3	4.3	–3.0	4.0	4.0	0.0
Medium-skilled	34.5	25.4	–9.1	6.1	9.0	2.9
High-skilled	16.4	16.9	0.5	2.8	5.6	2.8
Capital	20.7	19.5	–1.2	8.3	15.3	7.1
Total	78.9	66.0	–12.8	21.1	34	12.8

Notes and sources: See Table 1.

workers in contrast held up well as their shares did not, or only slightly, decline. The change in the factorial distribution of foreign value added did not mirror these domestic changes. Value added by less-skilled foreign workers increased somewhat but by much less than the decrease in Germany. Obviously, this is due to lower foreign wages, which is an important driver for international production fragmentation. In addition, it might also indicate that activities carried out by these workers are increasingly automated as they are typically routine-based (see Autor et al., 2003).[8] This hypothesis is buttressed by the finding that the income share of capital abroad rapidly increased, by more than seven percentage points. Substitution across factors is discussed more extensively in fourth subsection.

Increasing International Fragmentation in Automotive Production

Previous studies of globalization tended to claim that international production fragmentation is mainly taking place within regional trade blocs rather than being a truly global phenomenon. This claim is often based on observations of increasingly denser networks of intermediate input flows between countries belonging to the same region (e.g. Baldwin and Lopez-Gonzalez, 2013). However, gross trade flows are no longer representative of the value-added flows, and the value-added content of trade between countries within a region might well be lower than between countries across regions. As shown above, global value chain decompositions provide a particularly useful tool to analyze the geographical distribution of value added in production. In this section we focus on the global production of automotives and answer the question whether this process is mainly taking place within a regional bloc (regional fragmentation) or also involves fragmentation outside blocs (global fragmentation). In their study of the global automotive industry, Gereffi et al. (2008) argue that automotive manufacturers prefer to locate their assembly activities close to end markets, often enticed or forced by government policies. Specialized suppliers tend to cluster around these assembly activities. The production of more standardized parts and components generally takes place in Asia, however, as a result of opportunities to realize substantial returns to scale and labor cost reductions. Production chains of automotives thus seem to fragment both globally and regionally.

To analyze the geographical distribution of value added in the production of automotives we use the decomposition given in equation (1) where $\mathbf{C}$ is chosen as one unit of final demand for automotives coming for a given country-of-completion. For each country-of-completion we indicate the amounts of value added that originate domestically, regionally and globally. Regional value added is all value that is added outside the country-of-completion, but in the region to which this country-of-completion belongs. Global value added is the value added in all countries outside this region. By definition the domestic, regional and global value-added shares add up to unity. In line with Baldwin and Lopez-Gonzalez (2013), we distinguish three major regional trading blocs: EU, including the 27 member countries of the EU as of 2011; NAFTA, the North-American Free Trade Agreement countries: Canada, Mexico and the USA; and East Asia comprising China, Japan, South Korea and Taiwan. While the latter region does not have an exclusive multilateral trade agreement among its members, it is characterized by strong international trade and investment links.

In Table 3 we provide decomposition results for 2008, and the change in shares between 1995 and 2008. The results for the 24 countries are grouped by trade bloc and sorted within blocs according to final output value. So, for example, the table shows that the final output value of transport equipment in Germany in 2008 was US$248 billion, of which 19% was generated within Europe but outside Germany, and 15% outside Europe. Since 1995, value added outside Germany has increased by 13 percentage points, of which seven percentage points were outside the EU.

The first major finding is that in all countries, except for Canada, the share of domestic value added has declined between 1995 and 2008, and in some countries even by up to 20 percentage points. Nevertheless, the share of domestic value added is still substantial in 2008. For major countries in Europe, domestic shares are between 60% and 70%, and higher in the USA (77%) and Japan (83%). Smaller countries typically have lower domestic shares, which drop to less than 40% in the cases of Belgium, Hungary and Slovakia. The second finding is that for European automotive chains, the majority of foreign value added is still generated within the EU. For all chains with countries-of-completion in the EU, regional value-added shares are higher than global shares in 2008. This is rapidly changing: since 1995 global shares increased much faster than regional shares in all EU countries as more and more intermediates are sourced from outside Europe (except for chains ending in Hungary and Romania). This fits the findings by Los et al. (2015), who provide a more comprehensive study of various manufacturing product groups.

Will this fragmentation trend continue? It has been hypothesized that the global financial crisis would have major consequences for the organization of global production networks. Bems et al. (2011) concluded that international trade declined considerably more than world GDP in 2008. This was explained by demand uncertainty leading to the temporary adjustment of inventories within supply chains. Based on French firm-level data, Altomonte et al. (2012) show that this amplification (or bullwhip) effect was bigger in intra-group trade in intermediates than in market-mediated trade. The crisis might also mark a more structural break in the process of international fragmentation, however, as firms experienced the vulnerability of long production chains. Other factors such as rising fuel prices or an upward drift in Chinese wages might be additional drivers. Using the WIOD we can obtain insights into what happened in the first three years after the start of the crisis.

In Figure 4, we trace for six major automotive producing countries the share of foreign value added in the final output over the period 1995–2011. The trend lines confirm the overall increase in foreign value-added shares over the period 1995–2008 discussed above, but also points to differences across countries in the timing and speed of the value chain fragmentation process. Foreign shares for the major continental European countries were already on a rising trend in the 1990s (including in Italy and Spain, which are not shown here). After a short period of stabilization, the

Table 3. Regional Value-added Distribution of Final Output of Automotives by Country-of-completion

Country of completion	Final output (US$m) in 2008	Value added shares in 2008			Change in shares (2008 minus 1995)		
		Domestic	Regional	Global	Domestic	Regional	Global
European Union							
Germany	248,374	0.66	0.19	0.15	–0.13	0.05	0.07
France	117,710	0.60	0.24	0.16	–0.12	0.05	0.07
Great Britain	58,855	0.64	0.18	0.17	–0.07	0.01	0.06
Spain	56,055	0.61	0.25	0.14	–0.08	0.02	0.06
Italy	52,600	0.68	0.17	0.15	–0.09	0.03	0.07
Sweden	22,960	0.54	0.29	0.18	–0.11	0.03	0.08
Belgium	18,961	0.37	0.41	0.23	–0.05	–0.03	0.08
Poland	17,819	0.55	0.29	0.16	–0.20	0.10	0.10
Czech Republic	15,146	0.48	0.36	0.15	–0.11	0.05	0.06
The Netherlands	13,704	0.51	0.27	0.22	–0.01	–0.03	0.03
Austria	10,364	0.47	0.37	0.16	–0.12	0.06	0.06
Hungary	8,902	0.36	0.45	0.19	–0.20	0.15	0.05
Slovakia	8,610	0.32	0.44	0.24	–0.20	0.08	0.12
Romania	8,257	0.67	0.19	0.13	–0.09	0.05	0.04
East Asia							
China	210,714	0.79	0.05	0.16	–0.05	–0.01	0.07
Japan	204,072	0.83	0.04	0.13	–0.11	0.03	0.09
South Korea	73,515	0.64	0.13	0.24	–0.13	0.05	0.08
Taiwan	7,740	0.62	0.15	0.23	–0.05	0.03	0.02
NAFTA							
United States	348,461	0.77	0.05	0.18	–0.07	0.02	0.06
Canada	71,564	0.55	0.24	0.21	0.00	–0.07	0.08
Mexico	58,633	0.62	0.17	0.21	–0.02	–0.07	0.09
Other							
Brazil	68,271	0.77	0.05	0.18	–0.10	0.02	0.08
Russia	34,453	0.61	0.17	0.22	–0.23	0.08	0.14
Turkey	12,371	0.64	0.20	0.16	–0.17	0.07	0.09

