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Measuring Smile Curves in Global Value Chains *

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Aug 27, 2015

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Keywords: Smile curve, Global value chains, APL, Fragmentation of production
JEL classification: F6; F13; F15, D57

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1 Introduction

The rise of global value chains (GVCs) is considered one of the most important features of the rapid economic globalization in recent decades. The economic and popular literature has described phenomena relating to the rise of GVCs from different perspectives, such as fragmentation (Jones and Kierzkowski, 1990), offshore sourcing (Arndt, 1997), external orientation (Campa and Goldberg, 1997), disintegration of production (Feenstra, 1998), global production sharing (Yeats, 2001), vertical specialization (Hummels et al., 2001; Yi, 2003), outsourcing (Grossman and Helpman, 2002a,b), vertical production networks (Hanson et al., 2003), trade in tasks (Grossman and Rossi-Hansberg, 2008), the second great unbundling (Baldwin, 2011), and so on. Despite the use of these different terms, they all point to the same fact: value chains are sliced up in tasks and functions globally. That is to say, goods are produced "in a number of stages in a number of locations, adding a little bit of value at each stage" (Krugman, 1995). The theoretical cause for this shift is the reduction of service link costs (Jones and Kierzkowski, 1990), including the costs of trade, investment, coordination, and communications. Lower costs for these service links has enabled the international unbundling of factories and offices, which means that tasks can also be traded globally.

There are several positive aspects of GVCs, from the viewpoint of development economics. First, firms, especially in developing economies, do not need to build a whole course of production capacity. Instead, they just need to use their comparative advantages to concentrate in a specific production process, which makes participation in the global economy possible (Kowalski et al., 2015). Second, becoming a part of GVCs can create more employment opportunities (UNCTAD, 2013). For example, jobs are created in developing countries from iPhone assembly in China, call centers operations in the Philippines and India, Nike shoes production in Vietnam, and automobile and auto part production in Mexico and Thailand. Third, GVCs also provide the opportunity for technology transfer or spillover to developing countries through local learning (Pietrobelli and Rabellotti, 2010; Kawakami et al., 2012).

However, as mentioned in the OECD-WTO-World Bank Group report (2014), "Gains from GVC participation are not automatic. Benefits of GVCs can also vary considerably depending on whether a country operates at the high or at the low end of the value chain." Regarding the costs and risks of joining GVCs, a paradoxical pair of concerns between developed and developing countries may exist (e.g., Baldwin et al., 2014). Namely, because of the differences in comparative advantages across countries in GVCs, rich countries may tend to engage in high-end and intangible production activities such as R&D, design, and brand building in the pre-fabrication stages and after-sales services and marketing in the post-fabrication stages. Thus, rich countries may worry about the hallowing out of their economies as manufacturing jobs are offshored to low-technology, low-wage nations. Poor nations, on the other hand, may tend to focus on low-end and tangible production activities such as manufacturing and assembly. Thus, they may be increasingly worried that they are getting the wrong sorts of jobs and that their economies could be locked into GVCs at the bottom of the so-called "smile curve."

The concept of the smile curve was first proposed around 1992 by Stan Shih, the founder of Acer, a technology company headquartered in Taiwan. Shih (1996) observed that in the personal computer industry, both ends of the value chain command higher values added to the product than the middle part of the value chain. If this phenomenon is presented in a graph with a Y-axis for value-added and an X-axis for value chain (see Figure 13), the resulting curve appears in the shape of a smile. The smile curve logic has been widely used and discussed in the context of GVCs (e.g., Mudambi, 2008; Shin et al., 2012). However, most research has focused on firm-level analysis, rather than the economy-wide implications concerning (1) what relationship exists between developed and developing countries in the creation and distribution process of value-added in GVCs; (2) whether smile curves are deepening or becoming flatter in GVCs; (3) whether developing countries have been locked into the low end of GVCs; (4) which policies can help countries keep or improve their competitiveness in the smile curve; and (5) how developing countries are able to integrate into GVCs successfully and then move up from the low end to high end of the smile curve. Better answers to these questions are crucial for designing effective development strategies, industrial policies, and international governance.

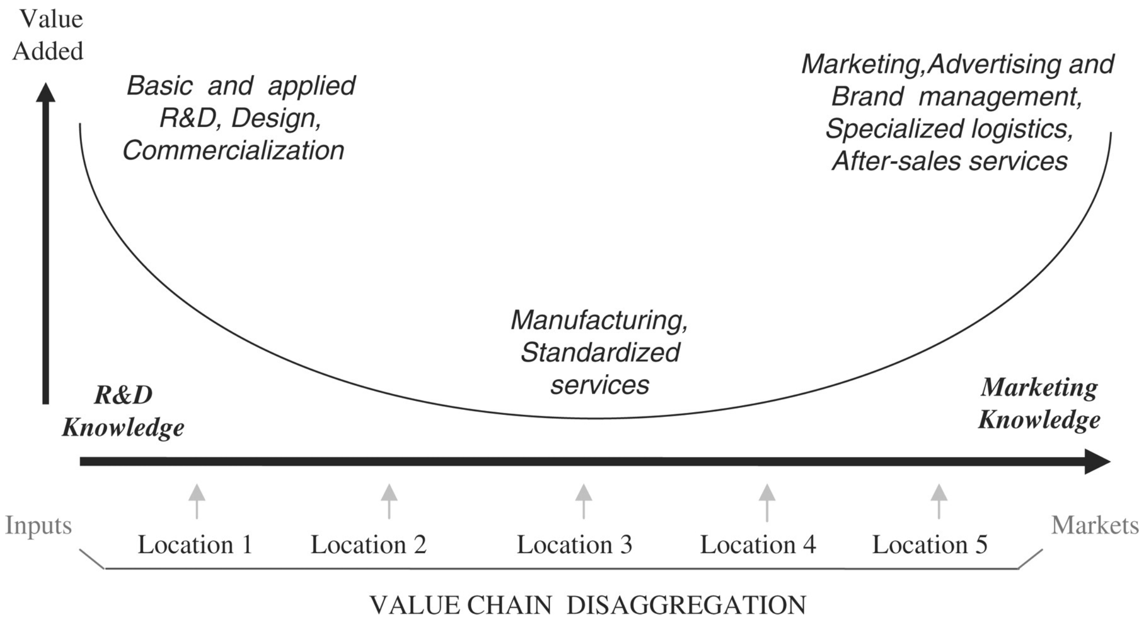


Figure 1: Conceptual framework of the smile curve
(Source: Mudambi, 2008.)

The logic of smile curve has been widely used in case studies of individual firms, but rarely identified, measured, and evaluated at the country level by using real data with explicit consideration of international production networks. The paper aims to identify smile curves from this broader perspective by taking advantage of existing international input-output (IO) measures to understand the degree and position of different countries' participation in GVCs.

Concerning the measurement of GVC participation, two main approaches are widely used. The first approach is based on the collection of survey data for a specific firm or product. For example, case studies examining China's role in Apple's supply chain (e.g., Linden et al., 2009; Dedrick et al., 2010) have received a great deal of attention. Xing and Detert (2010) examined the case of the iPhone and found that value added by China contributed just 3.6%

to the \$2.0 billion of iPhone exports to the US in 2009; the remainder of the value-added was from Germany, Japan, Korea, the US, and other countries. These studies rely on "tear down" analyses that assign the value of individual components to source companies and their countries. These firm- and product-based case studies can provide an intuitive understanding of GVCs in terms of the activities of multinational enterprises. However, these "tear down" case studies focus on only the supply chain of a specific firm and particular products, and are clearly not representative of the broader role of production networks and inter-industrial linkages in the whole value creation process. For example, when we examine the role of the Chinese economy in global production networks as a whole, the share of domestic value-added through gross exports of final products shipped to the United States was actually about 75% in 2009.

The second approach to measuring GVC participation is based on IO tables. Hummels et al. (2001) first proposed a measure based on the share of vertical specialization (VS) or the import content of exports by using single-nation IO tables. The VS share avoids the shortcomings of firm- or product-based measures to some extent since it can capture the intermediate imports used directly and indirectly to produce exports with consideration given to domestic inter-industrial production linkages. However, it should be noted that in a national IO table, imports and exports are treated as exogenous variables; the so-called spill-over and feedback effects from the rest of the world cannot be fully considered in the VS measure (e.g., imported intermediate goods may also include domestic content). In response to the limitations of the VS measure, international IO tables, which consist of detailed information on both inter-country and inter-industry linkages, have been used to measure GVCs in recent years. Studies taking this approach include Johnson and Noguera (2012), Stehrer (2012), Timmer et al. (2014a), and Koopman et al. (2014). Most of these papers, with the exception of Koopman et al. (2014), discuss the connections between their approaches and the approach of Hummels et al. (2001) in broad terms. Koopman et al. (2014) provides a unified mathematical framework for completely decomposing gross exports into its various components, including exported value-added, returning domestic value-added, foreign value-added, and other additional items that may be double counted. This framework establishes a precise relationship between value-added measures of trade and official trade statistics, which thus providing an observable benchmark for value-added trade estimates.

