Global Supply Chains: Towards a CGE Analysis

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Summary

1. Global supply chains (GSCs) now account for more than half the world's trade in manufactured products. This is trade resulting from decisions by firms producing final goods (such as Apple iPhones) to allocate underlying tasks (such as design, component production and assembly) to dedicated facilities in different countries. These decisions create cross-border flows of products at various stages of completion (e.g. iPhone components produced in Thailand and Vietnam sent to China for assembly). They also generate situations in which value added from one country makes multiple border crossings, including returning to the country from which it originated (e.g. Vietnamese labour embodied in Apple iPhone components exported to China and then returned to Vietnam embodied in assembled iPhones purchased by Vietnamese households).
2. Economic studies of the emergence and growth of GSC trade fall into four categories:
   (a) *theoretical*, i.e. algebraic explanations of stylized facts but with minimal, if any, use of statistical data;
   (b) *descriptive*, i.e. case studies describing production and trade arrangements for particular products such as Boeing's 787 Dreamliner;
   (c) *econometric*, i.e. studies that rely on econometric methods to determine relationships between a country's characteristics and the extent and nature of its participation in GSC trade; and
   (d) *input-output*, i.e. studies that use input-output data to determine the composition of trade flows in terms of value-added contributions from different countries.
3. What is now needed is computable general equilibrium (CGE) models that can help us answer the following types of questions. Which countries experience welfare gains and losses from the emergence of GSCs and how quantitatively significant are these gains and losses? Within each country, does GSC trade lead to reductions or increases in inequality? How does GSC trade affect the industrial composition of output, the occupational composition of employment, and the regional distribution of activity in each country? How does GSC trade affect wage rates by occupation and by educational level in each country? Do free trade agreements help or hinder GSC trade? What are the implications of anti-trade policies, such as those espoused by Donald Trump, for participation by China and other developing countries in global production sharing?
4. GSC is a new type of trade. It requires a new generation of CGE models that incorporate:
   (a) fragmentation of production processes;
   (b) economies of scale within each process;

(c) intermediate inputs that are tradable across national borders multiple times embodied in products at different stages of completion; and
(d) decision-making economic actors with a global rather than national perspective.

None of these phenomena is included in existing CGE models.

5. We describe a prototype model incorporating features required for a GSC-enhanced CGE model. For simplicity, the prototype has just one final good, Supplied Widgets, and two regions: region 1, a high-wage, high-productivity region which we often refer to as the U.S.; and region 2, a low-wage, low-productivity region which we often refer to as Asia. To introduce GSC features, we assume that the final good is produced via a sequence of four processes: Design; Components; Assembly; and Distribution. Each process is subject to scale economies. Outputs from Designs, Components and Assembly are tradeable and their regional location is determined by a global cost-minimizing agent. We use the prototype to paint a stylized picture of GSC history from 1990 to 2010.

6. Given the stylized picture of productivity and wage rates that we assume for each region, and trade costs between regions, the 1990 solution to the prototype model locates the bulk of Widget activity in the U.S. Trade in Widgets is Ricardian: assembled widgets flow from the U.S. to Asia. The U.S. has a trade surplus in Widgets and considerable employment in both Widget service (Design and Distribution) and manufacturing (Components and Assembly) activities. Consumers in the U.S. pay a lower prices for Widgets than those in Asia.

7. In going from 1990 to 1995, we assume that Asian unit labour costs in Widget activities fall relative to those in the U.S., reflecting rapid growth in Asian productivity. For Design and Assembly, unit labour costs in Asia remain higher than those in the U.S. but for Components Asian costs are now lower than in the U.S. We also introduce reductions in trade costs (tariffs, transport and communications). Although Asian unit labour costs in Components are lower than U.S. unit labour costs, the 1995 solution continues to locate all tradeable activities in the U.S. Extra trade costs associated with moving Components production to Asia outweigh the savings in production costs that would be generated.

8. In going from 1995 to 2000, we introduce a reduction in the Asian unit labour cost for Assembly but continue to assume that it is above that for the U.S. The new possibilities inherent in GSC trade are illustrated by the 2000 solution which shows that the seemingly innocuous reduction in Asian Assembly cost triggers a complete transfer of Components production from the U.S. to Asia together with a partial transfer of Assembly production. U.S. employment in Widget manufacturing activities falls and the substantial U.S. trade surplus in Widgets turns into a small deficit. Trade now exhibits GSC characteristics: Designs are exported from the U.S. to Asia and returned to the U.S. embodied in Asian Components. The price paid by U.S. households for the final Widget product increases in 2000 relative to its 1995 level.

9. In going from 2000 to 2010, we assume that the Asian unit labour cost for Assembly falls noticeably below that in the U.S. This triggers the end of Assembly in the U.S. The U.S. now has only service activities (Design and Distribution) in the Widget sector and a large trade deficit in Widgets. It might be expected that the U.S. would be compensated for these negative developments via lower prices to its Widget consumers. However, the price paid by U.S. households for the final Widget product increases in 2010 relative to its 2000 level. By 2010 U.S. consumers are paying more for Widgets

than Asian consumers. As Widget activity is successively transferred to Asia, U.S. consumers pay an increasing fraction of trade costs incurred in the Widget sector.

10. The story from our prototype model brings out two points. First, it is a story that could not be told with a current-generation CGE model. These models do not recognize fragmentation of production, scale economies and global decision making. Second, it is a story that captures elements of reality: production processes that shift rapidly between different parts of the world; growth in trade in unfinished goods relative to trade in finished goods; and the hollowing out of manufacturing processes in some developed countries. The story resonates with the antagonism felt in the U.S. towards free-trade policies.

11. To move from the prototype model to a real-world model will require developments in:
(a) *theory*. In the prototype model there is only one primary-factor input, labour. A real-world model would need specifications of investment, capital accumulation and regional labour availability by skill. GSC sectors would need to be embedded in the broader economy.
(b) *data*. Modellers now have access to GTAP and WIOD data for trade and input-output flows compiled on a comparable basis for multiple countries. The main limitation is that the industry classifications in these data do not distinguish Designs, Components and Assembly within traditional sectors such as Motor vehicles and parts. The most likely possibility for overcoming this problem is to disaggregate GTAP or WIOD data for key GSC sectors by using detailed trade data (say HS 6-digit) combined with U.N. data identifying Broad Economic Classifications (BEC).
(c) *computation*. Solution of the prototype model requires evaluation of discrete alternatives for the location of tradeable activities (Design, Components and Assembly). For the prototype, the number of alternatives is small and the computing is trivial. However, for a real-world model the number of alternatives can become very large. It is likely that smart algorithms will be required to keep the computations manageable.

12. Incorporating GSC features into CGE models will be a major task. But it is an urgent task. The absence of economy-wide models with credible GSC features leaves a vacuum in the policy-advising space. GSC networks are now a major part of world trade. Policy makers need guidance on how this type of trade affects manufacturing jobs, consumer prices and economic welfare.

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Abstract

Economists have analysed global supply chains (GSC) using pure theory, case studies, econometrics and input-output calculations. We now need a new type of computable general equilibrium (CGE) model to show how GSC trade affects welfare and its distribution between and within nations. The new model must recognize: fragmentation of production; scale economies; intermediate inputs that cross national borders multiple times embodied in products at different stages of completion; and decision-making by global agents. We describe a prototype that incorporates these features and gives interpretable results not attainable with a standard CGE model. We discuss steps to move from the prototype to a policy-relevant model.

Key words

Global supply chains; Computable general equilibrium modelling; Global decision making; Footloose activities; Trade costs

JEL codes: F12; F60; C68; C67

1. Literature overview and introduction

Disintegration of the production process across national boundaries within vertically integrated global industries has been an important feature of economic globalization in recent decades. This international division of labour opens up opportunities for countries to specialize in different slices (tasks) of the production process in global supply chains (GSC) according to their relative cost advantages.[1] With production separated into highly specialized processes in a wide range of industries, new opportunities for trade are created even for small countries at various stages of development and with different factor prices.

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[1] Alternative terms used in the recent international trade literature to describe this phenomenon include global production sharing, international production fragmentation, intra-process trade, vertical specialization, slicing the value chain, and offshoring.

