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**Quantification of the Contributions of Productivity Growth and Globalization to World
Consumption Growth Rates (1995-2008)**

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Quantification of the Contributions of Productivity Growth and Globalization to World Consumption Growth Rates (1995-2008)

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ABSTRACT

Over the past decades, per capita consumption levels of consumption levels have gone up in the world. Labor productivity growth is potentially the most important sources of these increases, but it is unclear what role international trade has played. Furthermore, the measurement of productivity growth has been blurred by the prominent role of trade in intermediate inputs. Offshoring a low-productivity activity within an industry might show up as productivity gains in an industry, while it is in fact trade that expands the production possibilities set. To shed more light on this issue we propose to compute “global value chain labor productivity growth” and show some indicators for 1995-2008 on the basis of the recently constructed World Input-Output Database (WIOD). Next, we formulate a simple accounting framework to show how changes in global value chain labor productivity, trade in final products, and changes in consumption and investment patterns contributed to growth in world consumption per worker.

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1. Introduction

Most studies that analyze productivity differences (over time or across countries) define the output of economies as GDP. This implies that investment and exports are also seen as output, whereas inhabitants generally only derive current welfare from consumption. Weitzman (1976, p. 156) wrote “... economic activity has as its ultimate end consumption, not capital formation”. Although we are fully aware of the facts that 1) investment is needed in order to increase the opportunities for producing consumption goods in the future and 2) it is ultimately impossible to purchase infinite amounts of imported products without exporting anything, we feel that GDP-based productivity studies could be usefully complemented by analyses that quantify sources of differences in consumption per worker. The empirical relevance of this approach can be illustrated by data from the World Input-Output Database (see Timmer, 2012, and www.wiod.org). In 1995, a country like Brazil consumed 89.9% of its GDP, while Germany, for example, only consumed 78.7% (for 2008, these percentages amounted to 87.6 and 76.4, respectively).¹

In earlier work (Dietzenbacher et al., 2007), we provided a consumption growth accounting framework in a national context. The accounting framework belongs to the class of Structural Decomposition Analyses (SDA), which are popular in the field of input-output analysis (see Miller and Blair, 2009, for a survey). Most SDAs are based on the demand-driven static Leontief model, but we purposefully opted for an underlying model with a supply-side character. This model considers the availability of a single production factor (labor) as exogenous. Together with other exogenous determinants (such as the intermediate input requirements per unit of output, investment demand and the composition of the consumption bundle), the value of the endogenous consumption level can be determined. An SDA based on this model allowed us to quantify the effects of labor productivity growth and changes in trade patterns (among other determinants) to consumption growth in a single country. Given the increasing globalization of production and consumption, this single country perspective implied a number of important limitations. The recent availability of input-output tables that describe the production, consumption and investment structures for the world (disaggregated into countries) allow us to alleviate some of these limitations, paying full justice to increasing international dependencies, such as caused by the emergence of Global Value Chains (GVCs, see Timmer et al., 2012). The aim of this paper is to develop the concept of “GVC labor productivity growth”, and to find out to what extent this phenomenon has contributed to growth in consumption per worker in the world economy.

¹ Shares include government consumption and have been computed on the basis of the World Input-Output Database, April 2012 release.

The rest of this paper is structured as follows. In Section 2, we propose the mathematical expressions that underlie the concept of GVC labor productivity growth. Section 3 summarizes the main aspects of the data that we use. Section 4 gives an overview of patterns regarding labor productivity developments in Global Value Chains. Next, Section 5 shows to what extent these developments have contributed to world consumption. Both the supply-side Structural Decomposition Analysis that provides our accounting framework and the results obtained will be discussed here. Finally, Section 6 concludes.

2. Labor Productivity in Global Value Chains: Methodology

In his discussion of the history of economic globalization, Baldwin (2006) identified two ‘waves of unbundling’. Before the first wave, virtually all materials and components that were used to produce final products (consumption and capital goods) were produced without crossing international borders and the final products were sold on domestic markets. The first wave of unbundling amounted to an unbundling of production and consumption: international trade in final products flourished, but intermediate inputs (materials and components) were mainly produced in the country in which the final products were produced. Relatively recent reductions in transportation costs and (more importantly) vast improvements of information and communication technology allowed for the emergence of Baldwin’s second wave of unbundling. Companies noticed opportunities to relocate part of the activities required in upstream stages of the production process, for example by sourcing components from specialized suppliers abroad, or to relocate the assembly activities (the production stage that yields the final product). In some cases, virtually all stages of production have been offshored, and only design and R&D activities remain in the country in which the entire production process took place (Apple’s production of electronic products is most probably the best-known example, see Dedrick et al., 2010).