Most of the existing measures mentioned above focus on showing the degree to which a country participates in GVCs, rather than its position in GVCs explicitly. A better understanding of the increasing complexity and sophistication of production networks requires new measures that can capture the "length" of the linkages between countries or industries or between producers and consumers for mapping the geometry of value chains. Dietzenbacher et al. (2005, 2007) proposed a new concept, the average propagation length (APL), to measure the number of production stages in production networks. The international application of the APL framework was brought into the Asian context and extended by Inomata (2008) and Escaith and Inomata (2013) through a time-series analysis using the Asian International IO tables. Fally (2011, 2012) characterized the position along a production line in terms of the distance to final use. Namely, industries that sell a relatively larger share of their outputs to industries further upstream are defined as being "more upstream". Antras et al. (2012) proposed the concept of "upstreamness", which is the number of stages that the product goes through before reaching the final demand. They also prove that their concept of "upstreamness" is consistent with Fally's (2011, 2012) distance definition. In addition, Miller and Temurshoev (2013) proposed two other indicators to identify the upstreamness and downstreamness of an industry. A recent paper by Chen (2014) extended the APL to group-wise APL, a general mathematical framework. In his work, both APL and the upstreamness measure by Antras et al. (2012) are proved to be special cases of the group-wise APL.

In contrast to the existing measures of "length" and "distance" in the GVC literature, our paper proposes a generalized and consistent accounting system that can be used to measure the distance in production networks between producers and consumers at the country, industry, and product levels from different economic perspectives. The important feature of our measure for distance is that we focus on the "value-added" propagation process in GVCs and provide more flexible ways to measure the position of countries and industries along GVCs. The most important contribution of this paper is that we provide some conceptual designs based on the IO technique to represent the process for the creation and distribution of value-added along GVCs in detail. For example, our measure can be used to examine the GVC concerning a specific good made in China that is consumed in the US, such as the case of iPhone. Using measures for both the strength and length of linkages between producers and consumers and the conceptual designs of GVCs, the identification of various economy-wise smile curves in GVCs becomes possible based on real data, in this case from the World Input-Output Database (WIOD)[1].

2 Methodology

2.1 Value added creation process in a closed economy

Our methodology is rooted in Leontief (1936) whose work demonstrates the complex linkages among different industries in an economy can be expressed as various inter-industry transactions organized into chessboard-type matrices, known as IO tables. Each column in the table represents the required inputs from other industries (including imports and direct value-added) to produce the given amount of the product represented by that column. After normalization, the technical coefficient table represents the amount and type of intermediate inputs needed in the production of one unit of gross output. Using these coefficients, the gross output in all domestic stages of production that is needed to produce one unit of final products can be estimated via the so-called Leontief inverse. When the output flows associated with a particular level of final demand are known, the total value-added throughout the economy can be estimated by multiplying these output flows with the value-added ratio (amount of value-added per unit of gross output) in each industry.

[1]The WIOD (www.wiod.org) provides world input-output tables for each year since 1995 covering 40 countries, including all 27 countries of the European Union (as of January 1, 2007) and 13 other major economies (see Appendix 1). These 40 countries represent more than 85 percent of world GDP. It contains data for 35 industries covering the overall economy, including agriculture, mining, construction, utilities, 14 manufacturing industries, and 17 services industries (see Appendix 2). The tables have been constructed by combining national input-output tables with bilateral international trade data, following the conventions of the System of National Accounts. For detailed information about the WIOD, see Timmer et al. (2014b).

In a national I-O table,

$$X = AX + Y \tag{1}$$

where X is the $N \times 1$ gross output vector, Y is the$N \times 1$ final demand vector, and A is the$N \times N$ IO technical coefficient matrix. In other words, all gross output (total supply) must be used either as an intermediate good or a final good (total demand). After rearranging terms, we can have

$$X = (I - A)^{-1}Y = BY \tag{2}$$

where B denotes the $N \times N$ block matrix, commonly known as a Leontief inverse, which is the total requirement matrix that gives the amount of gross output required for a one-unit increase in final demand. The relationship expressed in equation (2) is the Leontief insight. Under the common assumptions for solvability of the equations, B also can be expressed as a power series.

$$B = I + A^2 + A^3 + \cdots \tag{3}$$

The effects on the gross output X due to a demand pull Y which is given in equation (2), can be interpreted as a stepwise or round-by-round procedure in equation (3). The initial effect in round 0 states that Y itself needs to be produced. In order to produce this additional output, extra intermediate inputs are required directly, amounting to AY in round 1. Next, these extra intermediate inputs AY need to be produced themselves, requiring A^2Y of additional intermediate inputs in round 2, and so forth. Therefore, the effects of gross output effects X thus consist of an initial effect Y, a direct effect AY and indirect effects $(A^2 + A^3 + \cdots)Y$.

In an IO table, we define V as a $1 \times N$ direct value-added coefficient vector. Each element of V shows the share of direct value-added in gross output. This is equal to one minus the intermediate input share:

$$V = u[I - A] \tag{4}$$

where u is a $1 \times N$ unit vector. The elements in the direct value-added coefficient vector V can be also re-written as the following form:

$$v_j = va_j / x_j = 1 - \sum_{i}^{n} a_{ij} \tag{5}$$

where, va_j is the direct value-added of industry j. Then, we can define the total value-added coefficient (VB) matrix as follows:

$$VB = \begin{bmatrix} v_1 & v_2 & \cdots & v_n \end{bmatrix} \begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1n} \\ b_{21} & b_{22} & \cdots & b_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ b_{n1} & b_{n2} & \cdots & b_{nn} \end{bmatrix} = \begin{bmatrix} v_1b_{11} + v_2b_{21} + \cdots + v_nb_{n1} \\ v_1b_{12} + v_2b_{22} + \cdots + v_nb_{n2} \\ \vdots \\ v_1b_{1n} + v_2b_{2n} + \cdots + v_nb_{nn} \end{bmatrix}^T \tag{6}$$

Note that each element in the last term of equation (6) equals unity (Koopman et al., 2014). Then, we can decompose the industry level value-added and final goods production as a direct application of the Leontief insight expressed as follows:

$$\hat{V}B\hat{Y} = \begin{bmatrix} v_1 & 0 & \cdots & 0 \\ 0 & v_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & v_n \end{bmatrix} \begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1n} \\ b_{21} & b_{22} & \cdots & b_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ b_{n1} & b_{n2} & \cdots & b_{nn} \end{bmatrix} \begin{bmatrix} y_1 & 0 & \cdots & 0 \\ 0 & y_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & y_n \end{bmatrix}$$
$$= \begin{bmatrix} v_1 b_{11} y_1 & v_1 b_{12} y_2 & \cdots & v_1 b_{1n} y_n \\ v_2 b_{21} y_1 & v_2 b_{22} y_2 & \cdots & v_2 b_{2n} y_n \\ \vdots & \vdots & \ddots & \vdots \\ v_n b_{n1} y_1 & v_n b_{n2} y_2 & \cdots & v_n b_{nn} y_n \end{bmatrix} \tag{7}$$

The matrix in equation (7) shows the estimates of industrial value-added in final goods production. Each element in the matrix represents the value-added from a source industry directly or indirectly used in the production of final goods. In the matrix, walking along the row yields the distribution of value-added created from one industry used across all industries. Therefore, summing up the ith row of the matrix, we obtain the total value-added created by production factors employed in the ith industry. In other words, it equals the GDP of the ith industry. Expressing this mathematically, we have

$$v_i(b_{i1}y_1 + b_{i2}y_2 + \cdots + b_{in}y_n) = va_i = GDP_i \tag{8}$$

At the same time, in the same matrix, a column yields the contributions of value-added from all industries to the final goods produced by a particular industry. Adding up all elements in the jth column equals the total value of final goods by the jth industry, as shown by

$$v_1 b_{1j} y_j + v_2 b_{2j} y_j + \cdots + v_n b_{nj} y_j = y_j \tag{9}$$

These two different ways that decompose value-added and final goods production have their own economic interpretations and thus play different roles in economic analysis. In summary, the sum of the $\hat{V}B\hat{Y}$ matrix across columns along a row accounts for how each value-added originating in a particular industry is used by the industry itself and all its downstream industries. It traces forward industrial linkages across all downstream industries from a supply-side perspective. Since the sum of the $\hat{V}B\hat{Y}$ matrix across the rows along a column accounts for all upstream industries' value-added induced by a specific final good, it traces backward industrial linkages across upstream industries from a user's perspective. Based on the identity (equation (6)), all these sources should sum to 100% of the value of final products for any given industry.

2.2 Value added propagation length

In this section, we define the value-added propagation length from producers to consumers in a closed economic system. We have shown how value-added can be propagated through both forward and backward industrial linkages in an economy in equations (8) and (9) above. These two equations can be further transformed to

$$\frac{v_i}{va_i}(b_{i1}y_1 + b_{i2}y_2 + \cdots + b_{in}y_n) = 1 \tag{10}$$

$$v_1 b_{1j} + v_2 b_{2j} + \cdots + v_n b_{nj} = 1 \tag{11}$$

Re-writing the above equations as matrix form, we get

$$\hat{V}BY/\text{VA} = \hat{V}(I + A + A^2 + A^3 + \cdots)Y/\text{VA} = u \tag{12}$$

$$VB = V(I + A + A^2 + A^3 + \cdots) = u^T \tag{13}$$

where, u denotes a $N \times 1$ unit vector and VA denotes the value-added vector in IO table. In this paper, we define "/" as an element-wise vector division operator. In equation (12), the first term VIY/VA in the expansion form indicates the share of value-added absorbed by all final demand through the round 0 production process via forward industrial linkages in total value-added by industry. The second term VAY/VA represents the share of value-added absorbed by all final demand through round 1 of the production process via forward industrial linkages in total value-added by industry. The remaining terms show the induced value-added share in subsequent rounds of production processes via forward industrial linkages. Alternatively, in equation (13), the first term VI in the expanded form indicates the national value-added induced by one unit of final demand on a specific product through the round 0 production process via backward industrial linkages. The second term VA in the expanded form indicates the national value-added induced by one unit of final demand for a specific product through round 1 of the production process via backward industrial linkages. The remaining terms show the induced national value-added in subsequent rounds of production processes via backward industrial linkages.

