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The Comparative Advantage of Nations: How Global Supply Chains Change Our Understanding of Comparative Advantage

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The Comparative Advantage of Nations[1]:

How Global Supply Chains Change Our Understanding of Comparative Advantage

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[1] Title credit to Michael Porter's 1990 book, *The Competitive Advantage of Nations.*

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Abstract

As global supply chains proliferate and countries use more intermediate imports to produce exports, gross export statistics paint an increasingly misleading picture of comparative advantage. This paper uses the newly available World Input Output Database to decompose gross exports into domestic value-added and imported intermediate components in order to demonstrate that value-added measures of trade provide a better understanding of comparative advantage from the perspective of trade in tasks and by industry. Focusing on the United States, Japan, South Korea, Taiwan, China, and Mexico, this paper makes three main contributions. First, it finds that while the advanced economies continue to dominate tasks at the upstream of supply chains and the emerging economies remain prominent in downstream tasks like assembly, participation in global supply chains has been dynamic over time. In particular, from 1995-2009, Taiwan experienced a dramatic shift from contributing value-added in final goods to focusing on value-added in intermediates, taking on an important role in the middle of supply chains. China and Mexico are also beginning to transition upstream within global production chains as they contribute more value-added in intermediates. Second, focusing on the electronics industry, this paper finds that long-term trends in comparative advantage can diverge significantly when trade is understood in terms of domestic value-added in exports instead of gross exports. Notably, while gross trade statistics tell a sobering story of the decline of US competitiveness in the electronics industry, value-added trade statistics reveal the continued robustness of the United States' comparative advantage in electronics manufacturing. Third, using the value-added approach, this paper finds that contrary to popular fears, rather than losing comparative advantage in advanced manufacturing, the United States' comparative advantage is growing most robustly in the highest technology manufacturing industries.

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1 Introduction

1.1 Motivation

The iPhone, while designed by Apple in California, is not "made in the USA." Instead, the iPhone's production exemplifies the complexity of a globally fragmented supply chain. The iPhone's components, including the flash memory, the DRAM, and the applications processor, are sourced from various suppliers like Samsung of Korea and AKM Semiconductor of Japan, and the phone itself is assembled by a Taiwanese firm called Foxconn in a plant in Shenzhen, China, before it is exported from China to the rest of the world ("Slicing an Apple," *The Economist*, 2011).

Does China have a comparative advantage in iPhones because it exports iPhones? Official trade statistics demonstrate that China has an unusually sophisticated export basket for its per-capita income level—a basket that includes iPhones, of course (Rodrik 2006, 4). Anyone who understands the iPhone supply chain, however, can tell you that China has a comparative advantage in the *assembly* of iPhones. Just because a country is the final exporter of a good does not mean that it is responsible for the majority of that good's production. Global supply chains change our understanding of comparative advantage because we can no longer look at official gross export statistics to see who produces goods for whom. Because of the global fragmentation of supply chains, we must isolate how much value-added a nation contributes to the production of a good in order to illuminate the true comparative advantage of nations.

Misguided perceptions of competitiveness based on gross trade statistics affect the political debate by contributing to calls for protectionist trade policies which hurt consumers, jobs, and the economy. The goal of this paper is to help policymakers derive reliable interpretations of comparative advantage from official trade statistics so that they can implement better trade and macroeconomic policies. Although previous research has provided insight into how global supply chains work and the potential of gross trade statistics to mislead, these analyses have been snapshots of an individual product or economy in a single year. These snapshot analyses cannot answer the question that policymakers and the public care about: how has comparative advantage changed over time? Moreover, how do trends in comparative advantage in the US compare to those in other economies like Japan, South Korea, China, and Mexico? These questions can be addressed for the first time in the literature with the World Input Output Database (WIOD), newly released in April 2012. The WIOD is the first database to provide a methodologically consistent annual time series of world input-output tables to describe global value chains over an extended 15-year period for 35 industries and a range of countries.

Using the WIOD and the value-added approach to trade, this paper makes three main contributions to the literature. First, focusing on the United States, Japan, South Korea, Taiwan, China, and Mexico, I quantify the extent to which each country's participation in global supply chains is relatively upstream or downstream during the 1995-2009 timeframe and document for the first time in the literature how such participation in global supply chains has evolved over time. In particular, I focus on how the roles of newly industrialized and emerging economies have changed as the quality of domestic input suppliers increases and multinationals move more of their upstream production into these countries. Second, focusing on the electronics industry, I demonstrate for the first time in the literature how long-term trends in comparative advantage can diverge significantly when trade is understood in terms of domestic value-added in exports as opposed to gross exports. Third, I illustrate how the value-added approach also provides a new understanding of how comparative advantage has evolved over time for the United States, by manufacturing industry.

1.2 Overview

As China's assembly of iPhones illustrates, trade today is as much about "trade in tasks" as it is about "trade in goods." Trade today often occurs *within* products, where *for a single product*, the US specializes in design, Korea specializes in intermediate components, and China specializes in assembly, for example. Thus, quantifying the extent to which a country's participation in global supply chains is relatively upstream or downstream—more focused on upstream intermediate inputs or downstream assembly, for instance—is part of understanding a country's comparative advantage. The first part of this paper describes the relatively upstream or downstream positions of the United States, Japan, South Korea, Taiwan, China, and Mexico within global supply chains, and evaluates how these positions have evolved from 1995-2009. These economies that are highly integrated into global supply chains provide perspective on how developed, newly industrialized, and emerging economies participate in global supply chains.

Second, this paper utilizes domestic value-added in exports to re-compute revealed comparative advantage (RCA) in the electronics industry for the United States, Japan, Korea, Taiwan, China, and Mexico. The goal is to emphasize how the value-added approach to trade provides a more accurate understanding of comparative advantage in industries where the fragmentation of production is pervasive. Quantifying revealed comparative advantage based on domestic value-added in a country's exports as opposed to gross exports corrects for the distortions of imported intermediates in gross trade to provide a clarified understanding of the characteristics of a nation's production (Koopman et. al. 2012, 47). This paper contributes significantly to the literature by describing how long-term trends in the evolution of comparative advantage differ between the gross and value-added approaches to trade.

This paper demonstrates that task-wise, the US and Japan still dominate at the upstream of global supply chains, providing evidence that developed countries continue to carry out sophisticated tasks like design and the production of intermediate inputs. Emerging markets like China and Mexico on the other hand, tend to be relatively downstream, still focused on assembly to some degree. Meanwhile, the Asian Newly Industrialized Countries (NICs) have an important role in the middle of production chains, focused on importing and exporting intermediates. With the availability of an extended time period of world input-output data, I also illustrate the dynamic nature of global supply chains over time. I find that Taiwan in particular has shifted its focus from contributing value-added in final goods to contributing value-added in intermediates. Additionally, I find that emerging economies are also beginning to transition upstream within global production chains as they begin to produce and export more intermediates.

Focusing on the electronics industry, this paper highlights important differences between revealed comparative advantage (RCA) calculated using gross and value-added measures. Notably, within the electronics industry, the trend between gross and value-added RCA diverges significantly for the US: while gross trade statistics tell a sobering story of the decline of US competitiveness in the electronics industry, value-added trade statistics reveal the rising robustness of the United States' comparative advantage in electronics manufacturing. Additionally, as expected, relatively downstream economies like China appear less competitive in the electronics industry using value-added measures of comparative advantage, whereas relatively upstream nations like the US and Japan appear more competitive. Finally, focusing on the US, I demonstrate that from the value-added perspective, rather than losing comparative advantage in advanced manufacturing as commonly feared, the United States' comparative advantage is growing most robustly in high technology manufacturing industries.

Clearly, this paper provides strong support for the use of value-added measures of trade in order to obtain an accurate picture of the comparative advantage of nations in today's globalized economy. In an era in which fears of losing competitiveness have reached new highs in the US for example, the value-added approach to trade presents a healthy antidote to protectionist arguments. Value-added measures of trade demonstrate that far from losing competitiveness in advanced manufacturing industries like electronics, the US continues to have a robust and growing comparative advantage in these industries. The dramatic difference in trend for the US between analyzing comparative advantage using the value-added and gross trade approaches emphasizes the importance of helping policymakers interpret official trade statistics correctly.

Indeed, it is critical to help policymakers draw meaningful conclusions from official trade statistics because the trade and macroeconomic policy implications of these conclusions are pervasive. For example, understanding that the United States and many other high-income countries tend to specialize in the upstream of global production chains may prevent "self-inflicted injuries" from protectionist trade policies (Wei 2012, 6). Because the United States' imports from developing countries often contain a relatively high share of its own value-added, an increase in trade barriers for an upstream country like the US tends to hurt domestic upstream firms, creating "self-inflicted injuries" (Wei 2012, 6). Beyond trade policy implications, filling the gap between gross and value-added trade can also have important implications for growth and development strategies (see Box 1).

Box 1. Application of understanding trade flows in the context of the fragmentation of production

Using a 20th century view of trade and industrialization in which a nation's production contains only its own productive factors and technology can lead to misinterpretation of the data (Baldwin 2011, 25). For example, Hausmann, Hwang, and Rodrik (2007), argue that "what you export matters," or that countries that export higher productivity (more sophisticated) goods like China, grow faster. Understanding the role each country plays in global supply chains, however, reveals that these growth implications may be misinterpreted as Baldwin highlights. In their paper, Hausmann, Hwang, and Rodrik (HHR) construct a measure of the productivity level associated with a country's export basket called EXPY. They construct this measure by first generating an associated income or productivity level of a traded good (PRODY), which is calculated as the weighted average of the per-capita GDPs of the countries exporting a product, where the weights are the RCA of each country in that product. Next, they generate EXPY by calculating the export-weighted average of the PRODY for that country. HHR find that although EXPY is highly correlated with per-capita GDP, there are interesting discrepancies. Some high-growth countries like China have EXPY levels that are much higher than what would be predicted based on their income levels. China's EXPY, for instance, exceeds those of countries in Latin America with per-capita GDP levels that are a multiple that of China (Hausmann et. al. 2007, 3). HHR also find that EXPY is a strong and robust predictor of subsequent economic growth (Hausmann et. al. 2007, 3). With the global supply chains framework in mind, the HHR framework appears problematic. In their analysis, HHR use the 20th century view of industry to link country characteristics to goods; exports of poor nations must be technology-poor. From the perspective of 21st century trade, these inferences may no longer hold. For instance, a camera made in Japan associated with a high measured productivity or sophistication can be assembled in China, making China's EXPY appear unusually high compared to that of countries with similar or higher per-capita income levels (Baldwin 2011, 26). An understanding of China's role in global supply chains will allow scholars to reexamine why certain countries export more sophisticated products than others as well as the growth implications of exports. Examining the role a country plays in global supply chains and recalculating RCA based on the value-added approach, for example, may demonstrate that measures like EXPY which associate a country's exports with its productive characteristics can be misleading. Thus, understanding what role countries play within global supply chains will lead to a clarified understanding of the 21st century industrialization process, in which joining a supply chain rather than building a supply chain is the norm (Baldwin, 2011, 28).

Clearly, the effects of analyzing global trade in terms of the fragmentation of production are significant, especially for trade policy. The remainder of this paper is organized as follows: Section 2 gives an overview of the literature on the fragmentation of global supply chains and value-added trade. Section 3 outlines guiding questions, hypotheses, and the methodology used to evaluate these hypotheses. Section 4 discusses the World Input Output Database, the source of the data used in this paper. Section 5 presents results of the aggregate trade decomposition, evaluating the positions of key countries within global supply chains and how these roles have evolved from 1995-2009. Section 6 discusses the value-added approach to revealed comparative advantage, focusing on how RCA in value-added terms differs from RCA in gross terms for the electronics industry. Section 6 also illustrates how the value-added approach to comparative advantage clarifies our understanding of the United States' comparative advantage in manufacturing industries. Section 7 concludes.

2 Literature review

The literature on global supply chains and the value-added approach to trade consists of two major strands of analysis:

1. Tracking value-added in global supply chains at the micro level via individual product case studies;
2. Tracking value-added in global supply chains at the macro level using input-output data (Wei 2012, 2).

This paper goes beyond the current literature's focus on supply chains for an individual product or a single year in order to investigate how long-term trends in comparative advantage in the US compare to trends in economies like Japan, South Korea, and China.

2.1 Tracking value-added at the micro level via individual product case studies

Case studies on global supply chains examining micro-level data for an individual product have provided intuitive examples of the difference between gross and value-added trade (Wei 2012, 2). The most well-known case study is that carried out by Dedrick, Kraemer, and Linden (2008) in which the authors investigate IT supply chains (including Apple iPod and HP and Lenovo laptop supply chains) in order to determine which companies capture the most value-added in global production chains. Regarding the iPod, Linden and colleagues confirm that Apple captures the greatest value-added on each iPod sold and that the value-added captured in China is extremely low. Indeed, Linden et. al. find that while an iPod's factory gate price is $144, Chinese value-added contributes only $4 (Linden et. al. 2008, 21). Other case studies reveal similar discrepancies between gross and value-added trade. For example, Ali-Yrkko and colleagues analyze the Nokia N95 smartphone to confirm that developed countries continue to capture the majority of value-added from the production of advanced industrials goods (Ali-Yrkko et. al 2011). By highlighting extreme examples of the fragmentation of global production, these cases studies emphasize the need to examine the discrepancy between gross and value-added trade.

Clearly, product case studies offer an intuitive understanding of how global supply chains operate and why looking at gross trade can be misleading in many areas of economic analysis, from trade imbalances to comparative advantage. Moreover, case studies excel at pinpointing where companies are located within the production chain. However, there are several drawbacks to using the case-study approach to describe how countries participate in global supply chains. First, case studies cannot provide an understanding of the scope of a country's participation in global production chains beyond a particular product. Second, case studies like the Apple iPod study only describe intermediate inputs that are directly sourced in the immediately preceding link of the supply chain (OECD & WTO 2012, 4). They do not describe where intermediate inputs used in producing the iPod's intermediate inputs were sourced, for example. Third, case studies in the literature have lacked a time series dimension, and do not focus on how the position of countries within global supply chains has evolved over time. With the availability of the World Input Output Database's interregional input-output tables from 1995-2009, this paper provides a broader understanding of trade in tasks by describing not only how countries participate in global production chains at the level of aggregate trade, but also how the organization of global production has evolved over time. Moreover, unlike the case study method, using interregional input-output tables captures not only first-round intermediate input effects, but also the value-added effect of all previous rounds of inputs.

While case studies provide concrete examples of how comparative advantage can be misconstrued using gross trade, the case study approach does not provide a method of quantifying comparative advantage beyond a particular product. Moreover, case studies do not illustrate the degree to which long-term trends in comparative advantage by industry can diverge when indicators of comparative advantage are calculated using domestic value-added in exports instead of gross exports. This study recalculates revealed comparative advantage for the electronics industry using domestic value-added in exports. By doing so, I emphasize how the value-added approach to trade provides a more accurate understanding of comparative advantage in industries where fragmentation of production is pervasive. Moreover, this paper quantifies how a country's true comparative advantage evolves over time to investigate how long-term trends in comparative advantage vary by country.

2.2 Tracking value-added at the macro level using input-output data

Tracking value-added in global supply chains at the macro level using input-output data provides a more comprehensive and methodical approach to decomposing a country's gross exports into exports of value-added and "double counted" terms such as imported foreign intermediates (Wei 2012, 2).[2] Because interregional input-output tables quantify how production in a given industry uses inputs from all other domestic and foreign industries, rather than examining only one product in a certain sector, this method describes global value chains across all sectors and takes into account not only first-round intermediate input effects, but also the value-added effect of all previous rounds of inputs.

There are two strands of literature examining the fragmentation of global supply chains using interregional input-output tables. The first strand decomposes gross exports into its value-added and double counted components in order to track the degree of vertical specialization.[3] In their seminal paper, Hummels, Ishii, and Yi (2001), referred to as HIY, define a country's participation in "vertical specialization" as: 1) the use of imported intermediate inputs in the production of exports; and 2) the export of

[2] "Double counted" terms are terms that have already been counted in a country's gross exports. Thus, if a given country exports a product containing imported components, the imported components are considered "double counted" in the country's gross exports.

[3] Vertical specialization is another term commonly used in the literature to describe the fragmentation of supply chains, or cross-border specialization among countries.

intermediate goods used as inputs by another country to produce goods for exports (Wei 2012, 2). Making use of OECD and emerging market input-output tables, HIY estimate that vertical specialization accounts for up to 30% of world exports and has grown by up to 40% in the 25 years preceding their paper (2001, 1). HIY propose that the dramatic growth in cross-border specialization is due to the fact that trade barriers are repeatedly encountered as goods cross borders multiple times, so even small decreases in tariffs and transport costs can lead to significantly more cross-border specialization (2001, 1). Although HIY created a framework for estimating domestic value-added and imported intermediate components in exports, HIY's assumption that imported intermediate inputs contain no domestic content underestimates domestic value-added in exports (Koopman et. al. 2012, 4). The framework used in this paper allows imported intermediates to contain domestic content in order to more accurately estimate domestic value-added in exports.

Following HIY, Johnson & Noguera (2012a) define a measure of the intensity of vertical specialization called the VAX ratio, equal to the ratio of value-added to gross exports. Building a global input-output framework in four sectors, 1) agriculture, hunting, forestry, and fishing, 2) non-manufacturing industrial production, 3) manufacturing, and 4) services, Johnson & Noguera show that the VAX ratio has declined over the past 40 years, with large declines among countries undergoing "structural transformation"(2012b, 1).[4] Interestingly, Johnson & Noguera find that there are two major declines in the VAX ratio, one in the 1970s, and another much greater decline in the 1990s during which vertical specialization increased dramatically (2012b, 3). Although Johnson and Noguera

[4] Johnson & Noguera build their four sector input-output table using the OECD Input-Output Database and IDE-JETRO's Asian Input-Output tables.

illustrate the dramatic manner in which vertical specialization has increased in recent decades, they focus solely on the ratio of value-added to gross exports. Without a methodology for evaluating the structure of double counted components in gross exports, Johnson and Noguera do not estimate where countries are positioned within global supply chains or how participation in vertical specialization has changed beyond the fact that it has increased. By focusing on the structure of both a country's value-added exports and double counted components, this paper demonstrates the extent to which countries participate relatively upstream or downstream in global production chains and how participation has evolved over time. Moreover, while Johnson and Noguera's four sector input-output table may be sufficient to demonstrate a broad trend in increased vertical specialization, it almost certainly underestimates cross-border specialization effects and precludes analysis by industry. The World Input Output Database's 35 industries allow this paper to use estimates of domestic value-added in individual manufacturing industries like electronics to illuminate trends in comparative advantage by industry.