Notes: Domestic, regional and global value-added shares in final output from transport equipment industry in country-of-completion (ISIC rev. 3 industries 34 and 35) based on equation (1). Regional value added includes value added by countries in the region to which the country-of-completion belongs (EU, NAFTA or East Asia), but excludes value added in the country-of-completion itself. Global value added is the value added by all countries outside this region. By definition, domestic, regional and global shares add up to 100%. For Brazil the regional value-added share refers to the NAFTA countries. For Russia and Turkey the regional value-added share refers to countries in the EU.
Source: Authors' calculations based on the World Input–Output Database, November 2013 release.

trend picked up again in 2004 and the steady increases in international fragmentation continued until the onset of the crisis in 2008. The crisis induced a major dip, but this appeared to be a short-run effect. The foreign shares rebounded and in 2011 were back at the level of 2007 or even higher. Trends for automotive value chains outside Europe were different, insofar that the fragmentation process only really started to take off in the early 2000s. The crisis induced a decline in foreign value added for Japan and the USA, but levels rebounded in particular in the latter country after 2008.

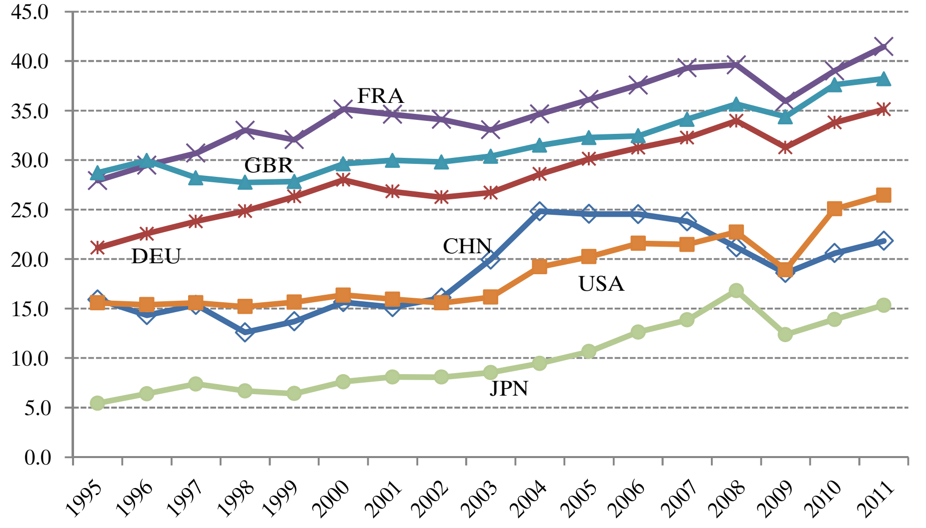

Figure 4. Foreign Value Added Share in Final Output of Automotives by Six Countries of Completion

Notes and sources: See Table 3. China (CHN), France (FRA), Germany (DEU), Japan (JPN), United Kingdom (GBR) and the United States (USA).

It remains to be seen, however, whether the prolongation of the crisis will have more structural effects after 2011. This analysis awaits more recent data.

The automotive chains for which the last stage of production takes place in China have a different pattern altogether. Foreign value-added shares in final output increased dramatically between 2002 and 2004, after China had just joined the WTO, but shares actually declined in the subsequent period, which continued until 2009. In 2010 and 2011, the foreign share increased again, but it is still well below its peak in the mid-2000s. This might be related to strong growth in domestic intermediates production, which substituted for formerly imported parts and components.

Shifting Competitiveness of Countries in Global Automotive Production

As shown so far, the value-added contribution of countries to domestic production chains is generally declining, but their contribution to foreign value chains is increasing. To analyze a country's competitiveness one therefore has to measure its contributions to all production chains, domestic and foreign. Timmer et al. (2013) propose the concept of "GVC income", which measures the value added by a country in activities related to the production of a given set of final manufacturing goods. In this section, we analyze the competitiveness of countries in the global production of automotives by summing over their contributions to any automotive chain in the world. Note that even when a country is not producing final goods, it still might add value by carrying out upstream activities in the automotive chain ending in other countries, such as production of sophisticated components, marketing or R&D. To calculate this GVC income we choose **C** as the vector of worldwide consumption of automotives completed anywhere in the world.

Figure 5 provides a breakdown of the value added in global automotive production by region. Global consumption of automotives increased from US$1052 billion in

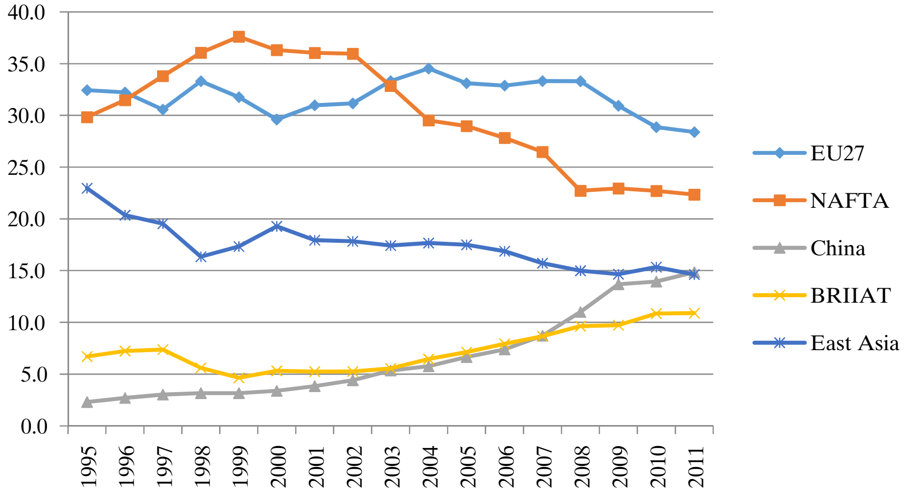

Figure 5. GVC Income from Production of Automotives (as % of world)

Notes and sources: Income share of regions in final output value of transport equipment produced anywhere in the world (ISIC rev. 3 industries 34 and 35), based on equation (1), see also Table 4. East Asia includes Japan, South Korea and Taiwan. BRIIAT includes Brazil, Russia, India, Indonesia, Australia and Turkey. EU27 includes all European countries that have joined the European Union as of 1 January 2004. NAFTA includes Canada, Mexico and the USA. Shares do not add up to 100% as the remainder is the share of all other countries in the world.