On the basis of the explanation of equations (12) and (13), the logic of APL (Dietzenbacher et al., 2005), and the concept of "upstreamness" (Antras et al., 2012), the industrial value-added propagation length through both forward and backward industrial linkages can be defined by using a weighted expression as shown below.

Definition 1: Forward industrial linkage-based value-added propagation length:

$$\begin{aligned} U = \hat{V}(1I + 2A + 3A^3 + \cdots)Y/\text{VA} &= \hat{V}(0I + 1A + 2A^2 + \cdots)Y/\text{VA} + u \\ = \hat{V}B^2Y &= \hat{V}(B^2 - B)Y/\text{VA} + u \end{aligned} \tag{14}$$

The index U measures the total number of stages, on average, through which the value-added of a specific industry reaches all final demand users by the way of forward industrial linkages. It can be simplified as the distance from a specific industry (value-added creator) to consumers. If U is a relatively large figure for a specific industry, it indicates that this industry is located in the upstream portion of the value chain since its value-added goes through many downstream production stages before reaching final users. On the other hand, a lower value of U indicates that the industry is closer to the downstream portion of the value chain since only a small number of stages are needed for this industry's value-added inputs to reach final users.

Definition 2: Backward industrial linkage-based value-added propagation length:

$$\begin{aligned} D = V(1I + 2A + 3A^3 + \cdots) &= V(0I + 1A + 2A^2 + \cdots) + u^T \\ = VB^2 &= V(B^2 - B) + u^T \end{aligned} \tag{15}$$

The index D measures the average number of production stages for a specific final product when it induces the value-added for all industries by the way of backward industrial linkages in the whole value chain. Unlike the index U, it is difficult to identify the position of a specific industry in value chains by using index D since it is measured from the perspective of the final user. In other words, D represents the length from a specific final product to all industries via the value-added propagation process. Therefore, compared to U, D can be simplified as the distance from a specific consumer (who consumes a specific final product) to suppliers.

It should be noted that both U and D give an average level of value-added propagation length by industry. These measures are similar to the "distance"-related definitions used in the literature. However, to slice up GVCs at more detailed levels, we need to define the distance from a specific supplier or a group of suppliers to a specific consumer or a group of consumers as shown below.

Given the same closed IO system, the value-added of a specific industry s (value-added creator or product supplier) induced by the demand of a specific final product k can be given as $V_s B Y_k$, where $V_s = \begin{bmatrix} 0 & 0 & \cdots & v_s & \cdots & 0 \end{bmatrix}$, represents the value-added input coefficient of industry s and $Y_k = \begin{bmatrix} 0 & 0 & \cdots & y_k & \cdots & 0 \end{bmatrix}^T$ represents consumers' demand on a final product k. If we denote $v_s b_{sk} y_k = va_{sk}$, then $\frac{v_s b_{sk} y_k}{va_{sk}} = 1$. For all value-added industries, the following relation holds in definition

$$\hat{V} B Y_k / \mathrm{VA}_k = \hat{V}(I + A + A^2 + A^3 + \cdots) Y_k / \mathrm{VA}_k = u \tag{16}$$

Following the definition of U, the value-added propagation length from sector s to final product $k(U_{sk}$, a scalar) can be given as follows:

$$U_{sk} = V_s(1I + 2A + 3A^2 + \cdots) Y_k / va_{sk} = V_s B^2 Y_k / va_{sk} \tag{17}$$

The above definition can also be given as a vector form for all industries:

$$U_k = \hat{V}(1I + 2A + 3A^2 + \cdots) Y_k / \mathrm{VA}_k = \hat{V} B^2 Y_k / \mathrm{VA}_k \tag{18}$$

where, U_k is a $N \times 1$ vector showing the industrial value-added propagation length to a specific final product k; $\mathrm{VA}_k = \begin{bmatrix} va_{1k} & va_{2k} & \cdots & va_{nk} \end{bmatrix}^T$; $v_i b_{ik} y_k = va_{ik}$.

For a group of final products, $Y_G = \begin{bmatrix} 0 & 0 & \cdots & y_m^G & \cdots & 0 \end{bmatrix}$, $m \in G$, we get $\sum_m^G v_i b_{im} y_m^G = va_{ig}$ and $\mathrm{VA}_G = \begin{bmatrix} va_{1G} & va_{2G} & \cdots & va_{nG} \end{bmatrix}^T$. Thus, the average distance from a specific industry to a group of final products G can be given as follows:

$$U_G = \hat{V}(1I + 2A + 3A^2 + \cdots) Y_G / \mathrm{VA}_G = \hat{V} B^2 Y_G / \mathrm{VA}_G \tag{19}$$

It is easy to know that $U_G = U$, when the group G is the entire final demand vector in the IO system, $Y_G = Y$.

The above definition for various lengths is from the perspective of the value-added creator (industry) and it measures the distance (the number of propagation stages) from a specific industry to a specific final product or a group of final products. From the consumers' perspective, U_{sk} can also be defined as D_{sk} representing the value-added propagation length from a specific final product k to a specific industry s.

If we donote $v_s b_{sj} y_j = va_{sj}$, then $\frac{v_s b_{sj} y_j}{va_{sj}} = 1$, Let $\text{VA}_s = \begin{bmatrix} va_{s1} & va_{s2} & \cdots & va_{sn} \end{bmatrix}^T$. By definiton, we have

$$V_s B\hat{Y}/\text{VA}_s = V_s(I + A + A^2 + \cdots)\hat{Y}/\text{VA}_s = u^T \tag{20}$$

Following the same manner used in the definition of U_k, the value-added propagation length from final products to a specific industry can be given as:

$$D_s = V_s(1I + 2A + 3A^2 + \cdots)\hat{Y}/\text{VA}_s = V_s B^2 \hat{Y}/\text{VA}_s \tag{21}$$

For a group of sectors T, $V_T = \begin{bmatrix} 0 & 0 & \cdots & v_m^T & \cdots & 0 \end{bmatrix}, m \in T$, let $\sum_m^T v_m^T b_{mj} y_j = va_{Tj}$ and $\text{VA}_T = \begin{bmatrix} va_{T1} & va_{T2} & \cdots & va_{Tn} \end{bmatrix}^T$, then the value-added propagation length from a specific final product to a group of value-added creators (industries) can be given as

$$D_T = V_T(1I + 2A + 3A^2 + \cdots)\hat{Y}/\text{VA}_T = V_T B^2 \hat{Y}/\text{VA}_T \tag{22}$$

Also when the group T covers the entire industries, $V_T = V$, we can simply have $D_T = D$.

The above indicators can be applied to a closed inter-country IO system. This can yield various distances depending on the definition of final product group or industry group. For example, grouping the all final products in the US, we can easily measure the U distance from specific Chinese industries to the US consumer. By grouping the entire final products of the world, the U distance from specific Chinese industries to the world market can be measured; by grouping the value-added of Chinese industries, we can also measure the D distance from a specific final product consumed in the US to Chinese producers. Grouping the entire value-added industries of the world allows us to measure the D distance from the specific final product consumed in the US to all producers.

2.3 Conceptual GVC settings

To give a more detailed mapping of the geometry of GVCs, we need three fundamental measures. The first one is the strength of linkages between countries or industries in the value-added propagation process; the second one is the length (distance) of linkages between producers and consumers in the value-added propagation process; the third one is the definition of the GVC itself. The measure for strength can be used to express the magnitude of the benefit (i.e., the absolute gain of value-added) for the country or industry that is involved in GVCs. The measure for length can be used to identify the position of a country or an industry in the value-added creation process. These two measures have been given in Section 2.1 and 2.2 respectively. The remaining work for this section is to create a conceptual GVC design.

GVCs can be seen from various perspectives. The most popular and simple GVC setting can focus on the export of a specific product and look at how value is added from one country or industry to another country or industry along whole production networks, and how the product is ultimately consumed by consumers. Take the case of an iPhone that is designed in California (US), assembled in China, and consumed in the US. Next, suppose the iPhone industry is reflected in China's part of an inter-country IO table. Then, it is easy to use China's iPhone exports to the US as a starting point for separating the whole value chain into pre-fabrication stages and post-fabrication stages. All countries and industries that directly and indirectly provide intermediate goods and services to China's production (assembly) of iPhone can be considered as participants in the pre-fabrication stages along the value chain. All countries and industries involved in the distribution process of imported iPhone to the US consumers can be considered as participants in the post-fabrication stages along the value chain.