Filling in where HIY and Johnson & Noguera left off, Koopman, Powers, Wang, and Wei (2010), referred to as KPWW, create a systematic framework for decomposing a country's gross exports into domestic value-added exports, domestic content that returns home, and foreign content in exports. The framework developed by KPWW estimates at which stage "double counted" terms enter into a country's export statistics. This framework makes it possible to quantify the degree to which a country's participation in global supply chains is relatively upstream or downstream (Wei 2012, 3). Koopman, Wang, and Wei update this framework in a more recent paper, "Gross Exports Accounting and Global Value Chain" (2012), which provides a snapshot of countries' positions in global supply chains during the year 2007.[5] For example, Koopman et. al. show that for the year 2007, about 40% of the double counting in U.S. exports came from its own domestic content returning home via imports, whereas nearly all of the double counting in China's processing exports came from imported foreign content (2012, 45-46). This demonstrates that US export producers tend to be upstream within global supply chains whereas Chinese export producers tend to be relatively downstream (Koopman et. al. 2012, 45-46). This paper contributes to the work by Koopman, Wang, and Wei by applying their gross exports decomposition framework to a methodologically consistent time series of input-output tables from 1995-2009 in order to describe not only the relative positions of countries within global supply chains for a particular year, but also how these positions have evolved over time.

In addition to examining the relative position of countries within global supply chains, Koopman et. al. use their novel framework to re-compute revealed comparative advantage by industry using domestic value-added in a country's exports instead of gross exports. The authors find significant differences in the RCA index rank for numerous countries in nearly all of the sectors examined. For the machinery and equipment sector, for instance, they find that China demonstrates a strong revealed comparative advantage when RCA is computed using gross trade, but a comparative disadvantage when RCA is re-computed using the value-added approach because of the high imported content in China's machinery and equipment exports (Koopman et. al. 2012, 48). Focusing on the electronics industry, this paper will expand upon their approach to illustrate how trends in

[5] This paper was recently accepted by the American Economic Review as "Tracing Value-Added and Double Counting in Gross Exports," Koopman, Wang, and Wei (2013). The authors constructed a global international database of value-added production for the year 2007 based on the Global Trade Analysis Project (GTAP) database.

gross and value-added RCA can differ significantly over time. Further, this paper examines how value-added measures of comparative advantage provide a new understanding of the United States' comparative advantage by manufacturing industry.

A second strand of literature that also uses interregional input-output tables decomposes value-added production, or GDP, rather than gross exports. Timmer et. al. introduce a new metric called GVC (global value chain) income, defined as the income generated in a country by participating in global manufacturing production, in order to analyze trends in the share of value-added by country in various industries (2012b, 2). Timmer demonstrates that the GVC income share of advanced countries, namely East Asia (Japan, South Korea, Taiwan), the U.S., and EU15, has been declining over time, while the GVC income share of emerging countries has been increasing over time (2012c, 15). Timmer and colleagues also utilize a country's share in the GVC income metric as an indicator of the country's competitive strength. However, because a country's size also affects its GVC income share, this paper uses revealed comparative advantage as a more relevant measure of competitive strength.

In a preliminary paper dated November 15, 2012 titled "Fragmentation, Income and Jobs: An analysis of European competitiveness," Timmer et. al. build upon their previous work examining GVC income shares in order to compute RCA using total value-added production: value-added exports plus value-added produced and consumed at home. Timmer et. al. use this measure of RCA as an index to measure EU competitiveness. The authors calculate revealed comparative advantage of the EU27 by group of manufactures (machinery, transport, chemicals, non-durables, food, and electronics) over the years 1995-2011 and also calculate RCA for individual EU countries by group of manufactures for the years 1995 and 2008. Timmer et. al. find that the EU27 has a strong and rising GVC-based RCA in machinery and transport equipment while RCAs in non-durables and chemicals are decreasing (Timmer et. al. 2012a, 5). While Timmer et. al. compute RCA using total value added production including domestically produced value-added directly consumed at home without engaging in trade, this paper builds upon the methodology developed by Koopman et. al. in computing RCA using domestic value-added in exports. This paper focuses on RCA computed using domestic value-added in exports to exclude the non-traded part of value-added production. Further, while Timmer et. al. focus on EU competitiveness, this paper focuses on key global supply chain participants, including the U.S., Japan, South Korea, Taiwan, China, and Mexico. Moreover, this paper goes beyond the work by Timmer et. al. by highlighting the extent to which long term trends in comparative advantage can differ when RCA is calculated using value-added instead of gross trade statistics.

3 Methodology

3.1 Guiding questions

This paper focuses on two guiding questions:

1. At the level of aggregate trade, what activities do countries specialize in within global production chains? Specifically, to what extent is a country's participation in global supply chains relatively upstream or downstream? How has global supply chain participation evolved over time?
2. Focusing on the electronics industry, how does revealed comparative advantage (RCA) differ when calculated using domestic value-added in exports instead of

gross exports, and how has RCA changed over time for each country investigated? How does value-added RCA change our understanding of the United States' comparative advantage in manufactures?

3.2 Gross exports decomposition methodology

This section outlines how a country's gross exports can be decomposed into domestic value-added and imported intermediate components in order to answer the questions outlined above. This paper builds on the vertical specialization methodology developed in the literature and refined in Koopman, Wang, and Wei (2012), which decomposes each country's gross exports into its sources and destinations of value-added in order to reveal a country's role within global supply chains.

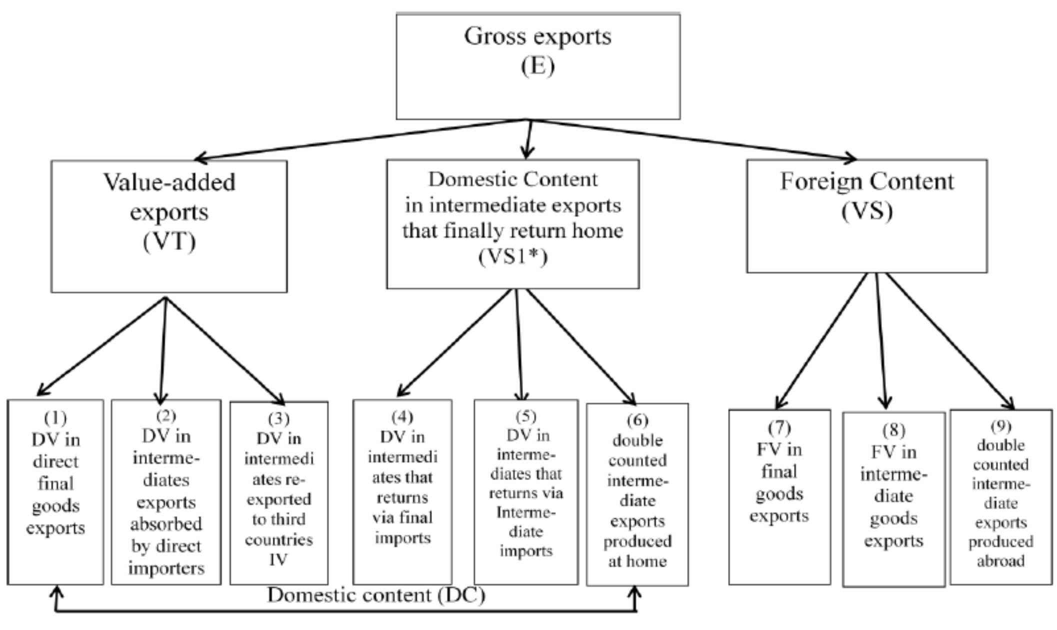
In short, gross exports can be decomposed into 9 components, outlined below in Figure 3.1. These 9 components can be grouped into three categories: 1) value-added exports, 2) domestic content that returns home, and 3) foreign content. Besides value-added exports, all other components within gross exports are "double counted" in the sense that they have crossed borders and been counted in gross exports at least twice. These three categories are elaborated upon below:

1. Value-added exports describe domestic value-added that is ultimately absorbed in a foreign country.
2. Domestic content that returns home describes: 1) domestic value-added that is initially exported through intermediates but ultimately returns home through imports, and 2) the part of the home country's intermediate exports that crosses borders more than twice before embedding in final goods for consumption. This second part is termed a "purely" double counted term in the literature. An

example of such a “purely” double counted intermediate export is the export of a US car part to Mexico which is processed in Mexico, exported back to the US for more processing, exported back to Mexico for further processing, and finally imported back into the US in a final car. When the initial car part is exported as part of a more processed intermediate back to Mexico, it is a purely double counted component in gross exports.

3. Foreign content describes: 1) imported foreign value-added that is embodied in the home country’s exports, and 2) “purely” double counted foreign intermediates, analogous to the “purely” double counted domestic intermediates described above.

Figure 3.1: Gross exports decomposition



Source: Koopman et. al. 2012, 52.

This gross exports decomposition framework is represented in *equation (1)* below (equation 36 in KWW 2012), which states that a country’s gross exports are equal to the sum of components (1) through (9) outlined in Figure 3.1(Koopman et. al. 2012, 37). In the framework:

1. There are G countries and N sectors;
2. r, s, and t represent three different countries, where a single subscript represents a domestic content measure and two subscripts represent a trade in value-added measure (Koopman et. al. 2012, 42);
3. E_{s*} is defined as a country's gross exports to the world;
4. u is a $1\ x\ N$ unity vector;
5. V_s is a $1\ x\ N$ row vector of direct value-added coefficient for country s;
6. A_{sr} is a $N\ x\ N$ block input-output coefficient matrix;[6]
7. B_{sr} is the $N\ x\ N$ Leontief inverse matrix, which is the total requirement matrix that describes the amount of gross output in producing country s required for a one-unit increase in final demand in destination country r;
8. X_{sr} is a $N\ x\ 1$ gross output vector describing gross output produced in s and absorbed in r, where $X_s = \sum_r^G X_{sr}$;
9. Y_{sr} is a $N\ x\ 1$ vector describing final goods produced in s and consumed in r, where $Y_s = \sum_r^G Y_{sr}$, and Y_s describes the global use of country s' final goods and is also a $N\ x\ 1$ vector (Koopman et. al. 2012, 15).

(1) $uE_{s*} = \{V_s \sum_{r\neq s}^G B_{ss} Y_{sr} + V_s \sum_{r\neq s}^G B_{sr} Y_{rr} + V_s \sum_{r\neq s}^G \sum_{t\neq s,r}^G B_{sr} Y_{rt}\} + \{V_s \sum_{r\neq s}^G B_{sr} Y_{rs} + V_s \sum_{r\neq s}^G B_{sr} A_{rs} (I - A_{ss})^{-1} Y_{ss}\} + V_s \sum_{r\neq s}^G B_{sr} A_{rs} (I - A_{ss})^{-1} E_{s*} + \{\sum_{t\neq s}^G \sum_{r\neq s}^G V_t B_{ts} Y_{sr} + \sum_{t\neq s}^G \sum_{r\neq s}^G V_t B_{ts} A_{sr} (I - A_{rr})^{-1} Y_{rr}\} + \sum_{t\neq s}^G V_t B_{ts} A_{sr} \sum_{r\neq s}^G (I - A_{rr})^{-1} E_{r*}$

[6] Note that $(I - A)^{-1}$ is used to apply the Leontief inverse to intermediate goods.

As Section 3.3 explains, decomposing gross exports into domestic value-added and imported intermediate components makes it possible to track at which stage domestic and foreign value-added components enter into a country's export statistics. Thus, variation in the structure of each country's value-added exports and double counted components highlights differences in each country's relatively upstream or downstream position within global supply chains. Moreover, this gross exports decomposition framework also makes it possible to isolate domestic value-added in exports, which is useful for calculating our value-added measure of RCA as Section 3.3 demonstrates. In this framework, domestic value-added in exports is expressed as the sum of components (1) through (5) and can be expressed as in *equation (2)* below (equation 37 in KWW 2013).

$$(2)\ DV_s = \left\{V_s \sum_{r\neq s}^{G} B_{ss}\, Y_{sr} + V_s \sum_{r\neq s}^{G} B_{sr}\, Y_{rr} + V_s \sum_{r\neq s}^{G} \sum_{t\neq s,r}^{G} B_{sr}\, Y_{rt}\right\} +$$

$$\{V_s \sum_{r\neq s}^{G} B_{sr}\, Y_{rs} + V_s \sum_{r\neq s}^{G} B_{sr}\, A_{rs} (I - A_{ss})^{-1} Y_{ss}\ \}$$

In addition to decomposing gross exports, it is also useful to measure the value of exported goods for a given country used as imported inputs by other countries to produce exports. This is termed $VS1$ in the literature. Originally developed by HIY as a measure of vertical specialization, $VS1$ is expressed mathematically in *equation (3)* below (see equation 42 in KWW 2012) (Koopman et. al. 2012, 39).

$$(3)\ VS1_s = V_s \sum_{r\neq s}^{G} B_{sr} E_{r*} = V_s \sum_{r\neq s}^{G} \sum_{t\neq s,r}^{G} B_{sr} Y_{rt} + V_s \sum_{r\neq s}^{G} \sum_{t\neq s,r}^{G} B_{sr} A_{rt} X_t +$$

$$V_s \sum_{r\neq s}^{G} B_{sr} Y_{rs} + V_s \sum_{r\neq s}^{G} B_{sr} A_{rs} X_s$$

Equation (3) states that VS1 is equal to: 1) domestic value-added used to produce other countries' exports of final goods, 2) domestic content used to produce other countries' exports of intermediate goods, 3) domestic value-added that returns via final imports, and

4) domestic content that returns via intermediate imports (including the "purely" double counted portion). VS1 is a useful measure of how upstream a country is within global supply chains because it quantifies the extent to which a given country's exports are used as inputs in other countries' exports.

3.3 Hypotheses

1) Aggregate decomposition: examining the role countries play in global supply chains

This analysis focuses on the United States, Japan, South Korea, China, Taiwan, and Mexico, six countries that are highly integrated into global supply chains. These countries provide an understanding of what activities advanced, newly industrialized, and emerging economies undertake within global production chains. Based on the results of previous snapshot analyses in the literature and intuition from product case studies, I expect the following results summarized below:

Hypotheses:

1.1. The United States and Japan tend to be upstream within global supply chains.

1.2. China and Mexico tend to be downstream within global supply chains.

1.3. Emerging economies (ie. China and Mexico) are starting to move further upstream within global production chains as they produce and export more intermediates.

In order to evaluate these hypotheses, I examine variation in the structure of each country's value-added exports and double counted components that highlights differences in how countries participate in global value chains. For example, if a country has a high proportion of intermediate exports sent indirectly through other countries (VS1), then the country is relatively upstream within global production chains. On the other hand, if a majority of the country's value-added is exported in final goods exports (component (1) in *equation (1)*), for example, then the country is relatively downstream within global supply chains. I examine the evolution of these measures to evaluate how countries' positions have changed over time, and specifically, whether emerging markets are moving upstream within global supply chains. For instance, evidence that emerging markets are exporting more of their value-added in intermediate as opposed to final goods would suggest that these countries are shifting their focus away from assembly work and towards providing intermediate inputs.

Although I hypothesize that on net, China and Mexico are moving upstream within global supply chains by producing and exporting more of their own intermediates, there are two conflicting forces that affect whether the data will support this hypothesis (Wei 2012, 3). First, as the quality of domestic input suppliers increases and multinationals move more of their upstream production into China, for instance, exporting firms increase local sourcing of their inputs and Chinese input suppliers may begin to export intermediates. Conversely, lower trade barriers (e.g., China's accession to the WTO in 2001) promote the use of more imported inputs. Whether China and Mexico are moving upstream in global supply chains depends on the relative speed with which domestic input suppliers and multinationals improve the quality of their products compared to the degree of further decreases in the cost of imported inputs (Wei 2012, 3).

2) Sectoral decomposition: re-calculating RCA using the value-added approach

Revealed comparative advantage (RCA), first proposed by Balassa in 1965, is defined as the share of a sector in a country's total gross exports divided by the share of a sector in the world's total gross exports. When RCA is greater than one, the country has a revealed comparative advantage in that sector, and when the RCA is less than one, the country has a revealed comparative disadvantage in that sector (Koopman et. al. 2012, 47). RCA is computed as in *equation (4)* below (Mikic et. al. 2009, 65).

$$(4) \qquad RCA_{gross} = \frac{\frac{(E_{ij})}{(E_{it})}}{\frac{(E_{nj})}{(E_{nt})}}$$

where:

1. E refers to gross exports
2. i refers to the country index
3. n refers to the set of countries
4. j refers to the commodity index
5. t refers to the set of commodities

Double counting in official trade statistics indicates that computing RCA with gross trade can be misleading (Koopman et. al. 2012, 47). For this reason, RCA should be re-computed using the value-added approach, as demonstrated by KWW 2012 for a number of sectors in the year 2007. KWW 2012 propose using domestic value-added in exports to compute RCA because domestic value-added, or GDP in a country's exports, describes the characteristics of a country's production (total domestic factor content in output). As described in *equation (2)*, domestic value-added in a country's exports is expressed as the sum of measures (1) through (5) in the KWW framework.[7] Thus, instead of using gross exports to compute RCA as in *equation (4)*, this paper will use domestic value-added in exports, represented in *equation (5)* by DV, to compute a value-added measure of RCA:

[7] Note that sector level estimates of domestic value-added in exports are computed in matrix language in SAS. Although expressing domestic value-added in exports at the sector level is relatively complex, it is conceptually analogous to understanding domestic value-added in exports at the aggregate level. See Appendix C for a two country two sector example of how domestic value-added in exports can be expressed mathematically at the sector level.