The second wave of unbundling should also have implications for productivity analysis. In industry-level growth accounting studies, it is implicitly assumed that the type of activities conducted in an industry did not really change over the period that is studied. Broadly speaking, labor productivity growth can be caused by capital intensification (capital can include all kinds of intangibles) and by multifactor productivity (MFP) growth (see, e.g., the work by Jorgenson, Timmer and Van Ark). The latter cause of growth is often related to technological change. Similar assumptions are made in level accounting studies (see, e.g. work by Caselli, Inklaar and Timmer), which do not try to quantify the contributions of the factors mentioned to changes over time, but to differences between comparable industries in multiple countries. The word “comparable” should be stressed in this respect, because it is highly questionable whether the American electronics industry (with its high share of design and R&D

activities) can meaningfully be compared with the Chinese electronics industry (which mainly consists of assembly activities).² This example regarding level accounting is also relevant for growth accounting since a modern “design and R&D-based” American electronics industry cannot be compared to the vertically integrated domestic industry that prevailed before the second wave of unbundling. In the new situation, part of the changes (or differences) in labor productivity cannot be attributed to capital intensification and MFP-growth anymore, but to trade-induced changes in activities (see Costinot et al., 2012, for a theoretical contribution on changes in the location of stages in production processes, and Los et al., 2012, for an account of similar implications for assessments of the impact of skill-biased technological change on low-skilled and medium-skilled labor in advanced countries).

Until recently, aspects of Global Value Chains such as those controlled by Apple could only be quantified by detailed case study work. Dedrick et al. (2010), for example, carefully determined the value of components brought together for assembly into iPods and checked from which suppliers and countries these originated. Hence, the value added generated in the production steps leading to the final product could be attributed to industries and countries. Economy-wide analyses were not possible, and questions about the degree to which results could be generalized towards other products remained unanswered. This situation has changed with the production of “intercountry input-output tables”, covering substantial parts of the world.³ Recently, several projects have constructed such tables, among which GTAP-based tables (see e.g. Peters, 2012), the EXIOPOL table (see Tukker et al., 2009), the tables constructed by IDE-JETRO (Okamoto and Inomata, 2005), the Eora tables (Lenzen et al., 2012) and the WIOD tables (see Timmer, 2012) on which this paper is based. Intercountry input-output tables give a complete representation of the value of transactions between industries (both domestic transactions and exports) and between industries and final uses, such as household consumption demand and gross fixed capital formation (also domestic flows and exports). Most of the tables mentioned above cover the entire world, which means that the complete world production structure has been detailed, up to the level implied by the level of industry aggregation.

Like national input-output tables, intercountry input-output tables (or world input-output tables, WIOTs) allow for computing the amounts of each of the intermediate inputs required for the production of one dollar of output. In the case of WIOTs, an explicit distinction can be made between inputs by country-of-origin. Hence, it is possible, for example, to compute how many cents of Spanish agricultural

² Note that this example is stylized. In reality, it is mainly a matter of different shares of activities, since the types of activities carried out in the electronics industries do have overlap.

³ The same type of tables is alternatively labeled “multiregional input-output tables”. In the mid-nineties, early intercountry input-output tables were already produced for core European Union countries. See e.g. Van der Linden and Oosterhaven (1995) and Dietzenbacher et al. (2000).

output is needed per dollar of French food manufacturing product. Since Spanish farmers use intermediate inputs from the domestic financial services industry, German consumer demand for French food products also generate value added and employment in the Spanish agricultural industry and its financial services industries. These effects can be quantified, in a way similar to how the value added generated by the Japanese hard disk industry for American demand for in China assembled iPods can be determined.

The second wave of unbundling is likely to have led to changes in the amount of labor needed to produce a dollar of final product. Multinationals usually do not care about the effects of potential relocation of activities (be it via foreign direct investment or via imports from subcontracting firms) on the productivity of the entire chain. These companies make decisions based on production costs (i.e., wages vs. labor productivity), reliability and flexibility of the workforce, transportation costs, the political situation, differences in regulations between the home country and the potential host country, etc. Hence, it remains to be seen how changes in trade patterns affected what we will call GVC labor productivity over the 1995-2008 period that we will analyze. In this approach, we will identify a particular GVC by the industry and country that produces the final product. Hence, although Apple and other US-based companies control a sizable part of the assembly activities in the Chinese electronics industry and although the most important company that subcontracts the assembly in mainland China (Foxconn) is Taiwanese, we consider the Global Value Chain for Chinese electronics. That is, our indicators are territory-based rather than ownership-based.

As will be discussed in more detail in the next section, the WIOD database contains intercountry input-output tables of the industry-by-industry type. Let us denote the number of countries by M and the number of industries that together make up the economy of a country by N . The labor requirements per unit of (gross) output are contained in an MN -vector that we will call \mathbf{h} .⁴ If \mathbf{Z} represents the $(MN \times MN)$ -matrix containing the values of all sales by the industries in rows to industries in columns and the MN -vector \mathbf{x} indicates the (gross) output of industries, the $(MN \times MN)$ -matrix with intermediate inputs requirements per unit of output can be obtained as $\mathbf{A} = \mathbf{Z}\hat{\mathbf{x}}^{-1}$. In order to compute the labor requirements per dollar of final product, all upstream activities in the associated GVC should be taken into account. This can be attained by considering the $(MN \times MN)$ -“Leontief inverse”, which is obtained as $\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-1}$ (see Miller and Blair, 2009). A typical element of the matrix \mathbf{L} gives the gross output to be produced by the row industry to satisfy unit final demand for the column industry. Thus, if \mathbf{L} is pre-multiplied by \mathbf{h}' , the MN -vector $\boldsymbol{\lambda}' = \mathbf{h}'\mathbf{L}$ gives the number of jobs in the global production system (i.e., aggregated over

⁴ Throughout the paper, matrices have been represented by bold capitals, while column vectors have been indicated by bold lowercases. Primes (') indicate transposition and hats (^) denote diagonalization.

countries and industries) required for the production of a dollar of final product for each of the *MN* Global Value Chains.