Two eye-catching examples of how countries are engaging in an intricate web of production-sharing arrangements are Boeing's 787 Dreamliner and Apple's iPad 3. As described by Grapper (2007), production outside the U.S. accounts for 70% of the many thousands of parts used in assembling the 787. Boeing itself is responsible for only about 10% by value (tail fin and final assembly) of the aircraft but holds rights to the 787 technology. There are 43 parts and component suppliers spread over 135 production sites around the world. The wings are produced in Japan, the engines in the United Kingdom and the United States, the flaps and ailerons in Australia and Canada, the fuselage in Japan, Italy, and the United States, the horizontal stabilizer in Italy, the landing gear in France, and the doors in Sweden and France. Some parts are produced in foreign affiliates of the Boeing Corporation, while others are supplied under subcontracting arrangements. This pattern of 'outsourced production' around the world is in sharp contrast to Boeing's earlier parochial emphasis on procuring components domestically: only about 1% of the Boeing 707 was built outside the U.S. in the 1950s. Boeing is now focussing on its advantages – design, supply-chain management, marketing and branding – rather than on areas in which offshore suppliers can provide the required components and services at low cost. Airbus followed Boeing's lead for its A350 jet. It has closed down some component-producing plants in Europe and is outsourcing work to China and elsewhere in producing this wide-body jet, which is positioned to compete with Boeing's 787.

Apple's iPad 3 involves manufacturing processes combining designs, components and final assembly provided by multiple suppliers in a number of countries. It is assembled in China and, since 2012, in Brazil by two Taiwan-based companies, Foxconn and Pegatrone. It is recorded in customs records as exports from China and Brazil. But in reality iPad 3 is 'made in the world'. The retina display is manufactured by Samsung of South Korea in its production plant in Wujiang City, China. The touch panel, the battery pack and the case are produced by separate Taiwanese firms that have operations in China and several other countries and presumably these include components from yet other countries. Apart from these easily identifiable parts, iPad 3 incorporates chips and other components provided by firms with headquarters in Japan, the USA, Canada and other developed countries but with manufacturing plants scattered around the world. The net addition of the final assembly process in China is estimated at around 6 per cent of the ex-factory price of the iPad 3.

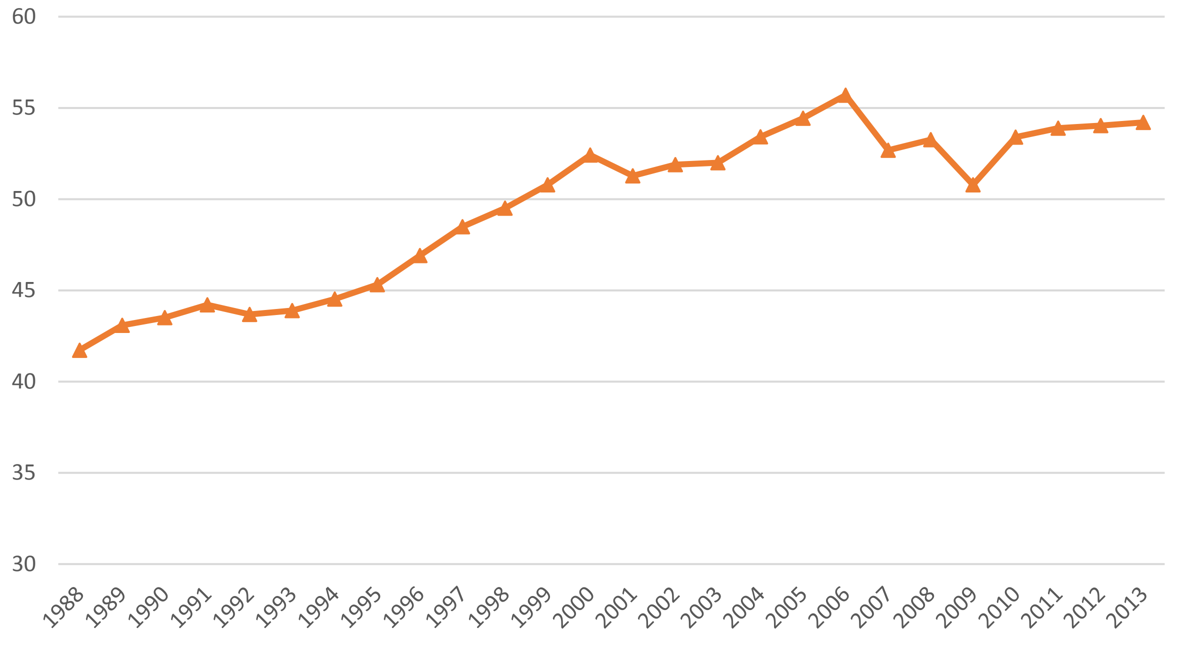
At the early stage of GSC formation, production sharing was basically a two-way exchange between the home and host countries undertaken by multi-national enterprises (MNEs): parts and components were exported to the low-cost, host country for assembly and the assembled components were re-imported to the home country to be incorporated in the final product. As supply networks of parts and components became firmly established, producers in advanced countries have begun to move final assembly of an increasing range of products (for example, computers, mobile phones and other hand-held devices, TV sets and cars) to developing countries. Many of the MNEs in electronics and related industries now undertake final assembly in developing-country locations, retaining only product design and coordination functions at home. Gradually, MNE subsidiaries began to subcontract some activities to local (host-country) firms, providing the latter with detailed specifications and even fragments of their own technology. Over time, many firms, which were not part of original MNE networks, have begun to undertake final assembly by procuring components globally through arm's-length trade, benefitting from the ongoing process of standardization of parts and components.

The coproduct coverage of GSCs has expanded from simply electronics component assembly to a wide range of products including various electrical goods, automobiles, medical/surgical equipment, LED lighting and pharmaceutical products. The share of parts and components, and final assembly ('GSC products', for short) increased from about 40% in the late 1980s to nearly 55% of total manufacturing exports (Figure 1). Developing countries, in particular China and other dynamic exporting countries in East Asia are now dominant in global supply chain exports. By 2013 about 57% of total GSC exports originated from developing countries, with China alone accounting for about 22%, [updated from figures in Athukorala (2014)].

Participation in GSCs depends on a country's production costs and service link costs. Here the term 'service links' refers to arrangements for connecting/coordinating activities into a smooth sequence for the production of the final good (Jones and Kierzkowski 2001). Service link costs include tariffs, transportation, communication and coordinating activities. The tariff structure is generally thought to be more important for the expansion of GSC trade than it is for conventional horizontal trade. This is because each slice/task of the production chain operates with a small price-cost margin, which can be erased by even a small tariff. The policy regime and the domestic investment climate also need to be conducive for involvement in production sharing. The decision of a firm to outsource production processes to another country, either by setting up an affiliated company or establishing an arm's length relationship with a local firm, entails 'country risks'. This is because supply disruptions in a given overseas location could upset the entire production chain. Such disruptions could be the result of shipping delays, political disturbances, labour disputes or natural disasters. In many instances it is impossible to fully offset these risks by writing *complete contracts* (Helpman 2006, Spenser 2005).

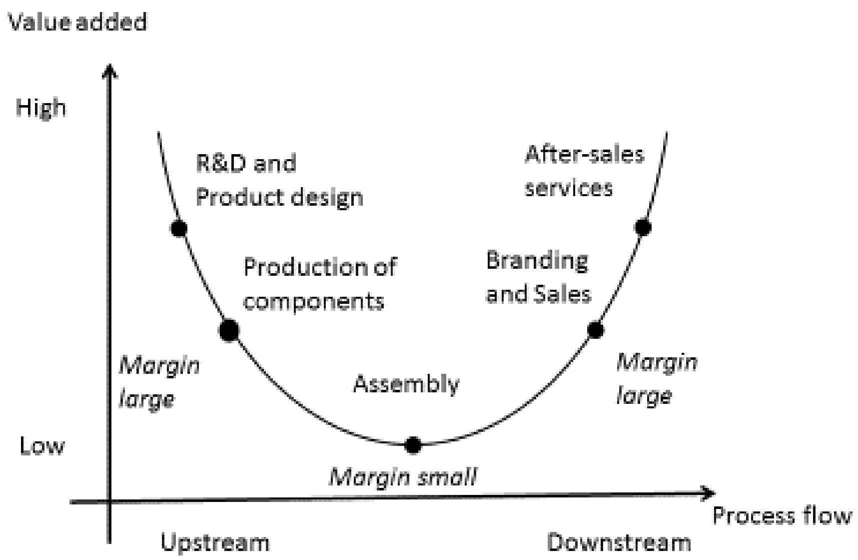
The nature of participation in GSC trade by countries at different stages of development has been studied using the 'smiling curve', see for example Hallward-Driemeier and Nayyar (2017), Chen (2004) and Shin *et al*. (2012). The smiling curve, first proposed by the founder of the Acer Corporation Stan Shih (1996), encapsulates the idea that the greatest value is captured by activities at the upstream and downstream ends of a supply chain (Figure 2). The lowest value added is captured in the middle of the chain (manufacturing and assembly). Middle-chain activities are not where most value gets added, because these activities are highly mobile and face more and more competition. For instance, in the computer industry, entry barriers are low and profit margins are thin for assembly. By contrast, product design (upstream end) and advertising and establishment of brand names (downstream end) come with high entry barriers reflecting requirements for scarce skills. Because firms that undertake activities at the two ends of the production chain are mainly in developed countries, while the middle chain activities are mainly in developing countries, the smiling curve indicates that the gains from GSCs may be distributed in favour of developed countries. The smiling curve is also cited as a motivation for developing countries to foster activities at the two ends of the chain. While suggestive, the smiling curve is not a sufficient analytical device for either testing the validity of conclusions concerning the current distribution of gains from GSC trade or for formulating strategies for changing this distribution. The smiling curve does not show how a country's prosperity is affected by GSC trade or GSC policies.

