Toward a Global Integrated Industry-level Production Account: A Proposal

Jon D. Samuels and Erich H. Strassner[1]
U.S. Bureau of Economic Analysis

Abstract

This article develops the framework for a global production account. We describe the relationship between existing KLEMS approaches and databases, international guidelines on GDP and productivity measurement, and our proposal toward a global integrated production account. The key feature of the account is an integrated world input-output table in current and constant prices, augmented with constant quality prices and quantities for primary factor inputs by industry, all converted with conceptually appropriate purchasing power parities. Uses of the framework include: 1) industry and country-level contributions to world economic growth, 2) price level indexes that serve as measures of industry-level competitiveness across countries, 3) total factor productivity level comparisons at the industry level, and 4) global production chain analysis. None of these are applications are currently possible with existing country-industry-level KLEMS databases.

Growth accounting at the industry level applied to KLEMS (Capital, Labour, Energy, Materials, and Services) accounts has proven to be an extremely useful tool for analyzing the sources of economic growth and cross-country comparisons of growth. Jorgenson (2017) describes the "World KLEMS initiative" as a consortium of national accountants, statistical offices, and researchers from academic and non-academic settings that has worked to produce consistent industry-level databases on economic outputs and inputs for more than 40 countries. The major takeaways from this line of research are that "capital and labour inputs have emerged as the predominant sources of economic growth in both advanced and emerging economies," and that "productivity continues to play an important role

1 Jon Samuels is a Research Economist at the U.S. Bureau of Economic Analysis (BEA), and Erich Strassner is Associate Director for National Economic Accounts. The views expressed in this article are solely those of the authors and not necessarily those of the U.S. Bureau of Economic Analysis or the US Department of Commerce. We thank Dale Jorgenson, Andrew Sharpe, Marcel Timmer, and an anonymous referee for very helpful suggestions. Emails: jon.samuels@bea.gov and erich.strassner@bea.gov

as a source of economic growth, but this role has diminished sharply in the aftermath of the Great Recession." The focus on World KLEMS to date has been on economic growth decompositions based on industry datasets at the country-level.

The purpose of this article is to develop the framework for a global production account. We describe the relationship between existing KLEMS approaches and databases, international guidelines on GDP and productivity measurement, and our proposal toward a global integrated production account. Our approach to discussing work toward a global integrated production account is example driven. The examples that we give provide useful context and background information for readers less familiar with the basic issues involved in measuring global production.

A contribution of our article is that it demonstrates valuable next steps for the World KLEMS consortium. We demonstrate proof of concept by appealing to existing work on productivity accounting within a KLEMS framework and on new research that integrates country-level KLEMS into bilateral productivity comparisons. In essence, our proposal argues that extending the two country (United States and Japan) model described below to the world economy amounts to proof of concept toward a global integrated world production account.

We describe data needs and conceptual issues, and important uses of such a dataset. These uses include: 1) industry and country-level contributions to world economic growth, 2) price level indexes that serve as measures of industry-level competitiveness, 3) total factor productivity (TFP) level comparisons at the industry level, and 4) global production chain analysis. None of these applications are possible with existing country-industry-level KLEMS databases.

One of our major conclusions is that much of the necessary data are available to construct a global production account; but an important next step is to assemble new data on industry-level purchasing power parities (PPPs). Building conceptually appropriate PPPs is not a trivial task.

A simple example of the difficulty in measuring output PPPs is consider the PPP for the production of paper. Let us say that we observe that the purchase price of paper is \$5 for a ream of paper in the United States and Y500 in Japan, and both countries also produce paper. Comparing production of paper requires information on relative price levels, not just national price indexes that are indexed to one in the base year.

Let us say that the United States

imports paper from China, and Japan imports paper from Canada. Flows of international trade across industries from the global production account allows for stripping these imported purchases (with their respective prices) from the relative purchase price of paper ($5/Y500) to infer domestic output prices of paper production in the United States relative to Japan to construct conceptually appropriate industry-level PPPs.[2] Extending this simple example to multiple countries and multiple trading partners demonstrates the need for global input output tables.

The article proceeds along the following outline. Section 1 overviews how the world production account is related to the production account in the system of national accounts (SNA). Sections 2 and 3 provide information on the building blocks of the world production account, starting with country-level production accounts and then industry-level production accounts at the country level. Section 4 is the core of the article and ties all of the information together to demonstrate the requirements for a global integrated production account. Once the framework is in place, section 5 covers selected applications of the global integrated production account, and section 6 presents some of the basics of implementation and other practical issues. Section 7 wraps up by covering potential extensions.

The Production Account as an Organizing Framework

The organizational framework for the global integrated production accounts is a production account for the world economy. The production account for the world economy is an extension of a production account at the national level. At the national level, the production account displays how income is generated, distributed, and used throughout a national economy (United Nations, 2008). The product side of the production account corresponds to country level Gross Domestic Product (GDP) and includes expenditure on personal consumption, private investment, net exports, and government consumption and investment. The income side of the account corresponds to Gross Domestic Income (GDI) and includes information on compensation of employees, net taxes on production and imports, operating surplus, and consumption of fixed capital.

From the outset, it is useful to distinguish between the production

2 Nomura, Miyagawa, and Samuels (2018) have a detailed accounting model to determine PPPs for the United States and Japan. This is discussed below. Inklaar and Timmer (2014) employ a simpler version that makes stronger assumptions.

account described in the System of National Accounts (SNA) and a KLEMS-based production account. The point of departure from a production account in the SNA and a KLEMS-based aggregate production account is that the KLEMS-based production account requires price deflators for both final outputs and primary inputs, while this is not strictly required in the SNA. By including price deflators for outputs and inputs, the KLEMS-based production account permits internally consistent measures of total factor productivity, which is defined as the ratio of real output to real input.

A purpose of integrating KLEMS into a world production account is to provide a national accounts consistent production account for the world economy, in current and constant prices that is consistent with information in the country-level KLEMS accounts. With this framework, the World Production account that we describe provides an internally consistent decomposition of the sources of world economic growth, and economic growth across world regions.