(5) $$RCA_{value-added} = \frac{\frac{(DV_{ij})}{(DV_{it})}}{\frac{(DV_{nj})}{(DV_{nt})}}$$

Section 6.1 compares comparative advantage in the electronics industry using the value-added and gross trade approaches to emphasize how the value-added approach to trade provides a more accurate understanding of comparative advantage in industries where fragmentation of production is pervasive. Because electronics components and finished goods have a high value-to-weight ratio, they are relatively cheap to transport and therefore exemplify the proliferation of global supply chains and the potential for gross trade statistics to mislead. Numerous studies in the literature have shown that the electronics industry exemplifies where official trade statistics can go wrong. For instance, Koopman, Wang, and Wei show that nearly all of the top 10 sectors with the highest imported value-added in China's exports for the year 2007 are in the electronics industry (Wei 2012, 7).[8] Because China, for instance, uses a significant amount of imported intermediates to produce its electronics exports, I expect its value-added RCA index to be lower than its gross RCA index. On the other hand, I expect RCA for the US and Japan for instance, to increase using value-added measures. As relatively upstream countries within electronics supply chains, their value-added contribution may be understated in gross trade terms compared to downstream countries like China. These expectations are summarized in Hypothesis 2.1.

[8] Additionally, it is important to re-examine the RCA for the electronics industry because studies in the literature on the implications of trade on growth may have misinterpreted standard trade statistics due to lack of available data. For example, in his paper, "What's So Special about China's Exports," Rodrik states that "among areas where China has been successful [in producing unusually sophisticated exports], consumer electronics stands out as one of those that would not have been expected a priori for a country at China's level of income"(Rodrik, 2006, 17).

Hypothesis 2.1: For the electronics industry, China will experience a decrease in RCA index from RCA calculated using gross exports to RCA calculated using domestic value-added in exports. The United States and Japan will experience an increase in RCA index from gross RCA to value-added RCA.

Building on the reevaluation of RCA for the electronics industry using domestic value-added in exports, Section 6.2 discusses how analyzing comparative advantage through the lens of value-added trade changes perceptions of US manufacturing competitiveness. I compute the value-added measure of RCA for the United States over the 1995-2009 timeframe in each of the manufacturing industries in the World Input Output Database. Using the OECD global technological intensity classification to categorize each of the manufacturing industries as "low-technology," "medium-low-technology," or "medium-high-technology to high-technology" enables a clear evaluation of what value-added measures of revealed comparative advantage reveal about the United States' comparative advantage by manufactures (Eurostat 2011, 2).

4 Data description

This study uses the World Input Output Database, a project funded by the European Commission to analyze the effects of globalization on trade, the environment, and socio-economic development. The database covers 40 major countries from 1995-2009 and has been available to the public since April 2012 at http://www.wiod.org/database/index.htm. The version of the WIOD used in this study is the version released in April 2012. A list of the countries in the WIOD database is provided in Table B.1 (Appendix B).

Within the WIOD, this study makes use of the World Input-Output Tables (WIOTs) at current prices, which cover the 40 countries in the WIOD that make up over 85% of world GDP (Timmer et. al. 2012d, 12). The WIOTs are completed with a region called the Rest of the World (RoW), a proxy for all other countries in the world which is modeled assuming an input-output structure equal to that of an average developing country (Timmer et. al. 2012d, 12).

An input-output table (I/O table) describes the interrelationships between industries in an economy according to the production and uses of products they produce and import from abroad (Handbook of Input Output Table Compilation and Analysis 1999, 4). Each industry listed across the top of the table is a consuming industry, and each industry listed down the side of the table is a supplying industry. A simplified input-output matrix is pictured in Figure B.1, where the values in the center box represent intermediate consumption, or the use of products as inputs in a production process.

A schematic outline of a simplified WIOT with only 1 industry and 3 countries (including a RoW region) is included in Figure B.2. The WIOTs used in this study are 35 industry by 35 industry symmetric input-output tables. Thus, each of the 40 countries and the Rest of the World has 35 industries, resulting in (40+1) x 35 = 1435 rows of producing industries, and 1435 columns of consuming industries. The 35 industries included in the WIOD are listed in Table B.2 and are classified by the Statistical Classification of Economic Activities in the European Community (NACE, Rev. 1) (Timmer et. al. 2012d, 9). Table B.3 describes the remaining variables besides intermediate consumption within the WIOTs. The unit of account is millions of USD in current prices. Exchange rates used to convert national currencies to USD are sourced from the IMF and are listed in Table B.4.

In total, this study uses all 15 world input-output tables in the WIOD, one for each of the 15 years from 1995-2009. This allows for a time series analysis of how each country's position within global supply chains has evolved and how value-added measures of comparative advantage have changed over the past decade and a half. Indeed, the WIOD improves greatly upon previously used datasets in the literature by providing full world input-output tables over an extended time period. Compared to other databases such as the GTAP, OECD, and IDE-JETRO databases which provide only one or a limited number of benchmark year input-output tables, the WIOD provides a time series of IO-tables constructed with a consistent methodology over time, for a limited set of 35 industries. Because the methodology often changes between the years for which IO-tables are constructed, previously used databases are only suitable for snapshot analyses in one particular year. The WIOD, on the other hand, provides an excellent resource for time-series analysis. Another major advantage of the WIOD is that the WIOD uses national supply and use tables (SUTs) rather than national input-output tables as its basic building blocks (Timmer et. al. 2012d, 5).[9] This is significant because the use of SUTs as the basic building blocks allows for harmonization with National Accounts. Totals from the national accounts are used as benchmark totals for years where SUTs are available and to estimate SUTs for missing years. Thus, all data are methodologically consistent over time and harmonized with the latest National Accounts (Timmer et. al. 2012d, 5).

[9] The process involves building from national supply and use tables (SUTs) to international SUTs where trade is split across trading partners, to eventually an integrated world input output table (WIOT) (Timmer et. al. 2012d, 5).

The WIOD also makes technical improvements over previously used datasets in the literature in order to improve reliability. In particular, the WIOD does not rely on the standard import proportionality assumption when determining the amount of imported intermediates from a given partner that are used to produce one unit of output. The import proportionality assumption assumes the share of imports in any product consumed as intermediate consumption or final demand is the same for all users (OECD-WTO 2012, 15). As an example, assume the US imports 100 tons of steel, of which 30 tons are from China. If 20 tons are used to make cars and 80 are used in other industries, of the 30 tons of Chinese steel, the proportionality assumption allocates 6 tons to the car industry. However, if the car industry is more likely to use Japanese steel than Chinese steel because Japanese steel is higher quality for example, then the proportionality assumption misallocates the distribution of steel imports to each user (example adopted from Dr. Zhi Wang and Daudin et. al. 2011, 1415). The WIOD addresses this problem by using detailed trade data at the HS6-digit product level taken from the UN COMTRADE database to allocate products to three use categories: intermediates, final consumption, and investment, based on an extension of the Broad Economic Categories (BEC) classification system as provided by the United Nations (Timmer et. al. 2012d, 27). Then, the proportionality method is applied only within each use category allocation (Timmer et. al. 2012d, 7). Allowing a country's geographic structure of imports to differ by use category improves upon the way imports are allocated to users and thus increases the reliability of value-added trade estimates (Timmer et. al. 2012d, 27).

Clearly, the WIOD is one of the most comprehensive global input-output databases available. Although the GTAP database provides a more comprehensive coverage of countries, including emerging countries of interest at the "low-end" of the value chain such as Vietnam, the WIOD provides a sense of the evolution of supply chain activity through its coverage of the dynamic 15-year time period from 1995-2009. Despite the WIOD's improvements over previously used datasets however, researchers should be aware that inconsistencies have been found in the process of consolidating separate databases, including national input-output tables and international trade statistics, and compromises were made to arrive at internally consistent World Input-Output Tables. For instance, the inconsistency between export and import trade flows in the COMTRADE data was resolved by focusing on import flows only.[10]

Also, although the WIOD's application of the Broad Economic Categories (BEC) classification technique is a significant improvement over the standard proportionality assumption, the BEC classification technique is not perfect. For example, the BEC classification technique has trouble identifying the end-use category of dual-use products such as fuels, automobiles, and certain food and agricultural products (Koopman et. al. 2010, 19). Additionally, the WIOD does not correct for processing exports for countries like China and Mexico.[11] Thus, it is important to be aware that Chinese and Mexican

[10] In compiling the WIOTs, because the WIOD team only uses a country's import data and uses the "Rest of the World" (RoW) category as the residual to balance global exports supply and import demand, exports to the RoW can be negative. These negative exports to the RoW are set to zero in this analysis. In the program used to calculate RCA, only negative export numbers are set to zero because in a single industry, gross exports can be zero, but value-added exports can still be positive. For example, assume the United States has no gross exports of steel so that all steel produced in America is consumed in America. While gross exports of steel are zero, value-added exports of steel can be positive if steel is indirectly exported through cars and planes for instance.

[11] The WIOD does not employ different input-output coefficients for production for exports versus production for domestic sales. This can be significant for countries like China and Mexico which engage in processing exports, where more imported inputs are used in production for exports compared to domestic sales because firms that engage in processing exports typically receive tariff exemptions on imported inputs (Wei 2012, 2). To integrate potentially different input-output coefficients into the WIOD is beyond the scope of this paper; however, Dr. Zhi Wang of the USITC is currently working with OECD staff to develop this capability. This paper notes that imported inputs for China and Mexico may be underestimated due to these data limitations.

domestic value-added may be overestimated.   Until today's statistical systems catch-up with the increasing fragmentation of world trade, however, the WIOD serves as one of the most comprehensive and reliable international input-output databases available.

5 Aggregate decomposition: evolution of global supply chain roles over time

Overview

This section investigates the extent to which a country's participation in global supply chains is relatively upstream or downstream and describes how this participation has evolved over the fifteen years between 1995 and 2009. To investigate each country's role in global supply chains, this paper decomposes aggregate trade, or total gross exports from each country to the world, into domestic value-added and imported intermediate components (see Section 3 on Methodology). Examining aggregate trade allows us to follow the supply chain across all goods and services, which is especially important for high income countries for example, which export significant value-added from their services sector (Koopman et. al. 2010, 42).

The structure of each country's value-added exports and imported intermediate components highlights variation in how countries participate in global supply chains. For instance, if a country has a high share of intermediate exports sent indirectly through other countries, then the country is relatively upstream within global production chains. Japan represents a stylized example of such an upstream participant when it exports an intermediate iPhone component to China and the intermediate component is exported through China as a finished iPhone to final consumers in the US. On the other hand, if most of the country's value-added exports are embodied in direct final goods exports, for example, then the country is relatively downstream within global supply chains. China represents a stylized example of such a downstream country when its value-added in assembly work for the iPhone is embodied in a final good export of iPhones from China to the US for instance.

This paper goes beyond previous one-year snapshot analyses in the literature to find consistent evidence over the 1995-2009 time period that developed nations like the US and Japan tend to be relatively upstream within global supply chains while emerging economies like China and Mexico tend to be relatively downstream. Meanwhile, Korea and Taiwan appear to be in the middle of supply chains, importing intermediates to export more intermediates. More interestingly, with the availability of world input-output tables over an extended time period, this paper provides a first look in the literature at the dynamism of participation in global supply chains. As predicted in Hypothesis 1.3, this paper finds evidence that developing countries are undergoing "industrial upgrading" to a certain extent. Over time, China and Mexico appear to be producing and exporting more intermediates, and shifting their focus away from assembly work. It turns out that Taiwan represents the most dramatic example of dynamism within global supply chains, however: over the fifteen years between 1995 and 2009, Taiwan experienced a considerable transition from a country that exported most of its value-added in final goods, to a country that exports most of its value-added in intermediates.

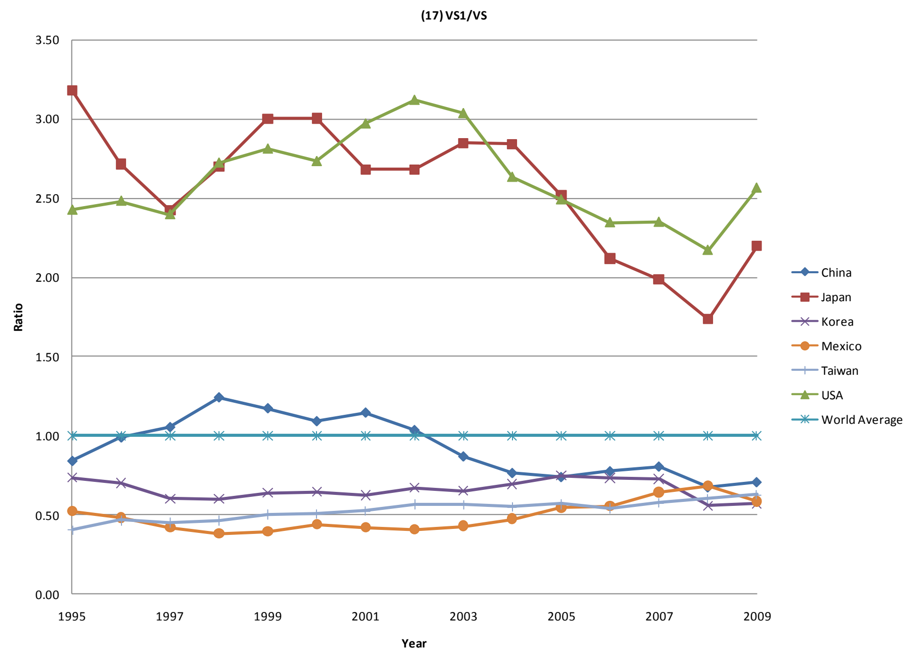
The following sections examine each of these results. Taking Hypotheses 1.1-1.3 in turn, I explain how the structure of each country's value-added exports and imported intermediate components highlights variation in how countries participate in global supply chains.

5.1 The United States and Japan at the head of global supply chains

This paper finds consistent evidence over the 1995-2009 time period that the United States and Japan specialize as relatively upstream participants within global supply chains. First, I find that out of the countries examined, the US and Japan have the greatest amount of exported goods used as inputs by other countries to produce exports. This measure is termed VS1 in the literature and demonstrates that other countries often import upstream intermediates from the US and Japan that they incorporate in their own exports. Meanwhile, the share of foreign content in US and Japanese exports is lowest among the countries examined. This measure, termed VS in the literature, demonstrates that relative to other countries, the US and Japan import a smaller share of foreign intermediates to produce their own exports. Since the US and Japan export more goods that are used as inputs in other countries' exports and import fewer foreign intermediates to produce their own exports, they are clearly relatively upstream in global supply chains. Finally, the fact that the US has the greatest share of domestic content exported that eventually returns back home provides further evidence of the United States' upstream role. After all, for domestic content exported to return home, it must be incorporated as an intermediate abroad before being exported back to US consumers.

Figure 5.1 graphically highlights the relatively upstream role of the US and Japan within global supply chains by illustrating that the US and Japan have the highest ratio of VS1 to VS among the countries examined. At the global level, VS1 and VS are equal because one country's intermediate exports sent indirectly through other countries are another country's foreign content. Therefore, the average VS1-to-VS ratio is equal to 1. A ratio larger than 1 indicates the country lies relatively upstream in global supply chains, providing intermediate inputs for other countries' exports. A ratio less than 1 means the country lies relatively downstream in global supply chains, using more intermediate inputs from other countries to produce exports.

Figure 5.1: US and Japan dominate at the upstream of supply chains
VS1 / VS, Ratio of intermediate exports sent indirectly through other countries to foreign content



Source: Author's calculations and USITC decompositions of WIOD data provided by Dr. Zhi Wang.

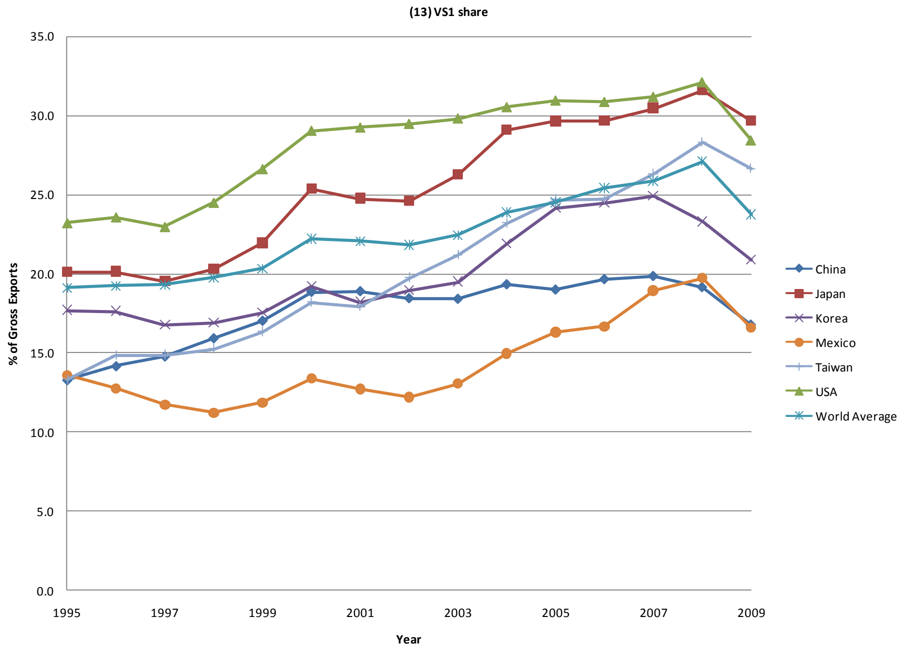
Besides demonstrating that the US and Japan appear relatively upstream, Figure 5.1 also shows that China, Korea, Taiwan, and Mexico appear comparably downstream within global production chains. Interestingly, Korea and Taiwan appear to have lower VS1/VS ratios than China.[12] Although Korea and Taiwan appear more upstream compared to China and Mexico from the perspective of VS1 (see Figure 5.2), as Figure 5.3 demonstrates, their low VS1/VS ratios are driven by high VS. As Section 5.2 touches upon however, this high VS turns out to be less an indication of downstream positioning and more an indication of a high degree of integration within global supply chains. While China and Mexico import foreign content mostly to export finished goods (see

[12] China's higher VS1/VS ratio versus Korea and Taiwan may partially be due to high VS for Korea and Taiwan due to a lack of natural resources. Japan's high VS1/VS ratio is especially striking given its need to import raw materials, suggesting Japan's extraordinary strength as an upstream advanced economy in producing both manufactured goods and services for global supply chains. Additionally, note that China and Mexico's foreign content (VS) may be underestimated due to pervasive processing exports.