Figure 1: Share of GSC products in total world manufacturing exports, 1988-2013 (at 2005 prices, %)



Source: Athukorala and Talgaswatha (2016).

Figure 2. Smiling curve



That understanding GSC trade requires new analytical techniques has been recognized by leading commentators. For example, the Deputy Director-General of the WTO, Alejandro Jara (2010) commented that "This change in paradigm from trade in goods to trade in tasks calls for a change in the analytical and statistical tools we use to measure and understand the real world". The conventional approach to analyzing trade patterns, which treats international trade as an exchange of goods produced from beginning to end in a given trading partner, is rapidly losing its relevance.

Economists have responded to the challenge of understanding GSC trade with studies that fall into four categories: theoretical; descriptive; econometric; and input-output. Theoretical studies include Antras and Chor (2013), Antras and Costinot (2011), Jones (2000), Jones and Kierzkowski (2001), Grossman and Rossi-Hansberg (2008 & 2013), and Yi (2003). These studies give algebraic and diagrammatic explanations of how GSCs can emerge and how they operate. Descriptive studies include both case studies and descriptions of the determinants of trade flows within the standard gravity modelling framework using trade data disaggregated into GSC trade and horizontal trade [Grapper (2007), Brown and Linen (2005), Helleiner (1973), Grunwald and Flamm (1985), Athukorala (2011) and Yeats (2001)]. Econometric studies have been used to investigate inter-country difference in participation in GSC trade and the nature of the tasks in GSCs that are allocated to countries at different stages of development. These studies include Athukorala (2009), Athukorala and Yamashita (2006 & 2009), Athukorala and Khan (2016), Baldwin and Taglioni (2011), Hanson *et al.* (2005), Golub *et al.* (2007) and Okubo *et al.* (2014). Input-output data and models have been used to describe the composition of trade flows in terms of value-added contributions from different countries in the supply chain [Amador and Cabral (2017), Dean *et al.* (2011), Koopman, *et al.* (2014), Mattoo *et al.* (2013), Johnson and Noguera (2012) and Productivity Commission (2015)].

What is now needed is computable general equilibrium (CGE) models that can help us answer the following types of questions. Which countries experience welfare gains and losses from the emergence of GSCs and how quantitatively significant are these gains and losses? Within each country, does GSC trade lead to reductions or increases in inequality? How does GSC trade affect the industrial composition of output, the occupational composition of employment, and the regional distribution of activity in each country? How does GSC trade affect wage rates by occupation and by educational level in each country? Do free trade agreements help or hinder GSC trade? What would be the implications of anti-trade policies such as those espoused by Donald Trump for participation by China and other developing countries in global production sharing?

The rest of this paper is about what type of CGE model we need for GSC analysis. Section 2 starts with a brief introduction to CGE modelling, especially its development in Australia. Then, we list the features that must be added to existing CGE models so that they can become effective tools for answering GSC questions. Section 3 sets out a simple 1-sector, 2-region GSC model. The sector produces Widgets through four activities: Design; Components; Assembly and Sales distribution. Section 4 analyses four solutions from the Widget model. We refer to these solutions notionally as 1990, 1995, 2000 and 2010. In the 1990 solution, all of Design, Components and Assembly activity is located in region 1, which we think of as the U.S. As we move to the later solutions, Components and Assembly successively move to region 2 (Asia) in response to reductions in trade costs and in region 2's unit labour costs. During this process, the nature of trade between the two regions changes from Ricardian to GSC. The benefits of the new trading arrangements are slanted towards Asia. The U.S. loses its manufacturing activity, experiences a shift in its trade balance towards deficit and, perhaps surprisingly, its consumers end up paying higher prices for Widgets.

Section 5 contains concluding remarks focusing on what needs to be done to go from the stylized analysis contained in this paper to a model with policy-relevant empirical detail.

2. CGE modelling: the state of play and what has to be done to create a GSC version

The defining features of CGE models are disaggregation, optimizing price-sensitive behaviour by multiple agents and economy-wide coverage. Disaggregation always includes production at the industry level. In addition, CGE models often include regional, occupational and household disaggregation. The agents in CGE models are typically profit maximizing or cost-minimizing industries, rate-of-return maximizing capital creators, and budget constrained utility-maximizing households. Demand and supply equations resulting from optimizing behaviour of agents, together with economy-wide constraints on the availability of labour, capital, land, foreign exchange, public sector revenue and possibly CO_2 absorption capacity, determine outcomes for prices, wages, employment, industry outputs and many other variables.

CGE modelling started with Johansen (1960)[2]. Since then, CGE models have been developed for literally hundreds of countries and applied to an enormous range of issues in trade, labour markets, environment, infrastructure provision, public finance and microeconomic reform.

Australia has played a leading role in the development of the field. The ORANI model of Australia was the world's first detailed (100+ industries) CGE model.[3] It was used regularly in the policy debates of the 1980s that led to the dismantling of Australia's tariff wall.[4] ORANI evolved into the dynamic MONASH model[5] which has been applied many times on policy issues by departments in Australia's commonwealth and state governments. ORANI/MONASH theory and GEMPACK software[6] created at Victoria University's Centre of Policy Studies (CoPS) underpins the multi-country model built by the Global Trade Analysis Project, see Hertel (1997). The GTAP model is used throughout the world to analyse trade issues.

However, GSC is a new type of trade. It requires a new generation of CGE models that incorporate:

- fragmentation of production processes;
- economies of scale within each process;
- intermediate inputs that are tradable across national borders multiple times embodied in products at different stages of completion; and
- decision-making economic actors with a global rather than national perspective (multi-national corporations).

None of these phenomena is included in existing CGE models.

Walmsley and Minor (2017) produce a version of GTAP that they refer to as a supply chain model. The standard version of GTAP identifies flows of commodity c from source country s to destination country d but then assumes that the source composition of imported c

[2] For an account of Johansen's work and the development of CGE modelling, see Dixon and Rimmer (2016).
[3] See Dixon *et al.* (1977 & 1982).
[4] Vincent (1990) describes policy applications of the ORANI model at Australia's Industries Assistance Commission.
[5] See Dixon and Rimmer (2002).
[6] See Pearson (1988) and Horridge *et al.* (2013).

in d is the same for all users. Walmsley and Minor make a valuable contribution by equipping GTAP with data that identify imports by source country for each using agent in d. However, this is not fundamental to supply chain analysis. A more fundamental contribution would be disaggregation of a GTAP commodity such as vehicles into processes such as design, components, assembly and sales & distribution.

3. A prototype model with essential GSC features

In this section we describe a prototype model incorporating the features required for a GSC-enhanced CGE model. The prototype has one final good, Supplied Widgets. Towards the production of this final good, there are four processes: Design; Components; Assembly; and Distribution. Design is used in Components, Components is used in Assembly, and Assembly is used in Distribution. In addition, each of these processes uses labour. Design, Components and Assembly are footloose. They can be undertaken in different countries. Distribution is not traded. It must occur where Supplied Widgets are consumed. All processes are subject to economies of scale. Decisions on the location of processes are made by a global agent that minimizes the total cost of satisfying world demand (demand in each region) for Supplied Widgets. In deciding where to locate processes, the cost-minimizing agent takes account of wage rates and productivity in each country, potential for economies of scale, and the tariffs and transport costs generated by the shipment of intermediate inputs (Design, Components and Assembly) between countries or groups of countries (regions).