The production account in Chapter 6 of the SNA (United Nations, 2008) has two sides that are in balance by construction. The first is the Resource side that includes the value of output of goods and services. The other side of the account is the Uses account which records intermediate consumption, and the balancing item Value Added. In the SNA, the generation of income account shows how resources in the economy (value added) equate to income in the form of compensation of employees, taxes on production and imports and subsidies, operating surplus, consumption of fixed capital, and mixed income.

These represent the three approaches to measuring GDP. In nominal terms, putting these accounts together yields the nominal side of the production account for KLEMS accounting. Specifically, the output side of the production account in KLEMS is the GDP, and the input side imposes the accounting identity that incomes generated in production are exhausted across capital and labour services. This is, in fact, how the SNA conceptualizes production: as activity that uses inputs of labour, capital, and goods and services to produce outputs of goods and services. In nominal terms there need not be any differences between production measured in the SNA and that required to construct an aggregate production account: nominal output is the value

3 Splitting income between self-employed labor and capital is an important component of constructing the KLEMS production account, but the key point is that total income corresponds to factor payments in the aggregate.

of production, and payments to inputs correspond to gross domestic income.[3]

For a production account to include information on productivity, nominal values of output and input must be decomposed into price and quantity. As a reminder, within the context of a single country, these prices and quantities are index numbers and thus are useful only to construct growth rates. Output price measurement is covered in chapter 15 of the SNA. Approaches to price measurement of inputs are included in chapters 19 and 20 of the SNA, although these are not a requirement of the system of national accounts. Total factor productivity is the ratio of the quantity of output to the quantity of input. Chapter 19 of the SNA discusses quality-adjusted labour input, which provides the labour input measure within the production account, while chapter 20 discusses capital services, which provides the quantity input measure within the account.

An industry-level production account at the country level permits a bottom-up analysis of the sources of economic growth within a country. The foundation of a country-level industry production account is a set of country-level supply-use accounts that include the value of outputs and intermediate inputs used by industry. Construction of the supply-use accounts in nominal terms is covered by the UN's "Handbook on Handbook on Supply, Use and Input-Output Tables with Extensions and Applications" (United Nations, 2017) and the Eurostat "Manual of Supply, Use, and Input-Output Tables" (Eurostat, 2008).

The output side of the account includes nominal and real industry output and value added. By aggregating over industries, the account yields an estimate of economy-wide country-level growth and industry contributions to GDP growth. The input side of the account includes nominal and real estimates of intermediate and capital and labour inputs used by industry. By aggregating inputs over industries, the account yields estimate of economy-wide input contributions.

Using a growth accounting model, the account can be used to decompose output growth to its sources across inputs. The growth in real output less real input is defined as total (or multi) factor productivity growth and accounts for the portion of economic growth not accounted for by input accumulation.[4] Significant progress has been made on constructing industry-level production accounts based on

4 We will note later that under the assumption of an aggregate production possibility frontier, aggregate TFP growth is not simply the weighted sum of industry level TFP growth. Aggregate TFP growth embeds a reallocation effect.

this method: work on this is covered under the World KLEMS initiative and has yielded industry-level production account KLEMS data for over forty countries.

Next, we relate ongoing KLEMS research and data development to the global production account that is the focus of this article. We term the global production account at the industry level the Global Integrated Production Account. While we will lay out the basic conceptual framework for such an account, it will not serve a comprehensive instruction manual on all of the topics used to frame and implement the account. Furthermore, the article is descriptive in nature about the data and related research and does not touch on policy related motivations for such work or the policy implications of findings.[5]

The foundation of the global production account is a world-input output (IO) account that shows how outputs are being produced and inputs are being used throughout the world economy. One of the most widely-used applications of world IO tables is to produce estimates of trade in value added (TiVA). The system of world input output accounts was introduced by Leontief (1974) and has been implemented recently by the Global Trade Analysis Project (GTAP),[6] the World-Input Output Database (WIOD) (Dietzenbacher, Los, Stehrer, Timmer, and De Vries, 2013), and the OECD-WTO initiative to measure trade in value added.[7]

Because country-level input-output accounts are in local currency units, a crucial aspect of the world input output accounts in the context of world production is conversion of country-level accounts to comparable units using purchasing power parities for outputs and inputs. Combing a system of world input-output tables with prices for industry outputs and inputs (including primary inputs) essentially yields the global integrated production account. We discuss how this works in the subsequent sections.

Country-level Production Accounts

We start with the description of a

5 A formal complementary examination of index number issues in multi-country comparisons of total factor productivity is available in Inklaar and Diewert, (2016).

6 The first official GTAP-MRIO tables to be produced by the GTAP consortium werescheduled to be released in the summer of 2017. The earlier GTAP-MRIO tables were part of the initiative of Peters, Andrew, and Lennox (2011).

7 There are other global initiatives as well including Lenzen, Moran, Kanemoto, and Geschke (2013), Tukker, et al. (2013), Meng, Zhang, and Inomata (2013), and Bruckner, Giljum, Lutz, and Wiebe (2012). Also, there was an update of EUKLEMS which was released in summer 2017. Another update is scheduled for summer 2019.

country-level production account because the same basic concepts are used in formulating the global production account. A production account at the country level includes data on the production on final goods and services and the primary inputs used to produce these goods and services in current and constant prices.

To obtain some intuition for the economic questions that production account data can help address, it is useful to review some of the more recent results. Jorgenson, Ho, and Samuels (2019) find that the preponderance of U.S. growth (about 80 per cent) is accounted for by the accumulation of inputs, while the remainder is accounted for by increases in TFP.

That study also uses the production account to analyze the dynamics of growth over post-war U.S. economic history. It identifies the IT investment boom from 1995-2000 and quantifies the disproportionate effects of the Great Recession on workers without a college degree within the GDP accounting framework. Importantly, because the contributions of the output and inputs sides are constructed to be consistent with the GDP accounts, the production account framework yields an internally consistent accounting of contributions. This has clear advantages over disparate measures related to employment, education, and investment that are tied to growth and productivity, but not linked to the national accounts.[8]

Moving past the United States example, similar production account data at the aggregate level is assembled by the Conference Board in its Total Economy Database (TED). The TED contains underlying aggregate production account information on output and inputs by most countries in the world economy.[9] Most of the measures are consistent with and built off national accounts data.

One major finding from this line of research is that, like the United States, the preponderance of growth is accounted for by the accumulation of inputs. It is important to note that the Conference Board TED database relies on the information available in individual country's national accounts, so that the TED database could not exist without all of the data produced by statistical offices throughout the world.