The construction of labor productivity indicators does not only require a measure of the labor inputs, but also a value added indicator. In the case of GVC productivity, obtaining the value added indicator is an easy job. Given that a dollar of final demand represents a dollar of value added in the entire global production system (the price of the final product as produced from scratch equals the sum of all value added by each of the *N* industries in each of the *M* countries, see Timmer et al., 2012). Hence, we can just use the inverses of the values in λ as labor productivity indicators.

After having discussed data issues in the next section, we will show how changes in trade patterns within GVCs, changes in capital intensities and technological change have resulted in changes in labor productivity within these GVCs.

3. Data

To implement the simple mathematical expressions introduced above, one needs to have a database with linked consumption, production and income flows within and between countries. For individual countries, this type of information can be found in input-output tables. However, national tables do not provide any information on bilateral flows of goods and services between countries. For this type of information researchers have to rely on datasets constructed on the basis of national input-output tables in combination with international trade data. Various alternative datasets have been built in the past of which the GTAP database is the most widely known and used (Narayanan and Walmsley, 2008). Other datasets are constructed by the OECD (Yamano and Ahmad, 2006) and IDE-JETRO (Okamoto and Inomata, 2005). However, all these databases provide only one or a limited number of benchmark year input-output tables which preclude an analysis of developments over time. And although they provide separate import matrices, there is no detailed break-down of imports by trade partner. For this paper we use a new database called the World Input-Output Database (WIOD) that aims to fill this gap. The WIOD provides a time-series of world input-output tables from 1995 onwards, distinguishing between 35 industries and 59 product groups. Using a novel approach national input-output tables of forty major countries in the world are linked through international trade statistics, covering more than 85 per cent of world GDP.

Another crucial element for this type of analysis are detailed value-added accounts that provide information on the use of various types of labour (distinguished by educational attainment level) and capital in production, both in quantities and values. While this type of data is available for most advanced

OECD countries as an output of the EU KLEMS project (O’Mahony and Timmer, 2009), it is not for many emerging countries.

*World Input-Output Tables (WIOTs): concepts and construction*⁵

In this section we outline the basic concepts and construction of our world input-output tables. Basically, a world input-output table (WIOT) is a combination of national input-output tables in which the use of products is broken down according to their origin. In contrast to the national input-output tables, this information is made explicit in the WIOT. For each country, flows of products both for intermediate and final use are split into domestically produced or imported. In addition, the WIOT shows for imports in which foreign *industry* the product was produced. This is illustrated by the schematic outline for a WIOT in Figure 1. It illustrates the simple case of three regions: countries A and B, and the rest of the world. In WIOT we will distinguish 40 countries and the Rest of the World, but the basic outline remains the same.

The rows in the WIOT indicate the use of output from a particular industry in a country. This can be intermediate use in the country itself (use of domestic output) or by other countries, in which case it is exported. Output can also be for final use⁶, either by the country itself (final use of domestic output) or by other countries, in which case it is exported. Final use is indicated in the right part of the table. The sum over all uses is equal to the output of industries, denoted by *x* in section 2.

Figure 1 Schematic outline of World Input-Output Table (WIOT), two countries + RoW

		Country A	Country B	Rest of World	Country A	Country B	Rest of	
		Intermediate	Intermediate	Intermediate	Final	Final	Final	
		<i>Industry</i>	<i>Industry</i>	<i>Industry</i>	domestic	domestic	domestic	Total
Country A	<i>Industry</i>	Intermediate use of domestic output	Intermediate use by B of exports from A	Intermediate use by RoW of exports from A	Final use of domestic output	Final use by B of exports from A	Final use by RoW of exports from A	Output in A
Country B	<i>Industry</i>	Intermediate use by A of exports from B	Intermediate use of domestic output	Intermediate use by RoW of exports from B	Final use by A of exports from B	Final use of domestic output	Final use by RoW of exports from B	Output in B
Rest of World (RoW)	<i>Industry</i>	Intermediate use by A of exports from RoW	Intermediate use by B of exports from RoW	Intermediate use of domestic output	Final use by A of exports from RoW	Final use by B of exports from RoW	Final use of domestic output	Output in RoW
		Value added	Value added	Value added				
		Output in A	Output in B	Output in RoW				

⁵ This subsection is very similar to the subsection on data issues in Los et al. (2012).

⁶ Final use includes consumption by households, government and non-profit organisations, and gross capital formation.

A fundamental accounting identity is that total use of output in a row equals total output of the same industry as indicated in the respective column in the left-hand part of the figure. The columns convey information on the technology of production as they indicate the amounts of intermediate and factor inputs needed for production. The intermediates can be sourced from domestic industries or imported. This is the Z matrix from section 2. The residual between total output and total intermediate inputs is value added. This is made up by compensation for production factors.

As building blocks for the WIOT, we used national supply and use tables (SUTs) that are the core statistical sources from which NSIs derive national input-output tables. In short, we derive time series of national SUTs. Benchmark national SUTs are linked over time through the use of the most recent National Accounts statistics on final demand categories, and gross output and value added by detailed industry. This ensures both intercountry and intertemporal consistency of the tables. As such the WIOT is built according to the conventions of the System of National Accounts and obeys various important accounting identities. National SUTs are linked these across countries through detailed international trade statistics to create so-called “International SUTs”. This trade-linking is based on a classification of bilateral import flows by end-use category (intermediate, consumer or investment), intermediate inputs are split by country of origin.