1995 to US$1654 billion in 2011 (in 1995 prices deflated by the US overall consumer price index (CPI)). The EU captured the largest part of this as income for domestic production factors in 1995 (32%). Its share remained stable until 2007, suggesting that in Europe has consolidated its position in global markets until the crisis, despite the global reorganization of automotive production. Table 4 shows that while shares of France and United Kingdom declined, shares of Eastern European countries rapidly increased. The German share in value added remained constant, which might come as a surprise given its rapid increase in exports. The domestic value-added content of German production of final manufactures dropped during this period, owing to offshoring to Eastern Europe and increasing imported intermediates (see Marin, 2011). At the same time, domestic demand for automotives was sluggish as incomes stagnated and booming exports had to compensate for declines in domestic sales (see Timmer et al., 2013, for further analysis). Dwindling domestic demand after the financial crisis in 2008 drove down the European share in global automotive production value, to 28% in 2011.

Conversely, the Chinese share in global automotive production value steadily increased since the early 2000s and continued throughout the crisis up to 15% in 2011 from less than 3% in 1995. This growth was due to growing demand for automotives produced in China, but also through greater participation of China in other automotive chains through delivery of relatively standardized parts and components. Shares from East Asia have been on a long decline. While South Korean shares remained constant and even increased after the crisis, Japanese shares dropped dramatically from 19% in 1995 to 11% in 2008 and further to 10% in 2011. A similar dramatic decline is observed for the USA, from a peak of about 30% of world GVC income in 1999 to 17% in 2008 and 16% in 2011. Increasing value-added shares in Canada and Mexico did not compensate for this drop and the

Table 4. Country GVC Income in Production of Automotives (as % of World)

	1995	*2002*	*2008*	*2011*
USA	25.29	29.39	17.38	15.79
Japan	19.05	14.10	11.07	10.06
Germany	11.79	11.12	11.76	10.59
France	6.12	5.30	4.95	3.76
United Kingdom	3.66	3.93	3.21	2.89
Canada	3.08	3.64	2.91	4.07
Italy	2.95	2.79	3.10	2.38
South Korea	2.94	2.87	3.25	3.86
China	2.31	4.41	11.01	14.85
Spain	2.25	2.19	2.44	1.95
Brazil	1.96	1.33	3.14	3.23
Mexico	1.47	2.94	2.44	2.50
Belgium	1.17	0.89	0.84	0.71
Sweden	1.09	0.98	1.03	1.06
The Netherlands	0.98	0.85	1.02	0.84
Taiwan	0.97	0.87	0.67	0.71
Russia	0.96	0.85	1.85	1.92
Turkey	0.64	0.40	0.70	0.66
Austria	0.52	0.60	0.73	0.64
Poland	0.36	0.47	1.01	0.91
Czech Republic	0.18	0.39	0.72	0.68
Hungary	0.11	0.23	0.37	0.32
Romania	0.10	0.11	0.40	0.33
Slovakia	0.06	0.11	0.28	0.23

Notes: Contribution of countries to final output of transport equipment industry (ISIC rev. 3 industries 34 and 35) in any country in the world, based on equation (1). Results for 24 most important countries that are covered in the WIOD database. Countries ranked on share in 1995.
Source: Authors' calculations based on the World Input–Output Database, November 2013 release.

NAFTA value-added share in automotive production has been on a steady decline until 2008. An interesting open question is on the basis of what activities different countries compete nowadays. Additional data on the type of activities carried out in firms in various places could reveal new patterns of competition and trade in terms of tasks. This is one of the avenues foreseen in further development of the WIOD.

For a proper interpretation of the GVC income concept (and any measure of value added in trade), it is important to note that input–output tables are constructed on the basis of the location principle rather than the ownership principle. As such, they are consistent with the concept of domestic product, but not with national income. GVC income thus measures the value added of production factors located on the domestic territory. As is well known, the building of global value chains involves sizeable flows of foreign investment and part of the domestic value added will accrue as income to multinational firms headquartered in other regions. To account for this, data on foreign ownership is needed, but this type of information is notoriously hard to acquire (Baldwin and Kimura, 1998; Lipsey, 2010).[9] As an alternative one might focus only on GVC income for labor, for which the domestic and national principle will be much more closely aligned. The WIOD provides the necessary data, as shown in the next section.

Factor Income Distribution in Global Automotive Production

Many models of international trade assume that factor shares in production are constant, as in constant elasticity of substitution (CES) or Cobb–Douglas production functions. This assumption is increasingly challenged as new evidence is forthcoming that technological change is not factor neutral and elasticities of substitution are not necessarily constant. According to the "routinization hypothesis" put forward by Autor et al. (2003), information technology capital complements highly educated workers engaged in abstract tasks, substitutes for moderately educated workers performing routine tasks, and has little effect on less-skilled workers performing manual and services tasks. A major obstacle in empirical work on this hypothesis so far is the observational equivalence of the effects of offshoring and technical change in case both have the same factor bias, as noted early on by Feenstra and Hanson (2003). Studies typically employ a cross-industry regression framework based on data for domestic industries, that is, a single stage of production. The WIOD provides a unique opportunity to test this hypothesis properly, as it allows one to identify all stages of the production process, both domestically and abroad.

To do so, we refer again to the decomposition given in equation (1) and let F refer to the share of a factor's value added in gross output. Factor income data is provided in the so-called *Socio-economic accounts*, which can be used in conjunction with the WIOTs as similar industry classifications are used. Labor skill types are classified on the basis of educational attainment levels as defined in the International Standard Classification of Education (ISCED): low-skilled (ISCED categories 1 and 2), medium-skilled (ISCED 3 and 4) and high-skilled (ISCED 5 and 6). Data has been collected for the number of workers involved in production, including employees, self-employed and family workers. Additional imputations of the labor income of self-employed and family workers were made to adjust for the underestimation of the labor income share in the national accounts statistics, in particular for less advanced nations (Gollin, 2002). Capital income is derived as a residual and defined as gross value added minus labor income. It represents remuneration for capital in the broadest sense, including physical capital (such as machinery and buildings), land (including mineral resources), intangible capital (such as patents and trademarks), and financial capital.