If aggregate country-level information were sufficient to analyze

8 The BLS in the U.S. produces official estimates of aggregate MFP growth for the U.S. economy, but these measures are not consistent with the official GDP estimates because they are designed to cover the business sector. The section below on industry-level production accounts notes a relatively new integrated industry-level produced jointly by the BEA and BLS that is consistent with the GDP accounts.

9 See https://www.conference-board.org/data/economydatabase/index.cfm?id=27762 for the latest data coverage.

world economic growth, the information gathered in the Total Economy Database would be nearly sufficient. For analyzing global production, however, a major missing component is information on the role of individual industries in the sources of economic growth. From a global perspective, without the industry dimension there is no way to track the interactions (and supply chains) that are the major point of emphasis in the analysis of global production.

Industry-level Production Accounts at the Country Level

An aggregate production account includes information on aggregate production and the sources of growth but does not permit industry-level comparisons that are important for understanding world production, competitiveness, and comparative advantage. The importance of distinguishing industries in the analysis of growth is intuitive. The production process for information technology equipment is different than the production of hotel accommodations on the output side and on the input side. This is evidenced by the different skill mix in labour input, asset composition in capital input, and the types of intermediate goods and services used in production. Production chains span industries across countries.

The international statistical community has made significant progress on assembling industry-level production account data at the country level. As discussed earlier, much of this activity has taken place by a consortium of researchers and economic statisticians within the World KLEMS and EUKLEMS initiatives. These initiatives are described by Jorgenson (2012) and O'Mahoney and Timmer (2009), with more recent results and analysis presented in Jorgenson, Fukao, and Timmer (2016) and Fall 2017 Special Issue of the *International Productivity Monitor* (Jorgenson and Sharpe, 2017). The major features of these KLEMS accounts are national accounts consistent production account data in current and constant prices at the industry level, decomposed into the inputs used in production: capital (K), labour (L), Energy (E), Materials (M), and Services (S), and TFP. Thus, the KLEMS approach provides an internally consistent decomposition of economic growth across industries within an economy and factors of production used by each industry.

Jorgenson, Ho, and Samuels (2019) construct an industry-level production account and use the account to analyze the sources of U.S. economic growth over the post-war period in the United States. They divide the economy into producers of Information Technology (IT), users of IT, and non-IT industries. This shows the rising contribution of IT production in U.S. GDP growth over the period. The shift of production of IT equipment to outside the United States reinforces the importance of having comparable accounts for other countries to track world production of IT equipment, which is now mostly imported into the United States.

Their results show the disproportionate share of aggregate U.S. total economy total factor productivity growth originated in IT-producing industries since the technology became commercialized. That is, the IT producing sector accounted for about 5 per cent of nominal aggregate value added, but a substantially larger share of aggregate TFP growth. Productivity analysis based on aggregate data would miss this important distinction between IT and other types of production and perhaps erroneously conclude that TFP growth was balanced across sectors of the economy. The authors argue that accounting for the industry dimension is important in assessing the prospects for economic growth going forward.

KLEMS work has now been adopted into official national accounting statistics by Australia, Sweden, Finland, Denmark, Italy, the U.K., the Netherlands, and Mexico. In the United States, the BEA and BLS produce an integrated industry-level KLEMS production account that is consistent with the official GDP accounts. This includes internally consistent accounting data on industry output and KLEMS inputs.[10]

The EUKLEMS and World KLEMS consortiums provide proof of concept on implementing country-level production accounts. These datasets are produced by a consortium of academic researchers and statistical offices and now cover about 40 countries using consistent KLEMS methodology. Research studies using these datasets confirm the importance of these data for basic macroeconomic analysis. For example, the findings based on the EUKLEMS database in van Ark, O'Mahony, and Timmer (2008) show that a large portion of the labour productivity gap between Europe and the United States is driven by a gap in TFP growth of the service industries.

Global Accounting and the World Production Account

The previous sections have provided a basic motivation for KLEMS

10 Some of the data is posted here http://www.worldklems.net/data.htm.

work and covered existing work that has used KLEMS to build production account data. But a key component of a global KLEMS framework is the accounting for international transactions of goods and services used in production across industries and countries. By combing country-level KLEMS accounts with information on world trade and trade prices in an integrated input-output system we are able to define a global integrated production account.

As noted earlier, to analyze economy wide aggregate production (GDP), the framework of the Conference Board TED and Jorgenson and Vu (2005) would be nearly sufficient. But isolating the role of individual industries within and across countries requires a framework that measures industry-level production and the linkages between industry purchases and sales and particular countries. A major impetus for this is the increase in offshoring of components production. For example, identifying the role of imports from China in U.S. manufacturing requires a framework that separately identifies intermediate flows across borders. Identifying the role of cross border flows of intangibles in production, for example blueprints used for a single period to produce a complicated semiconductor would be treated in an analogous way if there is a market transaction.[11]

To accommodate these linkages, the global KLEMS accounts expand the domestic input-output system to a set of world input output tables. Comparing TFP and price levels across countries and industries integrated into the global value chain requires tables adjusted for purchasing power parities.[12]

The foundation of the world production account is an extended set of supply, use, and input-output accounts. The extension from the country-level tables to the world account involves two basic modifications. The first is identifying which transactions represent flows across borders. To give a clarifying example: consider international linkages in the use of chemicals in U.S. production. The current Use table in the official BEA industry accounts shows the chemicals used by each industry, and the import use matrix estimates how imported chemicals are used by U.S.

11 If there is not a market transaction or if the intangibles are an investment purchase rather than an intermediate this becomes more complicated.This paper includes some preliminary discussions on this below.

12 Price level comparisons at the industry level are useful for analyzing international competitiveness. Jorgenson, Nomura, and Samuels (2016) implement this for the U.S. and Japan based on price level indexes for industry output and inputs. Price level indexes in the global production account are described in section 5 below.

producers. But the table does not include information on the country of origin of the imports, nor on the destination country for exported chemicals.[13] These country-specific links are critical for understanding interdependencies in the global economy. The second modification is to impose consistency in the measures of cross border flows across countries, such that the value of exports of a producing country corresponds to the value of imports in the purchasing country. This implies that a global production account with internal consistency requires an agreed upon method to resolve discrepancies in the measurement of trade flows.