These international SUTs are used to construct the symmetric world input-output table. The construction of our WIOT has a number of distinct characteristics, in comparison to other projects with related objectives.

We rely on national supply and use tables (SUTs) rather than input-output tables as our basic building blocks. SUTs are a natural starting point for this type of analysis as they provide information on both products and industries. A supply table provides information on products produced by each domestic industry and a use table indicates the use of each product by an industry or final user. The linking with international trade data, which are product based, and factor use that is industry-based, can be naturally made in a SUT framework.⁷

To ensure meaningful analysis over time, we start from industry output and final consumption series given in the national accounts and benchmark national SUTs to these time-consistent series. Typically, SUTs are only available for a limited set of years (e.g. every 5 year)⁸ and once released by the national statistical institute revisions are rare. This compromises the consistency and comparability of these tables over time as statistical systems develop, new methodologies and accounting rules are used, classification schemes change and new data becomes available. By benchmarking the SUTs on consistent

⁷ As industries also have secondary production a simple mapping of industries and products is not feasible.

⁸ Only recently, most countries in the European Union have moved to the publication of annual SUTs.

time series from the National Accounting System (NAS), tables can be linked over time in a meaningful way. This is done by using a SUT updating method (the SUT-RAS method) as described in Temurshoev and Timmer (2011) which is akin to the well-known bi-proportional (RAS) updating method for input-output tables. For this updating data on gross output and value added by industry is used, alongside data on final expenditure categories from the National Accounts.

Ideally, we would like to use official data on the destination of imported goods and services. But in most countries these flows are not tracked by statistical agencies. Nevertheless, most do publish an import IO table constructed using the ‘import proportionality’-assumption, applying a product’s economy-wide import share for all use categories. For the US it has been found that this assumption can lead to rather misleading results, in particular at the industry-level (Feenstra and Jensen, 2009; Strassner, Yuskavage and Lee, 2009). Therefore we are not using the official import matrices but use detailed trade data to make a split. Our basic data is bilateral import flows of all countries covered in WIOD from all partners in the world at the HS6-digit product level taken from the UN COMTRADE database. Based on the detailed description products are allocated to three use categories: intermediates, final consumption, and investment, effectively extending the UN Broad Economic Categories (BEC) classification. We find that import proportions differ widely across use categories and importantly, also across countries of origin. For example, imports by the Czech car industry from Germany contain a much higher share of intermediates than imports from Japan. This type of information is reflected in our WIOT by using detailed bilateral trade data. The domestic use matrix is derived as cell-level total use minus imported use.

Another novel element in the WIOT is the use of data on trade in services. As yet no standardised database on bilateral service flows exists. These have been collected from various sources (including OECD, Eurostat, IMF and WTO), checked for consistency and integrated into a bilateral service trade database (see Stehrer et al., 2010, for details). Although the maximum of existing information is used, there are clear gaps in our knowledge at lower levels of aggregation.

Based on the national SUTs, National Account series and international trade data, International SUTs were prepared for each country. As a final step, international SUTs are transformed into an industry-by-industry type world input-output table. We use the so-called “fixed product-sales structure” assumption stating that each product has its own specific sales structure irrespective of the industry where it is produced (see e.g. Eurostat, 2008). For a more elaborate discussion of construction methods, practical implementation and detailed sources of the WIOT, see Timmer et al. (2012).

The following countries have been included in the database. In Europe: Austria, Belgium, Bulgaria, Cyprus, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxemburg, Malta, the Netherlands, Poland, Portugal, Romania, Russia, Slovakia, Slovenia, Spain, Sweden, Turkey, the UK; In the Americas: Brazil, Canada, Mexico, and the

US; In Asia: China, India, Indonesia, Japan, South Korea and Taiwan; and in Oceania: Australia. African countries are not present in the database, other than as part of Rest of the World. For the Rest of the World, the production structure was constructed as the average structure of Brazil, China, India, Indonesia, Mexico and Russia.

Labor Data

For most advanced countries labour and capital 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. This is described in full in Erumban et al. (2012). Self-employed are included. The data used in this draft are expressed in numbers of jobs (000s) and are aggregated over the low-skilled, medium-skilled and high-skilled categories.

4. Empirics: Labor Productivity in Global Value Chains

In Section 2, we proposed to compute the amounts of labor required for a dollar of final output of an industry, aggregated over all industries and all countries that produce materials, components and services that are required. These numbers were incorporated into a vector called λ , which contains 1435 values in our empirical analysis (40 countries plus RoW, and 35 industries). We compute this vector for 1995 and 2008, using world input-output tables for these years. The table for 2008 has been deflated to reflect values measured in 1995.⁹ The inverse of the ratios between the λ -values for 2008 and 1995 gives an indication of GVC labor productivity growth rates. We have summarized the results in two ways, first by aggregating over GVCs of final products produced in a country (for all output and for manufacturing output only), and second by aggregating over GVCs of countries, for specific types of final output. The results in Tables 1 and 2 are obtained by weighting the constituent growth rates at country-industry level by their employment requirements in 1995.

