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IDE DISCUSSION PAPER No. 802

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Dec. 2020

Abstract

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Keywords: smile curve, multinationals, global value chain, trade in value-added, industrial upgrading, ICT

JEL classification: F6, F13, F15, D57

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Smile Curves in Global Value Chains: Multinationals vs Domestic Firms; the U.S. vs China

Bo MENG[1] **and Ming YE**[2*]

Abstract: This paper uses the "smile curve" mapping tool with a Y-axis for value-added ratio and an X-axis for production stages to identify value-added gains, positions, and interdependencies of multinationals and domestic firms along global value chains (GVCs). Taking the U.S. and China's ICT firms' exporting activities as a target, we find that China's domestic ICT firms' value chain appears as a smile curve differing from the U.S. domestic ICT firms' inverted-U curve, which reflects the considerable difference in their technical specialization in joining GVCs; multinationals are good at utilizing each country's comparative advantages and can thus arrange value chains as smile curves regardless of whether they are located in the U.S. or in China; China's domestic firms have increasingly plugged into most ICT value chains. All findings reflect how "sticky" the interdependency among countries along GVCs is and can thus help understanding the impact of the U.S.–China trade war.

Highlights

1) A "smile curve" analysis is applied to mapping the geometry of GVCs for ICT firms
2) Value-added gains and positions of multinationals and domestic firms are presented
3) China's domestic ICT firms' value chain appears as a smile curve
4) The U.S. domestic ICT firms' value chain shows an inverted-U curve
5) Multinationals' ICT value chains appear as smile curves no matter their locations
6) Some China's domestic service-suppliers are plugging into the high-end of GVCs

Key words: smile curve, multinational enterprise, global value chain, trade in value-added, industrial upgrading, ICT

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1. Introduction

Global Value Chains (GVCs) divide the production process so that goods may be produced in stages in a number of different countries with a little value-added at each stage in accordance with each country's comparative advantages (Krugman, 1991). Given the rapid development of GVCs over the past three decades, the "Made in" label, typical of manufactured goods (ranging from large planes to small electronic devices), which attributes them to a specific economy, has become an archaic symbol of a bygone era as most manufactured goods are now "Made in the World" (WTO-IDE, 2011). The phenomenon of the rise of GVCs, which accompanied a substantial improvement in the economic efficiency of multinationals, has significantly changed the nature and structure of international trade (Gereffi & Fernandez-Stark, 2011; WTO, 2019) as well as the topology of interdependency and influencing powers among countries (Xiao *et al.*, 2020). According to a recent report (UNCTAD, 2013), 80% of trade takes place in "value chains" linked to transnational corporations. Furthermore, as shown in Cadestin *et al.*, (2019), "multinationals account for roughly for one-half of international trade, one-third of output and GDP and one-fourth of employment in the global economy."

Meanwhile, the complexity and sophistication of GVCs due to the increasing inter- and intra-firm trade of intermediate goods and services, which may cross several national borders multiple times, have also created considerable difficulties, such as those in understanding "who creates added value for whom" and in formulating policies that enable countries, industries, and firms with different ownership to clearly identify their positions, gains, and potential risks in joining or engaging in GVCs. Better understanding on this issue has very important policy implications as pointed out by the so-called "Paradoxical Pair of Concerns" (Baldwin *et al.*, 2014) for both developed and developing countries when they join GVCs. That is to say, owing to the differences in comparative advantages across countries participating in GVCs, rich countries might tend to engage in high-end and intangible production activities, such as R&D, design, and brand building in the upstream stages and after-sales services and marketing in the downstream stages. Consequently, rich countries might worry about the hollowing out of their economies as manufacturing jobs are offshored to low-technology, low-wage countries. Meanwhile, poor countries might tend to focus on low-end and tangible production activities, such as manufacturing and assembly, and might therefore have concerns that they are getting the wrong types of jobs and that their economies might be locked into GVCs at the bottom (low-end) 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 value-added to the product than the middle part of the value chain. If this phenomenon is presented in a graph with value-added represented on the Y-axis and the value chain (stages of production located in different places) represented on the X-axis, the resulting curve appears in the shape of a smile. The logic of the smile curve has been widely used and discussed in the business literature of GVCs (e.g., Dedrick and Kraemer, 1998;

Mudambi, 2008; Shin *et al.*, 2012, etc.). Its theoretical explanation could be traced in the context of GVCs to three lines of literature.[1] They include the business literature concerning the value chain model (Porter, 1985), GVC governance (Gereffi *et al.*, 2005), the organizational choices of firms involved in supply chains (Antràs and Helpman, 2008; Acemoglu *et al.*, 2009; Antràs and Chor, 2013; Alfaro *et al.*, 2015), and the international trade literature concerning trade in tasks and fragmentation production (Jones and Kierzkowski, 1990; Feenstra, 1998; Arndt, 1997; Campa and Goldberg, 1997, Yeats, 2001, Hummels, Ishii and Yi, 2001; Yi, 2003, Grossman and Helpman, 2002a, b; Hanson *et al.*, 2003; Grossman and Rossi-Hansberg, 2008; Timmer *et al.*, 2014, 2018).