Figure 1 gives an example of a partially extended use table for a single country. Each row of the table corresponds to a commodity used in production, and each of these is subdivided into the country of origin. The allocation of intermediate uses by country is important for two reasons. First it allows one to tabulate the contribution of imports by country to growth at the industry level, and second allows for the possibility that import prices may differ by country.[14]

Before implementation issues are covered, it is worth noting that the extended KLEMS accounts do not necessarily require extended supply, use, and input-output accounts for every country in the world economy. Missing countries can be grouped together in a Rest of World (ROW) sector. Obviously, for countries that are grouped in the ROW sector, country-level contributions at the industry level cannot be separately identified.

It may be of interest to split the capital services into service flows by original sourcing country. The basic idea would be to track the country origins of investment spending and trace this through to the purchasing industry. In this setup, the investment good is sourced from another country, but the capital services it generates are a component of domestic value added. This is potentially relevant for addressing questions such as the contribution of intellectual property produced in the United States and purchased in China, for example.

Conceptually, trade in investment

13 Currently published statistics do not include information on industry of origin and country-industry-destination. Administrative data in the United States may include some information on this (in particular, industry of origin and country of destination), but because trade often flows through the wholesale sector, this is difficult to measure directly.

14 Under the assumption that import prices do not differ by country, the use of commodities by country could be collapsed but with this one would lose the capability of tracking the importance of a country's role in global trade.

15 Kuroda and Nomura (2004) discuss this basic idea in an application to Japan.

Figure 1: Extended Use Table

Extended Use Table						C	I	G	X				M
	Country c:	Industry 1	Industry 2	....	Industry J				Country 1	Country 2	....	Country N	
Commodity 1	Country 1	V_{X11t11}	V_{X12t11}	....	V_{X12t11}	V_{C1t1t}	V_{I1t1t}	V_{G1t1t}	V_{E1t11}	V_{E1t12}	...	V_{E1t1N}	V_{M1t11}
	Country 2	V_{X11t12}	V_{X12t12}	....	V_{X12t12}								V_{M1t12}
	⋮	⋮	⋮	⋮	⋮								⋮
	Country N	V_{X11t1N}	V_{X12t1N}	....	V_{X12t1N}								V_{M1t1N}
Commodity 2	Country 1	V_{X21t1N}	V_{X22t1N}	....	V_{X22t1N}	V_{C2t1t}	V_{I2t1t}	V_{G2t1t}	V_{E2t11}	V_{E2t11}	...	V_{E2t1N}	V_{M2t11}
	Country 2	V_{X21t12}	V_{X22t12}	....	V_{X22t12}								V_{M2t12}
	⋮	⋮	⋮	⋮	⋮								⋮
	Country N	V_{X21t1N}	V_{X22t1N}	....	V_{X22t1N}								V_{M2t1N}
Commodity I	Country 1	V_{XI1t1N}	V_{XI2t1N}	....	V_{XI2t1N}	V_{CIt1t}	V_{IIt1t}	V_{GIt1t}	V_{EIt11}	V_{EIt12}	...	V_{EIt1N}	V_{MIt11}
	Country 2	V_{XI1t12}	V_{XI2t12}	....	V_{XI2t12}								V_{MIt12}
	⋮	⋮	⋮	⋮	⋮								⋮
	Country N	V_{X21t1N}	V_{X22t1N}	....	V_{X22t1N}								V_{MIt1N}
VA	Capital Asset 1	V_{K11t1}	V_{K12t1}	....	V_{K12t1}								
VA	Capital Asset 2	V_{K21t1}	V_{K22t1}	....	V_{K22t1}								
VA	⋮	⋮	⋮	⋮	⋮								
VA	Capital Asset I	V_{KI1t1}	V_{KI2t1}	....	V_{KI2t1}								
VA	Labor Type 1	V_{L11t1}	V_{L12t1}	....	V_{L12t1}								
VA	Labor Type 2	V_{L21t1}	V_{L22t1}	....	V_{L22t1}								
VA	⋮	⋮	⋮	⋮	⋮								
VA	Labor Type I	V_{LI1t1}	V_{LI2t1}	....	V_{LI2t1}								
VA	Taxes on Production and Imports	$V_{T#1t1}$	$V_{T#2t1}$	....	$V_{T#2t1}$								
				....									
	Gross Output	$V_{Y#1t1}$	$V_{Y#2t1}$	....	$V_{Y#2t1}$								

Source: Authors' construction.

goods is trade in current and future capital services.[15] For example, if country B relies on capital originally produced in country A, analyzing changes in world demand requires taking into account that the investment good may only be produced in a single country.

The framework described above assumes that the pertinent economic transactions across borders are captured in a way that is consistent with the production arrangements that are of interest. But, it is widely recognized that global production arrangements are difficult to measure. A conceptual framework for measuring global production is described in United Nations (2015). This article does not go into detail on the conceptual and practical issues involved in measuring production arrangements, such as contract manufacturing that spans borders.

Combining a time series of extended country-level supply, use, and input-output tables with the price deflators for each cell of the tables, including the primary inputs, produces a global industry level production account. The production account includes output and inputs in current and constant prices.

Constructing the input quantity index that forms the basis of TFP measurement requires aggregating over heterogeneous input quantities. This aggregation is analogous to aggregating over heterogeneous components of final demand on the expenditure side of GDP calculations. Implementation issues surrounding price measurement and aggregation over inputs are covered in the implementation section below. One noteworthy issue is that the production account is constructed from the perspective of the producer so that the value of output should be valued at basic prices while the inputs used are valued a purchaser prices.[16]

The global production account described so far (in national currency units) expands the growth accounting to trace the role of inputs to its sources across countries. Within the basic framework, industry output growth occurs as a function of accumulating additional capital, labour, and intermediate inputs, and via the growth in total factor productivity.

With the global country-level industry production account, the contribution of imports by individual country is separately identifiable. The benefit of this additional level of accounting is that it traces the role of individual countries in the production process of individual industries. Examples of questions that this account can address include: what is the contribution of primary metal production in a specific foreign country to production of machinery in the home country. By aggregating contributions across commodities imported from a given country, the home country global country-level KLEMS account measures the total contribution of a foreign country to industry or aggregate production in the home country. Recent examples of work related to these questions are Timmer (2017) and Gu and Yan (2016).