Figure 5.8), Korea and Taiwan import foreign content mostly to export intermediates (see Figures 5.9 – 5.10). Moreover, for Taiwan in particular, foreign content is driven by a high share of "purely" double counted intermediates which grows as more borders are crossed (see Figure 5.10).[13] Thus, rather than indicating their downstream position within global supply chains, the high VS for Taiwan and Korea indicates their role in the middle of global production chains, importing intermediates to export intermediates. Indeed, the fact that Korea and Taiwan have both relatively high VS1 and high VS suggests that Korea and Taiwan tend to be located in the middle of production chains, playing a major role in both importing and exporting intermediate inputs.

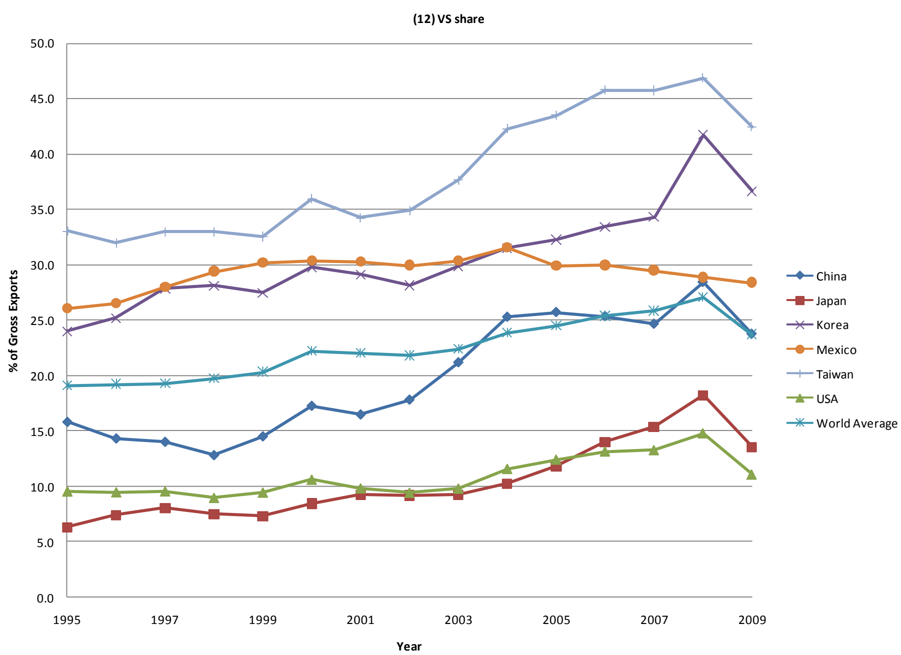
[13] These purely double counted items are the part of foreign content in the country's exports that crosses borders more than twice before embedding in final goods for consumption. Thus, it is not that Taiwan's exports contain an enormous share of foreign value-added, so much as the foreign value-added that is embedded in Taiwan's exports has crossed borders many times. Here, it is important to distinguish between this purely double counted type of foreign content and foreign value-added embodied in a country's final goods exports, for example. While the purely double counted foreign content highlights the country's high degree of integration into global supply chains, foreign value-added in a country's final goods exports is a greater indication of the country's need to import foreign value in order to export, implying a focus on assembly work, for instance.

Figure 5.2: VS1, Ratio of intermediate exports sent indirectly through other countries to gross exports



Source: Author's calculations and USITC decompositions of WIOD data provided by Dr. Zhi Wang.

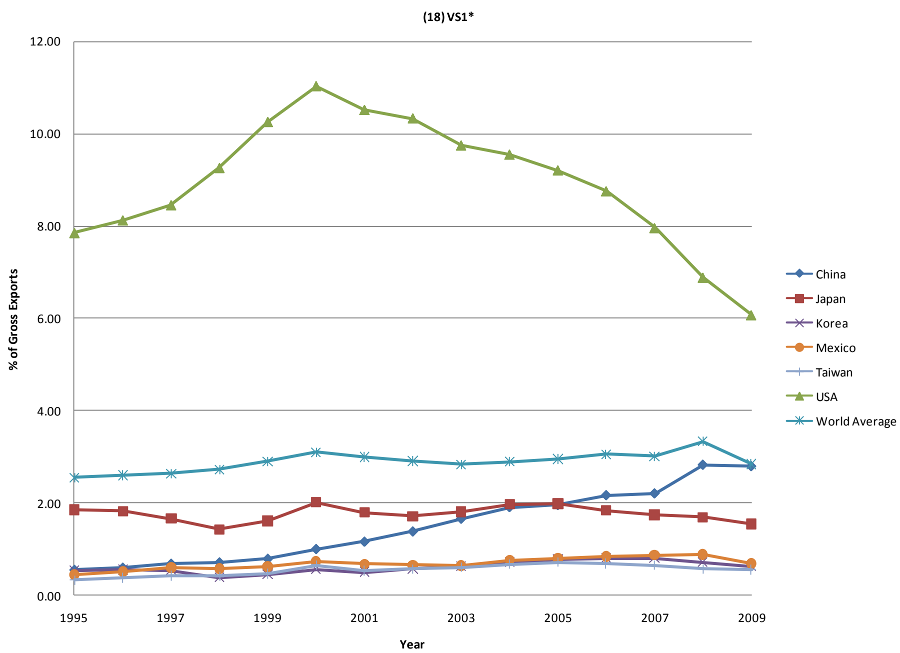
Figure 5.3: VS, Foreign content as a share of gross exports



Source: Author's calculations and USITC decompositions of WIOD data provided by Dr. Zhi Wang.

Figure 5.4 further highlights the relatively upstream role of the US within global supply chains by illustrating that the US has an unusually high share of domestic content exported that eventually returns back home, termed VS1* in the literature. While this certainly reflects the United States' large domestic market size, it is also another indication of the United States' relatively upstream position within global production chains. A high share of domestic content that returns home demonstrates that US exports are used by other countries as inputs in their own exports to US consumers.

Figure 5.4: VS1*, domestic content that returns home

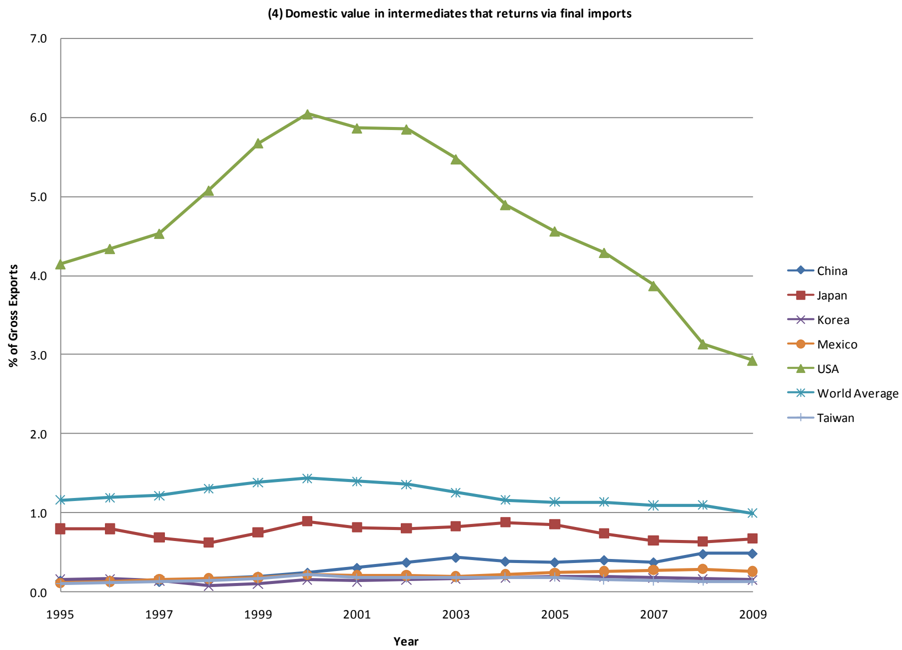


*Source: Author's calculations and USITC decompositions of WIOD **data** provided by Dr. Zhi Wang.*

Notably, while VS1* for the US has decreased since 2000, China appears to have experienced an increase in VS1* over time, demonstrating that it may be producing more intermediate components. The decline in VS1* for the US and the rise in this measure for China suggests that as predicted in Hypothesis 1.3, emerging economies like China are starting to move upstream within global production chains as they begin to produce and export more intermediates. Indeed, breaking domestic content that returns home (VS1*) into its individual components (Figures 5.5-5.7) shows that these gains in VS1* are not driven by domestic value that returns via final imports, which would partially reflect China's growing domestic market (Figure 5.5). In fact, China has made small but significant gains in domestic value that returns via intermediate imports (Figure 5.6) and a steep gain in purely double counted intermediate exports produced at home (Figure 5.7).[14] These gains suggest that China is moving upstream within global supply chains as it produces more intermediate components over time.

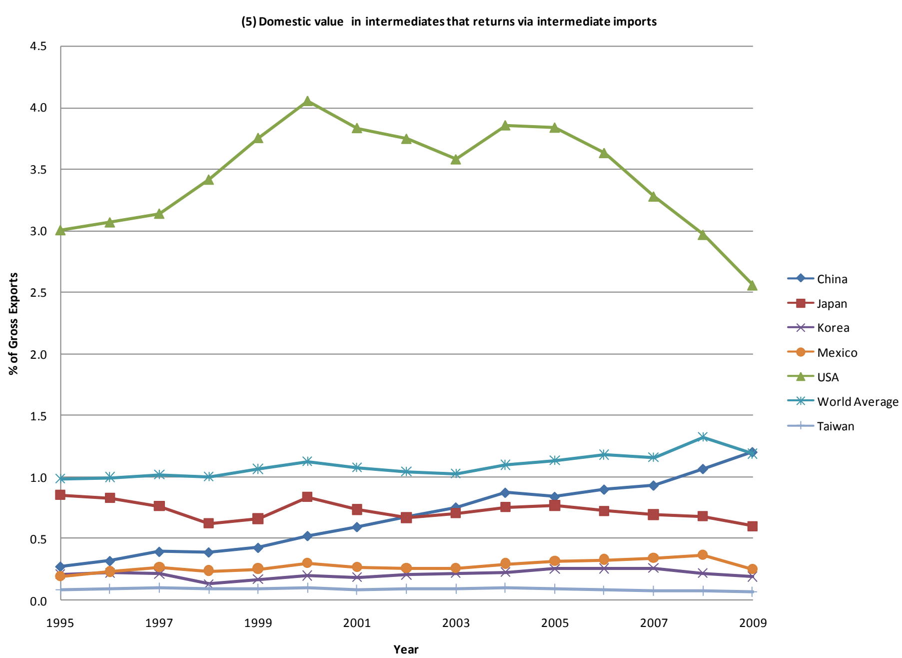
[14] These purely double counted intermediate exports produced at home represent China's intermediate goods exports that cross borders more than twice before embedding in final goods for consumption). These gains also suggest that although Japan, Korea, and Taiwan, for instance, produce intermediate components (iPhone components) that China imports to assemble into final exports (iPhones), China may actually provide some intermediates to these intermediates. Clearly, this example illustrates the power of decomposing gross exports via inter-country input output tables: to fully decompose a product such as the iPhone requires not just a list of iPhone component suppliers, but these suppliers' suppliers, and so on (OECD-WTO 2012, 2). The WIOD, which links production processes within and across countries, provides just such a powerful tool and allows us to illustrate gains in intermediate production in countries like China that may otherwise have been hidden in product case studies which often highlight China's role as a final assembler.

Figure 5.5: Domestic value that returns via final imports, as a share of gross exports



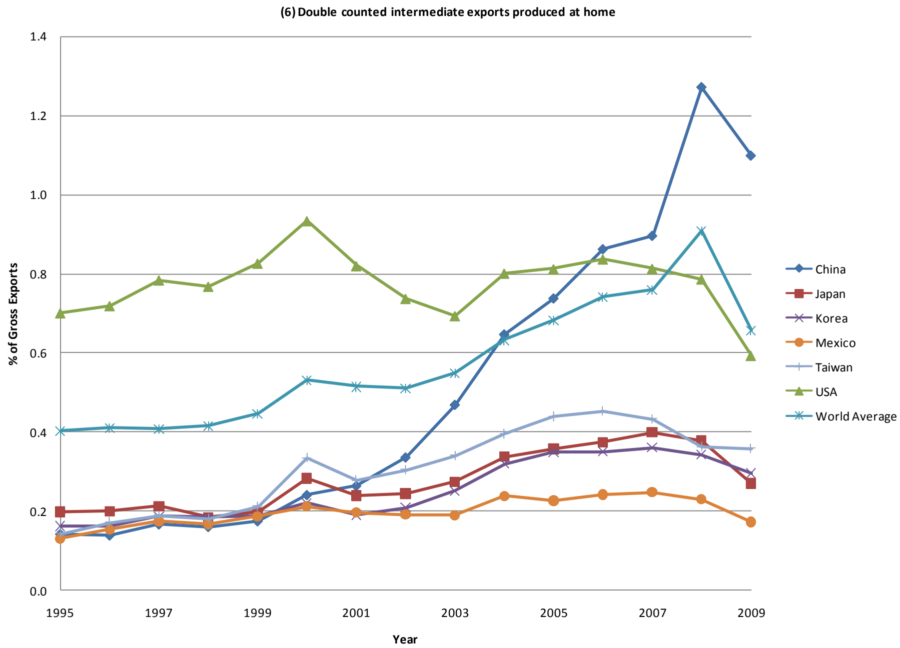
Source: Author's calculations and USITC decompositions of WIOD data provided by Dr. Zhi Wang.

Figure 5.6: Domestic value that returns via intermediate imports, as a share of gross exports



Source: Author's calculations and USITC decompositions of WIOD data provided by Dr. Zhi Wang.

Figure 5.7: Double counted intermediate exports produced at home, as a share of gross exports



Source: Author's calculations and USITC decompositions of WIOD data provided by Dr. Zhi Wang.

5.2 China and Mexico at the tail of global supply chains

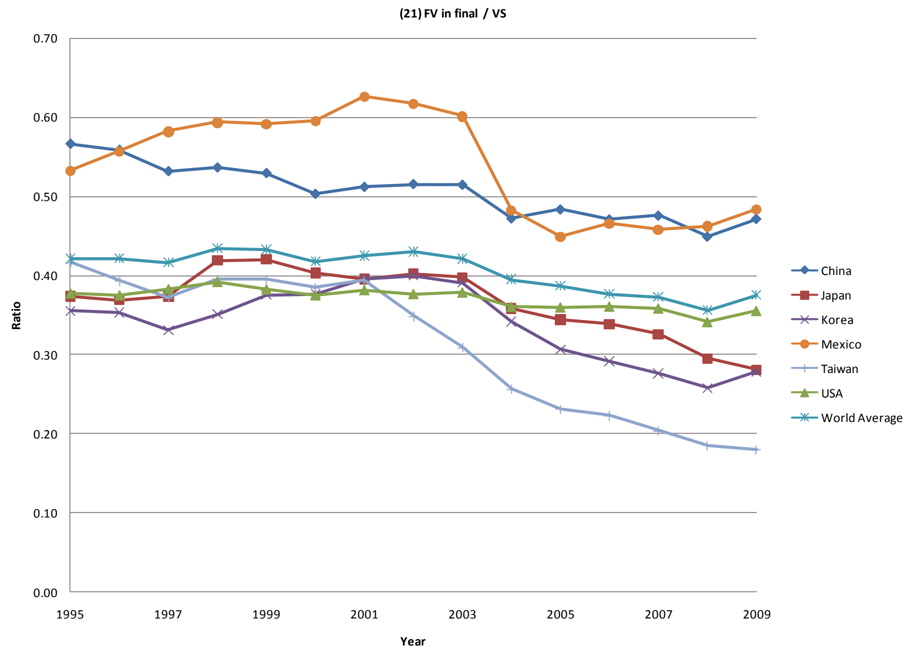
Section 5.1 presented preliminary evidence of China and Mexico's relatively downstream positions in global supply chains by looking at China and Mexico's low level of exported goods that are used as imported inputs by other countries. This section examines in detail the structure of these countries' value-added exports and foreign content within gross exports to present evidence over the 1995-2009 time period that China and Mexico specialize as relatively downstream participants within global supply chains. Focusing first on the structure of foreign content in gross exports, most of the imported foreign content that China and Mexico export is embodied in their exports of final goods. Going back to the stylized example of China importing foreign iPhone components in order to make a final iPhone export, this indicates that China and Mexico participate in downstream processes within global supply chains, importing foreign intermediates and assembling them into final products, for instance. Focusing next on the structure of domestic value-added exports, China especially, exports most of its domestic value-added in final goods exports as opposed to intermediate exports. This emphasizes that most of China's domestic value-added reaches its final destination directly rather than being passed along to other countries in the supply chain, providing further evidence of China's downstream position within global supply chains.