Using the logic of Leontief's backward linkage, we can calculate the value-added by country and industry induced in the pre-fabrication stages by China's exports of the iPhone to the US in an inter-country IO system. In the same manner (Leontief's backward linkage), we can also measure the value-added induced in the post-fabrication stages by country and industry from commerce, transportation, and marketing services (markup or margin) when imported iPhones are delivered to the US consumers, assuming that there is no difference in markup rate across products in the US domestic market[2]. By picking up the most important participants with value-added gain above a threshold percentage (e.g., 1% of the total induced value-added in the whole value chain) in both pre-fabrication and post-fabrication stages in the iPhone GVC, a map of the iPhone GVC can be created. Specifically in this map, the value-added ratio (i.e., value-added gain by producing one unit of output) is used as the measure on the Y-axis and the distance from industry to the US consumers (forward industrial linkage-based measure, U) is used as the measure on the X-axis. The above conceptual GVC setting can also be applied to the case of Japanese cars, Italian designer clothes, and any other specific final product or group of final products. This GVC mapping can finally help us identify if the so-called "smile curve" exists, and if so, what it looks like in the GVC context. It should be noted that in our example we trace the most benefited participants in the iPhone GVC by using a measure of strength based on Leontief's backward industrial linkage, and identify the position of these participants by using the measure of length based on Leontief's forward industrial linkage.

3 Empirical results

3.1 Industry upstreamness and downstreamness in the value-added creation process

As mentioned before, the two measures for value-added propagation length, U and D, are equivalent at both the aggregated average level (for all countries and industries in a closed inter-country IO system) and the lowest level (between an industry and a final product). In order to check how the fragmentation of production in GVCs has changed over time, we first calculate the aggregated average U (or D) for the whole world from 1995 and 2011 using the WIOD and show the result in Figure 2.

Obviously, the value-added propagation length for the whole GVCs shows an increasing tendency, especially after 2002. It first peaked in 2008 and then had a short decline after the

[2] If IO or use tables based on both purchase and basic prices are available, the markup by product can be easily identified.

2008 global financial crisis. This was followed by a quick recovery and value-added propagation length peaked again in 2011. These trends are generally consistent with our intuitive image of the expending fragmentation of production after China's accession to the WTO in 2001.

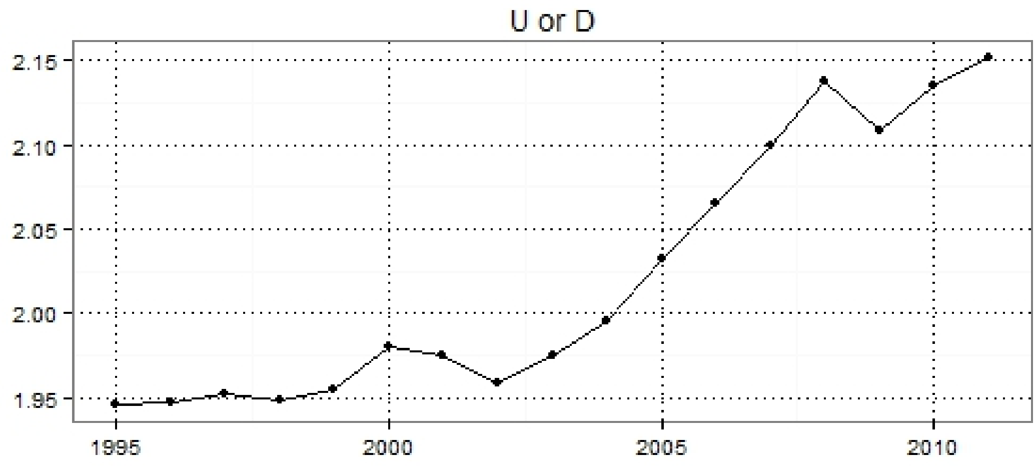
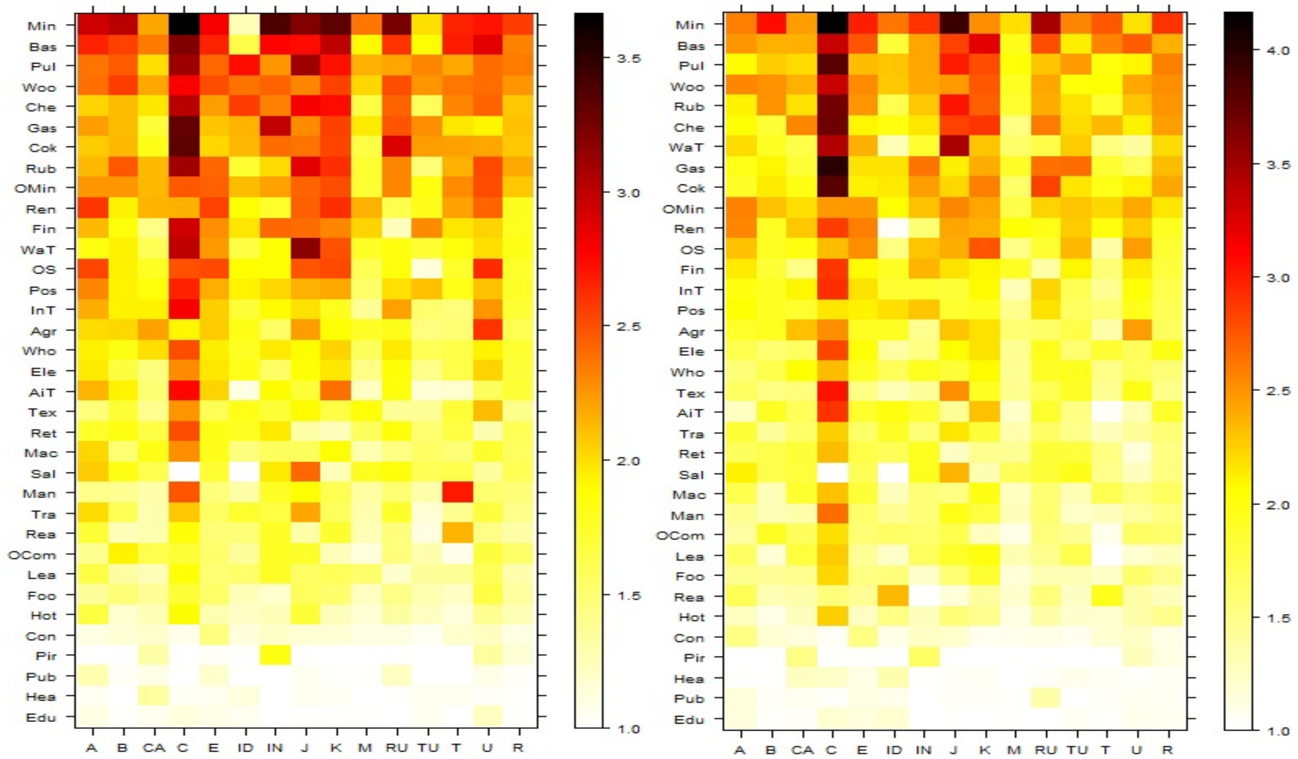
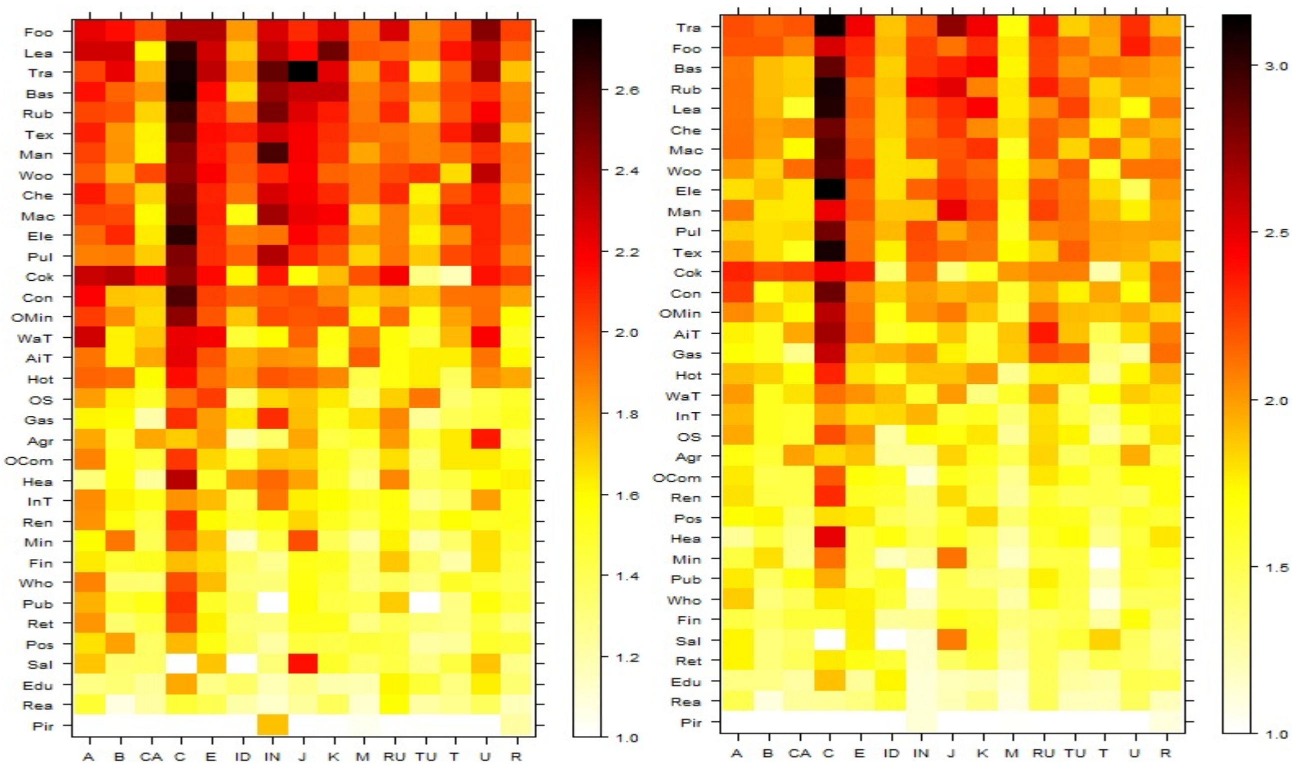


Figure 2: Trend in worldwide value-added propagation length, 1995-2011



(a) U(1995) (b) U(2011)

Figure 3: Value-added propagation length (U) by industry based on forward industrial linkages (Note: An explanation of the country codes (X-axis) and industry codes (Y-axis) are provided in Appendices 1 and 2, respectively.)