However, the smile curve phenomenon has rarely been identified, measured, or evaluated by employing real data with explicit consideration of international production networks. A few studies have tried to identify the smile curve phenomenon using input–output (IO) data at the industrial level (Kimura, 2003; 2006; Baldwin *et al.*, 2014), firm level (Saliola and Zanfei, 2009; Rungi and Del Prete, 2018), or using project-level FDI data (Stöllinger, 2019), and none of them have explicitly considered value-added propagation processes and country-sector positions along all stages of the value chain. Ye *et al.* (2015) provided the pioneering idea in identifying smile curves in GVCs, followed by Ito and Vézina (2016) and Meng *et al.* (2020). The originality and innovation of these works is that they consistently combine both the so-called "trade in value-added" concept (see Johnson and Noguera, 2012; Koopman *et al.*, 2014; Los *et al.*, 2016) in measuring value-added gains of countries and sectors along GVCs and the value-added propagation length (see Antràs *et al.* 2012; Miller and Temurshoev, 2013; Chen, 2014; Wang *et al.*, 2017) in measuring positions of countries and industries along GVCs. However, in what is similar to the previously mentioned literature, one of the most critical comments regarding these smile curve research studies is that no performance of multinationals that are considered the main players of GVCs can be explicitly identified in the existing smile curve analyses.

Concerning the role of multinationals in GVCs, a massive number of case studies (e.g., Linden *et al.*, 2009; Dedrick *et al.*, 2010; Xing and Detert, 2010; Xing, 2019, 2020) have been developed. 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 intuitive understanding of GVCs in terms of the activities of multinationals. However, these "tear down" case studies only focus on 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 or inter-firm linkages in the whole value creation process.

Owing to the recent novel data developed by the OECD, the analytical Activities of Multinational Enterprises (AMNE) database (including Inter-Country IO tables split according to firm ownership over the period 2005–2016; see Cadestin, *et al.*, 2018a) makes analyses of multinational production in value-added terms possible (see Cadestin, *et al.*, 2018b, 2019; Miroudot and Ye, 2019, 2020). This database also enables us to fill

[1] For a detailed genealogical map of theoretical frameworks for GVCs, one can refer to Inomata (2017).

the gap between approaches mentioned above in measuring smile curves in GVCs. With this new data, we borrow the smile curve concept and focus on Information and Communications Technology (ICT), including many representative fragmentation products (e.g., smartphones, PCs) exporting firms located in China and the U.S. We aim to identify value-added gains, positions, and interdependencies of both domestic and multinational firms when they participate in GVCs. Understanding the gains from GVCs and their distribution pattern across countries, sectors, and firm ownership is crucial for policymakers in the context of reconsidering how world trade and production work. So is having a better understanding of the nature and the impact of the recent U.S.–China trade conflict, along with better international governance in the era of GVCs.

2. Method and Data

2.1 Conceptual GVC setting for measuring smile curves

GVCs can be shown from various perspectives. To give a better mapping of the geometry of GVCs, we first need to give a clear conceptual setting about what we are going to measure. The most popular and simple approach is to focus on the export of a specific product produced by a specific type of firm and to look at how value is added from one country, sector, or type of firm to another country, sector, or type of firm throughout the entirety of production networks, along with how the product is ultimately consumed. For example, we can use Chinese domestic firms' ICT exports to the world market as a starting point for separating the whole value chain into upstream stages and downstream stages. All countries, sectors, and different types of firms that directly and indirectly provide intermediate goods and services to the production of ICT exports are considered participants in the upstream stages along the value chain. All countries, sectors, and different types of firms involved in the distribution process of those ICT products to world consumers are considered participants in the downstream stages.