Foreign content

Figure 5.8 graphically emphasizes the relatively downstream role of China and Mexico within global supply chains by illustrating that 50% of foreign content in China and Mexico's gross exports is embodied as foreign value-added in final goods exports. On the other hand, the US, Japan, Korea, and Taiwan have 40% or less of their foreign content embodied in final goods exports. Over time, however, China and Mexico seem to have experienced a decline in foreign value in final goods exports as a share of overall foreign content. This declining trend supports the hypothesis that emerging economies like China and Mexico are beginning to export more intermediates over time, as a greater portion of foreign value-added embeds into their exports of intermediate instead of final goods.[15]

[15] Of course, part of this decline is due to a general increase in the fragmentation of supply chains as the share of purely double counted intermediate exports produced abroad increases over time as value-added crosses borders with increasing frequency.

Figure 5.8: Foreign value in final goods exports, as a share of foreign content

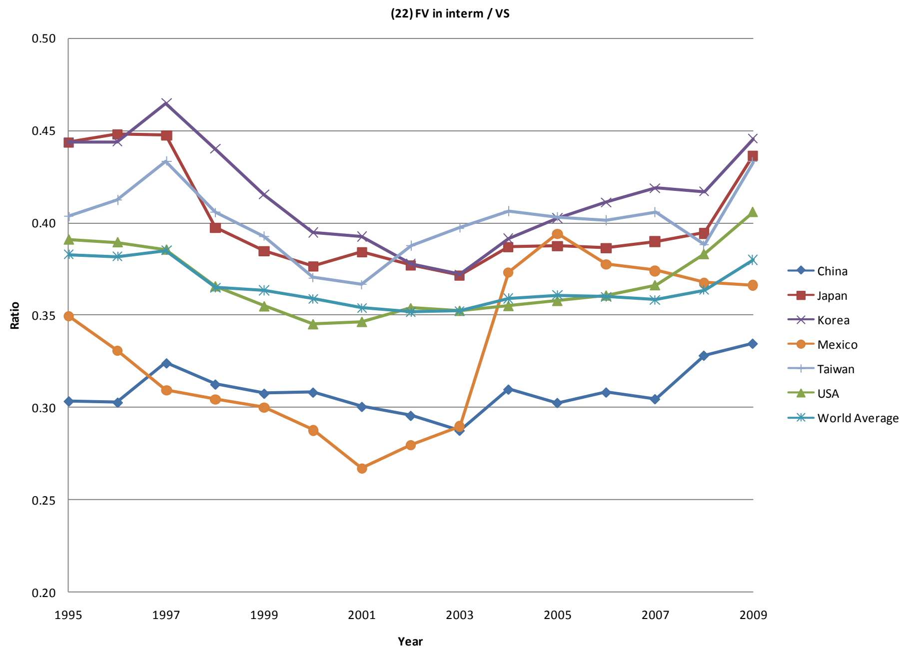


Source: Author's calculations and USITC decompositions of WIOD data provided by Dr. Zhi Wang.

Figures 5.9 and 5.10 provide further perspective on the comparably downstream positions of China and Mexico by illustrating that for the US, Japan, Korea, and Taiwan, foreign content tends to embed in more upstream segments of the supply chain. For these developed and newly industrialized economies, most of the foreign content in their exports is foreign value-added that is exported in intermediate goods, or purely double counted foreign intermediates that have crossed borders multiple times during the production process.[16]

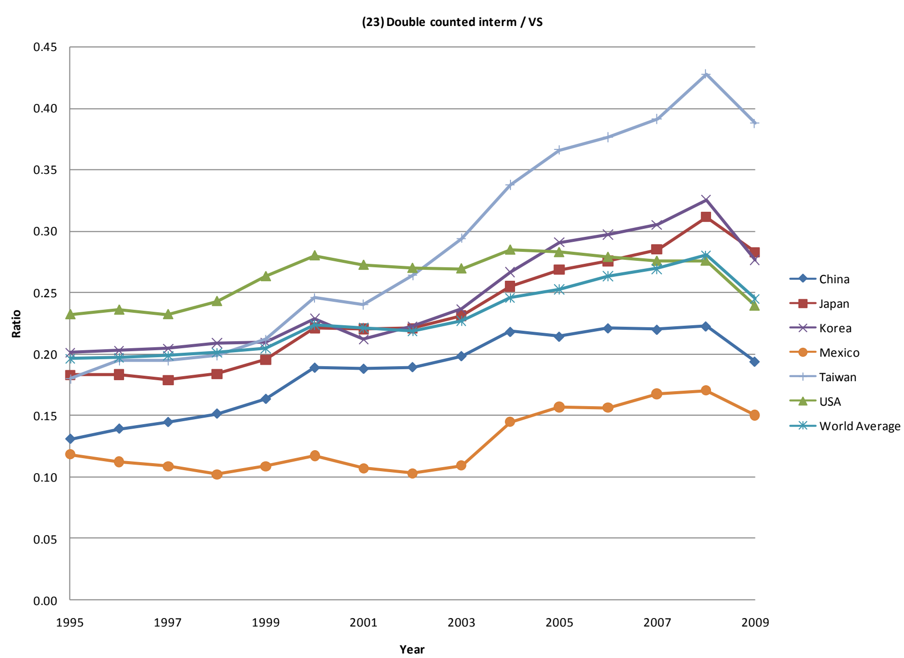
[16] Further research is necessary to elucidate the reason behind the large jump in foreign value in intermediate exports as a share of foreign content for Mexico in 2004. Anticipation of the effects of free trade agreements such as that between Japan & Mexico (2004) may provide a starting point (Villarreal 2012, 10).

Figure 5.9: Foreign value in intermediate exports, as a share of foreign content



Source: Author's calculations and USITC decompositions of WIOD data provided by Dr. Zhi Wang.

Figure 5.10: Purely double counted intermediate exports, as a share of foreign content

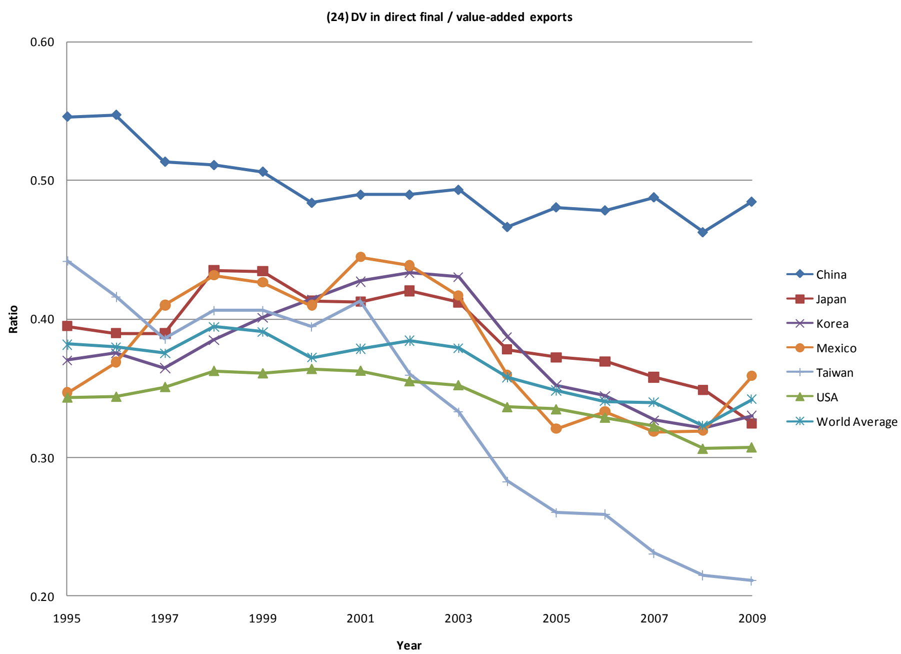


Source: Author's calculations and USITC decompositions of WIOD data provided by Dr. Zhi Wang.

Domestic value-added exports

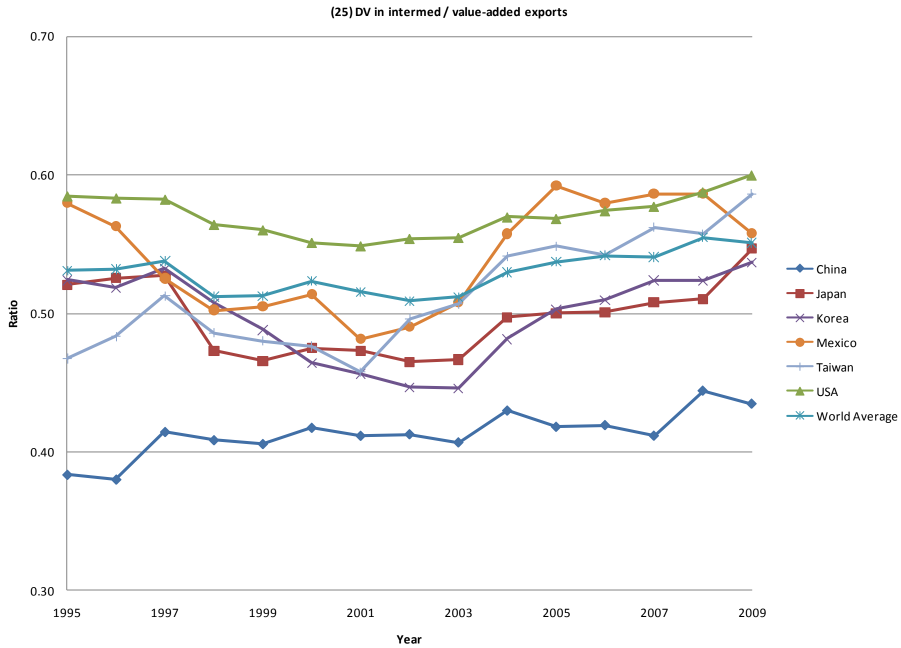
Figure 5.11 further underscores the relatively downstream role of China within global supply chains by illustrating that most of China's domestic value-added is exported through final goods exports. Interestingly, however, this measure has been on a consistent decline over time from 55% of value-added exports in 1995 to 48% in 2009, again supporting the hypothesis that China may be beginning to produce and export more intermediates over time. Indeed, as shown in Figure 5.12, within value-added exports, China's share of domestic value-added in intermediates absorbed by the direct importer has increased steadily from 38% in 1995 to 43% in 2009.

Figure 5.11: Domestic value in final goods exports, as a share of value-added exports



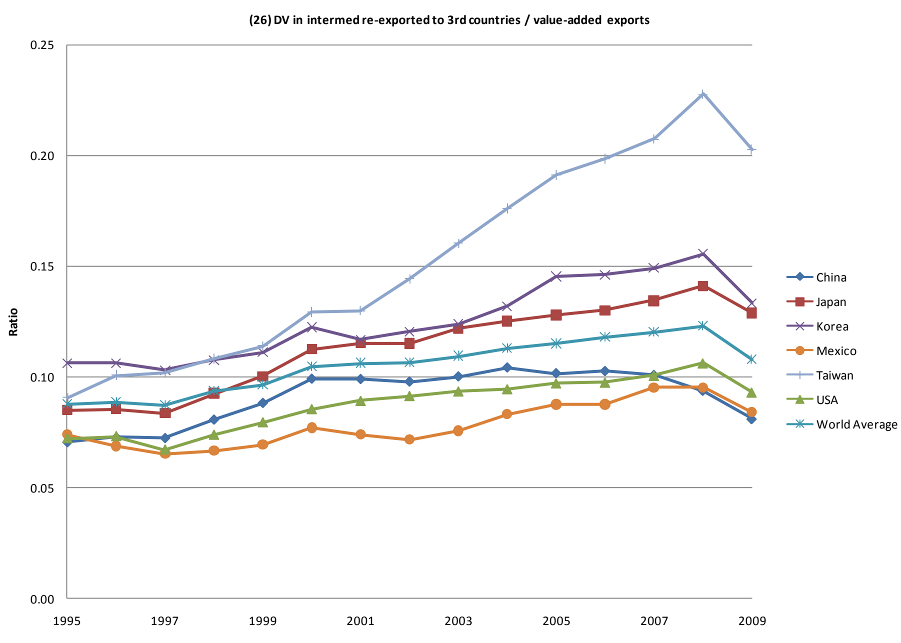
Source: Author's calculations and USITC decompositions of WIOD data provided by Dr. Zhi Wang.

Figure 5.12: Domestic value in intermediate exports absorbed by direct importers, as a share of value-added exports



Source: Author's calculations and USITC decompositions of WIOD data provided by Dr. Zhi Wang.

Figure 5.13: Domestic value in intermediates re-exported to third countries, as a share of value-added exports



Source: Author's calculations and USITC decompositions of WIOD data provided by Dr. Zhi Wang.

While evidence of China's greater focus on domestic value-added in intermediate exports is noteworthy, Taiwan represents one of the most striking demonstrations of dynamism in global supply chains over the past decade and a half. As Figure 5.11 illustrates, Taiwan experienced a more than 20 percentage point decline in domestic value-added in final goods exports as a share of value-added exports from 1995-2009. Figures 5.12 and 5.13 demonstrate that this decline is reflected in a rise in the share of domestic value-added exported in intermediates, especially in intermediates re-exported to third countries. This reveals Taiwan's evolution over the past decade and a half into a highly integrated member of key global supply chains as a producer of intermediate components. Taiwan's participation in the iPhone supply chain provides an excellent stylized example of Taiwan's exports of value-added in intermediates, which are then re-exported to third countries: when Taiwan exports iPhone components like the touch screen and camera to China, these components are re-exported to third countries like the US as a part of the final iPhone product (OECD-WTO 2012, 2).

5.3 Emerging economies starting to move upstream

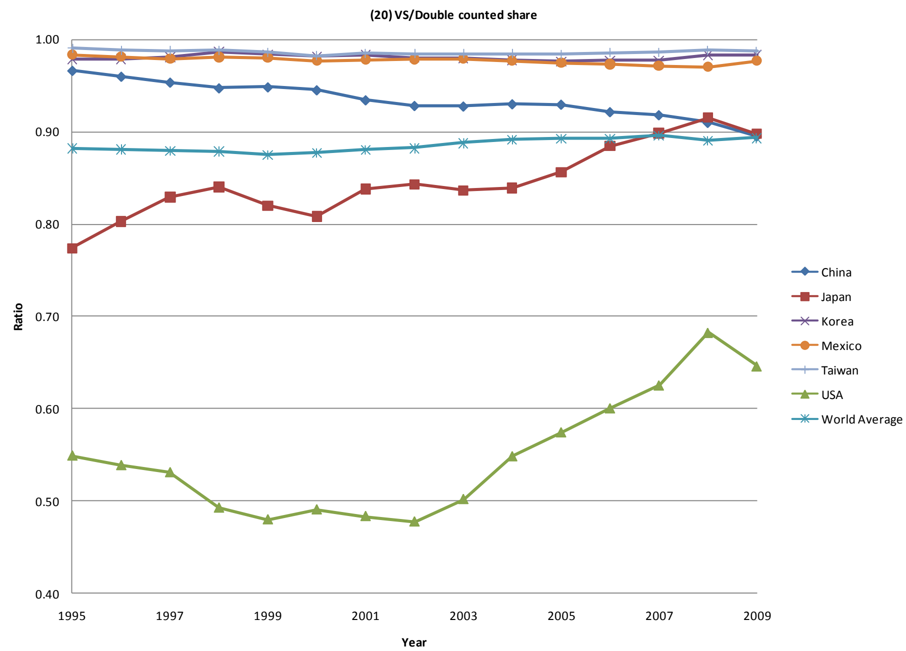
While Sections 5.1 and 5.2 present basic evidence that emerging economies are beginning to export more intermediates, this section provides further evidence of China's upstream migration by examining the structure of double counted components in gross exports. Besides domestic value-added exports, all other components within gross exports are double counted in the sense that they have crossed borders and been counted in gross exports at least twice. Thus, the double counted portion of gross exports includes domestic content that returns home through imports (VS1*) and imported foreign content (VS).[17] The structure of a country's double counted exports reveals a great deal about how the country participates in global supply chains. If most of the double counting within the country's gross exports represents its own value-added that returns home, then the country tends to export intermediates. On the other hand, if most of the double counting within the country's gross exports represents foreign content, then the country tends to import foreign intermediates in order to export.

As underscored in Figure 5.14, foreign content as a share of the double counted portion of gross exports has increased for the US and Japan but decreased for China from 1995-2009. As shown in Figure 5.3, foreign content as a share of gross exports increased for all countries examined during the time period due to the increasing fragmentation of supply chains. Therefore, in order for China's foreign content to decrease as a share of the double counted portion of gross exports (in order for $\frac{VS}{VS1^{*}+VS}$ to decrease), VS1* must increase at a faster rate than VS. In other words, the share of domestic content exported and incorporated abroad before returning home must increase faster than the share of foreign content imported in order to produce exports. Thus, China's decrease in foreign content as a share of the double counted portion of gross exports provides further evidence that China is producing more of its own intermediates over time. Meanwhile, the US and Japan are producing less of their own intermediates and utilizing more imported foreign content. These trends lend further support to the hypothesis that emerging economies are beginning to produce and export more intermediates over time as they shift their focus away from assembly. For China, for example, it appears that firms are increasing local sourcing of their inputs as the quality of domestic input

[17] Although VS1* is part of domestic content in exports, it is not part of value-added exports because it ultimately returns to the home country.

suppliers increases and multinationals move more of their upstream production into the country.

Figure 5.14: Foreign content, as a share of double counted portion of gross exports



Source: Author's calculations and USITC decompositions of WIOD data provided by Dr. Zhi Wang.