In Figure 6 we provide the income shares of the four factor inputs in the total final output value of global automotive production. Note that this is based on factors used anywhere in the world, for any automotive value chain. By construction, the shares add up to one. The results show that the changes in the shares are decidedly non-neutral. The income shares for low- and medium-skilled workers dropped by four and five percentage points over the 1995–2009 period. Income shares for high-skilled workers increased by three percentage points and for capital even by six percentage points. The trends appear to have changed over time. Up to the early 2000s the decline of low-skilled and increase of high-skilled shares dominated. Since then the divergent trends in medium-skilled labor and capital shares dominate, which provides suggestive evidence in favor of the routinization hypothesis. Timmer et al. (2014) find similar

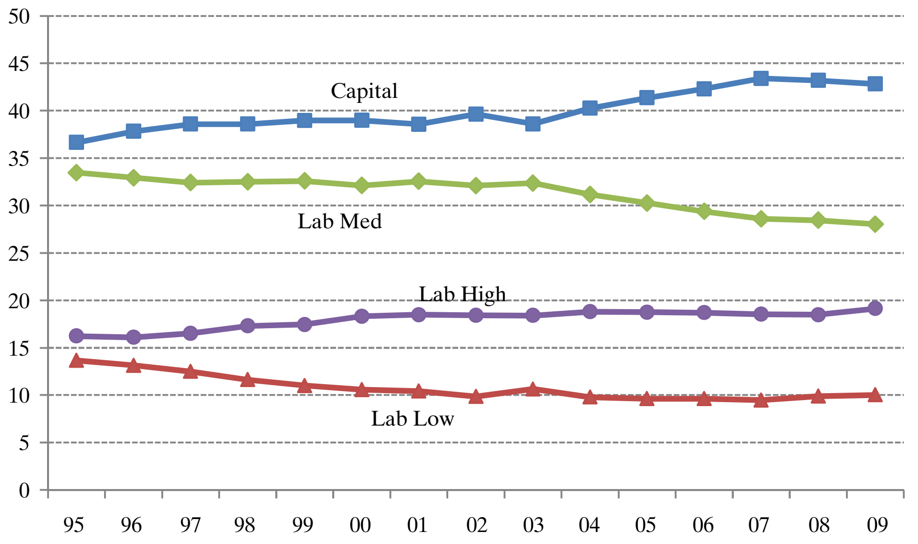

Figure 6. Factor Shares in Income from Production of Automotives (%)

Note: Share of factors in final output value of transport equipment produced anywhere in the world (ISIC rev. 3 industries 34 and 35), based on equation (1). Factors include capital, low-, medium- and high-skilled labour. Shares add up to 100%.
Source: Authors' calculations based on the World Input–Output Database, November 2013 release.

evidence for a larger set of GVCs and discuss possible reasons. Further econometric analysis is needed to disentangle effects of substitution and possible biases in technical change.

4. Prudent Use and Measurement Issues

As with any database, prudent use of the WIOD requires researchers to familiarize themselves with particular measurement issues. A WIOT is a synthetic database and constructed by combining various primary databases. Several assumptions in the construction process had to be made and various weaknesses in the data remain. We briefly discuss the most important of these to serve as health warnings for users of the WIOD, or for that matter, any international input–output table that currently exists. We also indicate avenues for further work, and discuss challenges in future statistical work that need to be faced for research on international production sharing to continue.

Imports by use category From national input–output statistics one can readily derive the use of products by industries and final consumers, but typically the country-of-origin of these products is unknown and therefore one has to breakdown product import statistics by category of use in the construction of a WIOT. Typically, national statistical institutes and researchers rely on the so-called import proportionality assumption, applying a product's economy-wide import share for all use categories.[10] In addition, to construct bilateral flows one assumes that shares of countries-of-origin in imports are similar across all uses of a product (as e.g. Johnson and Noguera, 2012a). That is, if 20% percent of Czech absorption of electronics is sourced from

Germany, then 20% of any Czech final or intermediate use of electronics is assumed to originate from Germany.[11] Various studies have found that this assumption can be rather misleading, as import shares vary significantly across use category. Feenstra and Jensen (2012) find that shares of imported materials may differ substantially across US industries. Based on additional data collection by a number of Asian statistical institutes, Puzzello (2012) finds that the use of the standard proportionality assumption typically understates the use of foreign intermediate inputs by countries, especially in those industries where they are most used.

To improve upon these standard proportionality assumptions, WIOD starts with imports as given in the supply tables and uses bilateral trade statistics to derive import shares for three end-use categories (intermediate use, final consumption and investment) by mapping detailed six-digit products based on extensive product descriptions—see Dietzenbacher et al. (2013) for details.[12] Based on UN COMTRADE trade data, we find that these ratios differ widely across use categories and countries-of-origin. Imports by the Czech Republic from Germany, for example, are characterized by a much higher share of intermediates than the Czech imports from Japan. The latter are mostly purchased by Czech consumers and the former for further processing by Czech industries. While improving existing practice, this procedure is still rough. The product–use category mapping constructed is not one-to-one, and various products can have multiple end-use categories, such as gasoline (intermediate or final consumption) or cars (household consumption or investment) requiring ad-hoc assumptions. It should also be noted that within each of the three end-use categories, the allocation is still based on a proportionality assumption, albeit at a lower level of aggregation: if 60% of Czech imports of electronics for intermediate use is sourced from Germany, then 60% of use of electronics by any Czech industry is assumed to originate from Germany. This harmonized procedure on import allocation is clearly a second-best solution and improvements await further systematic data collection on the sourcing and use of products by statistical institutes.

Rest-of-the-world region and mirror-flows In order to have a complete description of all flows in the global economy, the WIOD also contains an input–output model for the RoW region, which proxies for all other countries in the world, apart from the 40 already covered. Given the relatively large size of this region (with a share of world GDP of around 15%), this region cannot be ignored in analyses of global trade. From an empirical perspective, it is important how it is modeled, as also stressed by Johnson and Noguera (2012b). In the WIOD, it was modeled based on totals for industry output and final use categories from the UN National Accounts for non-covered countries, to capture the unusual large size of its mining and natural resource sectors compared with WIOD countries. This was combined with an input–output structure reflecting the average of a set of emerging countries (Brazil, China, India, Indonesia, Mexico and Russia). Having access to quality input–output tables for more countries would be instrumental to improve these estimates.