⁹ This has been done in a rather rough way (by means of gross industry deflators). In a future version of the paper, the annual time-series nature of the data material contained in the WIOD-database will be exploited by running chained analyses.

Table 1: GVC labor productivity growth rates for selected countries (ratios of levels for 2008 and 1995)

	GVC-lp-growth	Traditional lp-growth
Brazil	1.09	1.00
China	2.56	3.08
Czech rep.	1.35	1.06
France	1.10	1.35
Germany	1.06	1.17
Italy	0.95	0.91
Japan	1.11	1.16
Korea	1.42	1.96
Russia	1.70	1.54
Spain	0.90	0.92
Taiwan	1.53	2.29
USA	1.14	1.26
Rest of the World	1.26	1.39

The results in Table 1 show that GVC-labor productivity growth rates are generally smaller than traditional growth rates (13-years growth rates could easily be obtained by subtracting 1 from the reported ratios). These have been obtained by first obtaining levels (summing VA by industry for a country and dividing by the sum of all industry employment) and then taking the ratios of the levels for 2008 and 1995. There are exceptions, however, like Brazil and the Czech Republic. A likely explanation is that these countries managed to attract assembly activities, which means that their GVCs included more foreign high-productivity intermediate input production activities in 2008 than in 1995. For most countries, however, GVC labor productivity grew at lower rates than traditional labor productivity. For advanced countries, this is most likely due to the fact that labor productivity levels are generally lower in countries to which production stages are relocated (labor productivity levels in Eastern Europe, for example, are lower than in Western Europe, although the productivity growth rates in some Eastern European countries are relatively high). For emerging countries like China and Korea, GVC labor productivity growth is also relatively low in comparison to traditional growth rates. This is most likely due to the fact that foreign services also contribute to GVC labor productivity. Emerging countries generally specialize in manufacturing activities, but substantial amounts of services (business services,

financial services, transport services, etc.) are required to produce final output. In most services industries, productivity growth has been slower.¹⁰

Table 2 presents GVC labor productivity ratios for 2008 and 1995 for a selected number of industries (worldwide):

Table 2: GVC labor productivity growth rates for selected industries (ratios of levels for 2008 and 1995, ordered)

	GVC-lp-growth
Electrical and Optical Equipment manufacturing	2.79
Machinery manufacturing, Nec	2.58
Textiles and Textile Products	2.14
Transport Equipment manufacturing	2.02
Basic Metals and Fabricated Metals manufacturing	2.00
Construction	1.65
Mining and Quarrying	1.61
Agriculture, Hunting, Forestry and Fishing	1.51
Education	1.51
Hotels and Restaurants	1.34
Electricity, Gas and Water Supply	1.26

The results show that GVC labor productivity growth rates vary, with manufacturing GVCs being represented mostly in the upper parts of the distribution. What should be kept in mind is that the relative importance of GVCs for industries like ‘Mining and Quarrying’ and ‘Agriculture, etc.’ is much smaller than in conventional analyses, since most of the activities in these industries are not aimed at producing final output, but at producing intermediate inputs that end up in final products of other industries. This is a phenomenon that also applies to many services industries, like ‘Renting of Materials and Equipment’ and ‘Financial Intermediation’. The productivity changes that occurred in industries like these are incorporated in the productivity developments in the GVCs for industries that mainly provide final products.¹¹

¹⁰ Some of these statements will be backed up with numbers in a future draft of the paper.

¹¹ A next version will compare productivity growth rates by industry measured using the GVC-approach introduced here and traditional labor productivity growth indicators.

5. Consumption Growth Accounting for the World

As the results of the previous section shows, labor productivity changes within GVCs between 1995 and 2008 are characterized by a lot of heterogeneity. It might be interesting to see how these changes have contributed to worldwide consumption growth, over the same period. The static open input-output model (the main workhorse for input-output researchers) is not suitable to address this question, because it considers consumption (and other demand for final products) as exogenous, and derives value added and employment as endogenous outcomes. The model is purely demand-driven. This is useful for e.g. assessing the most likely short-term impacts of a stimulus package, but is much less appropriate when studying growth over a 13-year period. Hence, we propose a framework that resembles an earlier input-output model proposed by us, which takes labor supply as given for a period, and derives the attainable consumption level as an endogenous result.

Equation (1) is very common in applications of the static open input-output model to employment issues.

$$L = \mathbf{h}'\mathbf{x} = \mathbf{h}'(\mathbf{I} - \mathbf{A})^{-1}\mathbf{b}^F F \quad (1)$$

In this equation, L stands for total (i.e. economy-wide) employment, while F represents the level of aggregate final demand and \mathbf{b}^F is an MN -vector of shares of each of the MN final outputs in final demand (i.e., it is a vector representing the composition of final demand). We propose to consider L as exogenous, and can derive the ensuing final demand level F as

$$F = \frac{L}{\mathbf{h}'(\mathbf{I} - \mathbf{A})^{-1}\mathbf{b}^F} \quad (2)$$

This equation shows that the final demand attainable is high if labor supply is high, if the labor requirements per units of final demand ($\mathbf{h}'(\mathbf{I} - \mathbf{A})^{-1}$) are low and if the composition of final demand is such that final demand shares of commodities that do not require lots of labor inputs in their GVCs are large.¹²

Next, we should model how the share of consumption demand in total final demand is determined. We consider consumption demand as a residual, in the sense that the world economy first supplies exogenously determined demands for investment goods. These are considered necessary to sustain current