(a) D(1995) (b) D(2011)

Figure 4: Value-added propagation length (D) by industry based on backward industrial linkages

At the industry level, U and D have different economic explanations. The industrial U is based on the forward industrial linkage representing the distance from a specific industry (producers) to consumers. Therefore, U can be used as a proxy to reflect the position (upstreamness or downstreamness) of an industry in value chains. In order to check whether this indicator works well and matches our intuitive image of industries' positions in GVCs, we use the WIOD to calculate U for selected countries by industry and show the result in Figure 3.

As mentioned previously, the larger the U indicator, the more upstream the position of the relevant industry in value chains. Clearly, certain industries are located at the upstream portion of value chains (far from consumers) for most countries. These industries include raw material industries such as mining (2); manufacturing industries that produce fundamental parts and components such as basic metals (12), pulp and paper (7), wood (6), and chemicals (9); and utility industries as electricity, gas, and water supply (17)[3]. Industries that are located at the downstream portion of value chains (closer to consumers) mainly produce final goods or services for customers. These downstream industries include food (3), hotels and restaurants (22), construction (18), private households with employed persons (35), public administration (31), health and social work (33), and education (32). These results are very consistent with our intuitive and natural image of industries' positions in value chains. The remaining industries are

[3]The figure in parentheses indicates the original industry codes used in the WIOD. For more detail, refer to Appendix 1.

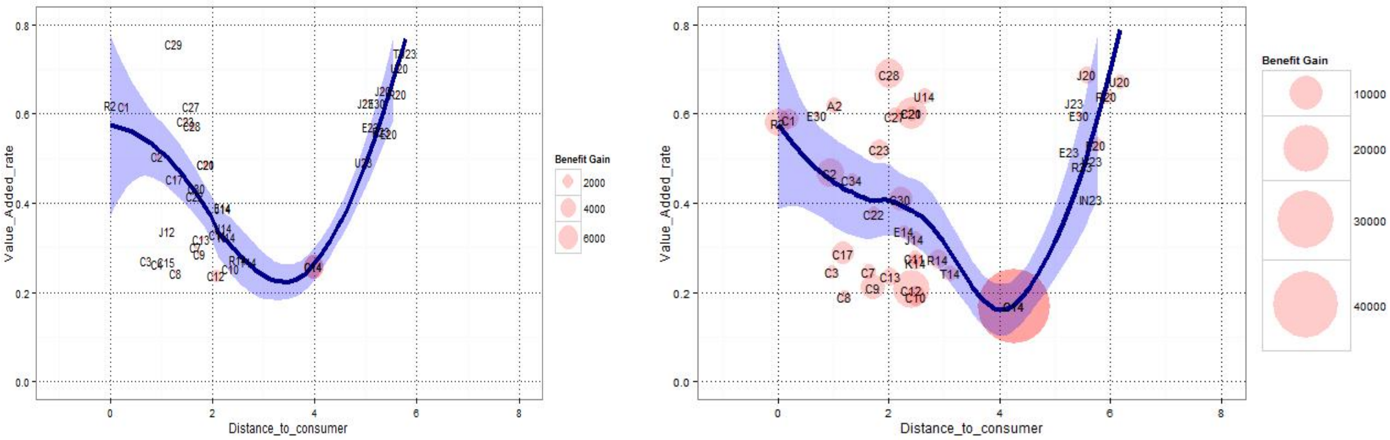
located between the upstream and downstream positions. For some industries, their positions are partly a result of the relatively rough industry classification used. For example, goods such as agriculture (1) and services such as air transport (25) can represent either intermediate inputs by industries or final consumption by household. The position rankings for industries are relatively stable when investigating the time-series calculation results for all countries in the WIOD (the situations for 1995 and 2011 are shown here for reference). Though the evolution of industrial and trade structure may impact the position of industries, the general position of most industries are not likely to change frequently or significantly since the most important determinants of position are inherent properties of an industry.

On the other hand, the indicator D is based on the backward industrial linkage which measures the distance from a specific final product to all producers. By definition, this indicator is difficult to use as a proxy for the position of an industry in value chains, but it can show how far a specific final product is from the value-added creators. We show the calculation results for D by country and industry in Figure 4. This indicator also looks relatively stable over time. However, it shows a very different ranking comparing to that of U in Figure 3. Most of the manufacturing products have relatively longer value-added propagation lengths, while most services shows relatively short lengths. This is intuitively understood because producing manufacturing products requires various intermediate inputs which are produced at stages further upstream. As a result, the larger the D indicator is, the more complex the production process of the final product is. In this meaning, D can be considered a proxy for the complexity of the production technology for a specific final product.

3.2 Examples of smile curves in GVCs

Once the measurement results are available for the strength and length of connections between countries or industries, we can confront the challenge of drawing the smile curves in various conceptual value chains. Here, a good starting point for us to consider is the case of the iPhone. However, in the existing inter-country IO tables, it is difficult to isolate the iPhone industry individually. Here, we first take the industry category of electrical and optical equipment (14) in the WIOD as a proxy to show how and to what extent countries and industries are involved in the value chain of China's exports of electrical products (which includes the iPhone).

As shown in Figure 5, the Y-axis gives the industrial value-added rate (value-added gained by producing one unit US$ output); the X-axis gives the distance, measured by the value-added propagation length, between a specific industry that is a participant in the corresponding value chain and the world consumers. The size of the circles represents the absolute value-added gained by joining the corresponding value chain(Unit: million US$ at constant prices); the smooth line is fitted by local polynomial regression smoothing weighted by their value-added gained; and the shadowed area shows the confidence interval around the smoothed line.



(a) 1995 (b) 2011

Figure 5: Value chains for Chinese exports of electrical and optical equipment

Note: The letters and figures along the smile curve indicate the benefiting countries and industries (for an explanation of these codes, see Appendices 1 and 2).

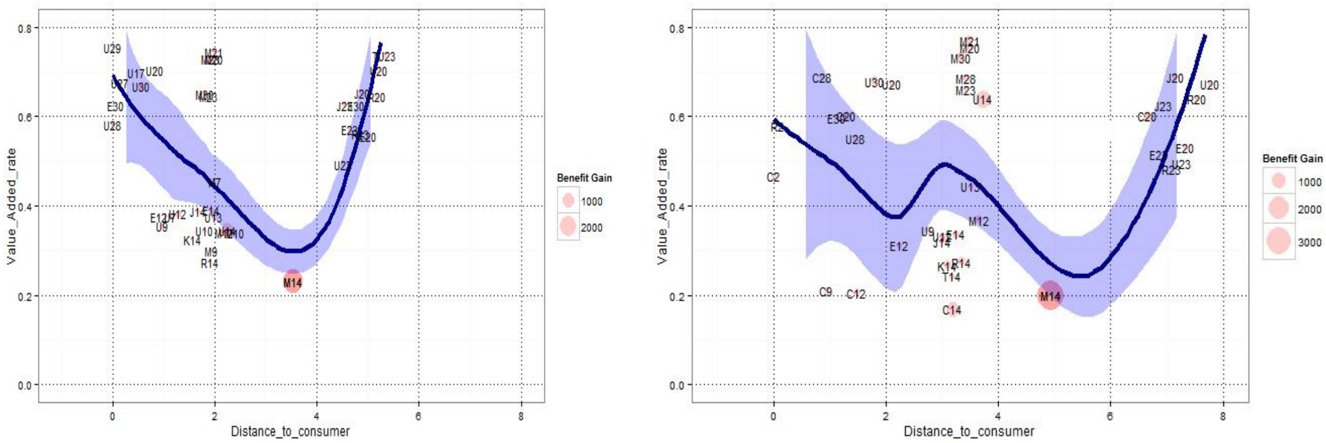
Clearly, the value chain for Chinese exports of electrical and optical equipment to the world market appears as a smile curve for both 1995 and 2011[4]. Several observations can be made from these curves. First, for both years we find that China's electrical and optical equipment industry (14) is the largest beneficiary in terms of value-added gain in this value chain. This is self-evident since China's electrical and optical equipment industry itself should be the most impacted industry by China's production of electrical and optical equipment exports through the backward and intra-industrial linkages. Second, many other Chinese domestic industries also benefited by participating in the pre-fabrication stages of this value chain. This is also self-evident since most of intermediate inputs needed to produce electrical and optical equipment in China are presumed to come from the Chinese domestic market. Third, the electrical and optical equipment industries in other countries located in the upstream portion of this value chain also get a relatively large portion of the value-added gain. This is mainly because of the cross-border, intra-industrial trade. Lastly, after-service industries such as wholesale (20) and inland transportation (23) in the US, Japan, and EU are the main beneficiaries in the post-fabrication stage of this value chain. This is also easy to understand since Chinese electrical and optical equipment exported to the US, Japan, and EU need to be delivered to their domestic consumers, mainly through the use of their domestic wholesale and transportation service industries.