A particular issue related to RoW estimates is how to solve the well-known inconsistency of global import and export flows. In the WIOD, we ensured consistency of bilateral flows by inferring bilateral exports as mirror flows from the bilateral import statistics. To achieve consistency of imports and exports for each product at the global level, the RoW was treated as an additional trade reporter alongside the 40 WIOD countries. A ***RAS*** procedure on the shares was applied to reconcile bilateral trade flows.[13] It is important to note that in this way negative exports to the RoW were avoided, which might arise when exports were defined residually instead (as total exports reported by a country minus bilateral imports from this country as reported by all other WIOD countries). However, the downside of this approach is that the country shares in imports that were originally computed from the UN COMTRADE trade data are not necessarily maintained in all bilateral cases.

The WIOD approach is in-between two alternatives in achieving global balance. The first is to gather additional (unpublished) information to resolve manually any inconsistencies in the bilateral trade statistics from national statistical institutes, as done in the Asian International IOTs (Meng et al., 2013). Alternatively, in a more radical approach global balancing could be achieved by making use of reliability guestimates of the underlying basic data sources through confrontation of various datasets and a priori ranking of sources' reliability. A prominent example of this is the work by Lenzen et al. (2013), which revolves around a highly automated routine procedure. Obviously the resulting world tables depend critically on the choice of reliability settings. In any of the approaches, a better reconciliation of the basic export and import mirror flows would be major step forward in improving this estimation, which should include a comprehensive treatment of international trade and transportation margins (Streicher and Stehrer, forthcoming 2015).

Trade in services and intangibles One of the novel features of the WIOD is the detailed coverage of bilateral trade in services, integrating various international data sources, including UN, OECD, Eurostat, IMF and WTO data. This covers so-called Mode 1 (cross-border) services trade, which are supplied from one territory to another. In total about 20 economic activities according to the Balance of Payments classification were distinguished and mapped onto the services industries. In addition, the WIOD also contains data on consumption abroad by resident consumers or firms (such as tourism expenditures, so-called Mode 2), which can make up a sizable part of trade in various countries. As is well known, services trade data has not been collected at the same level of detail and accuracy as goods trade data. There is still much to be improved, in particular in the coverage of intra-firm deliveries (Francois and Hoekman, 2010).

Related to this is the problem of profit recording and the practice of transfer pricing. Originally, the main concern was about the misreporting of intra-firm trade values, as firms used accounting prices for intra-firm flows of goods to benefit from cross-country differences in tax codes (Clausing, 2003). More recently, attention has shifted to the practice of profit shifting involving the implicit pricing of the use of intangibles such as brand names, trademarks, software and other knowledge systems by affiliates. The use of these intangibles is typically not compensated for by a direct money flow from the users. For example, the case studies of electronic products by Dedrick et al. (2010) suggest that the profits by lead firms are not made by charging other firms in the production chain for the use of intangibles, but by having the exclusive right to sell the particular product with a premium through its own, or otherwise tightly controlled, sales channels.[14] The German automotive industry discussed in section 3 provides a case-in-point. In 2005, the last stage of production of a Porsche Cayenne before being sold to German consumers took place in Leipzig (Dudenhöffer, 2005), but the activity involved was the placement of an engine in a near-finished car assembled in Bratislava, Slovakia. Most likely there was no payment for the use of Porsche technology by the Slovak assemblers. Instead, most of the profits for Porsche will be realized when the car is sold through dedicated showrooms. Further research into how current statistical systems are dealing with different price concepts—basic (production) prices vs market (retail) prices—and the recording of profits should therefore be high on the statistical agenda.

Technology heterogeneity A particular limiting assumption in any input–output table is the assumption of homogeneity within industries. A column in a WIOT only provides the average production structure across all firms in a particular industry. These structures might be rather different for various types of firms. For example, Chen et al. (2012) and Koopman et al. (2012) found that for China the import content of exports differed substantially between foreign processing firms and domestic firms. Likewise, differences in the import content between maquiladoras and non-processing firms for Mexico are found by De la Cruz et al. (2011). Based on data for European firms, Altomonte et al. (2013) found technological differences across exporters and non-exporters. Information on heterogeneity in production processes from firm-level data (e.g. by exporter status or firm size) is an important avenue for future work, since aggregation errors in value chain analyses would be reduced.[15]

Exports and imports for processing A final issue is the treatment of so-called "processing trade". The construction of the WIOTs follows the standards of the SNA 1993, which stipulates that trade is recorded according to the change-in-ownership principle (ISWGNA, 1993). Movement of products across borders should only be recorded as imports and exports if there is a change in ownership involved or if processing involves a "substantial" physical change in the goods (ISWGNA, 1993, p. 665). In practice, countries differ considerably in the application of these principles because of increasing problems in the definitions of ownership and "substantial". For some countries, official input–output tables only report the net value-added effect of processing trade flows, excluding the associated gross trade flows, but to properly reflect the underlying technology all imports should be recorded under intermediate consumption by the processing country. We therefore harmonized across countries by adding imports and exports of the processing industries back into the original tables when the required additional information was available (such as for the USA and China). However, some inconsistencies across countries likely remain as national statistical practices are unclear on this point.

Unfortunately, the new System of National Accounts (ISWGNA, 2010) does no longer allow for exceptions to the ownership principle. This financial perspective on trade will obscure the actual flow of goods, which is needed to study global production networks. It is hoped that national statistical institutes will continue to also report trade flows under the old system, which is crucial for future studies of international supply chains.

5. Future Developments with WIOD

Global input–output tables have become an important data source for research in various fields of economics, including international trade, economic growth and (international) macro, in particular when used in conjunction with analytical tools developed in input–output economics. Since April 2012, the WIOD provides an open-access platform for this type of analysis and its usefulness was illustrated in this paper by means of an analysis of the evolution of the global automotive production network between 1995 and 2011. Other potential applications of the WIOD could address various topics in macro-economics, such as models of structural change mapping consumption structure on the sectoral structure of the economy by modeling intermediate inputs demand (Herrendorf et al., 2013), the transmission of fluctuations and synchronization of business cycles across sectors and countries (Bems et al., 2011; Acemoglu et al., 2012), the role of input–output linkages in propagating productivity shocks and their effects on factor reallocation (Jones, 2011), and measuring upstreamness (the distance of an industry to final use, see Dietzenbacher and Romero, 2007; Antràs et al., 2012). The additional socio-economic data available in the WIOD would allow for testing standard trade theories by determining 'shadow migration' vectors and then rerunning the usual tests with shadow-migration adjusted endowments rather than unadjusted endowments as traditionally used (as suggested by Baldwin and Venables, 2013).[16]

The WIOD is meant to be a dynamic resource and various extensions are currently being undertaken. Activities are underway to provide constant-price input–output tables to allow for analyses based on changes in volumes alongside values. This is needed in for example estimates of substitution across inputs and rates of technological change, both in econometric studies as well as in growth accounting analysis (e.g. the seminal study by Jorgenson et al., 1987). To allow for comparisons of volumes across countries, relative prices of output and inputs have been developed (Inklaar and Timmer, 2014). In addition, the WIOTs will be backdated to 1970 to allow for a longer time perspective. International fragmentation of production is not a recent phenomenon as suggested by increasing trade in intermediates in the 1970s and 1980s (Johnson and Noguera, 2012b).