In summary, the global production account deflated with local (conceptually appropriate price indexes) provides additional detail on the contribution of imported inputs from individual countries. But this account in national currency units fails to address many issues related to global production, such as country contributions to world production, price competitiveness, comparative advantage, and labour, capital and TFP level comparisons. For example, the country-level account in national currency units can describe the growth rate of industry TFP, but cannot identify the relative position of two countries TFP levels. Addressing these requires a World Production Account adjusted for purchasing power parities.

A world production account requires prices adjusted for purchasing

16 For example, sales taxes are excluded from the value of production, but property taxes are included as a cost of employing capital input. See for example, Jorgenson and Landefeld (2006).

power parities to deflate inputs and outputs at the industry level. The intuition is that comparisons of production across countries require that the outputs and inputs in production be in consistent units. For example, the production of cars in Japan in Yen and cars in Germany in Euros cannot simply be added together to create the total real production of cars in the two countries.

While there is considerable work on expenditure side PPPs, and exchanges rates are readily available, these are not appropriate conceptually for industry-level comparisons. Exchange rates capture the relative price of each country's currency, but even after conversion using nominal exchange rates, price gaps for individual products exist and these price gaps reflect the relative costs of production in each country. This leads to the use of PPPs to make comparisons across countries.

The basics on the construction of PPPs is given in the OECD and Eurostat manuals. The World Bank International Comparison Program produces PPPs for most countries (World Bank, 2005). Expenditure side PPPs capture the relative price differences for final demand, but there is not a one-to-one correspondence between these prices and industry-level output price relatives. For example, the final price of fruit consumed in the United States is a bundle of fruit produced in the United States and imported fruit and includes the retail margin. It is the production price that is necessary to compare price competitiveness of fruit production on world markets. As another example, automobile parts could be produced by the fabricated metals industry, the electrical equipment industry, the miscellaneous manufacturing industry, the plastics industry or others, so a single expenditure side PPP for auto parts bundles the prices of the auto parts produced by different industries (and the margin).

We do not go into detail about the construction of the PPPs for outputs and inputs, but this is a critical component of the World Production Account because industry price competitiveness measures require industry-specific output price relatives and productivity measures require information on real outputs and inputs. One approach, used by Nomura, Miyagawa, and Samuels (2018) is to build a system of accounting relationships that determine the PPPs for each cell of the input-output table given a subset of information on price relatives. The anchor of their PPP measurement system is an internally consistent bilateral input output table covering the United States and Japan. Thus, an extension of this approach to determine world economy PPPs would require a similar set of tables for the world economy. Given the significant progress of initiatives like the World Input Output Database, GTAP, and OECD-WTO, one would think that this is a surmountable obstacle.

The key intuition for the need of a global input output system is that 1) the global accounting ensures consistency in measures of interest (for example, the contribution of a country's exports to countries that use these imported intermediate inputs are consistent), and 2) in cases where there are missing data, global accounting relationships can be used to infer unavailable data.[17] A simple case is when import prices for a country are unavailable, but export prices from its main trading partners are available; the export prices could be used to infer the unmeasured import prices.

For a relatively small set of products like agricultural and mining commodities, unit prices can be used to determine output PPPs directly.[18] But for most products a price accounting model, like that in Nomura, Miyagawa, and Samuels (2018) must be used to determine conceptually appropriate PPPs for each cell of the IO table. Using unit prices more broadly not only would result in the well-known unit value bias, but conceptually appropriate price relatives are generally unavailable in the data.[19]

In the majority of cases, the price model works by transforming PPPs for final demand published by the International Comparisons Program (ICP) at the World Bank to product level prices, which are then aggregated to industry output price relatives using weights from the bilateral input-output table. To give a stylized sense for how the model works: given a data point on a purchase price relative from the ICP, the accounting model strips off trade margins, import prices, and any relevant taxes paid in Japan and the United States from the purchase price to construct a domestic output price relative.

Importantly, not all PPPs can be derived using information on final purchase prices because not all products are sold to final demand. Semiconductors are an important example of a product that is not sold to final demand. In cases like these, Nomura, Miyagawa, and Samuels (2018) rely on a unique dataset produced by METI (2012) that gives information

17 An example here is the work of Nomura, Miyagawa, and Samuels (2018) where import prices from China are used to infer unavailable industry output price relatives in the United States and Japan.

18 Inklaar and Timmer (2014) also have an approach for linking industry output and expenditure PPPs.

19 See Diewert and von der Lippe (2010) for a basic discussion on the issues related to unit value bias.

on purchase price relatives for intermediate uses. Similar to the price data on final demand, the price accounting model transforms these purchase prices for intermediates to domestic output prices. The detailed PPPs are matched to KLEMS Use tables to construct PPPs for industry outputs and intermediate inputs by aggregating over detailed PPPs while maintaining the appropriate price concepts. For example, PPPs for intermediate inputs reflect prices of domestic production, but also the prices of imported intermediate inputs; domestic output price PPPs must split out the intermediate price component.

PPPs for capital and labour are required as well. For labour PPPs, details on rates of labour compensation cross classified by each type of worker in the production account form the basis of the PPP. For capital PPPs, relative prices of investment goods are converted to relative services prices using the user cost of capital annualization factor. Relevant work on this is described in Jorgenson, Nomura, and Samuels (2016). Once PPPs for the base year are assembled, these can be extrapolated backwards and forwards over time using the country-level price deflators that underlie the industry-level production account at the country level.[20]

Applications of the World Production Account

This section discusses some of the applications that are feasible after assembling the World Production account data described above. The applications include measures of price competitiveness at the industry level, industry-level TFP level comparisons, and industry, country, and regional contributions to world economic growth.[21] The world production account also permits global value chain (GVC) analysis, like that of Timmer, Erumbam, Los, Stehrer, and de Vries (2014) and Timmer (2017), but with real measures of global trade and production in addition to the nominal measures that are more typically employed in GVC analysis. With the global production account, one could trace the impact of total factor productivity to downstream industries across the world economy.