¹² Note that $\mathbf{h}'(\mathbf{I} - \mathbf{A})^{-1}$ equals λ , the inverse of GVC labor productivity as introduced in Section 2.

production possibilities in the future, respectively. The fraction of labor supply that remains is used for the production of consumption goods (both household consumption and government consumption) and the intermediate inputs required for their production. This modeling implies that the share of consumption in total final demand is not exogenously fixed. For given parameters \mathbf{A} , \mathbf{h} , \mathbf{b}^C , and for exogenously specified investment demand \mathbf{v} (a vector of dimension MN) and labor supply L , the total consumption level is obtained. In virtually the same way as (2) is derived from (1) for the case of aggregate final demand F , a solution for two categories of final demands:

$$C = \frac{L^{sup}}{\mathbf{h}'(\mathbf{I} - \mathbf{A})^{-1}\mathbf{b}^C} - \frac{\mathbf{h}'(\mathbf{I} - \mathbf{A})^{-1}\mathbf{v}}{\mathbf{h}'(\mathbf{I} - \mathbf{A})^{-1}\mathbf{b}^C} \quad (3)$$

Note that both the numerators and denominators on the right hand side are scalars.

The first term of the right hand side of (3) indicates the level of consumption attainable if all labor resources would be devoted to the production of consumption goods and the intermediate inputs required to produce these. The second term in the right hand side measures by what amount this consumption level is actually reduced due to the production of investment goods, and the intermediate inputs required for these. They reduce the labor resources available for the production of consumption goods in the short run. In the long run, however, current production of investment goods is required to keep the labor demands per unit of output (i.e. the parameters \mathbf{h}) at stable or even lower levels in future periods, see the arguments put forward by Weitzman (1976) as briefly described in the introduction. If no capital goods are produced now, all future output would have to be produced by labor alone. Supposing that deliveries for consumption purposes can be viewed as a residual might seem most appropriate for centrally planned economies. In market economies, however, capacity-restricted firms also take investment demand (required by themselves and by customers to remain capable of producing and competitive in the longer run) in consideration when deciding on the production levels of commodities for consumption purposes. Hence, we feel that our methodology is also relevant to analyze consumption growth in market economies.

In our analysis, we will focus on two sources of changes in consumption structure \mathbf{b}^C , which both change the relative importances of GVCs. First, we will look at changes in the types of final products consumed, for example as a consequence of Engel curve effects (i.e., GVCs for luxury products will become more important than GVCs for basic wants). Second, final products delivered by some countries may gain in competitiveness relative to the same type of final output from other countries. If German car manufacturers decide to increase the share of their cars assembled in China at the expense of assembly in

Germany itself, both the level of and changes in productivity in the Chinese GVC for cars will become more important. A similar argument can be constructed for changes in the composition of the investment demand vector \mathbf{v} . Let us define \mathbf{s}^C and \mathbf{s}^V as MN -vectors obtained by stacking M identical vectors with shares of each of the N final outputs in world consumption demand and world investment demand, respectively. If we then define \mathbf{d}^C and \mathbf{d}^V as MN -vectors obtained by stacking M vectors with shares of each of the M countries in delivering each of these N final outputs for consumption and investment, respectively, then we can write $\mathbf{b}^C = \mathbf{d}^C \circ \mathbf{s}^C$ and $\mathbf{v} = \mathbf{d}^V \circ (\mathbf{s}^V V)$, in which \circ represents cell-by-cell multiplication and V is worldwide investment demand. If we also substitute λ for $\mathbf{h}'(\mathbf{I}-\mathbf{A})^{-1}$ (see Section 2), then we can write

$$C = \frac{L}{\lambda'(\mathbf{d}^C \circ \mathbf{s}^C)} - \frac{\lambda'[\mathbf{d}^V \circ (\mathbf{s}^V \cdot V)]}{\lambda'(\mathbf{d}^C \circ \mathbf{b}^C)} \quad (4)$$

Given this expression, changes in the total consumption level can be attributed to changes in the values of the variables represented by the symbols in the right hand side of equation (4). To get insight into the determinants of welfare change, it is useful to consider changes in consumption per worker, i.e. C/L . Dividing both sides of (4) by L and defining $c \equiv C/L$, $v \equiv V/L$ and $e \equiv E/L$ yields

$$c = \frac{1}{\lambda'(\mathbf{d}^C \circ \mathbf{s}^C)} - \frac{\lambda'[\mathbf{d}^V \circ (\mathbf{s}^V \cdot v)]}{\lambda'(\mathbf{d}^C \circ \mathbf{s}^C)} \quad (5)$$

The ratio of worldwide consumption per unit of labor in two periods (indicated by indices 0 and 1) can be written as:¹³

$$\frac{c_1}{c_0} = \frac{1 - \lambda_1'[\mathbf{d}_1^V \circ (\mathbf{s}_1^V \cdot v_1)]}{1 - \lambda_0'[\mathbf{d}_0^V \circ (\mathbf{s}_0^V \cdot v_0)]} \cdot \frac{\lambda_0'(\mathbf{d}_0^C \circ \mathbf{s}_0^C)}{\lambda_1'(\mathbf{d}_1^C \circ \mathbf{s}_1^C)} \quad (6)$$

¹³ It should be mentioned that equation (6) only holds exactly if the investment vector does not contain negative entries. Hence, we disregard changes in inventories, the values of which often take negative values. This implies that changes in inventories are implicitly seen the production of consumption goods. In reality, inventories only partly consist of consumption goods.