In terms of the evolution of the smile curves in Figure 5, the main finding is that the whole curve moves down. This movement implies that the value-added rate for most participants (industries in different countries) in this value chain decreased between 1995 and 2011.

[4]Here, we pick up the most important participants (countries and sectors) with value-added gain above a threshold percentage (1% of the total induced value-added in the whole value chain) in both pre-fabrication and post-fabrication stages in this smile curve. Appendix 3 shows the corresponding smile curve when all the beneficiary countries and industries are selected.

In other words, producing one unit of output requires more intermediate inputs, including intermediate imports for most participants in this value chain. Using the Chinese electrical and optical equipment industry as an example, the value-added rate decreased very fast. Several reasons likely explain this phenomenon. The first reason is increased processing trade in this industry. The participation pattern of China in the GVC at the early stage is the acceptance of outsourcing tasks such as the assembly of iPhones. Compared with the traditional production of electrical and optical equipment, the assembly process is much more labor intensive and depends on a greater amount of foreign intermediate inputs. Despite the increasing domestic labor cost at an absolute level in China, decreasing usage of capital and increasing usage of intermediate imports may result in a decline in the value-added rate for this industry. Second, the confidence interval of the smile curve becomes much wider. This is mainly because of the expanding differentials of value-added rates among value chain participants. Evidence strongly supports this phenomenon. For example, the value-added rate of the US electrical and optical equipment industry moved up from 0.34 in 1995 to 0.64 in 2011, while the value-added rate for this industry in China went down from 0.25 in 1995 to 0.18 in 2011. In other words, the US electrical and optical equipment industry increasingly concentrated on high value-added production of more complex intermediate goods (e.g., computer processors), whereas China took on more tasks such as assembling final products with low value-added per unit production. Third, the whole length of the smile curve is getting much longer. This reflects the fact that a higher volume of intermediate goods is produced in subsequent stages or processes across different countries, and these goods are then exported to other countries for further production. Fourth, the Chinese electrical and optical equipment industry is located at the low end of the smile curve, but its value-added gain is increasing in absolute terms (note the change in circle size between 1995 and 2011). In other words, China is taking an increasingly large piece of the pie in the value chain, although the value-added gain in producing one unit of electrical goods in USD is declining.

There is no guarantee that value chains will always look like a smile curve. Figure 6 shows the mapping result for Mexico's value chain in term of its exports of electrical and optical equipment. In 1995, a very clear V-shaped smile curve can be identified. However, in 2011, the shape of the curve changes significantly and becomes a W-shaped curve. To examine the reasons behind this phenomenon, we must first look at the evolution of the main players involved in Mexico's electrical and optical equipment value chain between 1995 and 2011. In 1995, the main participants in the pre-fabrication stages of this value chain are composed of Mexican domestic industries such as chemicals (M9), and metal products (M12), as well as a number of US industries such as rubber and plastics (U10), machinery (U13), and electrical and optical equipment (U14). However, at least three factors contributed to the remarkable changes in the shape of this smile curve. One is the rapidly increasing presence of China in Mexico's value chain. As seen in 2011, many low value-added Chinese industries such as chemicals (C9) and basic metals (C12) replaced other countries' position in the Mexican value chain and these Chinese industries became the main players with a relatively large value-added gain in the pre-fabrication stage of this value chain. The second factor is the rapid technological upgrades happening in the US electrical and optical equipment industry (U14), which is increasing its value-added rate and still maintains a relatively large value-added gain. The third factor is the increasing value-added rate and the absolute value-added gain of Mexico's service industries in the pre-fabrication stage. In addition, China's presence in the high-end of this value chain is also noteworthy. For example, China's financial intermediation (C28) and wholesales (C20) industries play an increasingly important role in the pre-fabrication and post-fabrication stages of the Mexican electrical and optical equipment value chain, respectively. This shift may have also contributed to the overall expansion of Mexico's electrical product value chain since the whole length (Y-axis) of this chain increases from 5.4 to 7.3 between 1995 and 2011.



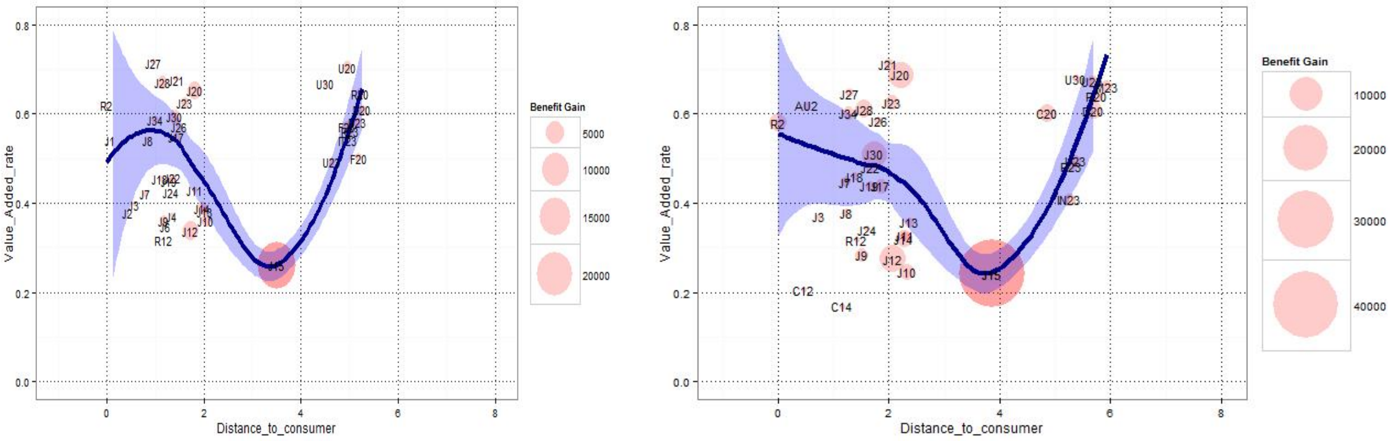
(a) 1995

(b) 2011

Figure 6: Value chains for Mexican exports of electrical and optical equipment

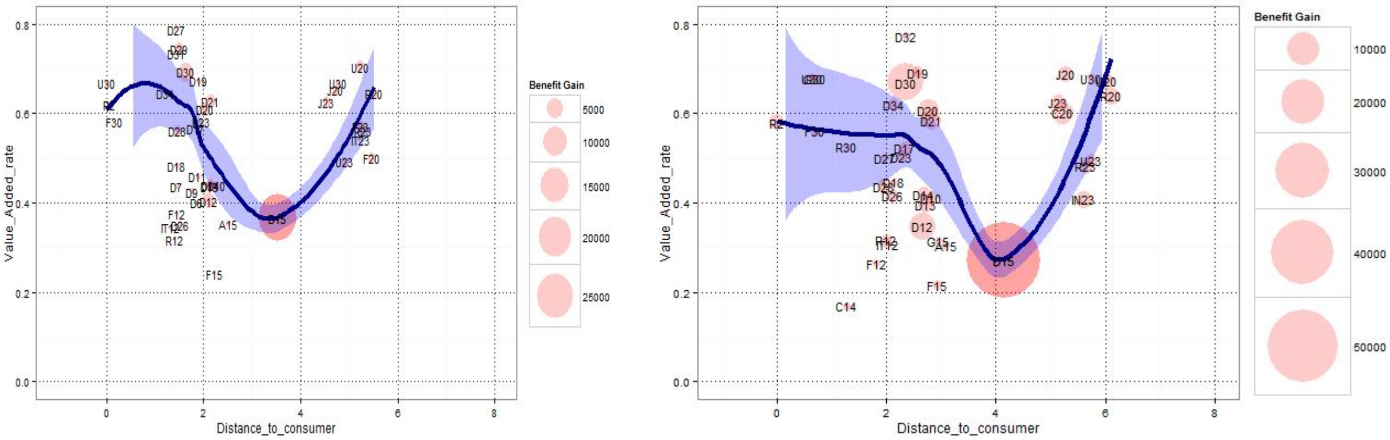
The iPhone is one of the most typical products that have been widely used to explain the phenomenon of global fragmentation of production. Next, we take up the example of German and Japanese automobiles to investigate their value chains. Figure 7 shows the value chain for Japanese auto exports for 1995 and 2011. In general, both figures show a v-shaped smile curve, while the curve for 2011 looks much deeper and wider than that for 1995. This implies that the value chain for cars that are produced in Japan and ultimately consumed in foreign countries has more production stages on average. At the same time, the process of producing one unit car in this value chain requires more intermediate inputs, including intermediate imports, and fewer primary inputs. In addition, we find that the most benefiting participants in the pre-fabrication stages of this value chain are Japanese domestic industries in both years. However, the differences in value-added rates across domestic industries increased remarkably. Most notably, the value-added rate for most domestic manufacturing industries decreased between 1995 and 2011. The competitive pressure from foreign participants in the pre-fabrication stages of this value chain is likely the most important reason for this change. As shown in the chart for 2011, China's chemical (C12) and electrical and optical equipment (C14) industries have become involved in Japan's auto value chain with a relatively lower value-added rate. For example, if the price of intermediate inputs and the production technology are the same for both the Chinese and Japanese chemical industries (12), the Chinese product with a lower value-added rate should be more competitive.

A similar pattern of change can also be found in the German auto value chain as shown in Figure 8. Namely, the smile curve is getting much deeper and wider; more foreign participants including French and Chinese industries with relatively low value-added rates are increasingly involved in the pre-fabrication stages in the German auto value chain.