Conclusions

Undoubtedly, inter-country input-output data over an extended time frame of analysis provide a much richer perspective of the role countries play within global supply chains than a one-year snapshot analysis provides. This extended time frame of analysis provides the first multi-year evidence in the literature that developed nations like the US and Japan remain relatively upstream within global supply chains, emerging economies like China and Mexico tend to be relatively downstream, and newly industrialized economies like Korea and Taiwan play an important role as the "middle-men" of global supply chains. More significantly, however, this extended time frame of analysis allows this paper to provide a first look in the literature at the dynamism of participation in global supply chains. This dynamism is crucial to understanding how global supply chains work because it shows how "trade in tasks" evolves over time. This paper finds evidence that emerging economies like China and Mexico are producing and exporting more intermediates and shifting their focus away from assembly work as the quality of their input suppliers increases with time. Moreover, I also find evidence of the evolution of Taiwan's role within global production chains: Taiwan experienced a considerable transition from 1995, when nearly half of it value-added was exported in final goods, to the present, when most of its domestic value-added is exported in intermediates. This highlights an upstream shift in Taiwan's role towards being an important player in the middle of supply chains. As the next section highlights, understanding how a given country participates in global supply chains—whether it participates relatively upstream or downstream—also offers a sense of whether that country's comparative advantage in industries significantly affected by global supply chains may be overstated or understated when calculated using gross trade statistics.

6 Sectoral analysis: value-added approach to revealed comparative advantage

Overview

This section empirically investigates how revealed comparative advantage (RCA) differs when calculated using domestic value-added in exports instead of gross exports. Because gross exports include imported components, they do not accurately describe the characteristics of a nation's production. Section 6.1 compares RCA calculated using the gross and value-added approaches for the electronics industry, as an illustration of how the value-added approach to trade provides a more accurate indication of comparative advantage in industries where fragmentation of production is pervasive. More significantly, this paper provides a first look in the literature at trends in value-added RCA over the 1995-2009 time period in order to illustrate the evolving comparative advantage of nations. Focusing on the United States, Section 6.2 discusses how analyzing comparative advantage through the lens of value-added trade changes perceptions of US manufacturing competitiveness.

The results presented in this section dramatically change our understanding of comparative advantage in the electronics industry, especially for the United States. In fact, the trends for gross and value-added RCA diverge significantly for the US during the 1995-2009 period: while gross trade statistics point to the decline of US competitiveness in the electronics industry, value-added trade statistics reveal the rising robustness of the United States' comparative advantage in electronics manufacturing. In general for the electronics industry, as predicted in Hypothesis 2.1, relatively downstream economies like China appear less competitive using value-added measures of comparative advantage, whereas relatively upstream nations like the US and Japan appear more competitive. Finally, using value-added measures of revealed comparative advantage demonstrates that rather than losing comparative advantage in advanced manufacturing, the USA's comparative advantage is growing most robustly in the highest-technology manufacturing industries.

6.1 Value-added vs. gross revealed comparative advantage: electronics industry

The RCA index was computed at the country-sector level for all countries and sectors in the WIOD using both the value-added and gross trade approaches. Results for the electronics industry are examined in Figures 6.1- 6.6 below. Note that the measures of sectoral value-added used to compute revealed comparative advantage for the electronics industry, for example, refer to value produced by the factors of production employed in the electronics industry and then embodied in gross exports of all downstream sectors, as opposed to the value-added employed in upstream sectors that are used to produce electronics in the exporting country (Koopman et. al. 2012, 48).[18] In each figure two sets of RCA indices are graphed and compared over the 1995-2009 time period, gross RCA and value-added RCA, where the solid horizontal line emphasizes when the RCA index is greater than one and indicates a comparative advantage.

As expected, there are significant differences in RCA between the gross and value-added approaches. China and Mexico fell in RCA using the value-added approach whereas Japan, Korea, and the US rose in RCA (Figures 6.1-6.6). This matches our intuition from the analysis of countries' positions within global supply chains in Section 5 and case studies of the electronics sector, where the US and Japan tend to be upstream within global supply chains while China and Mexico tend to be relatively downstream. Because China, for instance, uses a significant amount of imported intermediates to produce some of its electronics exports, its value-added RCA falls compared to its gross RCA. On the other hand, RCA for the US, Japan, and Korea move up using value-added measures: as relatively upstream countries within electronics supply chains, their value-added contribution is understated in gross trade terms when compared to downstream countries like China. Nevertheless, with the caveat from Section 5 that China's role within supply chains is still very different from that of the US and Japan, China's trend in value-added RCA is encouraging for China's industrial development. As Figure 6.1

[18] While these two ways of looking at value-added are different at the sector level, they are the same at the aggregate level (all industries).

shows, China has steadily moved up in RCA in the electronics industry over time, supporting the hypothesis of “industrial upgrade” to a certain extent. Similarly, Korea and Taiwan have also experienced significant gains in RCA from 1995-2009, with Taiwan, for example, rocketing up in value-added RCA from just over 1.5 to well over 3.0 from 1995-2009 (Figure 6.5). Meanwhile, Japan has experienced a decline in RCA from 1995-2009, implying that the other East Asia nations—Korea, Taiwan, and China—may be beginning to displace Japan in its dominance of electronics manufacturing (Figure 6.3).

Most strikingly, comparing the differences in value-added and gross RCA trend over fifteen years paints a different picture of the evolution of comparative advantage in important cases. As mentioned, gross RCA often overstates or understates a country’s comparative advantage, depending on where the country is positioned within the global supply chain. In most cases, however, the trend in gross RCA over time roughly matches that of value-added RCA. For instance, while China’s gross RCA overstates its comparative advantage in electronics, it captures the overall rising trend in China’s comparative advantage in the electronics industry despite showing a significantly more dramatic run-up in this trend (Figure 6.1). However, gross and value-added RCA for the United States illustrate *opposite* trends over time (Figure 6.6). According to gross RCA, the United States’ RCA has steadily declined over the past fifteen years from a comparative advantage of just over 1.1 in 1995 to a comparative disadvantage of less than 0.9 by 2009. In contrast, value-added RCA shows that the United States’ RCA has steadily increased over the 1995-2009 period from an RCA of just below 1.1 to over 1.3. This difference in trend between gross and value-added RCA is highly economically significant: while gross trade statistics tell a sobering story of the decline of US competitiveness in the manufacture of electrical and optical equipment, value-added trade statistics reveal the continued robustness of the United States' comparative advantage in the electronics industry. Thus, it appears that the US continues to contribute significant value-added in the creation of intermediate inputs, for example, despite having outsourced much of the manufacturing of its electronics devices abroad.

Figures 6.1 – 6.6: Gross vs. value-added revealed comparative advantage for the Electrical & Optical Equipment industry (c14)

Manufacture of office machinery and computers
Manufacture of electrical machinery and apparatus n.e.c.
Manufacture of radio, television and communication equipment and apparatus
Manufacture of medical, precision and optical instruments, watches and clocks

Figure 6.1

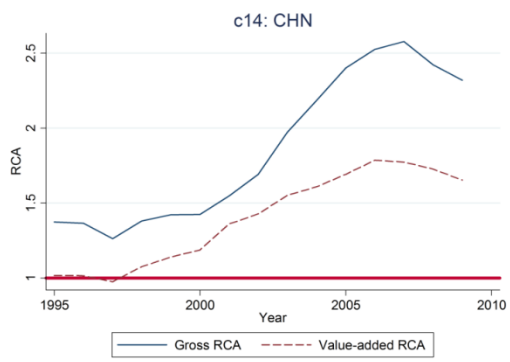


Figure 6.2

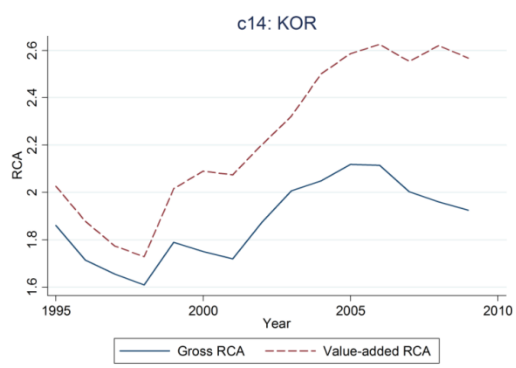


Figure 6.3

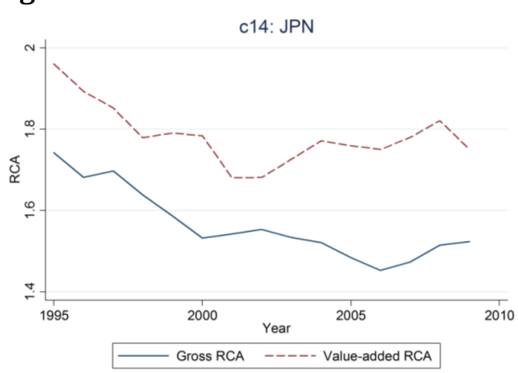


Figure 6.4

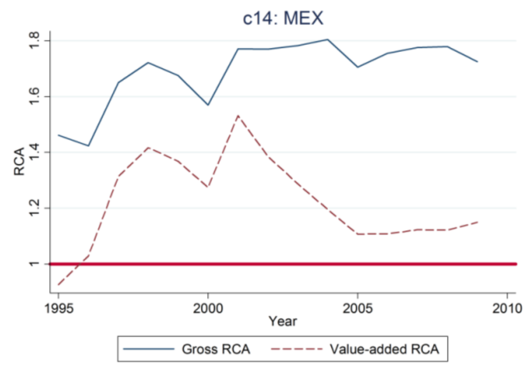


Figure 6.5

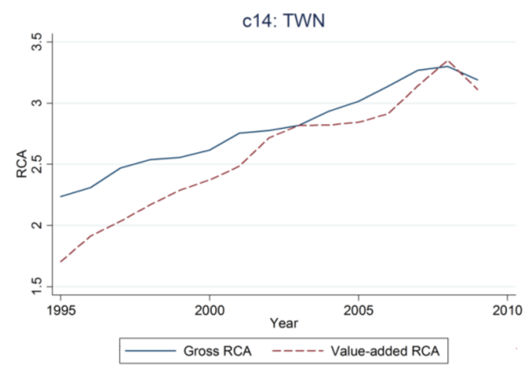
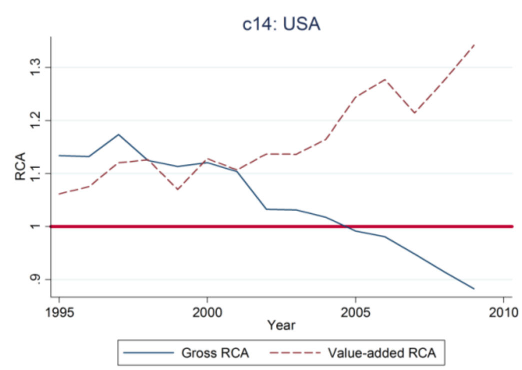


Figure 6.6



Source: Author's calculations and USITC decompositions of WIOD data provided by Dr. Zhi Wang.

Using value-added instead of gross trade statistics is clearly important to understanding true trends in comparative advantage. Moreover, these trends in revealed comparative advantage are robust to large fluctuations in exchange rates from 1995-2009, such as South Korea's devaluation of the won in 1998 following the Asian financial crisis.[19] In order to demonstrate that trends in revealed comparative advantage are not greatly influenced by fluctuations in exchange rates, I use a constant exchange rate (2004) for the whole 1995-2009 period to recalculate gross exports and domestic value-added in exports for all years, then use these recalculated export statistics to re-compute RCA. Examining the electronics industry, the effect of exchange rate fluctuations is minimal, with a less than 3% difference at the most between value-added RCA calculated using constant exchange rates and value-added RCA calculated using current year exchange rates.[20] This demonstrates that when different international currencies are used, fluctuations in exchange rates used to convert these currencies into US dollars do not have much of an impact on electronics exports as a share of total world exports, despite the fact that a few countries that have experienced large changes in exchange rates during 1995-2009 are key players in electronics exports (ie. South Korea). Thus, the RCA

[19] Note that it is not that changes in exchange rates do not have an effect on exports (for example, a devaluation could stimulate exports), but that a change in the exchange rate should not greatly affect the composition of the country's exports. However, when calculating RCA, the changes in exchange rates will affect the structure of global exports when different international currencies are used, especially when the sector examined is heavily dominated by one or a few countries. This method of using a constant exchange rate corrects for this effect on RCA. Of course, the exchange rate effect examined here takes the exchange rate as an exogenous variable. As an endogenous variable, the effect of exchange rate fluctuations is more complex since the exchange rate has an effect on trade structures. The effect of the exchange rate may vary by country based on how much imported content is in a country's exports, for example. See Appendix A for further discussion.

[20] This method corrects for the exchange rate effects of WIOD countries only. Figures for the Rest of the World (RoW) are used as given in the WIOTs, since external data for RoW was already given in dollars (UN data in dollars). The effect of the RoW should have minimal impact on the calculation of exchange rate effects on RCA since no countries in the RoW are major players in the electronics industry, for example. Therefore, the RoW has very little impact on electronics exports as a share of total world exports.

trends illustrated do not appear to be greatly influenced by changes in exchange rates used to convert international currencies into US dollars.

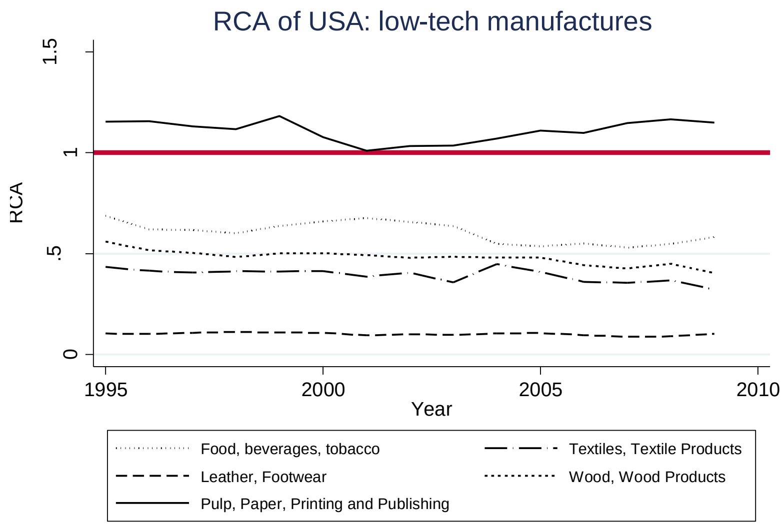
Undoubtedly, as the example of the electronics industry illustrates, indicators of competitiveness such as revealed comparative advantage are affected by the measurement of trade in gross versus value-added terms. Indications of comparative advantage calculated using gross exports can be misleading in different directions depending on whether the country is relatively upstream or downstream within global supply chains. Thus, analyses of comparative advantage must account for the fragmentation of production in order to provide an accurate depiction of a country's true comparative advantage in industries where global supply chains play a major role.

6.2 Value-added approach to comparative advantage: United States

The rapid rise of Korea, Taiwan, and China in manufactures has created a pervasive fear that even advanced manufacturing competitiveness in industrialized economies like the U.S. and Japan face a painful decline. Clearly, this fear is not unfounded as demonstrated by the rapid rise of Korea, Taiwan, and China in revealed comparative advantage in the electronics and optical equipment manufacturing industries, which are classified by the OECD as the "high technology" manufacturing industries (Eurostat 2011, 2). Although the apparent rise of RCA in China, for example, is much less rapid using measures of value-added trade, the high and rising trend is undeniable as Chinese domestic input suppliers increase their quality over time, and multinationals move more and more of their upstream production into China (Wei 2012, 3). Indeed, in their Report to the President on Capturing Domestic Competitive Advantage in Advanced Manufacturing, the President's Council of Advisors on Science and Technology (PCAST) recently sounded the alarm that the United States' leadership in advanced manufacturing is at risk (PCAST 2012, V). Looking at measures of value-added trade, however, demonstrates that opportunities in advanced manufacturing are certainly not over. In fact, the value-added perspective to comparative advantage reveals that the United States' comparative advantage is growing most robustly in the manufacture of electronics and optical equipment, the highest technology manufacturing industry.

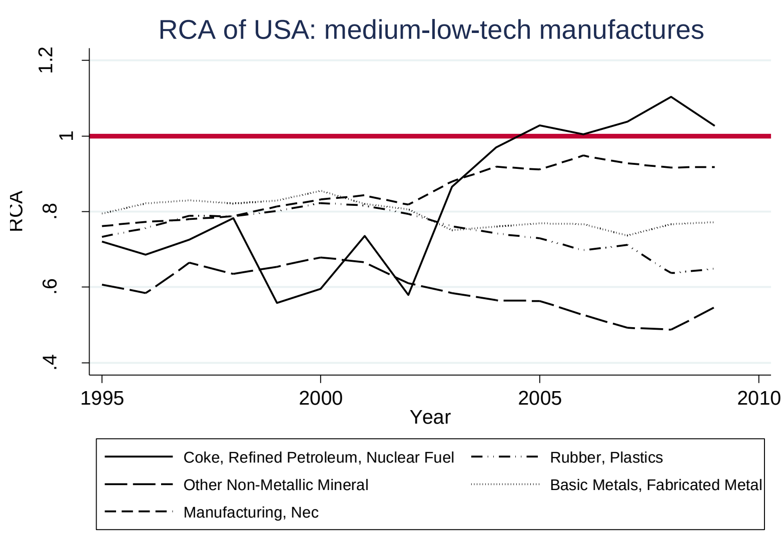
Figures 6.7 – 6.9 graph the United States' revealed comparative advantage calculated using domestic value-added in exports for all manufacturing industries in the World Input Output Database, divided by OECD global technological intensity classification (Eurostat 2011, 2). As Figures 6.7-6.9 illustrate, the US tends to have a comparative advantage in medium-high-technology (transport equipment) and high-technology manufacturing industries (electronics and optical equipment). Moreover, although the US shows flat or declining RCA in most low and medium-low-technology industries (with the exception of manufacturing n.e.c. and the coke, refined petroleum and nuclear fuel industries), revealed comparative advantage appears to be highest and increasing most robustly in electronics and optical equipment manufacturing, the industries classified as high-technology manufacturing industries.