Another line of development is to focus on subnational fragmentation processes through the development of input–output tables in which the geographical units are regions rather than countries. In many countries, some regions perform much better in an economic sense than others. Stimulation policies targeted at weaker regions should not consider these in isolation, but within a broader network of interregional and global value chains. One of the major challenges in constructing such tables is the modeling of interregional trade flows using information from transportation surveys or estimation of gravity equations. Regional production accounts can also be used to analyze differences in regional specialization patterns.

We also expect many additional insights by delving more deeply into the nature of jobs. With fragmentation, the task-content of jobs is changing. Countries are likely to specialize in particular tasks and activities in production chains. This is only roughly captured by analyzing demand for workers characterized by educational attainment levels. In particular, it has been often suggested that advanced nations specialize in activities such as R&D, design, marketing and after-sales services, thereby becoming "headquarter economies". We currently develop panel data on the occupational structure of the workforce in various countries that, in combination with the WIOTs, could be used to substantiate these claims.

As a final note, we believe that the future development of this type of data should ideally be shouldered by its incorporation in regular statistical programs. Given the international nature of these tables, this must involve coordination by international agencies. Therefore we welcome the current OECD–WTO initiative in taking this work forward in the international statistical community (OECD and WTO, 2013), and hope that underlying sources and materials will become publicly available. With the WIOD we hope to have shown that the benefits of open access can be substantial to economists and the research community at large.

Appendix

WIOD Construction

The WIOD consists of world input–output tables, discussed in the section below, and additional factor input data discussed in the second part of the Appendix.

World Input–Output Tables

A world input–output table (WIOT) is basically an extension of a national input–output table in which the origins and destinations of imports and exports are made explicit. A WIOT is built up from published and publicly available statistics from national statistical institutes around the world, plus various international statistical sources such as OECD and UN National Accounts, UN COMTRADE and IMF trade statistics. As building blocks for the WIOTs, we used national supply and use tables (SUTs). In short, we derive time-series of national SUTs and link these across countries through detailed bilateral international trade statistics to create so-called international SUTs. These are subsequently used to construct the WIOTs. In this section we discuss how we dealt with four major challenges in data construction: harmonization of basic SUT data; derivation of time-series of SUTs; disaggregation of imports by country of origin and use category, and global closure. This will be brief and non-technical; more detail can be found in Dietzenbacher et al. (2013).

Harmonization of national SUT data The WIOTs have been constructed on the basis of sets of national supply and use tables (SUTs) that are the core statistical sources from which statistical institutes derive national input–output tables. A supply table is of the product-by-industry type and indicates for each product the values of its deliveries by domestic industries or imports. A use table indicates the values of purchases of each product by each of its destinations: intermediate use by domestic industries, domestic final demand or exports. It is also of the product-by-industry type. SUTs provide a more natural starting point for building WIOTs than national input–output tables. The latter contain less information and are typically derived from the former with additional assumptions. Moreover, SUTs can easily be combined with trade statistics that are product-based and employment statistics that are industry-based. It also allows one to take the multi-product nature of firms into account: the outputs of firms are classified in a supply table on a product basis, such that these might be recorded in different product classes.

National supply and use tables were collected from national statistical institutes and harmonized in terms of concepts and classifications. They have been tailored to dimensions of 35 industries and 59 product groups. The 35 industries cover the overall economy and are mostly at the two-digit ISIC rev. 3 level or groups thereof. These include agriculture, mining, construction, utilities, 14 manufacturing industries, telecom, finance, business services, personal services, 8 trade and transport services industries and 3 public services industries (see Appendix Table A2). The product groups are more finely defined and are all two digits in the 2002 Classification of Products by Activity (CPA), including 23 manufacturing products. This level of detail was dictated by the available data, reflecting the lowest common denominator across countries. Construction involved aggregation of more detailed source data and sometimes disaggregation based on additional data from detailed production surveys. The national SUTs have also been harmonized to a basic price concept. Basic prices reflect all costs borne by the producer, whereas purchasers' prices reflect the amounts paid by the buyer. The difference between the two is given in so-called valuation matrices with product-specific trade and transportation margins and net taxes. National SUTs in basic and purchasers' prices are separately estimated and reported in the WIOD. The tables expressed in basic prices are more appropriate for most applications (see section 3). International trade flows were accordingly expressed in "free on board" (fob) prices through estimation of international trade and transport margins.

Time-series of national SUTs A second challenge in data construction is the derivation of time-series of SUTs. National tables are only available for particular benchmark years that are unevenly spread over time and asynchronous across countries. Moreover, they are not designed for comparisons over time, which becomes clear when comparing data from the SUTs with the national accounts statistics. While the latter are frequently revised, the former are not.[17] To deal with both these issues simultaneously, a procedure was applied that imputes SUT coefficients subject to hard data constraints from the National Accounts Statistics (NAS). As such, the solution matches exactly the most matches exactly the revised NAS data on final expenditure categories (household and government consumption and investment), total exports and total imports, and gross output and value added by industry. The unknown product shares are imputed using a constrained optimization method akin to the well-known bi-proportional (***RAS***) updating method (Temurshoev and Timmer, 2011). In this way the tables will also satisfy another important accounting identity that is related to the measurement of GDP in the System of National Accounts: the sum of value added over all industries (representing incomes for labor and capital) will be equal to the sum of final domestic use expenditures and the net trade balance (exports minus imports).[18] Appendix Table A1 gives for each country the years for which a benchmark national SUT was available and used in the construction of the time-series.