In the prototype, the world consists of just two regions: region 1, a high-wage, high-productivity region which we often refer to as the U.S.; and region 2, a low-wage, low-productivity region which we often refer to as Asia.

We use the prototype to paint a stylized picture of GSC history from 1990 to 2010 in which the bulk of Widget activity is transferred in stages from the U.S. to Asia.

Technology and data in the prototype model

Table 1A(a) shows intermediate inputs per unit of output for Design, Components, Assembly and SalesDist. We assume for both regions and all years that Design uses no intermediate inputs. Output of a unit of Components requires one unit of Design. Output of a unit of Assembly requires one unit of Components, and output of a unit of SalesDist requires one unit of Assembly.

Table 1A(b) shows *standard* labour costs per unit of output (SLC) for Design, Components, Assembly and SalesDist for the two regions in 1990. Standard costs refer to the situation in which the activity is conducted at a scale suitable for supplying the domestic market only. In 1990, standard labour costs per unit of output are much higher in Asia than the U.S. for the three traded commodities: Design, Components and Assembly. This is despite wages being low in Asia relative to the U.S. [0.25 compared with 1, Table 1A(e)]. High unit labour costs in Asia reflect low productivity. For example, the figures in Table 1A imply that Asian labour productivity in Design is 1/12th of U.S. labour productivity (3 times higher unit labour cost for Asia relative to the U.S. with ¼ the U.S. wage rate).

Table 1A. Technology assumptions and data for 1990

	Design	Components	Assembly	SalesDist
(a) Intermediate inputs for producing 1 unit of output of each commodity in both regions				
Design	0	1	0	0
Components	0	0	1	0
Assembly	0	0	0	1
SalesDist	0	0	0	0
(b) Standard labour costs per unit of output (SLC)				
Region 1 (US)	1	1	1	1
Region 2 (Asia)	3	1.5	2	1
(c) Powers of transport costs & tariffs (T)on imports by importing region				
Region 1 (US)	1.1	1.2	1.2	1
Region 2 (Asia)	1.1	1.2	1.2	1
(d) Demand for final product:				
Region 1 (US)				X(4,1) = 1
Region 2 (Asia)				X(4,2) = 0.5

(e) Wage rate		
Region 1 (US)	1.0	
Region 2 (Asia)	0.25	

Table 1B. Solution for 1990

	Price	Output	Employment	Exports, qty	Exports, value
Region 1					
Design	0.950	1.5	1.425	0.0	0.0
Components	1.900	1.5	1.425	0.0	0.0
Assembly	2.850	1.5	1.425	0.5	1.425
SalesDist	3.850	1.0	1.000	0.0	0.0
Total			5.275		1.425
			VA=5.275		
Region 2					
Design	3.000	0.0	0.0	0.0	0.0
Components	2.545	0.0	0.0	0.0	0.0
Assembly	4.280	0.0	0.0	0.0	0.0
SalesDist	4.420	0.5	2.0	0.0	0.0
Total			2.0		0.0
			VA=0.5		

KWW export decomposition	**FOB exports**	**Domestic VA absorbed externally**	**Domestic VA exported and returned**	**Foreign VA in exports**	**Tariff/transport content of exports**
Region 1	1.425	1.425	0	0	0
Region 2	0	0	0	0	0
Region 1's trade surplus	1.425				

We introduce economies of scale by assuming that labour costs per unit of output [LC(c,r)] are 5 per cent lower for a region that supplies the world (itself and the other region):

$$LC(c,r) = SLC(c,r) * SCALE(c,r) \tag{1}$$

where

$$SCALE(c,r) = \begin{cases} 0.95 & \text{if region r supplies c for both regions} \\ 1 & \text{if production of c is nonzero in both regions} \end{cases} \tag{2}$$

Table 1A(c) shows powers of trade costs (tariffs and transport) in 1990. Shipping Design from region 1 to region 2 costs 10 per cent of the fob value of the shipped product (power equals 1.1). Shipping Components and Assembly from region 1 to region 2 costs 20 per cent of the fob value. For SalesDist there are no trade costs (power equals 1) but this is irrelevant because SalesDist is not traded. For simplicity we assume that the 2 to 1 trade costs are the same as the 1 to 2 trade costs.

We use the notation X(4,j), j = 1, 2, to denote the demand for commodity 4 in region j. Commodity 4 is SalesDist which consists of a Supplied Widget. As indicated in Table 1A(d), we assume that in 1990 region 1 consumes 1 unit of commodity 4 and region 2 consumes 0.5 units. These demands are treated as exogenous. In a full general equilibrium model they would be endogenous.

Solving the widget model

Table 2 shows the 27 possible locational arrangements for the world-wide Widget industry. Each of the three traded activities can be located in one region or the other region or both.

When an activity is located in both regions, then we assume that each region is satisfying just its own requirements for that activity. For example, if both regions are producing Components then the entire output of the U.S. Component industry goes to the U.S. Assembly industry and the entire output of the Asian Component industry goes to the Asian Assembly industry. It will never be cost minimizing for domestic and imported Components to co-exist in the same market. This is because Components produced in the two regions are perfect substitutes.

We assume that a global decision maker considers the 27 possible scenarios and chooses one that enables world-wide demands for Supplied Widgets [X(4,1) and X(4,2)] to be satisfied at minimum cost. That is, the global decision maker finds scenario s to minimize Cost(s) given by

$$Cost(s) = P(4,1:s) * X(4,1) + P(4,2:s) * X(4,2) \tag{3}$$

where P(4,j:s) is the price of a Supplied Widget (commodity 4) in region j under scenario s.

P(4,j:s) is calculated as part of the solution of a Leontief price system. For each s this is a system of 8 equations to determine the prices P(c,r:s) of the four products in the two regions, according to:

Table 2. Global production scenarios

Design	Produced only in US	Produced only in Asia	Each region satisfies own requirements
Components	Produced only in US	Produced only in Asia	Each region satisfies own requirements
Assembly	Produced only in US	Produced only in Asia	Each region satisfies own requirements
SalesDist	Each region satisfies own requirements		

$$\begin{aligned} P(c,r:s) = & \sum_{e=1}^{4} P(e,r:s) * A(e,r;c,r:s) \qquad \textit{domestic intermediate inputs} \\ & + \sum_{e=1}^{4} P(e,rr:s) * A(e,rr;c,r:s) * T(e,rr,r) \quad \textit{imported intermediate inputs} \\ & + SLC(c,r) * SCALE(c,r:s) \quad \textit{labour inputs} \end{aligned} \tag{4}$$

for c = 1, 2, 3, 4; r = 1, 2; and rr ≠ r.

The coefficients in the system for scenario s are:

A(e,**r** ; c,**r**:s).

This is the input of commodity e produced in region r per unit of output of commodity c in region r in scenario s. For any given value of s, evaluation of A(e,r ; c,r:s) is straightforward. For example, if for a given value of s, **all** Design is produced in region 1 then

A(Design,**1** ; Components,**1**: s) = 1.

A(Design,**1** ; k,**1**: s) = 0 for k ≠ Components *[Design is an input to Components only]*

A(Design,**2** ;k,**2**: s) = 0 for all k *[for this s Design is produced in region 1 only]* [7]

To take a second example, if for a given value of s, Design is produced in both regions, then

A(Design,**r** ; Components,**r**: s) = 1 for all r *[both regions use their own Design]*.

A(Design,**r** ; k,**r**: s) = 0 for k ≠ Components *[Design is an input to Components only]*

A(e,**rr** ; c,**r**:s).

This is the input of commodity e produced in region rr per unit of output of commodity c in region r in scenario s, rr ≠ r. Thus we are referring to imported inputs. If all Design is produced in region 1, we have

A(Design,**1** ; Components,**2**: s) = 1.

A(Design,**1** ; k, **2**: s) = 0 for k ≠Components *[Design is an input to Components only]*

A(Design,**2** ;k,**1**: s) = 0 for all k *[for this s, Design is produced in region 1 only]*

If Design is produced in both regions

A(Design,**1** ; k, **2**: s) = 0 for all k *[for this s, region 2 uses its own Design only]*

A(Design,**2** ;k,**1**: s) = 0 for all k *[for this s, region 1 uses its own Design only]*

T(e,**rr**,**r**).

This is power of the tariff/transport costs applying to flows of e from region rr to region r. The 1990 levels of the T's can be seen in Table 1A(c).