20 In practice, relying on a singe benchmark PPP can open up room for errors that compound over time because benchmark PPPs take into account a combination of weights across countries while national deflators use only national weights. We thank the referees for the suggestion to highlight this point.

21 The examples discussed here mostly focus on bilateral comparisons. If a single country is chosen as a numeraire for a Global Production account, this is generalizable in terms of comparisons to the reference country. Multilateral comparisons, however, bring rise to well-known index number issues. See Inklaar and Diewert (2016) for a discussion of TFP level comparisons in a multilateral context.

For example, one could examine the impact of improvements in chip processing total factor productivity in China to the computer industry in Japan. Analysis of production chains hinges on consistent information on world production with a complete accounting of sources across countries.

Industry-level Comparisons of Price Competitiveness

The World Production Account as described includes a time series of industry gross output, constant quality industry output prices, and base-year PPPs for industry output. By extracting this information for two countries and combining it with information on the nominal exchange rate for the two countries, it is straight forward to produce industry-level comparisons of price competitiveness. In the base year, the PPP divided by the exchange rate yields the price level index (PLI). If the price level index is above 1.0, the output of that country is relatively expensive in comparison on international markets. The price level index in the base year can then be extrapolated backwards and forwards in time using time series observations of the industry output prices in local currency units and the exchange rate to form a time series of PLI for industry output. Nomura, Miyagawa, and Samuels (2018) includes a PPP level comparison between the Japan and the United States in 2011. Their results show that the prices of agricultural production are significantly higher in Japan, as are the prices of wholesale and retail services and utilities (relative to the nominal exchange rate of 79.8 Yen/$ in 2011), while the prices for miscellaneous manufacturing products are often lower in Japan.

Comparisons of industry output price competitiveness embed the competitiveness of prices of goods that are used as intermediate inputs. In recognition of this, Jorgenson, Nomura, and Samuels (2016) focus on price level comparisons for industry value added, which by construction aggregate to GDP-level price differences.[22] Jorgenson, Nomura, and Samuels (2016) present price level indices for value added by industry comparing Japan and the United States. These results demonstrate that at the exchange rate of 2005, the trade industries in Japan were the largest contributors to the overall price gap between Japan and the United States while the motor vehicles and medical care industries had the largest dampening effects on the overall price gap.

22 These are built off the Nomura and Miyagawa (2015) PPP system.

Industry-level TFP Level Comparisons

To examine how the global KLEMS account can be used to compare TFP levels across countries, it is useful to reorganize the country level supply, use, and input-output tables into a bilateral table that aligns the outputs and inputs of the two countries being compared. Figure 2 shows such a reorganized table. Using this reorganized table and the PPPs for the two countries from the World Production Account, it is possible to construct the relative TFP level between any two countries. Jorgenson, Nomura, and Samuels (2016) describe the detailed steps in making TFP level comparisons. The basic steps are:

- Define the PPP for each elemental item.
- Define the price level index for each cell as the ratio of the PPP to the nominal exchange rate.
- Define the volume measure for each component cell as the ratio of the nominal value in local currency units divided by the price level in national currency units; for example, the nominal value in dollars divided by the price per unit in dollars and the nominal value in Yen divided by the price per unit in yen. Note that this is not the price indexed to one in the base year; this is the actual nominal price level per unit.
- Define the volume level index for each cell of the input-output table and each component of primary inputs as the as the ratio of the volume measure in one country relative to the other.
- Define industry-level volume level indexes by constructing a tornqvist aggregates of volumes across elemental items, using the average share in each country as weights.
- The TFP level index is defined as the volume level index for output divided by the volume level index for inputs.

Jorgenson, Nomura, and Samuels (2016) find that industries in Japan that are insulated from international competition like wholesale and retail trade are TFP laggards. Results of this nature reinforce the importance of TFP level comparisons constructed within the framework of an industry-level production account.

Industry Contributions to World Economic Growth

A major motivation for the World Production account is that it enables a consistent comparison of the contributions of individual industries, countries, and regions to world economic growth. (Jorgenson and Vu, 2013)

Figure 2: Extended Input-Output Table Reorganized for Industry TFP Level Comparison

		Country 1 Industry 1	Country 2 Industry 1	Country 1 Industry 2	Country 2 Industry 2	....	Country 1 Industry J	Country 2 Industry J
Commodity 1	Country 1	V_{X11t11}	V_{X11t21}	V_{X12t11}	V_{X12t21}	....	V_{X12t11}	V_{X12t21}
	Country 2	V_{X11t12}	V_{X11t22}	V_{X12t12}	V_{X12t22}	....	V_{X12t12}	V_{X12t22}
	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
	Country N	V_{X11t1N}	V_{X11t2N}	V_{X12t1N}	V_{X12t2N}	....	V_{X12t1N}	V_{X12t2N}
Commodity 2	Country 1	V_{X21t1N}	V_{X21t2N}	V_{X22t1N}	V_{X22t1N}	....	V_{X22t1N}	V_{X22t2N}
	Country 2	V_{X21t12}	V_{X21t22}	V_{X22t12}	V_{X22t22}	....	V_{X22t12}	V_{X22t22}
	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
	Country N	V_{X21t1N}	V_{X21t2N}	V_{X22t1N}	V_{X22t2N}	....	V_{X22t1N}	V_{X22t2N}
Commodity I	Country 1	V_{XI1t1N}	V_{XI1t2N}	V_{XI2t1N}	V_{XI2t2N}	....	V_{XI2t1N}	V_{XI2t2N}
	Country 2	V_{XI1t12}	V_{XI1t22}	V_{XI2t12}	V_{XI2t22}	....	V_{XI2t12}	V_{XI2t22}
	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
	Country N	V_{X21t1N}	V_{X21t2N}	V_{X22t1N}	V_{X22t2N}	....	V_{X22t1N}	V_{X22t2N}
VA	Capital Asset 1	V_{K11t1}	V_{K11t2}	V_{K12t1}	V_{K1221}	....	V_{K12t1}	V_{K12t2}
VA	Capital Asset 2	V_{K21t1}	V_{K21t2}	V_{K22t1}	V_{K22t2}	....	V_{K22t1}	V_{K22t2}
VA	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
VA	Capital Asset I	V_{KI1t1}	V_{KI1t2}	V_{KI2t1}	V_{KI2t2}	....	V_{KI2t1}	V_{KI2t2}
VA	Labor Type 1	V_{L11t1}	V_{L11t2}	V_{L12t1}	V_{L12t2}	....	V_{L12t1}	V_{L12t2}
VA	Labor Type 2	V_{L21t1}	V_{L21t2}	V_{L22t1}	V_{L22t2}	....	V_{L22t1}	V_{L22t2}
VA	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
VA	Labor Type I	V_{LI1t1}	V_{LI1t2}	V_{LI2t1}	V_{LI2t2}	....	V_{LI2t1}	V_{LI2t2}
VA	Taxes on Production and Imports	$V_{T\#1t1}$	$V_{T\#1t2}$	$V_{T\#2t1}$	$V_{T\#2t2}$	....	$V_{T\#2t1}$	$V_{T\#2t2}$
						....		
	Gross Output	$V_{Y\#1t1}$	$V_{Y\#1t2}$	$V_{Y\#2t1}$	$V_{Y\#2t2}$	....	$V_{Y\#2t1}$	$V_{Y\#2t2}$