(a) 1995 (b) 2011

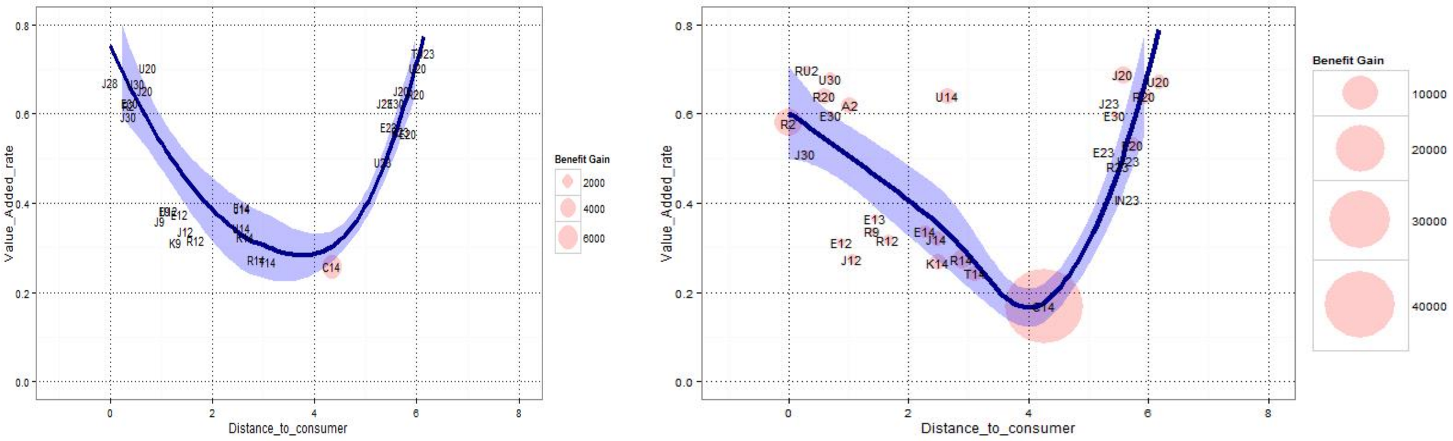
Figure 7: Value chains for Japanese auto exports



(a) 1995 (b) 2011

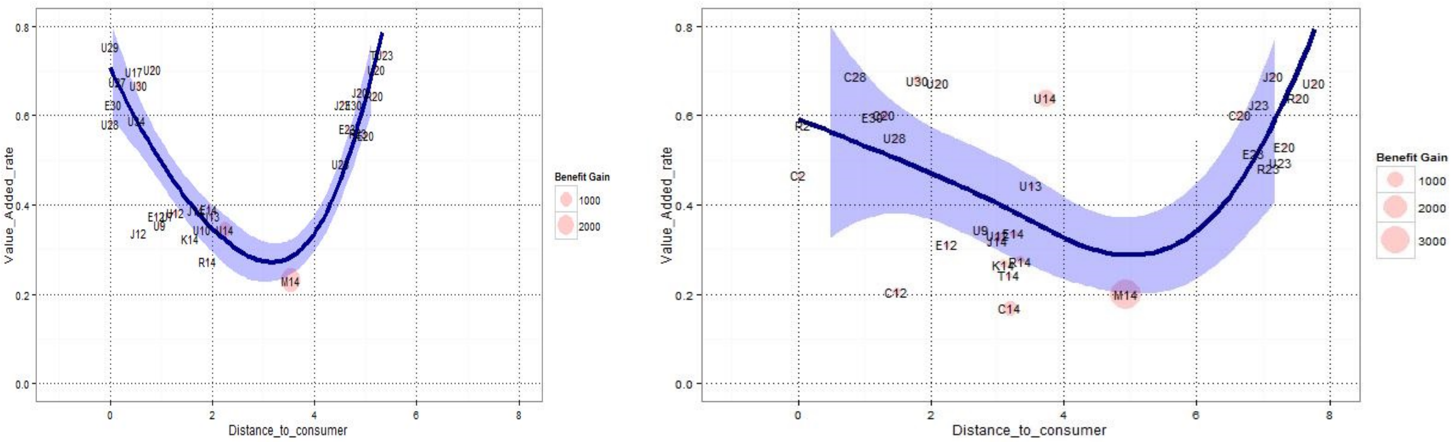
Figure 8: Value chains for German auto exports

In order to focus on the foreign participants in the value chains shown above, we remove all domestic industries and show only the most benefiting foreign industries in Figures 9 to 12. Several findings can be made from these figures. First, smile curves for all selected value chains are becoming much deeper and wider. Second, China's participation is becoming much more notable in the Mexican electrical product value chain and the Japanese and German auto value chains. Third, some eastern EU countries such as Poland and the Czech Republic play a more important role in the German auto value chain.



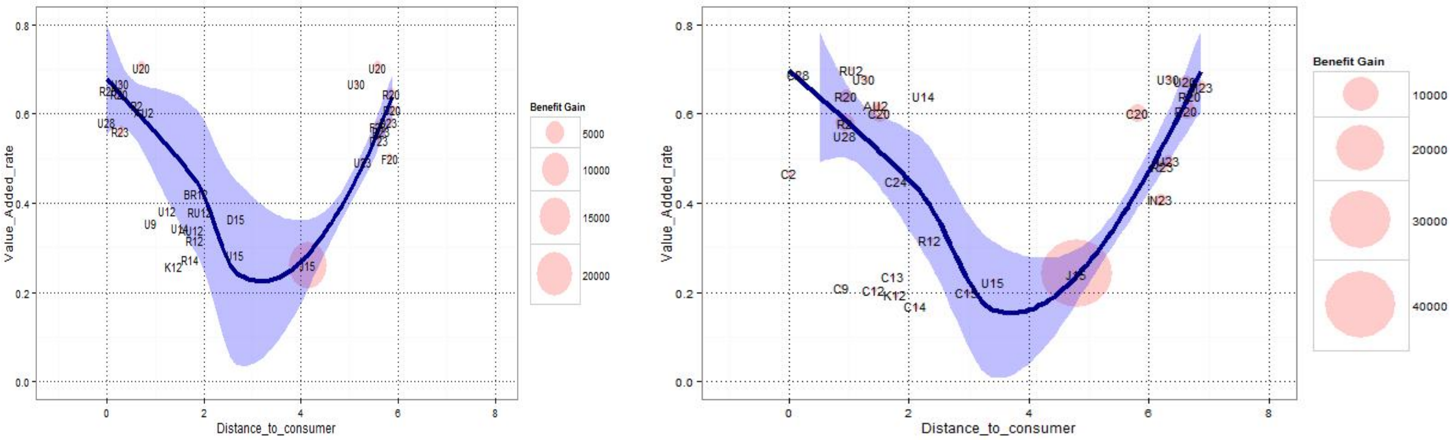
(a) 1995 (b) 2011

Figure 9: Foreign participants in the Chinese electrical and optical equipment value chain



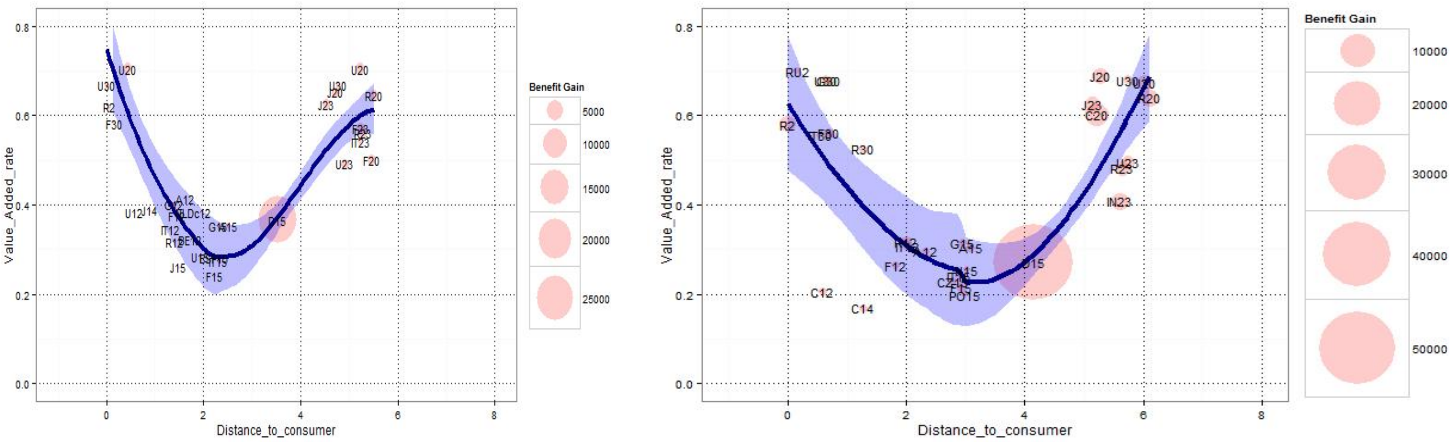
(a) 1995 (b) 2011

Figure 10: Foreign participants in the Mexican electrical and optical equipment value chain



(a) 1995 (b) 2011

Figure 11: Foreign participants in the Japanese auto value chain



(a) 1995 (b) 2011

Figure 12: Foreign participants in the German auto value chain

4 Conclusion remarks

The increasing complexity and sophistication of GVCs brings an urgent challenge to policy makers since "you can't manage what you can't measure." One of the most important starting points for better understanding GVCs is to first develop good measures that can clearly show the position and degree of participation of countries and industries in GVCs. For example, the logic of the "smile curve" has been widely used to explain the different roles that developed and developing countries play in the value-added creation process of globally fragmented production. However, to the best of our knowledge, this smile curve "hypothesis" has never been carefully investigated by using real data with explicit consideration on both the benefits to, and the position of, participating countries and industries in GVCs until now.