[7] The A's are input-output coefficients: they show inputs **per unit** of output. If there is zero output, then the value of the A doesn't matter. In this case we use A values that would be appropriate for non-zero values of output.

SLC(c,r).

This is the standard labour cost per unit of output for commodity c in region r. The 1990 levels can be seen in Table 1A(b).

SCALE(c,r:s).

This is the scale coefficient that applies to the production of commodity c in region r in scenario s. Given the scenario s, SCALE(c,r:s) is easily evaluated from equation (2).

4. Four solutions of the prototype model: 1990, 1995, 2000 and 2010

The solution for 1990

Table 3 shows the cost of satisfying world widget demands in 1990 under each of the 27 possible scenarios. To arrive at the cost figure for scenario s, we first evaluate the A and SCALE coefficients for that scenario. Then we insert these coefficient values into the equation system (4) together with the 1990 data for T and SLC. Now we can solve for the eight prices P(c,r:s) for all c and r. From here we can evaluate Cost(s) according to equation (3).

Scenario 1, that is, producing all of Design, Components and Assembly in the U.S. gives the lowest possible cost, $6.06. This cost level also appears for scenarios 3, 7 and 9. In effect, these scenarios are the same. As in scenario 1, in scenarios 3, 7 and 9 the U.S. produces all of the world's Design, Components and Assembly. To understand this point consider scenario 3. In this scenario both regions satisfy their *own* Design requirements. But Asia has no Design requirements because Design is used only as an input to Components which, in scenario 3, are produced entirely in the U.S. Consequently in scenario 3 the U.S. produces all of Design, as well as all the Components and Assembly.

From the point of view of seeing how our model works, it is interesting to ask the question: what is the highest cost scenario? Given the cost data in Table 1A, which shows that Asia is uncompetitive in Design, Components and Assembly, it is tempting to guess that the highest cost scenario is to produce these commodities entirely in Asia, scenario 14. However, scenario 11 has higher costs ($13.0634 compared with $11.9975). In scenario 11 the U.S. produces Components. Production costs for Components are lower in the US than in Asia. But this advantage for scenario 11 relative to scenario 13 is outweighed by the extra trade costs required in 11 to ship Asian Design to the US and US Components to Asia.

We return now to the minimum cost scenario. Having established that scenario 1 (or equivalently 3, 7 or 9) will be chosen by the global decision maker, we can work out other features of the 1990 solution.

Table 1B shows prices, output, employment and exports for both regions and each of the commodities. Starting with the U.S. (region 1), we see that the price of Design is 0.950. This reflects the standard labour-cost per unit of output [1.0, see Table 1A(b)] and the scale factor (0.95, recognizing that the U.S. produces world output). The U.S. price of Components is 1.90, made up of a labour cost of 0.95 and a Design input cost of 0.95. The U.S. Assembly price is 2.850, made up of a labour cost of 0.95 and a Components input cost of 1.90. The U.S. SalesDist price is 3.850: 2.850 for Assembly and 1 for labour in SalesDist (no economies of scale). U.S. output for each of Design, Components and Assembly is 1.5. Given the input-output coefficients in Table 1A(a), these output levels are required to support the total demand for the final product [X(4,1) +X(4,2) = 1.5]. U.S. output of SalesDist is 1.0, to support U.S.

*Table 3. Costs in 1990 of satisfying world Widget demands under 27 scenarios**

Scenario	Design	Components	Assembly	COSTS
1	US	US	US	6.06
2	Asia	US	US	9.556
3	both	US	US	6.06
4	US	Asia	US	7.7624
5	Asia	Asia	US	11.228
6	both	Asia	US	11.228
7	US	both	US	6.06
8	Asia	both	US	9.556
9	both	both	US	6.06
10	US	US	Asia	8.606
11	Asia	US	Asia	13.0634
12	both	US	Asia	8.606
13	US	Asia	Asia	8.929
14	Asia	Asia	Asia	11.9975
15	both	Asia	Asia	11.9975
16	US	both	Asia	8.929
17	Asia	both	Asia	11.9975
18	both	both	Asia	11.9975
19	US	US	both	6.54
20	Asia	US	both	10.036
21	both	US	both	6.54
22	US	Asia	both	7.699
23	Asia	Asia	both	10.7675
24	both	Asia	both	10.7675
25	US	both	both	6.7225
26	Asia	both	both	9.81
27	both	both	both	7.75

* When US [Asia] appears in a cell this means that US [Asia] supplies all of the commodity identified in the column. When "both" appears, this means that each region supplies its own requirements of the commodity identified in the column, that is, there is no trade in the commodity.

final demand of 1 [X(4,1) = 1]. U.S. employment in each of Design, Components and Assembly is 1.425. This is the U.S. scale-adjusted labour requirement per unit of output for these activities (0.95) times output (1.5). U.S. SalesDist employment is 1, computed as labour requirement per unit of output of 1 times output of 1. Total U.S. employment in the Widget sector is 5.275, and with the wage rate being 1 this is also Widget-sector value added. The U.S. exports 0.5 units of Assembly to satisfy the requirements of Asia's SalesDist activity. With the Assembly price being 2.850, the value of U.S. exports is 1.425. U.S. imports are zero.

Equation (4) generates production prices for Design, Components and Assembly in Asia. However, these can be disregarded because Asia does not undertake these activities. The Asian price for SalesDist is 4.420. This is the price paid by Asian consumers for a Supplied Widget. It is made up of the labour cost per unit of SalesDist [1.0, Table 1A(b)] plus the cost of one unit of Assembly (recall from Table 1A(a) that one unit of Assembly is required per unit of SalesDist). The Assembly cost per unit (3.420) is the cif import price (2.850) times the power of the tariff (1.2). Only the SalesDist activity creates Widget employment in Asia, 2 units. This reflects a unit labour cost of 1, a wage rate of 0.25 and an output level for SalesDist of 0.5. Value added in Asia's Widget sector is 0.5 (=0.25*2). Asia's Widget sector exports are zero and its imports (U.S. exports) are 1.425.

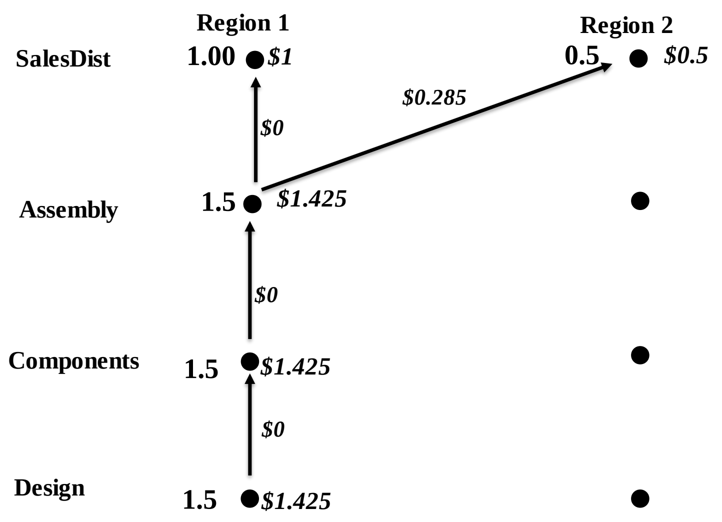
The bottom panel of Table 1B is a Koopman, Wang and Wei (KWW, 2014) decomposition of 1990 trade. For each region's exports this decomposition shows: embedded value added produced in the region that is absorbed abroad; embedded value added produced in the region that is returned embedded in the region's imports; and foreign value added embedded in the region's exports. There is an addition item, usually minor, that covers tariffs and transport costs embedded in the region's exports via imported inputs. In the 1990 solution, the KWW decomposition shows a typical pre-GSC situation. Trade is traditional (known as Ricardian). All of the value added embedded in the exports of a region is produced in that region and absorbed in the importing region.

Figure 3 is the material trade routes (MTR) diagram for 1990. It shows output and value added at each production node, and trade costs between production nodes. The box at the bottom of the figure provides two calculations of the cost of satisfying world Widget demands. This cost can be calculated by adding value added over nodes and trade costs between nodes. It can also be calculated as the value of final demands as in equation (3).

The solution for 1995

Table 4A gives assumptions for 1995. We highlight items that have changed value from their 1990 value in Table 1A. We don't include panel (a) in Table 4A because none of the items in that panel has changed from its 1990 value.