Source: Input-Output Table for Industry TFP Level Comparison

provide the foundation for this.[23]

Constructing industry contributions to world GDP requires defining World GDP growth. This necessarily involves weighting the GDP, i.e. aggregate value added growth rates of each country by its share in the world economy. Because these weights compare GDP (or industry) output across countries, they must be adjusted for purchasing power parities.

The basic steps are:

- Convert nominal output, input, and value added in the base year to the common currency via the PPPs in the base year.
- Extrapolate these using the corresponding series indexes in national currency units.
- World GDP growth is then the Tornqvist index over industry value added growth rates, each

23 The approach to aggregating across countries to define world production (and contributions to world production) is still an active area of research. Feenstra, Inklaar, and Timmer (2015) use interpolated PPPs to aggregate across countries, while Diewert and Fox (2014) present an approach that produces "harmonized" estimates that account for PPP differences over time and country-level growth and inflation rates. Thus, the final approach to a world production account will need to address these different approaches. Like other areas of implementing economic accounts, open areas of research should not be an impediment to producing statistics that incorporate reasonable and defensible practices.

weighted by its share of nominal (PPP adjusted) world GDP.

- The contribution of an individual country is its share times its growth rate.

Sources of World Economic Growth

A fundamental reason for constructing an integrated world production account in current and constant prices is to understand the sources of economic growth via the lens of the growth accounting model. The growth accounting models posits that world economic growth is a function of the growth of capital, labour, and TFP growth across countries. The Conference Board Total Economy database constructs estimates of the sources of growth across countries at the world level under the assumption of a common PPP for outputs and inputs, while Nomura (2017) demonstrates a sources of growth method that incorporates PPPs for inputs as well as outputs. Both of these approaches are possible under the global production account described above, with the important benefit that the global industry account yields industry level contributions to growth.[24]

Implementation

The basic framework described above does not address many of the practical and implementation issues that are involved in constructing the global integrated industry level production account. This section lays out some of the issues that need to be resolved before such an account can be made fully consistent.

Implementation Basics

A fundamental requirement is a common classification scheme. Industries and commodities must be classified in a common way to match up comparable production processes. The primary inputs (capital by asset and labour by demographic group) in the value added row should be classified on the same scheme across countries. This is necessary for the construction of the purchasing power parities. That is, the underlying assumption of the framework is that at the level in which the prices of outputs and inputs are being used to construct the PPPs, the object being compared is homogenous.

The global production account requires a world input-output account. One example of this is the approach described in Dietzenbacher,

24 This discussion abstracts from reallocation effects which typically arise when imposing assumptions underlying the model of production. See Samuels (2017) for a discussion of reallocation effects across countries.

Los, Stehrer, Timmer, and De Vries (2013), termed WIOD (the World Input-Output Database). In addition to describing the basic framework, the article also covers the implementation choices that were made to integrate available data. This could serve as a model for the nominal industry outputs and intermediate inputs that are required to assemble the global production account. It is important to note a key feature that would also be required in the global industry-level production account proposed in this article: an International Trade Account of imports and exports by end use and origin-destination industry that is consistent across countries.[25] It is necessary to ensure that these goods and services are consistently classified and estimated across countries and purchaser categories.

For instance, it is often difficult to determine to which industry or final demand traded goods and services flow to. This has led to assumptions such as the import proportionality assumption, or a modified version of this that brings in information on broad economic classification of traded goods. Because information of this nature is required to estimate national level supply-use tables, this should not be a stumbling block for estimating the global industry-level production account, though a consensus on which method to use would be preferable.

One implementation choice made by WIOD is to convert data reported and constructed in national currency units to a common currency unit by using exchanges rates. Because relative prices for industry outputs and inputs differ across countries, using purchasing power parities for industry outputs and inputs is an important distinguishing characteristic between WIOD and the global production account discussed here.

A fundamental assumption of the accounts is that prices are in constant quality units. Therefore, in cases where this assumption is suspect, decisions would have to be made to bring prices available at the country level into harmonization with the rest of the world. The Conference Board TED database discusses this, and based on earlier research harmonizes certain (IT) prices across countries.

Given limited data on countries throughout the world, the prospects for constructing an input-output table with respective price indexes and PPPs are uncertain. Therefore, an important step in formulating an ac-

25 Reconciling trade flows across countries is not trivial, and is currently an area of active research. But, WIOD has implemented one approach to this, which suggests that this is not an insurmountable problem.

tion plan for implementing the global integrated production account should consider ways to reduce the data needs. One approach to this is to impose assumptions that restrict the data requirements, such as all industries in a country pay the same price for a commodity. Or that imports from a country across industries are used proportionally across industries (the import comparability assumption.) These assumptions are similar in nature to procedures currently used to assemble official input-output tables, so should not be seen as a new impediment to producing these types of statistics so long as the assumptions are transparent.

For labour input, the classification of workers across categories imposes the assumption that an hour worked by the same category of workers is of the same quality over time. Thus, once this classification is set, the index of labour input is in constant quality units by assumption. For capital inputs, investment prices must be translated into the annual user cost of capital. This formulation requires estimates of industry rates or return, depreciation, asset capital gains, and constant quality investment prices. Choices would need to be made about depreciation rates across countries and on how to calculate the rate of return.