Figure 6.7: RCA of USA by manufactures, low-technology



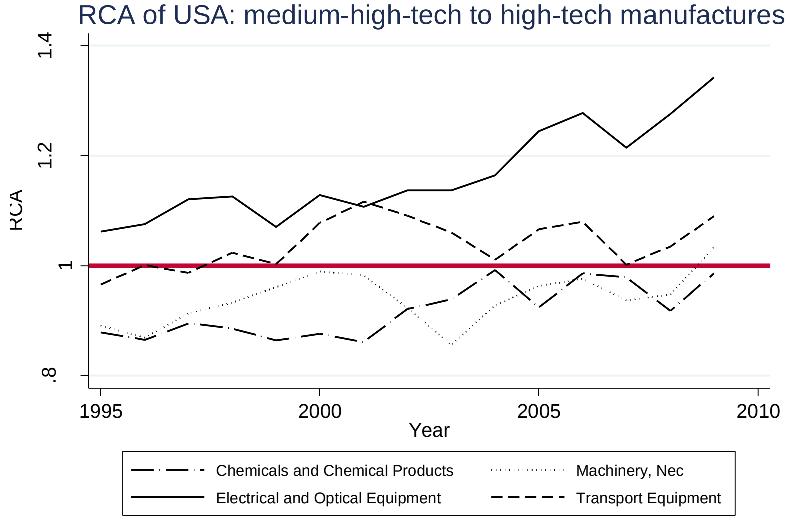
Source: Author's calculations and USITC decompositions of WIOD data provided by Dr. Zhi Wang. Manufacturing industries classified according to their global technological intensity, NACE Revision 1.1, OECD classification (Eurostat, 2011, 2).

Figure 6.8: RCA of USA by manufactures, medium-low-technology



Source: Author's calculations and USITC decompositions of WIOD data provided by Dr. Zhi Wang. Manufacturing industries classified according to their global technological intensity, NACE Revision 1.1, OECD classification (Eurostat 2011, 2).

Figure 6.9: RCA of USA by manufactures, medium-high-technology to high-technology



Source: Author's calculations and USITC decompositions of WIOD data provided by Dr. Zhi Wang. Manufacturing industries classified according to their global technological intensity, NACE Revision 1.1, OECD classification (Eurostat 2011, 2).

Evidently, the World Input Output Database's extended timeframe of analysis combined with the value-added approach to trade demonstrate that rather than losing comparative advantage in advanced manufacturing, the USA's comparative advantage is growing most robustly in the highest technology manufacturing industries. While the President's Council of Advisors on Science and Technology may be correct that "the United States has, in fact, run a trade deficit in advanced technology products every year since 2002," the value-added approach to revealed comparative advantage demonstrates that they are not correct in deducing that the United States faces a decline in advanced manufacturing competitiveness (PCAST 2012, 8). First, comparative advantage has little to do with the trade deficit, which is a function of the US consuming more than it saves.[21] Second, as these results highlight, to correctly interpret official trade statistics in

[21] Savings – Investment = Current Account.

calculating measures of comparative advantage, we must use measures of domestic value-added in exports instead of gross exports.

Conclusions

This section underscores the importance of using domestic value-added in exports as opposed to gross exports in understanding the true comparative advantage of nations in industries where the fragmentation of production is pervasive. Taking the electronics industry as a prime example of this phenomenon, this section unveils important differences in revealed comparative advantage calculated using gross and value-added measures. In line with our understanding of how the US, Japan, Korea, Taiwan, China, and Mexico participate within global supply chains from Section 5, I find that within the electronics industry, relatively downstream economies like China appear less competitive using value-added measures of comparative advantage, while relatively upstream nations like the US and Japan appear more competitive. More importantly, this section provides a first look in the literature at the extent to which long-term trends in revealed comparative advantage can differ using the value-added and gross trade approaches. In fact, while gross trade statistics describe the decline of US competitiveness in the electronics industry, value-added trade statistics reveal the robust growth of the United States' comparative advantage in electronics manufacturing.

Using the value-added approach to re-examine the comparative advantage of the US by manufacturing industry also calls into question popular beliefs about US manufacturing competitiveness. In fact, I find that rather than losing comparative advantage in advanced manufacturing, the United States' gains in comparative advantage are most robust in the highest-technology manufacturing industries. Of course, that is not to say that China, for instance, is not doing very well, or that all industrialized countries are maintaining competitiveness. Indeed, while China's RCA index in electronics has increased significantly since 1995, Japan's RCA index in electronics has experienced a slow decline.[22] In comparison to Japan then, the United States demonstrates a positive momentum in advanced manufacturing that is especially encouraging.

7 Conclusion

In fiscal 2012 alone, Apple sold 125 million iPhones, all of which were outfitted with touchscreen controllers from the US, DRAM memory from Korea, and cameras from Taiwan ("Apple Hardware Sales," Etherington 2012) , (OECD-WTO 2012, 2). All of these parts found their way through the Apple iPhone supply chain to China, where they were assembled and exported to the rest of the world. While these 125 million iPhones were a milestone for Apple, they barely represent the tip of the iceberg in the phenomenon called "the fragmentation of production." This fragmentation of production across countries is especially prevalent in electronics, and by now a widespread and sophisticated process that touches nearly every industry.

Although companies like Apple have wasted no time in embracing global supply chains, the economics literature has been comparably slow in incorporating this trend, largely because of a lack of available data. Using the newly available World Input-Output Database, this paper makes three main contributions to the literature.

First, in Section 5, I document how participation in global supply chains has evolved over time. I show that although advanced economies still dominate at the

[22] Although China's increase in RCA index from 1995-2009 is impressive, it is important to keep in mind from Section 5 that China's role in supply chains is still very different from that of the United States or Japan.

upstream of supply chains, newly industrialized and emerging economies are participating in more upstream activities as they produce more intermediate inputs over time. For example, as highlighted in Section 5.2, Taiwan experienced a considerable transition from 1995, when nearly half of it value-added was exported in final goods, to the present, when most of its domestic value-added is exported through intermediates. Additionally, as underscored in Section 5.3, China and Mexico too, have been producing and exporting more intermediates over time while the United States and Japan appear to be utilizing more foreign content. Thus, while advanced nations certainly still dominate at the upstream of global supply chains, emerging markets are increasingly providing intermediate inputs as the quality of their input suppliers increases over time and multinationals move more of their upstream production to emerging economies.

My second contribution is to show for the first time in the literature how long-term trends in comparative advantage can diverge significantly when trade is understood in terms of domestic value-added in exports as opposed to gross exports. Indeed, in Section 6.1, I demonstrate that while gross trade statistics tell a sobering story of the decline of US competitiveness in the electronics industry, value-added trade statistics reveal the rising robustness of the United States' comparative advantage in electronics. Further, building upon our understanding of how countries participate in global supply chains from Section 5, I highlight that relatively downstream economies like China appear less competitive using value-added measures of comparative advantage, as their gross exports tend to overstate their productive capacity. On the other hand, relatively upstream nations like the US and Japan appear more competitive in value-added terms.

My third contribution is to illustrate how the value-added approach also provides a new understanding of how comparative advantage has evolved over time for the United States by manufacturing industry. Contrary to the fears expressed by the President's Council about the declining competitiveness of advanced manufacturing in the United States, I find in Section 6.2 that rather than losing comparative advantage in advanced manufacturing, the United States' comparative advantage is growing most robustly in the highest technology manufacturing industries.

Clearly, this paper contributes significantly to the literature on value-added trade by highlighting how global supply chain participation and value-added measures of comparative advantage have evolved over time. However, this contribution would not be possible without the work of the World Input Output Database team in compiling the first set of methodologically consistent world input output tables that span an extended time period. Despite this significant step forward in the literature, it is important to note that the level of aggregation in the WIOD data (35 industries) means that measures of cross-border specialization are likely underestimated. While this level of aggregation is necessary to maximize cross country comparability for example, such aggregation can create biases if exporting companies within a certain industry employ different production processes and produce different products from non-exporting companies (OECD-WTO 2012, 16), (Ahmad and Araujo 2011, 3). For example, aggregation can lead to underestimation of cross-border specialization if exporting companies tend to import more intermediates (Ahmad and Araujo 2011, 3).[23] Nevertheless, by

[23] This aggregation bias, as it is termed in the literature, has been confirmed for the US by Bernard et al. (2007). Using matched plant-level import and export data for the period 1992 to 2000, they find that U.S. plants that tend to import more also tend to export more. However, the aggregation bias is likely not particularly significant for developed nations like the US. Indeed, a study by the US National Research

demonstrating the potential for value-added trade statistics to be significantly more illuminating regarding the comparative advantage of nations, this paper encourages future work in exploring methods of differentiating between types of companies in a sector in order to improve the quality of value-added trade estimates (OECD-WTO 2012, 16).[24]

In its Report to the President on Capturing Domestic Competitive Advantage in Advanced Manufacturing, the President's Council of Advisors on Science and Technology (PCAST) sounds the alarm that the United States' leadership in advanced manufacturing is at risk. Lamenting large trade deficits in manufactured goods, including in advanced technology products, the President's Council contends that the US is gradually ceding its position as a leader in advanced manufacturing to countries like Korea, Japan, and China (PCAST 2012, 7, 10). While the US trade deficit is undeniable, the results of this paper cast doubt upon conclusions that the US faces declining competitiveness in advanced manufacturing industries. Although Japan is slowly ceding its dominance in electronics manufacturing, perhaps to neighbors like Taiwan, Korea, and China, this paper finds that the United States is actually gaining comparative advantage in advanced manufacturing industries when we look at comparative advantage using domestic value-added in exports. This is significant because as the report by the President's Council highlights, notions of competitiveness are highly relevant to policymakers. In an era when policymakers are too often tempted to implement protectionist trade policies in response to large trade deficits and a misguided sense of

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Council (NRC) compares foreign content computed from a 9 product US IO table and a 91 product IO table. The NRC study finds the differences to be quite small. Using the 91 product table, the NRC team finds that direct imported inputs make up 6.7% of exports, and direct and indirect comprise 10.4%. This does not differ significantly from the results of the 9 product analysis, in which direct imported inputs comprise 5.7% of exports and direct and indirect comprise 9.5% (Leamer et. al. 2006, 35).

[24] The use of micro-data, for example, is one possible method (OECD-WTO 2012, 16).

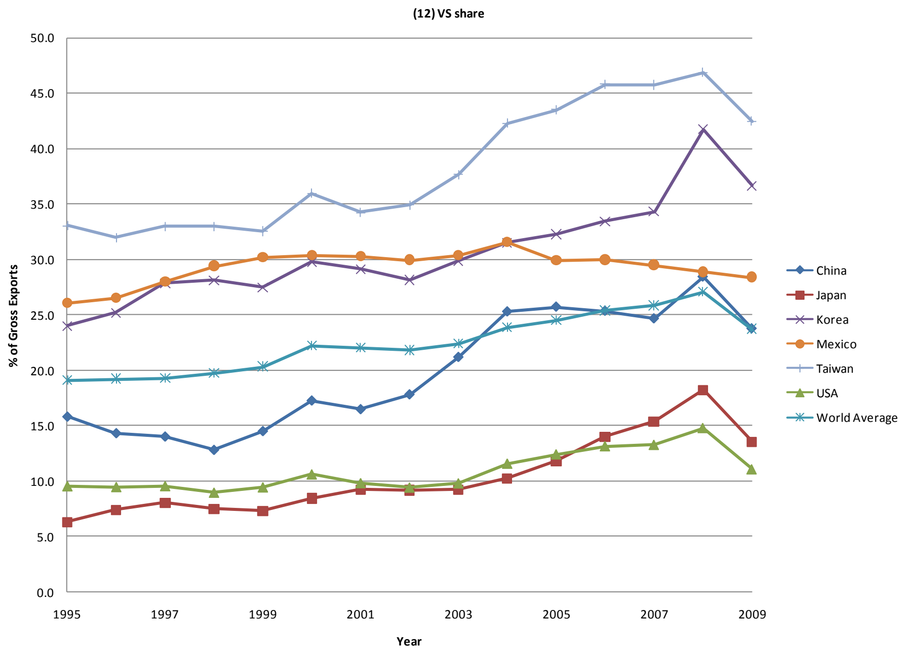
competitiveness, this paper emphasizes the United States' capacity for resilience in a world in which we work together to create products that are not necessarily Made in China, or Made in the U.S.A, but Made in the World.[25]

[25] See the WTO's "Made in the World" initiative: http://www.wto.org/english/res_e/statis_e/miwi_e/miwi_e.htm.

Appendix A: The influence of exchange rates and relative prices on estimates of value-added trade

Measures of value-added trade are affected by two separate forces: 1) globalization and the fragmentation of supply chains reflecting changes in technology and changes in factor costs, and 2) changes in exchange rates and other relative prices (e.g. oil). It is important to note that measures of the share of imported intermediates in gross exports are sensitive to changes in exchange rates and other relative prices such as oil. For example, as shown in Figure 5.3 (reproduced below in Figure A.1), there is a sharp increase in foreign content as a share of gross exports (VS) from 2007-2008 and a decrease from 2008-2009. This is likely due to an exchange rate effect from 2007-2008 and a price effect from 2008-2009. The dollar appreciated versus other currencies in 2008, and since major commodities are priced in dollars, the appreciation of the dollar would cause the value of imported content in gross exports to rise, causing a rise in the share of foreign content in gross exports. The subsequent fall in foreign content from 2008-2009 may be due to a price effect, where the prices of raw materials declined in 2009, causing imported content in gross exports to decline.

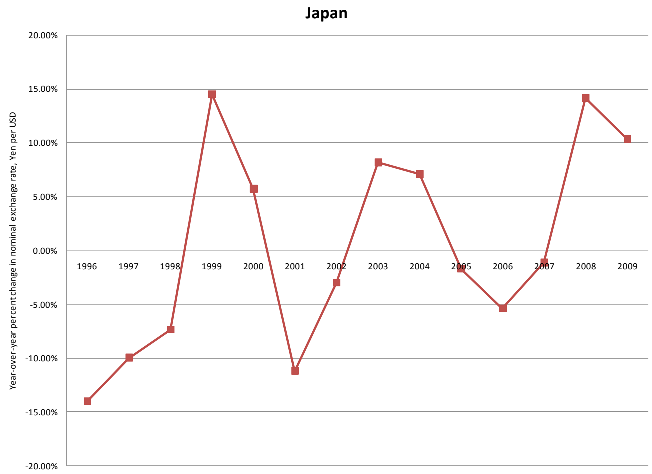
Figure A.1: VS, Foreign content as a share of gross exports



Source: Author's calculations and USITC decompositions of WIOD data provided by Dr. Zhi Wang.

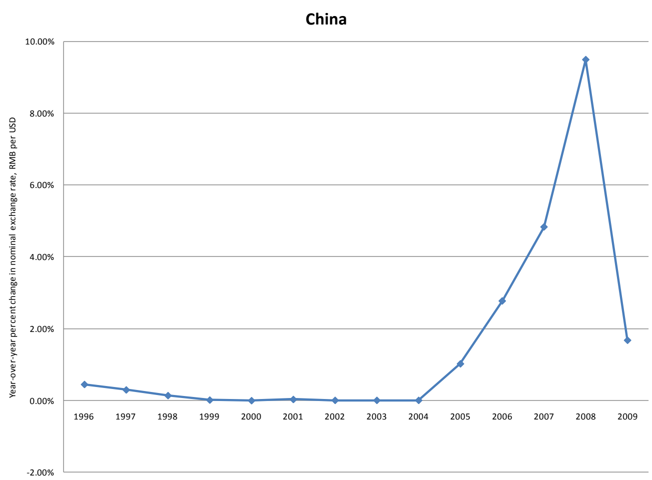
In addition, taken as an endogenous variable, fluctuations in exchange rates may also influence measures of comparative advantage for each country to various degrees depending on how much imported content is in a country's exports, for example. For instance, both Japan and China have experienced notable exchange rate appreciations in recent years, Japan since the financial crisis in 2008, and China since the appreciation of the RMB in July 2005. (Figures A.2 and A.3 illustrate the year-over-year percent change in nominal exchange rate versus the USD for the Japanese Yen and Chinese RMB). The influence of these exchange rate fluctuations on Japan's comparative advantage may be larger than on China, however, because Chinese exports tend to contain more foreign content versus Japanese exports (see Figure A.1). In particular, the low domestic value-added share in Chinese exports to countries like the US may partially explain why China's exports to the US have continued to expand rapidly in spite of the significant appreciation of the RMB since 2005 (Wei 2012, 4). This example offers another illustration of the importance of incorporating an understanding of global supply chains and value-added trade into discussions of comparative advantage, and points to an avenue of future research in developing an econometric model to explain changes in RCA indices over time that use the exchange rate and other economic variables that may affect RCA as regressors to further illuminate the effect that exchange rate fluctuations have on measures of comparative advantage.

Figure A.2: Year-over-year percent change in nominal exchange rate, Yen per USD



Source: WIOD, from IMF statistics.

Figure A.3: Year-over-year percent change in nominal exchange rate, RMB per USD



Source: WIOD, from IMF statistics.

Appendix B: Data

Table B.1: List of countries in WIOD database

European Union			North America	Asia & Pacific
Austria	Germany	Netherlands	Canada	China
Belgium	Greece	Poland	United States	India
Bulgaria	Hungary	Portugal		Japan
Cyprus	Ireland	Romania	**Latin America**	South Korea
Czech Republic	Italy	Slovak Republic	Brazil	Australia
Denmark	Latvia	Slovenia	Mexico	Taiwan
Estonia	Lithuania	Spain		Turkey
Finland	Luxembourg	Sweden		Indonesia
France	Malta	United Kingdom		Russia

Source: WIOD Contents, Sources, and Methods.