Figure 3. Material trade routes (MTR) diagram: 1990



Total cost of satisfying final demands = $6.060
= (1.425+0+1.425+0+1.425+0+1+0.285+0.5)
= 3.850*1+4.420*0.5

Table 4A. Technology assumptions and data for 1995

	Design	Components	Assembly	SalesDist
(b) Standard labour costs per unit of output (SLC)				
Region 1 (US)	1	1	1	1
Region 2 (Asia)	2	0.9	1.25	1
(c) Powers of transport costs & tariffs (T)on imports by importing region				
Region 1 (US)	1.05	1.05	1.1	1
Region 2 (Asia)	1.05	1.05	1.1	1
(d) Demand for final product: initial situation				
Region 1 (US)				X(4,1) = 1
Region 2 (Asia)				X(4,2) = 0.75
	(e) Wage rate			
	Region 1 (US)	1.0		
	Region 2 (Asia)	0.3		

Table 4B. Solution for 1995

	Price	Output	Employment	Exports, qty	Exports, value
Region 1					
Design	0.950	1.75	1.663	0.00	0.000
Components	1.900	1.75	1.663	0.00	0.000
Assembly	2.850	1.75	1.663	0.75	2.137
SalesDist	3.850	1.00	1.000	0.00	0.000
Total			5.989		2.137
			VA=5.989		
Region 2					
Design	2.000	0.00	0.000	0.00	0.000
Components	1.897	0.00	0.000	0.00	0.000
Assembly	3.245	0.00	0.000	0.00	0.000
SalesDist	4.135	0.75	2.500	0.00	0.000
Total			2.500		0.000
			VA=0.75		
KWW export decomposition	**FOB exports**	**Domestic VA absorbed externally**	**Domestic VA exported and returned**	**Foreign VA in exports**	**Tariff/transport content of exports**
Region 1	2.137	2.137	0	0	0
Region 2	0	0	0	0	0
Region 1's trade surplus	2.137				

Between 1990 and 1995, conditions for GSC trade begin to emerge. As shown in Table 4A(c), the powers of transport/tariff costs fall in both directions (from 1.1, 1.2 and 1.2 in 1990 to 1.05, 1.05 and 1.1 in 1995). At the same time, standard labour costs per unit of output in Design, Components and Assembly fall in Asia. This reflects improving productivity which more than offsets a moderate wage rise [from 0.25 in 1990 to 0.3 in 1995, panel (e)]. The reduction in Asia's standard labour costs for Components is sufficient to make the Asian Components industry competitive relative to the U.S. Components industry (standard labour cost in Asia of 0.9 compared with 1.0 in the U.S.). The only other change that we make in the 1995 assumptions relative to 1990 is to assume extra final demand in Asia [X(4,2) = 0.75 instead of 0.5, panel (d)].

We anticipated that the 1995 solution would show a shift of Components production from U.S. to Asia. However, as can be seen from Table 4B, this did not happen. World production of Design, Components and Assembly remains in the U.S. and trade remains Ricardian (KWW decomposition, bottom of Table 4B).

Figures 4 and 5 help us to understand why Components remain in the U.S. despite the U.S. having higher standard labour costs than Asia. If Components move to Asia then, as shown in Figure 5, Designs would be shipped from the U.S. to Asia, Components would be shipped from Asia to the U.S., and trade costs would increase for Assembly going from 1 to 2. The extra trade costs on the red dashed lines in Figure 5 are 0.248 (= 0.083 + 0.162 + 0.003). The saving in production cost for Components is 0.167 (= 1.663 – 1.496). Thus, relocation of Components production would generate a net cost increase of 0.081 (= 0.248 – 0.167).

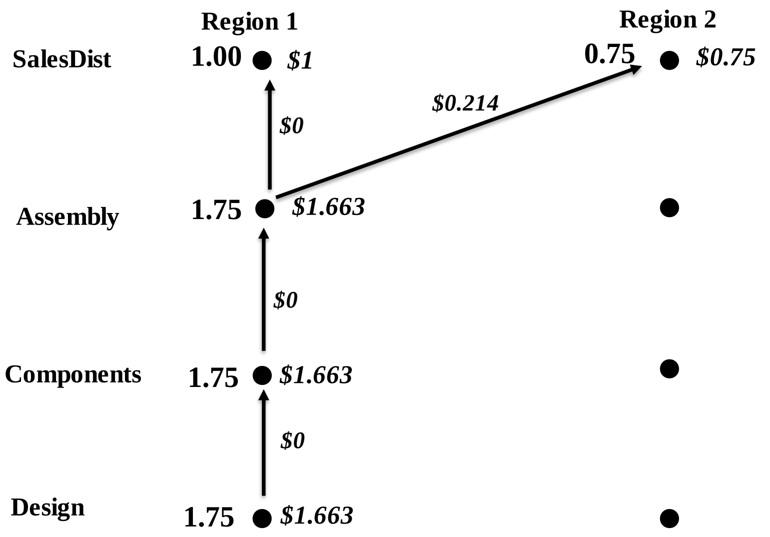
The solution for 2000

The only change in assumptions introduced between 1995 and 2000 is a reduction in standard labour cost for Asian Assembly [from 1.25 in 1995 to 1.15 in 2000, compare panel (b) in Tables 4A and 5A]. This isn't sufficient to reduce Assembly costs in Asia below those in the U.S.

Even though we assume no reduction between 1995 and 2000 in trade costs or in the costs of Asian Components, the reduction in Asian Assembly costs triggers relocation of world production of Components to Asia. Even though Asian Assembly is not competitive, Assembly production commences in Asia. The dramatic regional shift in Widget activities caused by the seemingly innocuous reduction in standard labour costs for Asian Assembly can be seen by comparing the MTR diagrams for 1995 and 2000, Figures 4 and 6.

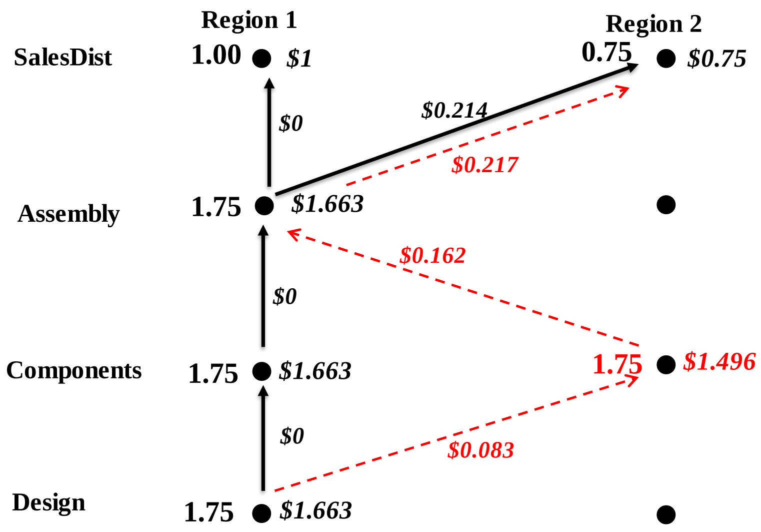
In 2000, the global optimizer relocates Components production to Asia to take advantage of low production costs and avoids some of the extra trade costs by setting up sufficient Assembly in Asia to meet the needs of the Asian SalesDist activity. Putting some Assembly in Asia reduces the 2-to-1 Components flow relative to requirements without the Asian Assembly industry and at the same time eliminates the need for a 1-to-2 Assembly flow. This is worthwhile despite the loss of scale economies in Assembly. The new configuration of production and trade could not take place until 2000 when there was a reduction in Assembly costs in Asia, but not necessarily a reduction to below the U.S. level.

Figure 4. Material trade routes (MTR) diagram: 1995



Total cost of satisfying final demands = $6.952
= (1.663+0+1.663+0+1.663+0+1+0.214+0.75)
= 3.850*1+4.135*0.75

Figure 5. Why not move Components to region 2 in 1995?



Why doesn't region 2 produce all Components when its SLC for components falls to 0.9?
To work out the answer, compare production & trade costs on the red dashed and black paths.
Why does relocating Components affect 1-to-2 trade costs for Assembly even though there is no effect on volume shipped? Relocating affects value shipped and hence *ad valorem* trade costs, by 0.003 (=0.217 – 0.214).