The main difficulty in mapping countries and industries in GVCs along a smile curve is how to consistently measure both the length and strength of value-added propagation between producers and consumers based on various perspectives of GVCs. The existing IO-based measures of length such as APL and the concepts of upstreamness and downstreamness give us a good starting point, but lack an overall and consistent accounting framework from the perspectives of both producers and consumers. This paper shows that the length of value-added propagation can be measured by using either Leontief's forward industrial linkage or Leontief's backward industrial linkage. At the lowest level between a specific industry (producer) and a specific final product (consumer) and at the highest level (aggregating all countries and industries), there is no difference between these two measures. However, at the country and industry levels, these measures have very different economic explanations. Namely, the length of value-added propagation based on forward industrial linkage measures the distance from a specific industry to consumers; while the backward industrial linkage length measures the distance from a specific final product to producers. Therefore, the former can be used to identify the position (upstreamness or downstreamness) of industries in value chains, while the latter can be used to identify the level of complexity in the production processes of final products.

Another important contribution of the paper is that we provide various conceptual GVC settings based on the measure of backward industrial linkage. This can help us separate a value chain into pre-fabrication stages and post-fabrication stages, and at the same time identify the countries or industries benefiting most at each stage in terms of their absolute value-added gain. By combining the measures of position and participation level for countries and industries in a given conceptual GVC, the so-called smile curve can be mapped.

Using time-series data from the WIOD from 1995 to 2011, smile curves for various conceptual GVC are mapped and presented, including for Chinese and Mexican electrical product value chains and German and Japanese auto value chains. Most smile curves have been getting much deeper and wider over time. This clearly reflects the deepening vertical specialization and the expanding cross-border fragmentation of production in the corresponding value chains during the data period. At the country level, Chinese manufacturing industries, especially the electrical and optical equipment industry, with the lowest value-added rate enhanced their participation in the pre-fabrication stage of the Mexican electrical product value chain, as well as in both the Japanese and German auto value chains. In contrast, the US electrical and optical equipment industry is still one of the main participants in the Chinese and Mexican electrical product value chain and the Japanese auto value chain, but these value chains seem to be experiencing a very rapid technology upgrades as a result of the US industry's high value-added rate.

The method of mapping smile curves proposed in the paper can be considered a touchstone for better understanding of the position and value-added gain from participation in various GVCs by countries and industries. The relevant indicators can provide a useful tool in analyzing the determinants of a country's role in GVCs as well as providing policy-oriented analysis of how to help countries be involved in, and make upgrades to, GVCs.

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Appendix 1 Country or country group classification

Country name	Code	EU	Country name	Code	EU	Country name	Code	EU
AUS	A		AUT		$\surd$	BEL		$\surd$
BGR		$\surd$	BRA	B		CAN	CA	
CHN	C		CYP		$\surd$	CZE		$\surd$
DEU		$\surd$	DNK		$\surd$	ESP		$\surd$
EST		$\surd$	FIN		$\surd$	FRA		$\surd$
GBR		$\surd$	GRC		$\surd$	HUN		$\surd$
IDN	ID		IND	IN		IRL		$\surd$
ITA		$\surd$	JPN	J		KOR	K	
LTU		$\surd$	LUX		$\surd$	LVA		$\surd$
MEX	M		MLT		$\surd$	NLD		$\surd$
POL		$\surd$	PRT		$\surd$	ROM		$\surd$
RUS	RU		SVK		$\surd$	SVN		$\surd$
SWE		$\surd$	TUR	TU		TWN	T	
USA	U		RoW	R				

Appendix 2 WIOD industry classification

Sectors No.	Sectors	Abbreviation
1	Agriculture, Hunting, Forestry and Fishing	Agr
2	Mining and Quarrying	Min
3	Food, Beverages and Tobacco	Foo
4	Textiles and Textile Products	Tex
5	Leather, Leather and Footwear	Lea
6	Wood and Products of Wood and Cork	Woo
7	Pulp, Paper, Paper, Printing and Publishing	Pul
8	Coke, Refined Petroleum and Nuclear Fuel	Cok
9	Chemicals and Chemical Products	Che
10	Rubber and Plastics	Rub
11	Other Non-Metallic Mineral	OMin
12	Basic Metals and Fabricated Metal	Bas
13	Machinery, Nec	Mac
14	Electrical and Optical Equipment	Ele
15	Transport Equipment	Tra
16	Manufacturing, Nec; Recycling	Man
17	Electricity, Gas and Water Supply	Gas
18	Construction	Con
19	Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel	Sal
20	Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles	Who
21	Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods	Ret
22	Hotels and Restaurants	Hot
23	Inland Transport	InT
24	Water Transport	WaT
25	Air Transport	AiT
26	Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies	OS
27	Post and Telecommunications	Pos
28	Financial Intermediation	Fin
29	Real Estate Activities	Rea
30	Renting of M&Eq and Other Business Activities	Ren
31	Public Admin and Defence; Compulsory Social Security	Pub
32	Education	Edu
33	Health and Social Work	Hea
34	Other Community, Social and Personal Services	OCom
35	Private Households with Employed Persons	Pir

Appendix 3 A smile curve example

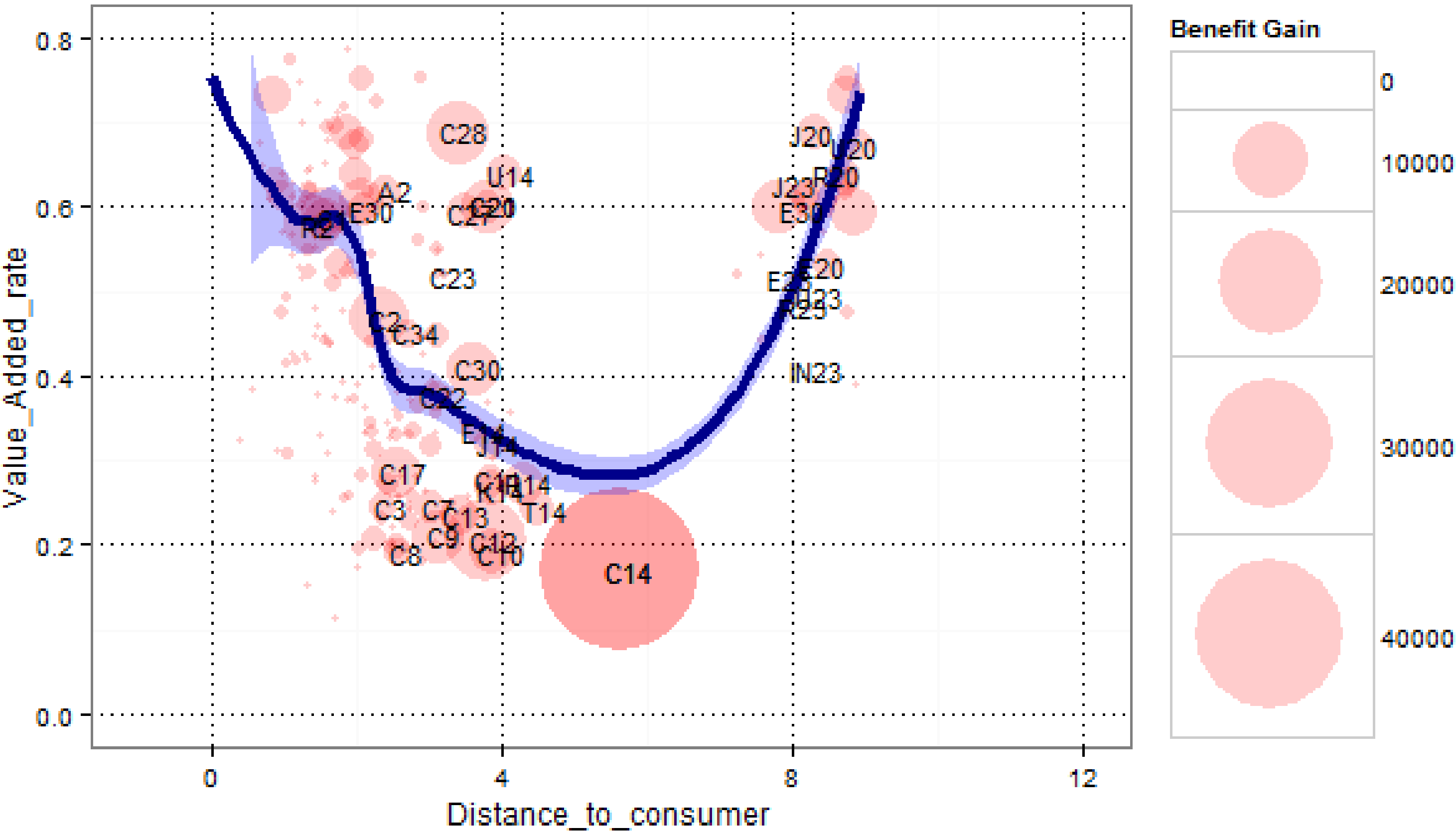

Figure 13: The smile curve for Chinese exports of electrical and optical equipment with all beneficiary countries and industries (2011)