Table B.2: List of 35 industries in WIOTs

NACE	WIOT Industry number	Industry
AtB	1	Agriculture, Hunting, Forestry and Fishing
C	2	Mining and Quarrying
15t16	3	Food, Beverages and Tobacco
17t18	4	Textiles and Textile Products
19	5	Leather, Leather and Footwear
20	6	Wood and Products of Wood and Cork
21t22	7	Pulp, Paper, Paper , Printing and Publishing
23	8	Coke, Refined Petroleum and Nuclear Fuel
24	9	Chemicals and Chemical Products
25	10	Rubber and Plastics
26	11	Other Non-Metallic Mineral
27t28	12	Basic Metals and Fabricated Metal
29	13	Machinery, Nec
30t33	14	Electrical and Optical Equipment
34t35	15	Transport Equipment
36t37	16	Manufacturing, Nec; Recycling
E	17	Electricity, Gas and Water Supply
F	18	Construction
50	19	Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel
51	20	Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles
52	21	Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods
H	22	Hotels and Restaurants
60	23	Inland Transport
61	24	Water Transport
62	25	Air Transport
63	26	Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies
64	27	Post and Telecommunications
J	28	Financial Intermediation
70	29	Real Estate Activities
71t74	30	Renting of M&Eq and Other Business Activities
L	31	Public Admin and Defence; Compulsory Social Security
M	32	Education
N	33	Health and Social Work
O	34	Other Community, Social and Personal Services
P	35	Private Households with Employed Persons

Source: WIOD Contents, Sources, and Methods.

Table B.3: List of variables in WIOTs

Row Variable	Definition
Total intermediate consumption	Total use of products as inputs within the specified industry (column), equal to the sum of rows 7 through 1441 for a specific column
Taxes less subsidies on products	What purchasers pay in tax on products to (or receive in subsidies on products from) a government unit
Cif/ fob adjustments on exports	Adjustment for cost, insurance and freight / free on board
Direct purchases abroad by residents	Final consumption expenditure adds direct purchases abroad by residents
Purchases on the domestic territory by non-residents	Final consumption expenditure subtracts purchases on the domestic territory by non-residents
Value added at basic prices	Value added based on the price the supplier receives for the good / service exchanged (basic price)
International Transport Margins	Margin on transport
Output at basic prices	Total output in the industry specified, equivalent to the sum of all of the above

Column Variable	Definition
Final consumption expenditure by households	Outlays which households make on new goods and services
Final consumption expenditure by non-profit organisations serving households (NPISH)	Includes compensation of employees, intermediate consumption, consumption of fixed capital, taxes less subsidies, minus any payment received from households for services
Final consumption expenditure by government	Includes compensation of employees, intermediate consumption, consumption of fixed capital, taxes less subsidies, minus any payment received from households for services
Gross fixed capital formation	(Investment)Additions to the assets of producers which have an expected lifetime of use of one year or more.
Changes in inventories and valuables	Works in progress (inventories), goods acquired as a store of value (valuables)
Total Output	Total output by the industry specified, equivalent to the sum of all columns to the left in the specified row

Source: WIOD Contents, Sources, and Methods.

Table B.4: Exchange rates used in WIOTs

Exchange rates used in constructing the International SUTs and WIOTs
US$ per Unit of Local currency

Country	*Acronym*	_1995	_1996	_1997	_1998	_1999	_2000	_2001	_2002	_2003	_2004	_2005	_2006	_2007	_2008	_2009	_2010
Australia	AUS	0.7415	0.78295	0.74406	0.6294	0.64533	0.58235	0.51764	0.5439	0.65188	0.73658	0.76384	0.75335	0.83856	0.85527	0.7913	0.9195
Austria	AUT	1.36646	1.30031	1.12904	1.11319	1.0658	0.9236	0.8956	0.9456	1.1312	1.2439	1.2441	1.2556	1.3705	1.4708	1.3948	1.3257
Belgium	BEL	1.36996	1.30344	1.12923	1.11293	1.0658	0.9236	0.8956	0.9456	1.1312	1.2439	1.2441	1.2556	1.3705	1.4708	1.3948	1.3257
Bulgaria	BGR	14.893	7.75075	0.64323	0.56916	0.54526	0.47226	0.45804	0.48297	0.57815	0.63552	0.63626	0.64189	0.70077	0.75157	0.7127	0.67814
Brazil	BRA	1.09202	0.99533	0.92804	0.86229	0.55432	0.5473	0.4284	0.35355	0.32699	0.34242	0.4126	0.4597	0.5136	0.54533	0.50014	0.56848
Canada	CAN	0.72884	0.73347	0.7224	0.67484	0.6731	0.67361	0.64587	0.63736	0.71581	0.76998	0.82579	0.88179	0.93517	0.94289	0.87887	0.97094
China	CHN	0.11975	0.12028	0.12063	0.12079	0.1208	0.12079	0.12082	0.12082	0.12082	0.12082	0.12205	0.12543	0.13149	0.14397	0.14638	0.14772
Cyprus	CYP	1.2942	1.2552	1.13987	1.13201	1.07923	0.94269	0.9106	0.96165	1.13288	1.25051	1.26248	1.27637	1.37523	1.4708	1.3948	1.3257
Czech Republic	CZE	0.03769	0.03685	0.03173	0.03109	0.02897	0.02602	0.02631	0.03069	0.03551	0.03899	0.04179	0.04433	0.04945	0.059	0.0528	0.05248
Germany	GER	1.36626	1.30024	1.12945	1.11308	1.0658	0.9236	0.8956	0.9456	1.1312	1.2439	1.2441	1.2556	1.3705	1.4708	1.3948	1.3257
Denmark	DNK	0.17872	0.1725	0.15161	0.14946	0.14353	0.12409	0.12025	0.12707	0.15208	0.16708	0.16704	0.16832	0.18396	0.19712	0.18704	0.17814
Spain	ESP	1.33555	1.31412	1.13792	1.1153	1.0658	0.9236	0.8956	0.9456	1.1312	1.2439	1.2441	1.2556	1.3705	1.4708	1.3948	1.3257
Estionia	EST	1.36599	1.30647	1.12834	1.11319	1.06743	0.92464	0.89232	0.94484	1.13117	1.2435	1.2453	1.2563	1.3704	1.47027	1.39349	1.32769
Finland	FIN	1.36319	1.29488	1.1469	1.11405	1.0658	0.9236	0.8956	0.9456	1.1312	1.2439	1.2441	1.2556	1.3705	1.4708	1.3948	1.3257
France	FRA	1.3153	1.28259	1.12531	1.11347	1.0658	0.9236	0.8956	0.9456	1.1312	1.2439	1.2441	1.2556	1.3705	1.4708	1.3948	1.3257
United Kingdom	GBR	1.57847	1.56174	1.6377	1.65641	1.61822	1.51611	1.43996	1.50126	1.63437	1.8318	1.8204	1.84263	2.00168	1.85324	1.56448	1.54611
Greece	GRC	1.47176	1.41575	1.24959	1.15473	1.11399	0.93593	0.8956	0.9456	1.1312	1.2439	1.2441	1.2556	1.3705	1.4708	1.3948	1.3257
Hungary	HUN	0.008	0.00656	0.00537	0.00467	0.00422	0.00356	0.00349	0.00389	0.00446	0.00494	0.00502	0.00476	0.00545	0.00587	0.00498	0.00483
Indonesia	IDN	0.00044	0.00043	0.00036	0.0001	0.00013	0.00012	0.0001	0.00011	0.00012	0.00011	0.0001	0.00011	0.00011	0.0001	0.0001	0.00011
India	IND	0.0309	0.02823	0.02756	0.02427	0.02323	0.02227	0.02119	0.02057	0.02148	0.02207	0.02268	0.02208	0.02423	0.02313	0.02067	0.02188
Ireland	IRL	1.26306	1.26058	1.1955	1.12286	1.0658	0.9236	0.8956	0.9456	1.1312	1.2439	1.2441	1.2556	1.3705	1.4708	1.3948	1.3257
Italy	ITA	1.18937	1.25523	1.13828	1.11672	1.0658	0.9236	0.8956	0.9456	1.1312	1.2439	1.2441	1.2556	1.3705	1.4708	1.3948	1.3257
Japan	JPN	0.0107	0.0092	0.00828	0.00767	0.00878	0.00928	0.00824	0.00799	0.00864	0.00925	0.00909	0.0086	0.0085	0.0097	0.0107	0.01141
Korea	KOR	0.0013	0.00124	0.00107	0.00072	0.00084	0.00088	0.00077	0.0008	0.00084	0.00087	0.00098	0.00105	0.00108	0.00092	0.00079	0.00087
Lithuania	LTU	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.27281	0.32727	0.35999	0.36105	0.36366	0.3968	0.42628	0.40358	0.38441
Luxembourg	LUX	1.36996	1.30344	1.12923	1.11293	1.0658	0.9236	0.8956	0.9456	1.1312	1.2439	1.2441	1.2556	1.3705	1.4708	1.3948	1.3257
Latvia	LVA	1.89652	1.81579	1.72167	1.69602	1.70923	1.65079	1.59279	1.61882	1.75066	1.85151	1.77361	1.78596	1.94904	2.0897	1.98301	1.8886
Mexico	MEX	0.15727	0.13164	0.12633	0.1101	0.10471	0.10579	0.1071	0.10377	0.09276	0.08863	0.0918	0.09179	0.09151	0.09065	0.07412	0.07916
Malta	MLT	1.21633	1.19111	1.11291	1.10516	1.07491	0.98115	0.95415	0.99169	1.1395	1.24651	1.24322	1.25985	1.37974	1.4708	1.3948	1.3257
Netherlands	NLD	1.37374	1.3076	1.13085	1.11243	1.0658	0.9236	0.8956	0.9456	1.1312	1.2439	1.2441	1.2556	1.3705	1.4708	1.3948	1.3257
Poland	POL	0.41252	0.37152	0.30611	0.28796	0.2526	0.23046	0.24438	0.2452	0.25724	0.27482	0.30942	0.32256	0.36259	0.42061	0.3229	0.33255
Portugal	PRT	1.32779	1.30003	1.14548	1.11476	1.0658	0.9236	0.8956	0.9456	1.1312	1.2439	1.2441	1.2556	1.3705	1.4708	1.3948	1.3257
Romania	ROU	4.97649	3.27163	1.41439	1.13311	0.66351	0.46644	0.34528	0.30259	0.30127	0.30703	0.34364	0.35655	0.41074	0.40011	0.32879	0.31548
Russia	RUS	0.21938	0.19553	0.17306	0.12796	0.04073	0.03555	0.0343	0.03199	0.0326	0.03471	0.03536	0.0368	0.03912	0.04038	0.03162	0.03294
Slovak Republic	SVK	1.0142	0.98303	0.89628	0.85525	0.71859	0.65695	0.62326	0.6667	0.82098	0.93536	0.97288	1.0166	1.22284	1.41667	1.3948	1.3257
Slovenia	SVN	2.0248	1.77159	1.51717	1.444	1.32165	1.08169	0.98831	0.99919	1.15858	1.24685	1.24548	1.25559	1.3705	1.4708	1.3948	1.3257
Sweden	SWE	0.14043	0.14916	0.13111	0.12583	0.12105	0.10952	0.09698	0.10302	0.12395	0.13629	0.13424	0.13574	0.14813	0.15344	0.13142	0.13903
Turkey	TUR	21.9167	12.6667	6.83333	3.91667	2.51217	1.68717	0.88873	0.66616	0.67171	0.69817	0.74441	0.70219	0.77065	0.77671	0.64657	0.66593
Taiwan	TWN	0.03777	0.03642	0.03489	0.0299	0.03099	0.03203	0.02959	0.02892	0.02905	0.02992	0.03109	0.03074	0.03045	0.03173	0.03026	0.0316
United States	USA	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Source: IMF Statistics

Source: WIOD, from IMF Statistics.
National SUTs serve as the building blocks for the WIOT. National SUTs are in national currencies and are converted to US dollars for the WIOT using official exchange rates from IMF listed above. The IMF market exchange rates used by the WIOD are simple annual averages of monthly exchange rates.

Figure B.1: Input-output flow table and accounts

	Industry A	Industry B	Industry C	Final demand	Total output
Industry A	0	20	45	35	100
Industry B	30	0	30	140	200
Industry C	0	80	0	70	150
Value added	70	100	75		
Total input	100	200	150		

Source: UN Handbook of Input-Output Compilation and Analysis.

Figure B.2: Schematic outline of WIOT, three regions

		Country A Intermediate *Industry*	Country B Intermediate *Industry*	Rest of World Intermediate *Industry*	Country A Final domestic	Country B Final domestic	Rest of Final domestic	Total
Country A	*Industry*	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	*Industry*	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)	*Industry*	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				

Source: Timmer et. al. 2012c, 15.

Appendix C: Domestic value-added in exports at the sector level

Below is a two country two sector case (in which one country exports to another country, which is also the rest of the world) of how domestic value-added in exports can be expressed mathematically at the sector level. For the first sector (1), the domestic value added in exports in a 2-country 2-sector inter-country input-output model can be expressed as in *equation C(1).*[26] Although expressing domestic value-added in exports at the sector level is relatively complex, it is conceptually analogous to domestic value-added in exports at the aggregate level. *Equation C(1)* states that the domestic value-added in exports in sector 1 for country s can be expressed as the sum of: 1) domestic value from sector 1 in final goods exports from s to r, 2) domestic value from sector 1 in intermediate exports from s that are absorbed by r, 3) domestic value from sector 1 (exported in intermediates from country s) that returns to country s via imports of final goods, and 4) domestic value from sector 1 (exported in intermediates from country s) that returns to country s via imports of intermediate goods.

C(1)

$$
\begin{aligned}
DV_1^{sr} =& \begin{bmatrix} v_1^s & 0 \end{bmatrix} \begin{bmatrix} b_{11}^{ss} & b_{12}^{ss} \\ b_{21}^{ss} & b_{22}^{ss} \end{bmatrix} \begin{bmatrix} y_1^{sr} \\ y_2^{sr} \end{bmatrix} + \begin{bmatrix} v_1^s & 0 \end{bmatrix} \begin{bmatrix} 1-a_{11}^{ss} & -a_{12}^{ss} \\ -a_{21}^{ss} & 1-a_{22}^{ss} \end{bmatrix}^{-1} \begin{bmatrix} a_{11}^{sr} & a_{12}^{sr} \\ a_{21}^{sr} & a_{22}^{sr} \end{bmatrix} \begin{bmatrix} b_{11}^{rr} & b_{12}^{rr} \\ b_{21}^{rr} & b_{22}^{rr} \end{bmatrix} \begin{bmatrix} y_1^{rr} \\ y_2^{rr} \end{bmatrix} \\
&+ \begin{bmatrix} v_1^s & 0 \end{bmatrix} \begin{bmatrix} 1-a_{11}^{ss} & -a_{12}^{ss} \\ -a_{21}^{ss} & 1-a_{22}^{ss} \end{bmatrix}^{-1} \begin{bmatrix} a_{11}^{sr} & a_{12}^{sr} \\ a_{21}^{sr} & a_{22}^{sr} \end{bmatrix} \left\{ \begin{bmatrix} b_{11}^{rr} & b_{12}^{rr} \\ b_{21}^{rr} & b_{22}^{rr} \end{bmatrix} \begin{bmatrix} y_1^{rs} \\ y_2^{rs} \end{bmatrix} + \begin{bmatrix} b_{11}^{rs} & b_{12}^{rs} \\ b_{21}^{rs} & b_{22}^{rs} \end{bmatrix} \begin{bmatrix} y_1^{ss} \\ y_2^{ss} \end{bmatrix} \right\} \\
&= (v_1^s b_{11}^{ss} y_1^{sr} + v_1^s b_{12}^{ss} y_2^{sr} + v_1^s l_{11}^{ss} (a_{11}^{sr} b_{11}^{rr} y_1^{rr} + a_{12}^{sr} b_{21}^{rr} y_1^{rr} + a_{11}^{sr} b_{12}^{rr} y_2^{rr} + a_{12}^{sr} b_{22}^{rr} y_2^{rr}) \\
&+ v_1^s l_{12}^{ss} (a_{21}^{sr} b_{11}^{rr} y_1^{rr} + a_{22}^{sr} b_{21}^{rr} y_1^{rr} + a_{21}^{sr} b_{12}^{rr} y_2^{rr} + a_{22}^{sr} b_{22}^{rr} y_2^{rr}) \\
&+ v_1^s l_{11}^{ss} (a_{11}^{sr} b_{11}^{rr} y_1^{rs} + a_{12}^{sr} b_{21}^{rr} y_1^{rs} + a_{11}^{sr} b_{12}^{rr} y_2^{rs} + a_{12}^{sr} b_{22}^{rr} y_2^{rs}) \\
&+ v_1^s l_{12}^{ss} (a_{21}^{sr} b_{11}^{rr} y_1^{rs} + a_{22}^{sr} b_{21}^{rr} y_1^{rs} + a_{21}^{sr} b_{12}^{rr} y_2^{rs} + a_{22}^{sr} b_{22}^{rr} y_2^{rs}) \\
&+ v_1^s l_{11}^{ss} (a_{11}^{sr} b_{11}^{rs} y_1^{ss} + a_{12}^{sr} b_{21}^{rs} y_1^{ss} + a_{11}^{sr} b_{12}^{rs} y_2^{ss} + a_{12}^{sr} b_{22}^{rs} y_2^{ss}) \\
&+ v_1^s l_{12}^{ss} (a_{21}^{sr} b_{11}^{rs} y_1^{ss} + a_{22}^{sr} b_{21}^{rs} y_1^{ss} + a_{21}^{sr} b_{12}^{rs} y_2^{ss} + a_{22}^{sr} b_{22}^{rs} y_2^{ss})
\end{aligned}
$$

[26] l here, as shown, represents the Leontief inverse, $(I - A)^{-1}$, and is used as applied to intermediate goods.

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