In terms of coverage, decisions would need to be made about which countries are in the World Account and which are either grouped in a ROW classification.

A major hurdle to assembling the world account in comparable units is PPPs for outputs and inputs at the country level for all the economies to be included in the account. Nomura, Miyagawa, and Samuels (2018) implement this with extensive data on price relatives between the United States and Japan, but significant attention and perhaps resources would be needed to design a system that is capable of constructing similar PPPs for other countries at the industry level. The applications described above require a choice of the base year for the PPPs and TFP level estimates are not invariant to this choice.[26]

Labour

The point of departure for measuring labour input in the KLEMS accounts is the recognition that not all worker hours are equivalent. One important dimension that workers differ (and is relatively easy to measure) is their educational attainment.

Research on industry TFP typically

26 As noted above, this is because weights used in PPP and the national deflators will differ. The ICP handbook provides details. See World Bank (2005).

cross-classifies workers and worker hours by industry, gender, class (employee versus self-employed), age, and education. The EUKLEMS project has a minimum classification policy of three skill groups (corresponding to education), three age groups (corresponding to experience), with each cross classified by gender and industry. Jorgenson, Ho, and Samuels (2019) employs a much finer set of characteristics to classify labour by industry. Arriving at a common classification across countries for labour hours that accounts for worker heterogeneity is an important component of constructing an integrated world production account because this ensures that worker quality is kept constant in country comparisons.

Capital

The point of departure for measuring capital input in the KLEMS accounts is the concept of capital services. The OECD productivity manual covers issues involved in measuring capital services.

Other Practical Issues

The PPP model in Nomura, Miyagawa, and Samuels (2018) relies on a commodity by commodity table. In constructing such a table, choices need to be made about non-comparable imports, and scrap, and translation between industry-commodity, industry-industry, and commodity-commodity tables.

As noted above, a consistent account will require a reconciliation or balancing of inconsistent flows. That is, trade flows will need to be reconciled, or balanced away to form an internally consistent account. Who will do this balancing and what choices will be made to do so? As noted above, the WIOD program and OECD Regional-Global TiVA Initiatives have circumvented this issue, and these serve as proof of concept for tractable approaches to reconciling trade statistics.

It is worth noting that while the account described in this article would be a tremendous leap from currently available accounts, the formulation does not address some very fundamental questions about productivity in the global economy. First, an underlying assumption is that at the implementation level (industry, commodity, capital by asset, labour by type of worker) output and inputs are homogeneous. In the case of United States and Japan, for example, it is easier to defend the assumption that the medical equipment commodity produced in Japan is similar to that produced in the United States, and that workers of age 45-54 with a Master's degrees have similar productivities. But this becomes more difficult in comparisons to other countries.

Classification issues and choices are made throughout national accounts. Similar choices need not be an impassable roadblock for constructing a global production account. Nevertheless, when interpreting these statistics it is important to keep these issues in mind; for example, the U.S. electronics industry could be engaging in different activity than the electronics industry in Vietnam.

Finally, one still cannot specifically identify and compare production arrangements, like Apple for example, that are spread across multiple establishments and countries with design taking place in one place, and production in another, resulting in important shipments (possibly unpriced) of intangible assets across borders. This production process is counted in the framework described in this article. However, it is not separately identifiable. Chen, Los, and Timmer (2018) do provide a method to identify the role of intangibles in value chains by backing out their contribution as a residual.

Implementation Summary

This section has described the basic implementation issues surrounding the proposed World Production Account. It is clear that many issues, choices, and compromises would accompany building such an account. The cleanest prototype in terms of matches between conceptual framework and data is the PPP work in Nomura, Miyagawa, and Samuels (2018) and industry level comparisons in Jorgenson, Nomura, and Samuels (2016) for the two country case (United States and Japan). One path forward is to build similar source datasets for other countries. This includes bilateral input-output tables and price surveys like those conducted by METI (2012). Obviously, bilateral tables would need to be extended to cover world trading partners (like the work done in WIOD and others) and price surveys would need to cover price differences across all countries in the world economy. To this end, it would be ideal to build partnerships across statistical agencies and the academic community. One model for building relevant data is the APEC-TiVA initiative which is a public-private partnership that has taken on the issue of measuring trade in value added.[27]

Extensions

The purpose of this article has been to introduce the basic framework required to implement a world production account at the industry level, yielding a global integrated pro-

27 See http://www.apectivagvc.org/.

duction account. The account provides the foundation for comparisons of industry-level price competitiveness, TFP-level comparisons, country and industry level contributions to world economic growth, and global production chain analysis. The World KLEMS and EUKLEMS initiatives have provided a basic proof of concept for implementing country level growth accounts. The global integrated industry-level production (KLEMS) account involves formulating an integrated set of world input-output tables in current prices and constant prices adjusted for purchasing power parities.

We have provided the basic formulations to implement the world production account. But there are potential extensions that are worth noting. A first possible extension is to build into the production account a method to assess the importance of input reallocation in economic growth. In Jorgenson, Ho, and Samuels (2019) the reallocation effect manifests as the difference between aggregate TFP growth and industry TFP growth. This is relatively small in the United States, but potentially of interest for other countries. We have not addressed how to measure reallocation in the context of the world production account.

Finally, the formulation of the world production account has assumed that, within industries, the production process of globally engaged establishments and establishments that are not globally engaged is the same. Recent work by Fetzer and Strassner (2015) suggests that it may be important to disentangle globally engaged firms in the input-output tables. One particular motivation for that work is to refine estimates of trade in value added (TiVA). If the statistical community considers this an important dimension for TiVA estimates (and the corresponding supply, use, and input-output tables on which they are based), this same classification could be incorporated into the world extended production (KLEMS) accounts presented in this article.

One way to think about this extension is that it would require a new classification into globally-engaged establishments and other establishments for all of the components of the global production account. The OECD Expert Group on Extended Supply-Use Tables has addressed this issue as well (OECD 2015), but results from the World KLEMS initiative demonstrate the importance of growth accounting using currently available supply-use tables.[28] This in-

28 See https://www.oecd.org/sti/ind/tiva/eSUTs_TOR.pdf.

dicates that next steps on the global production account could make use of the existing input-output structures and data without having to build new supply use-tables from the ground up.

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