Now, the methodology proposed by Dietzenbacher *et al.* (2007) can be used to express the right hand side of equation (6) as the product of 6 factors. Each of these terms gives the change in the consumption per unit of labor which would have been observed if only a single variable would have changed between period 0 and period 1. That is

$$\frac{c_1}{c_0} = (7.1) \cdot (7.2) \cdot (7.3) \cdot (7.4) \cdot (7.5) \cdot (7.6) \quad (7)$$

with

$$(7.1) = \frac{1 - \lambda_1'[\mathbf{d}_1^V \circ (\mathbf{s}_1^V \cdot v_1)]}{1 - \lambda_0'[\mathbf{d}_1^V \circ (\mathbf{s}_1^V \cdot v_1)]} \cdot \frac{\lambda_0'(\mathbf{d}_1^C \circ \mathbf{s}_1^C)}{\lambda_1'(\mathbf{d}_1^C \circ \mathbf{s}_1^C)},$$

$$(7.2) = \frac{1 - \lambda_0'[\mathbf{d}_1^V \circ (\mathbf{s}_1^V \cdot v_1)]}{1 - \lambda_0'[\mathbf{d}_0^V \circ (\mathbf{s}_1^V \cdot v_1)]} \cdot \frac{\lambda_0'(\mathbf{d}_1^C \circ \mathbf{s}_1^C)}{\lambda_0'(\mathbf{d}_1^C \circ \mathbf{s}_1^C)},$$

$$(7.3) = \frac{1 - \lambda_0'[\mathbf{d}_0^V \circ (\mathbf{s}_1^V \cdot v_1)]}{1 - \lambda_0'[\mathbf{d}_0^V \circ (\mathbf{s}_0^V \cdot v_1)]} \cdot \frac{\lambda_0'(\mathbf{d}_1^C \circ \mathbf{s}_1^C)}{\lambda_0'(\mathbf{d}_1^C \circ \mathbf{s}_1^C)},$$

$$(7.4) = \frac{1 - \lambda_0'[\mathbf{d}_0^V \circ (\mathbf{s}_0^V \cdot v_1)]}{1 - \lambda_0'[\mathbf{d}_0^V \circ (\mathbf{s}_0^V \cdot v_0)]} \cdot \frac{\lambda_0'(\mathbf{d}_1^C \circ \mathbf{s}_1^C)}{\lambda_0'(\mathbf{d}_1^C \circ \mathbf{s}_1^C)},$$

$$(7.5) = \frac{1 - \lambda_0'[\mathbf{d}_0^V \circ (\mathbf{s}_0^V \cdot v_0)]}{1 - \lambda_0'[\mathbf{d}_0^V \circ (\mathbf{s}_0^V \cdot v_0)]} \cdot \frac{\lambda_0'(\mathbf{d}_0^C \circ \mathbf{s}_1^C)}{\lambda_0'(\mathbf{d}_1^C \circ \mathbf{s}_1^C)},$$

$$(7.6) = \frac{1 - \lambda_0'[\mathbf{d}_0^V \circ (\mathbf{s}_0^V \cdot v_0)]}{1 - \lambda_0'[\mathbf{d}_0^V \circ (\mathbf{s}_0^V \cdot v_0)]} \cdot \frac{\lambda_0'(\mathbf{d}_0^C \circ \mathbf{s}_0^C)}{\lambda_0'(\mathbf{d}_0^C \circ \mathbf{s}_1^C)}$$

The second factor of (7.2), (7.3) and (7.4) are equal to one and could have been omitted, but have been maintained to give insight into the structure of the decomposition. The same goes for the first factor of (7.5) and (7.6). (7.1) provides the counterfactual ratio between consumption per worker in year 1 and year 2, if only the GVC labor productivities would have changed, and all other parameters would have remained equal, like in well-known shift-share analyses. The second factor represents the counterfactual consumption growth if the shares of countries in which the final stage of the production process for investment goods takes place would have changed, everything else equal. In a similar vein gives (7.3) the consequences of changing investment composition by type of final product, while (7.4) considers the total

level of investment demand (in per worker terms). (7.5) isolates the effects of changes in the country shares regarding the supply of final consumption goods and (7.6) focuses on the consequences of changing relative importances of GVCs as a consequence of differences in the composition of consumption in terms of the type of final products bought (Engel curve effects, other changes in tastes, or substitution effects due to changes in relative prices).

It is well known that structural decompositions are not unique. One could, for example, also opt for the so-called “mirror image” (de Haan, 2001). For example, (7.2) gives the effect of changes in \mathbf{d}^V . The mirror image of (7.2) would be obtained by replacing indices 1 by 0, and vice versa, for all variables except \mathbf{d}^V . The same procedure can be applied to each of the other 5 factors. Dietzenbacher and Los (1998) showed that many more possible equations are equally valid. They also found that the magnitudes of the contributions of the sources of growth as found in structural decomposition analyses may heavily depend on the specific decomposition equation chosen.¹⁴ To handle this non-uniqueness issue, they suggest computing the results for each and every formula and present the average value for each factor as the contribution to the total effect. De Haan (2001) shows that space, time and effort can be saved, because averages of single pairs of mirror images appear to be very close to the average over all possible decomposition forms. Hence, following Dietzenbacher et al. (2004), we compute Fisher indices (geometric averages) for pairs of factors obtained from equation (7) and its mirror image.