Table 5A. Technology assumptions and data for 2000

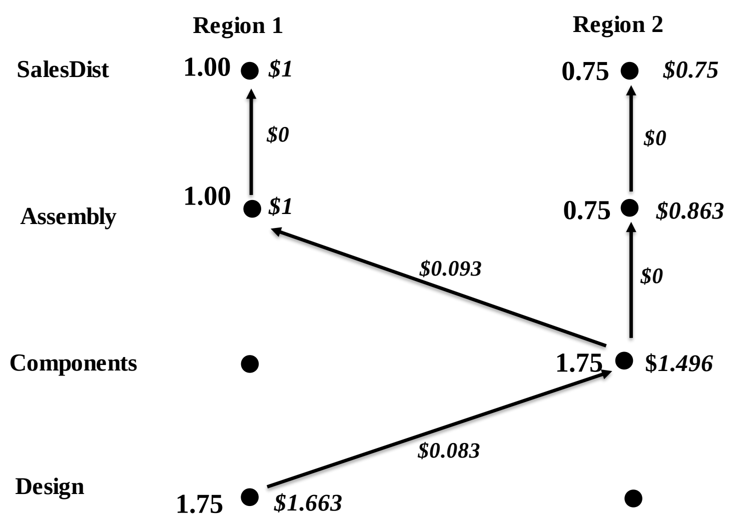
	Design	Components	Assembly	SalesDist
(b) Standard labour costs per unit of output (SLC)				
Region 1 (US)	1	1	1	1
Region 2 (Asia)	2	0.9	1.15	1

Table 5B. Solution for 2000

	Price	Output	Employment	Exports, qty	Exports, value
Region 1					
Design	0.950	1.75	1.663	1.75	1.663
Components	1.950	0.00	0.000	0.00	0.000
Assembly	2.945	1.00	1.000	0.00	0.000
SalesDist	3.945	1.00	1.000	0.00	0.000
Total			3.663		1.663
			VA=3.663		
Region 2					
Design	2.000	0.00	0.000	0.00	0.000
Components	1.852	1.75	4.987	1.00	1.852
Assembly	3.002	0.75	2.875	0.00	0.000
SalesDist	4.002	0.75	2.500	0.00	0.000
Total			10.362		1.852
			VA=3.109		
KWW export decomposition	**FOB exports**	**Domestic VA absorbed externally**	**Domestic VA exported and returned**	**Foreign VA in exports**	**Tariff/transport content of exports**
Region 1	1.663	0.713	0.950	0	0
Region 2	1.852	0.855	0	0.950	0.047
Region 1's trade surplus	-0.189				

To understand what has happened in quantitative terms, we start by recalling from the analysis of Figure 5 that simply relocating Components from the U.S. to Asia would increase the cost of satisfying global Widget demands by 0.081. This analysis is still valid for 2000. But with Asian Assembly costs lower in 2000, another possibility arises for exploiting low-cost Components production in Asia: move not only Components but part of Assembly as well. This possibility is analysed in Table 6 which compares moving just Components to Asia (strategy 1) with moving Components together with sufficient Assembly production to meet Asia's Assembly requirements (strategy 2). As shown in Table 6, these strategies differ with regard to: 2-to-1 trade costs for Components; 1-to-2 trade costs for Assembly; and value added costs for Assembly. Looking at Figures 5 and 6 we can compare these three costs under strategies 1 and 2. The calculations in Table 6 reveal that the second strategy generates a saving of 0.086 compared with the first strategy. Implementing strategy 2 by first implementing strategy 1 and then partially moving Assembly generates a gain 0.005 (= -0.081+0.086) relative to the 1995 situation.

Figure 6. Material trade routes (MTR) diagram: 2000



Total cost of satisfying final demands = $6.948
= (1.663+0.083+1.496+0.093+1+0+1+0+0.863+0+0.75)
= 3.945*1+4.002*0.75

Table 6. Why it is a good idea in 2000 to move Components and part of Assembly

Strategy	(1) Move Components only to region 2	(2) Move Components and part Assembly to region 2	Savings from strategy (2) relative to (1)
2→1 Component trade costs	0.162	0.093	0.069
1→2 Assembly trade costs	0.217	0	0.217
Total value added at Assembly stage	1.663	1.863	-0.200
Total			0.086

Table 5B shows that the movement of Components production and part of Assembly production from the U.S. to Asia has dramatic effects on Widget employment in the two regions and on their Widget trade balance. Between 1995 and 2000, U.S. Widget employment falls from 5.989 (Table 4B) to 3.663 (Table 5B). Asian Widget employment rises from 2.50 to 10.362. The trade balance moves from a U.S. surplus of 2.137 (Table 4B) to a deficit of 0.189 (= 1.852 – 1.663, Table 5B).

As can be calculated from Figure 6, the global average cost of Supplied Widgets in 2000 is 3.970 (=6.948/1.75). This is slightly lower than in 1995 when the average cost was 3.973 (= 6.952/1.75, Figure 4). Despite this, U.S. Widget consumers pay more for Supplied Widgets in 2000 than they did in 1995 (3.945 compared with 3.850, Tables 5A and 4A). By contrast, Asian consumers pay less for Widgets in 2000 than in 1995 (4.002 compared with 4.135).

The KWW decomposition in Tables 4B and 5B shows a fundamental change in the nature of trade. Whereas in 1995 trade was Ricardian with only completely assembled Widgets crossing the 1-to-2 international border, in 2000 trade exhibits GSC characteristics. Intermediate inputs make more than one border crossings: Designs go from 1-to-2 and then go from 2-to-1 embedded in Components. In 2000, more than half of U.S. value added embedded in U.S. exports returns embedded in U.S. imports (0.950 returned while only 0.713 is absorbed externally), and more than half of the value of Asian exports is foreign value added (0.950 out of 1.852).

Solution for 2010

Between 2000 and 2010 the only change in assumptions is a further reduction in standard labour costs for Assembly in Asia, from 1.15 in 2000 (Table 5A) to 0.9 in 2010 (Table 7A). We found that standard labour costs for Assembly in Asia had to be considerably lower than those in the U.S. to trigger the completion of the move of Assembly from the U.S. to Asia. For completion, Asia must have sufficient cost advantage in Assembly to outweigh the trade costs of sending Assembly from Asia to the U.S. As can be seen in Table 7B, a 10 per cent advantage in standard labour costs for Asian Assembly is sufficient but in calculations not shown here we found that a five per cent cost advantage was not sufficient.

With Assembly now completely located in Asia, the U.S. has lost all of its Widget manufacturing activity. Between 2000 and 2010 Widget employment for the U.S. has fallen from 3.663 to 2.663 and the U.S. trade deficit in Widgets has increased from 0.189 to 1.044 (= 2.707- 1.663).

The MTR diagram for 2010 is in Figure 7. Looking at the calculation at the foot of the figure we can see that the global average cost of Supplied Widgets in 2010 is 3.862 (=6.759/1.75), down from 3.970 in 2000. However, just as there was no benefit for U.S. consumers from the reduction between 1995 and 2000 in the global average cost, there is no benefit from the further reduction between 2000 and 2010. Tables 5B and 7B show that the price of Supplied Widgets to U.S. consumers increases between 2000 and 2010 from 3.945 to 3.978. For Asian consumers, the price falls from 4.002 to 3.707.

The KWW decomposition in Table 7B shows no change in the nature of U.S. exports from the picture presented in Table 5B. As in 2000, in 2010 the U.S. exports Design. U.S. exports contain no foreign value added. A little over half (0.950 out of 1.663) of U.S. exported value added is returned embedded in imports. In 2000 the returned value added was embedded in imported Components. In 2010 it is embedded in imported Assembly.

Asian exports are higher in 2010 than in 2000, 2.707 compared with 1.852. All of the growth in Asia’s exports is accounted for by extra Asian value added absorbed in the U.S. (1.710 compared with 0.855). Asia increases its exported value added by exporting Assembly rather than Components. Asia’s Assembly exports embody not only Assembly value added from Asia but also Components value added from Asia.