Use categories of imports A third challenge was the breakdown of imports of a product for each use category by country and industry of origin. This type of information is not available in published supply and use tables. Typically, researchers rely on the so-called import proportionality assumption, applying a product's economy-wide import share for all use categories (as e.g. Johnson and Noguera, 2012a). To improve upon this, bilateral trade statistics have been used in WIOD to derive import shares for three end-use categories. Bilateral import flows of all countries covered in WIOD from all partners in the world at the six-digit product level of the Harmonized System (HS) were taken from the UN COMTRADE database. We used the detailed product descriptions to refine the well-known BEC ("broad economic categories") codes, which allocates imported goods to intermediate use, final consumption use, or investment use. Within each end-use category, the allocation was based on the proportionality assumption (as dictated by a lack of additional information). For intermediate use by industries, for example, we applied ratios between imported use and total use that were equal across industries, but differed from the corresponding ratio for consumption purposes. By using detailed bilateral trade data this type of information is incorporated into the national SUTs. We labeled the resulting tables "international" SUTs.

Global closure In order to obtain a description of the structure of the global economy according to the concept of a SUT, we integrated the "international" SUTs for all 40 countries into a "world" SUT. In doing this, we inferred bilateral exports as

Table A1. Countries in WIOD and Years for Which Benchmark Table was Used

Country	*Benchmark years*
Australia	1996, 2003, 2004
Austria	1995, 1997, 1999–2007
Belgium	1995, 1997, 1999–2007
Brazil	2000–2008
Bulgaria	2000–2004
Canada	1997–2006
China	1997, 2002, 2007
Cyprus	2001 (based on Greece)
Czech Republic	1995–2007
Denmark	1996, 1999–2007
Estonia	1997, 1999–2007
Finland	1995–2007
France	1995, 1997–2007
Germany	1995, 1997–2007
Greece	2000–2009
Hungary	1998, 1999, 2002–2007
India	1998, 2003, 2006
Indonesia*	1995, 2000, 2005
Ireland	2001–2007
Italy	1995–2007
Japan*	1995–2007
South Korea*	1995, 2000, 2005
Latvia	1996, 1998
Lithuania	1996, 1998, 2003–2005
Luxembourg	1995–2006
Malta	2000, 2001
Mexico	2003
The Netherlands	1995–2007
Poland	1996–2007
Portugal	1995–2006
Romania	2000, 2003–2006
Russia	1995
Slovak Republic	1995–2007
Slovenia	2000–2007
Spain	1995–2007
Sweden	1995–2007
Taiwan*	1996, 2001, 2006
Turkey	1996, 1998, 2002
UK	1995–2008
USA	1998–2010

Note: *For Indonesia, Japan, South Korea and Taiwan, only national input–output tables are available from the statistical offices. These have been separated into a supply and use table using additional data on secondary production structures, whenever possible.

Table A2. Industries in WIOT

ISIC rev.3 code	*Industry name*
AtB	Agriculture, hunting, forestry and fishing
C	Mining and quarrying
15t16	Food, beverages and tobacco
17t18	Textiles and textile products
19	Leather, leather products and footwear
20	Wood and products of wood and cork
21t22	Pulp, paper, printing and publishing
23	Coke, refined petroleum and nuclear fuel
24	Chemicals and chemical products
25	Rubber and plastics
26	Other non-metallic mineral
27t28	Basic metals and fabricated metal
29	Machinery, not elsewhere classified
30t33	Electrical and optical equipment
34t35	Transport equipment
36t37	Manufacturing, not elsewhere classified; recycling
E	Electricity, gas and water supply
F	Construction
50	Sale and repair of motor vehicles and motorcycles; retail sale of fuel
51	Wholesale trade, except of motor vehicles and motorcycles
52	Retail trade and repair, except of motor vehicles and motorcycles;
H	Hotels and restaurants
60	Inland transport
61	Water transport
62	Air transport
63	Other supporting transport activities
64	Post and telecommunications
J	Financial intermediation
70	Real estate activities
71t74	Renting of machinery & equipment and other business activities
L	Public administration and defence; compulsory social security
M	Education
N	Health and social work
O	Other community, social and personal services
P	Private households with employed persons

mirror flows from the bilateral import statistics as given in the "international" SUTs. Hence, we ensured that import and export flows between partner country–industry pairs mirror each other. In a final construction step, the "world" SUT, which is also of the product-by-industry type, was transformed into a world input–output table of the industry-by-industry type. Many applications require such a square matrix reflecting the economic linkages across industries. The WIOT was constructed by using the so-called "fixed product sales" model, which assumes that each product has its specific use structure, irrespective of the industry that produced it.[19] To have a closed model of the world economy, we also defined a RoW region that proxies for all other countries in the world. Exports to this region for each product and country from the set of WIOD countries are defined residually to achieve consistency of global trade flows. It

Table A3. Additional Columns and Rows in WIOT

Final use columns (by country)
Final consumption expenditure by households
Final consumption expenditure by non-profit organisations serving households (NPISH)
Final consumption expenditure by government
Gross fixed capital formation
Changes in inventories and valuables
Total output (total)
Additional rows
Total intermediate consumption
Taxes less subsidies on products
Cif/ fob adjustments on exports
Direct purchases abroad by residents
Purchases on the domestic territory by non-residents
Value added at basic prices
International transport margins
Output at basic prices

ensures that exports summed over all countries of destination (including the RoW region) are equal to total exports as given in the national SUTs.

It was modeled based on totals for industry output and final use categories from the UN National Accounts for non-covered countries, to capture the unusual large size of its mining and natural resource sectors compared with WIOD countries. This was combined with an input–output structure reflecting the average of a set of emerging countries. Exports to this region need to be modeled as well. A simple approach would be to define these residually to ensure that for each WIOD country the summation of exports over all destinations equals total exports as given in the national SUTs. However, in this way it becomes possible that exports to the RoW are negative as all inconsistencies between import and export mirror-flows tend to accumulate in the residual. An alternative approach was followed in which the RoW was treated as an additional trade reporter alongside the other 40 countries. Bilateral trade shares were re-calculated using a RAS procedure and shares that were originally computed from the UN COMTRADE data are not necessarily maintained in all cases.

The WIOTs have the dimensions of 1443 rows and 1641 columns. It contains 1435 industry–country pairs as suppliers in the rows (41 countries times 35 industries) with additional rows covering value added and various adjustment items (see Appendix Table A3). There are again 1435 industry–country pairs as users of intermediates in the columns and 205 additional columns for final users per country (41 countries times 5 types of final use,[20] see Appendix Table A3). The values in WIOTs have been expressed in millions of US dollars and exchange rates were used for currency conversion of the SUTs, which originally contain values in national currencies.