Table 3 gives the results of the decomposition, as obtained by computing the Fisher index over each of the factors in equation (7) and its ‘mirror image’.

Table 3: Sources of global consumption growth (ratios of levels for 2008 and 1995)

Actual growth in global consumption per worker	1.18
Counterfactuals	
GVC productivity growth only (7.1)	1.71
GVCs delivering investment goods only (7.2)	0.86
Investment composition only (7.3)	1.01
Investment level per worker only (7.4)	0.94
GVCs delivering consumption goods only (7.5)	0.80
Consumption composition only (7.6)	1.04

¹⁴ Dietzenbacher and Los (1998) focused on this issue with respect to so-called additive decomposition forms. Their results carry over to multiplicative forms, such as pursued in this paper, as well.

The results show that labor productivity growth within GVCs was by far the most important driver of the 18% increase in consumption per worker worldwide, in the period 1995-2008. If this would have been the only factor of change, consumption would have grown at a pace almost four times as fast. Neither Engel curve effects or related changes in consumption patterns, nor changes in the composition of investment demand reduced this rate substantially. The results for these factors even exceed 1 (although only marginally). Apparently, worldwide consumption demand has moved towards products for which the amounts of labor required in GVCs are somewhat smaller relative to what was consumed in 1995.

Actual consumption growth turns out to be considerably smaller than what could have been attained as a consequence of GVC labor productivity growth due to shifts in the GVCs that produce final outputs. If we take the effects of delivery of investment goods (factor 7.2) and delivery of consumption goods (factor 7.5) together, and would have assumed everything else equal, global consumption per worker would have been 31% lower in 2008. These percentages quantify the importance of two effects, which are both related to the differences in labor productivity levels between advanced and emerging countries. First, growing numbers of consumers in emerging countries gained in purchasing power (relative to consumers in advanced countries), as a consequence of which they also consumed more services, many of which are nontradable and could therefore only be produced at productivity levels that are relatively low. Second, as a consequence of the second wave of unbundling, assembly stages of production processes were often relocated from advanced countries to emerging countries. In our accounting framework, such strategic changes (which can also be the consequence of the desire to be close to growing consumer markets) imply that shares of output by GVCs of advanced countries are eaten away by shares of output by GVCs of emerging countries. Many of these experience rapid productivity growth (which is reflected in the results for factor 7.1), but relative productivity levels are still low.

6. Conclusions and Reflection

This paper is a first attempt to introduce the concept of Global Value Chain labor productivity growth and attempts to quantify the effects of this phenomenon on worldwide growth of consumption per worker. In our view, consumption per worker can be seen as a measure of labor productivity that can complement the traditional GDP per worker indicators, in the sense that it focuses on actual (material) welfare. Investment is needed to make future consumption possible, but returns to investment are not certain and can vary across countries. In our view, consumption per worker gives an indication of what countries (or, in this paper, the world) has achieved up till the year considered.

Global Value Chain labor productivity is a concept that enables us to show to what extent the amount of labor required to produce a unit of final output of an industry in a country has changed, irrespective of the country in which stages of production are located. In order to apply this concept empirically, world input-output tables are needed. In this paper, we use data from the recently published World Input-Output Database (www.wiod.org). The tables in this database can be seen as representations of the world production structure (and changes therein) for the period 1995-2008.

We gave some preliminary indications of the rate of GVC labor productivity growth (aggregated over GVCs by country and over GVCs by industry) and used the results as one of the determinants in an accounting framework for growth in global consumption per worker. We found that global consumption per worker grew by about 18% over 1995-2008. If GVC labor productivity growth would have been the only factor that changed, this growth would have exceeded 70%. The increasing importance of GVCs of emerging countries like the BRICs, which still have considerably lower GVC labor productivity *levels* than GVCs of advanced countries, appeared to be the main consumption-reducing factor.

In a next draft of this paper, more quantification of phenomena described above will be given. At least one underlying assumption of the consumption growth accounting framework requires more attention, and in our view also additional computational work. Labor supply is supposed to be a limiting factor for consumption growth. Over (the early part of) the time period that we considered in our analysis, China appears to have been a country in which lots of potentially available labor was initially not used. A similar argument against the approach can be brought forward with respect to countries that are incorporated in our Rest of the World. To address this issue, we might want to apply a slightly adapted consumption growth decomposition in which the labor requirements per unit of output for activities in China and RoW are set to zero, and we only consider consumption growth in the remaining countries. By doing so, we assume that labor supply levels in the other countries are the limiting factor. In order to avoid this pressure, labor in e.g. the US can be substituted by non-scarce labor in China or RoW. This is in a sense similar to assuming that the pressures of a limited labor force can be avoided by substituting another production factor (e.g. physical capital) for labor. In both cases, the extent to which substitution actually takes place is restricted by price differences and technological (im)possibilities. The opportunities for substitution between labor in different countries that have emerged during the second wave of unbundling can therefore also provide an interesting area for further developments in productivity studies. Such analyses would delve deeper into the proximate sources of GVC labor productivity growth.

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