Table 7A. Technology assumptions and data for 2010

	Design	Components	Assembly	SalesDist
(b) Standard labour costs per unit of output (SLC)				
Region 1 (US)	1	1	1	1
Region 2 (Asia)	2	0.9	0.9	1

Table 7B. Solution for 2010

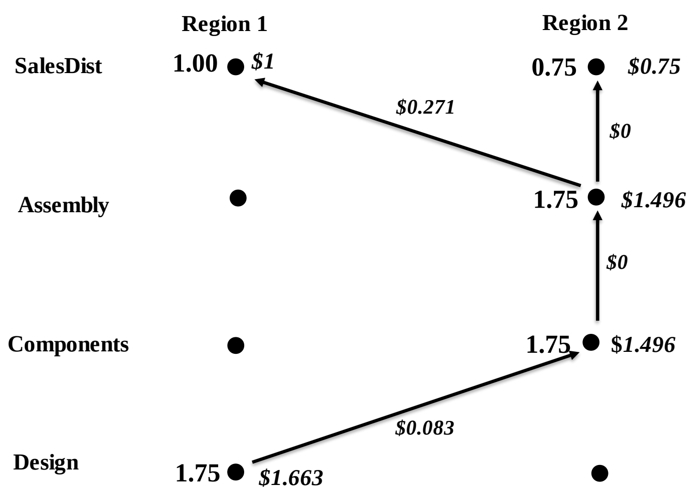
	Price	Output	Employment	Exports, qty	Exports, value
Region 1					
Design	0.95	1.75	1.663	1.75	1.663
Components	1.95	0	0	0	0
Assembly	2.945	0	0	0	0
SalesDist	3.978	1	1	0	0
Total			2.663		1.663
			VA=2.663		
Region 2					
Design	2	0	0	0	0
Components	1.852	1.75	4.987	0	0
Assembly	2.707	1.75	4.987	1	2.707
SalesDist	3.707	0.75	2.5	0	0
Total			12.474		2.707
			VA=3.743		
KWW export decomposition	**FOB exports**	**Domestic VA absorbed externally**	**Domestic VA exported and returned**	**Foreign VA in exports**	**Tariff/transport content of exports**
Region 1	1.663	0.713	0.950	0	0
Region 2	2.707	1.710	0	0.950	0.047
Region 1's trade surplus	-1.044				

Overview of results: 1990 to 2010

Going from 1990 to 2010, the U.S. has lost its manufacturing employment (Components and Assembly) in the Widget sector. Simultaneously, it has converted a large trade surplus in Widgets into a large trade deficit. In 1990 the U.S. exported Assembly to Asia with no offsetting imports. In 2010, the U.S. imports Assembly with a relatively small offsetting export of Design.

A final piece of simulated bad news for the U.S. is that the change in trade patterns between 1990 and 2010 doesn't benefit U.S. consumers of Widgets. Because U.S. consumers in 2010 pay most of the trade costs incurred by the world-wide widget industry, the price of Supplied Widgets in the U.S. has slightly increased. Table 8 summarizes the story.

Figure 7. Material trade routes (MTR) diagram: 2010



Total cost of satisfying final demands = $6.759
= (1.663+0.083+1.496+0+1.496+0.271+1+0+0.75)
= 3.978*1+3.707*0.75

Table 8. Summary of results from the supply chain widget model

1990	1995	2000	2010
Region 2 is uncompetitive in the 3 tradeable activities All design and manufacturing is in country 1 Large trade surplus for 1 Large service and manufacturing employment for 1 Region 2 employs only service workers Trade is in assembled goods only: 1→2 (Ricardian)	Region 2 becomes competitive in components and trade costs fall But design and manufacturing remains in region 1	Assembly costs in region 2 fall but are still uncompetitive Surprisingly this switches component production entirely from 1 to 2. Region 2 starts assembly for the domestic market only. Region 1 loses most of its manufacturing employment Region 1 now has a small trade deficit rather than a large trade surplus Trade is entirely in intermediate goods The price of finished	Region 2 now dominates in both assembly and components, but domination in assembly didn't occur until 2's assembly SLC was well below that of 1 Region 1 has now lost all manufacturing jobs in widgets Region 1's trade deficit becomes large Design but not components continue to be traded and trade in assembled goods re-emerges Again, the price of finished goods in region 1 increases

5. Concluding remarks and next steps

The story in section 4 is hypothetical. But it brings out two points. First, it is a story that could not be told with a current-generation CGE model. These models do not recognize fragmentation of production, scale economies and global decision making. Second, it is a story that captures elements of reality: production processes that shift rapidly between different parts of the world; growth in trade in unfinished goods relative to trade in finished goods; and the hollowing out of manufacturing processes in some developed countries. The story resonates with the antagonism felt in the U.S. towards free-trade policies.

The challenge now is to move from a stylized framework to a real-world model. To achieve this we need to solve problems in theory, data and computing.

With regard to theory, we need to add to the Widget specification capital and resource constraints. Our present specification exaggerates the mobility of GSC activities. The existence of capital specific to an activity slows down the movement of activities between locations, and constraints on the availability of suitable labour limit the extent to which a world-wide activity can be undertaken in any particular location. Enhanced versions of the Widget specification for relevant sectors such as electronics and vehicles must then be embedded into a complete CGE model. This is necessary so that we can see resource flows into and out of GSC activities in winning and losing regions. For example, if GSC trade reduces manufacturing employment in a region, what happens to the displaced workers? Will real depreciation generate opportunities for export expansion and employment in other industries such as tourism or is the losing region left with a long-term structural adjustment problem?

With regard to data, we can draw on at least two major compilations of trade flows and input-output tables. These are the databases provided by the Global Trade Analysis Project (GTAP) and the World Input-Output Database Project (WIOD).[8] These organizations produce databases that can be represented as in Table 9.[9] If there are n commodities/industries and g countries, then Z^{sr} for s, r = 1, 2, …, g is an n *x* n matrix whose i,jth component is the value in the base year of commodity i sent from region s to industry j in region r. Y^{sr} is an n dimensional vector whose ith component is the base-year value of commodity i sent from region s to final use in region r. $X^{s'}$ and $Va^{s'}$ are n-dimensional vectors whose ith components are base-year values of output and value added in industry i in region s. GTAP and WIOD databases have been used in the construction of many CGE models. From the point of view of constructing a CGE model for GSC analysis the problem with these databases is commodity/industry aggregation. While both the GTAP and WIOD databases are highly detailed in the region dimension, neither has adequate detail for GSC analysis in the commodity/industry dimension. GTAP identifies 57 commodities/industries and WIOD 56. A typical GTAP and WIOD commodity is "Manufacture of motor vehicles, trailers and semi-trailers". For GSC analysis, we need trade flows for this commodity disaggregated into sub-commodities or activities such as Design, Components and Assembly. One possibility for achieving the necessary disaggregation is to use underlying 5 or higher digit SITC data from the U.N. Comtrade database. Athukorala and Talgaswatta (2016) show how flows at the 5-digit level can be classified as GSC Components and Assembly using guidance from the U.N. Broad Economic

[8] Relevant websites are https://www.gtap.agecon.purdue.edu/ and http://www.wiod.org/home .

[9] This table is reproduced from Wang *et al.* (2017).

Table 9. General Inter-Country Input-Output table

Inputs \ Outputs		Intermediate Use				Final Demand				Total Output
		1	2	⋯	g	1	2	⋯	g	
Intermediate Inputs	1	Z^{11}	Z^{12}	⋯	Z^{1g}	Y^{11}	Y^{12}	⋯	Y^{1g}	X^1
	2	Z^{21}	Z^{22}	⋯	Z^{2g}	Y^{21}	Y^{22}	⋯	Y^{2g}	X^2
	⋮	⋮	⋮	⋱	⋮	⋮	⋮	⋱	⋮	⋮
	g	Z^{g1}	Z^{g2}	⋯	Z^{gg}	Y^{g1}	Y^{g2}	⋯	Y^{gg}	X^g
Value-added		$Va^{1'}$	$Va^{2'}$	⋯	$Va^{g'}$					
Total input		$X^{1'}$	$X^{2'}$	⋯	$X^{g'}$					

Classification (BEC). In section 4 we performed stylized historical analysis. As well as disaggregation, realistic historical analysis would require data for several periods on standard unit labour costs, transport costs and tariffs. This requirement is reduced to a single period for analysis concerned with "what if" questions, that is deviations away from a base-year situation induced by policy or other shocks.

On computation, the 1-sector, 2-region, 3-tradeable activity GSC model described in this paper presented no difficulties. In arriving at each solution we evaluated 27 scenarios. This was done in a faction of a second. However, the number of scenarios increases rapidly with the number of GSC sectors, the number of regions and the number of tradeable activities. It is likely that smart algorithms will be required to keep the computations manageable.

Incorporating GSC features into CGE models will be a major task. But it is an urgent task. The absence of economy-wide models with credible GSC features leaves a vacuum in the policy-advising space. GSC networks are now a major part of world trade. Policy makers need guidance on how this type of trade affects manufacturing jobs, consumer prices and economic welfare more generally.

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