Supplementary Data on Labor and Capital Inputs

In addition to the WIOTs, the WIOD provides data on the quantity and prices of factor inputs, including data on workers and wages by level of educational attainment and capital inputs. This data is provided in the so-called *Socio-economic accounts*. One unique characteristic of the WIOD is that this type of data can be used in conjunction with the WIOTs as similar industry classifications are used. Compared with existing international data sources such as Barro and Lee (2013), the WIOD provides an extension in two directions. First, it provides industry-level data, which reflects the large heterogeneity in the skill levels used in various industries. Second, it provides relative wages by skill type that reflect the differences in remuneration of workers with different levels of education. Labor skill types are classified on the basis of educational attainment levels as defined in the International Standard Classification of Education (ISCED): low-skilled (ISCED categories 1 and 2), medium-skilled (ISCED 3 and 4) and high-skilled (ISCED 5 and 6).[21]

This type of information is not part of the core set of national accounts statistics reported by NSIs. For most advanced countries labor data is constructed by extending and updating the EU KLEMS database (www.euklems.org) using the methodologies, data sources and concepts described in O'Mahony and Timmer (2009). For other countries additional data has been collected according to the same principles, mainly from national labor force surveys, supplemented by, among others, earnings surveys for relative wages. Care has been taken to arrive at series that are time consistent, as most employment surveys are not designed to track developments over time and breaks in methodology or coverage frequently occur. Data has been collected for the number of workers involved in production, including employees, self-employed and family workers.[22] Additional imputations of the labor income of self-employed and family workers were made to adjust for the underestimation of the labor income share in the National Accounts Statistics, in particular for less advanced nations (Gollin, 2002).

Capital compensation is derived as a residual and defined as gross value added minus labor income. Hence it is the gross compensation for capital, including profits and depreciation allowances. Because of its derivation as a residual, it reflects the remuneration for capital in the broadest sense. This does not include only traditional reproducible assets such as machinery and buildings, but also includes non-reproducible assets. Examples are mineral resources and land, intangible assets (such as R&D knowledge stocks, software, databases, brand names and organizational capital) and financial capital. The WIOD also includes measures of the capital stocks. These are based on a perpetual inventory method building up from investment series for those assets that are currently covered by the national accounts statistics.[23]

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Notes

1. See Tukker and Dietzenbacher (2013) for an overview of existing global input–output databases.
2. See Miller and Blair (2009) for an introduction to input–output analysis.
3. For ease of exposition, we denote all final demand (including investment demand) as consumption in this section.
4. To see this, let $\mathbf{Z}$ be a column vector of which the first element represents say the global consumption of cars produced in Germany, and all other elements are zero. Then $\mathbf{Z}$ is the final output of the German car industry and $\mathbf{BZ}$ is the vector of intermediate inputs, both German and foreign, needed to assemble the cars in Germany. But these intermediates need to be produced as well and $\mathbf{B}^2\mathbf{Z}$ indicates the intermediate inputs directly needed to produce $\mathbf{BZ}$. This continues until the mining and drilling of basic materials required to start the production process are taken into account. Summing up across all stages of production, the gross output generated in any country–industry that contributes to the production of cars from Germany is given by $\mathbf{Z} + \mathbf{BZ} + \mathbf{B}^2\mathbf{Z} + \mathbf{B}^3\mathbf{Z} + \ldots$, which is a geometric series and can be rewritten as $(\mathbf{I} - \mathbf{B})^{-1}\mathbf{Z}$.
5. For this comparative exercise, we took value-added measures from WIOD that include net taxes on intermediate inputs as well as international trade margins, as Koopman et al. (2014) did.
6. Note that this is only the case when there is sizeable production for domestic demand as well. If the majority of production is for exports, this bias would be limited.
7. Nothing in the method prevents one making this distinction though, which would be particularly relevant if production for exports is fundamentally different from production for domestic demand. This might in particular be the case for poor countries where export production is geared towards higher quality products, but is much more unlikely for car production in advanced nations. Data on differences in production across destination markets is scarce, as discussed in section 2.

8. A similar decomposition using hours worked reveals that the majority of the changes here are mainly due to changes in quantities of domestic labor used rather than changes in relative wages across skill types. It is also interesting to note that because of the rapid expansion of German car production, the total number of domestic workers involved barely declined, but shifted from working in the transport equipment industry to working in services industries.
9. To establish the full link from value added to factor incomes and finally to personal income distributions, one would additionally need data on the actual ownership of firms.
10. Many national statistical institutes publish a separate import matrix as part of the national input–output statistics. They are typically based on the assumption of import proportionality, but applied at a lower level of aggregation than the published tables. Hence, they reflect compositional differences rather than survey data on sourcing and use of products.
11. Absorption of a product is defined as usual, as domestic output plus imports minus exports.
12. Thus we refine the well-known BEC ("broad economic categories") codes used for example by Koopman et al. (2014).
13. The acronym ***RAS*** indicates the bi-proportional character of the updating technique: matrix $\boldsymbol{A}$ is being updated with $\boldsymbol{R}$ containing a diagonal matrix of elements modifying rows of $\boldsymbol{A}$, and $\boldsymbol{S}$ a diagonal matrix of column modifiers.
14. This will show up as a difference between the final purchasers' and ex-factory basic prices of the product. The latter price concept includes trade and transport margins. The WIOD provides national tables using both price concepts. A particular example is the existence of so-called "factoryless goods producers" such as Apple, see Bernard and Fort (2013).
15. See Nomaler and Verspagen (2014) for an experimental analysis of how aggregation errors might impact analyses based on the Leontief inverse.
16. The WIOD also contains so-called environmental accounts providing data on energy use, carbon dioxide emissions and other polluting emissions to air at similar industry and country detail. This has spawned a stream of studies on the ecological consequences of trade including carbon foot printing and energy use (see e.g. Voigt et al., 2014).
17. More recently, national statistical institutes of some countries in the EU and the US Bureau of Economic Analysis have moved to the publication of annual SUTs that include revisions as well.
18. Value added should be measured at purchasers' prices (that is including net taxes on products) for this identity to hold.
19. Alternative assumptions could be made here, and similarly a product-by-product type table could be derived. Each model has its specific advantages, see Miller and Blair (2009). Interested users can produce alternative WIOTs by themselves as the underlying international SUTs have been made public as well.
20. Final use includes all products that are consumed by households and the government, or used for investment purposes. The WIOT also includes "changes in inventories" as a final use category, capturing possible intertemporal differences between production and use.
21. Despite attempts at international harmonization, comparisons of skill shares across countries have still to be made with care, given the differences in national educational systems. Developments over time in skill-shares can be traced with more confidence.
22. Although hours worked would be a preferable measure of labor inputs, this data is not abundantly available.
23. The assets covered by the system of national accounts 1993 are mainly related to reproducible physical capital and software. In the new system of national accounts 2008 another step is made towards inclusion of other intangibles, in particular R&D stocks. Corrado et al. (2012) provided experimental estimates for a wider set of intangibles.