With regard to how to visualize the above conceptual GVC, we need two fundamental measures. The first measure is used to express the magnitude of the benefit (i.e., the absolute gain of value-added) for countries, sectors, and firms that are involved in GVCs. The second measure is the distance between producers and consumers in the value-added propagation process, which can be used to identify the position of a country, sector, or firm in a GVC. These two measures have been propounded by Ye *et al.* (2015) and expounded by Meng *et al.* (2020). In the following sections, we simplify the terminology of mathematics used in their methods.

2.2 Value-added gains from exporting

Following the definition of trade in value-added (TiVA: Johnson and Noguera, 2012), we can use an IO model to measure value-added gains induced by exporting final goods and services. The advantage of using TiVA is that it can trace value-added created upstream (GDP by sector) and absorbed downstream (final demands by product) without any double counting because all transaction of intermediates across countries, sectors, and firms are treated as endogenous variables (see Koopman *et al.*, 2014).

For ease of explanation, consider a closed national IO model as follows:

$$\mathbf{x} = \mathbf{A}\mathbf{x} + \mathbf{y}, \quad (1)$$

where $\mathbf{x}$ is the $\mathrm{N} \times 1$ gross output vector with N sectors, $\mathbf{y}$ is the $\mathrm{N} \times 1$ final demand vector, and $\mathbf{A}$ is the $\mathrm{N} \times \mathrm{N}$ input coefficient matrix (the share of intermediate input in output). In other words, all gross output (total supply) must be used either as an intermediate product or as a final product (total demand). This equation expresses the ex-post equilibrium of market supply and demand in a closed economy. After rearranging terms, we have the following:

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} = \mathbf{L}\mathbf{y}, \quad (2)$$

where $\mathbf{L}$ denotes the $\mathrm{N} \times \mathrm{N}$ 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. We define $\mathbf{v}$ as a $1 \times \mathrm{N}$ value-added coefficient vector. Each element ($\mathrm{v_s}$) in $\mathbf{v}$ shows the share of value-added in the gross output of sector s. Then, we can measure the value-added gained ($\boldsymbol{\pi}_\mathrm{k}$) by sector induced by exports ($\mathbf{e}_\mathrm{k}$) of a final product k as follows:

$$\boldsymbol{\pi}_\mathrm{k} = \hat{\mathbf{v}}\mathbf{L}\mathbf{e}_\mathrm{k}, \quad (3)$$

where, $\hat{\mathbf{v}}$ is the diagonal matrix of $\mathbf{v}$, $\mathbf{e}_\mathrm{k}$ is the $\mathrm{N} \times 1$ vector, with just an element of the exported final product k. Without loss of generality, this model can be applied to an inter-country input–output (ICIO) model.

2.3 GVC position index

By definition, in an IO system, the following equation always holds true:

$$\mathbf{vL} = \mathbf{v}(\mathbf{I} + \mathbf{A} + \mathbf{A}^2 + \mathbf{A}^3 + \cdots) = \mathbf{u}' \quad (4)$$

where $\mathbf{u}'$ denotes the transformed $\mathbf{u}$ (an $\mathrm{N} \times 1$ unit vector). The value-added ($\mathbf{v}_\mathrm{s}$) of a specific sector s induced by the final demand ($\mathbf{y}_\mathrm{k}$) of a specific product k can be given as $\mathbf{v}_\mathrm{s}\mathbf{L}\mathbf{y}_\mathrm{k}$ (a scalar). Following Antràs *et al.* (2012) and Meng *et al.* (2020), the distance from a specific sector s (value-added creator) to consumers of a specific final product k, can be defined as follows:

$$\mathrm{D_{sk}} = \mathbf{v}_\mathrm{s}(1\mathbf{I} + 2\mathbf{A} + 3\mathbf{A}^2 + 4\mathbf{A}^3 + \cdots)\mathbf{y}_\mathrm{k}/\mathbf{v}_\mathrm{s}\mathbf{L}\mathbf{y}_\mathrm{k} = \mathbf{v}_\mathrm{s}\mathbf{L}^2\mathbf{y}_\mathrm{k}/\mathbf{v}_\mathrm{s}\mathbf{L}\mathbf{y}_\mathrm{k}. \quad (5)$$

The aforementioned indicator measures the total number of value-added propagation steps, on average, when the value-added of a specific sector upstream is embodied in all downstream steps and ultimately reaches the final demand of a specific product. Without loss of generality, this distance measure could be applied to the ICIO model as well.

2.4 Data

Data used is the OECD analytical AMNE database, wherein the conventional ICIO tables are split according to firm ownership (D: domestic- and F: foreign-owned) over the period 2005–2016, with 60 economies (including the "rest of the world" as one economy) and 34 sectors in the ISIC Rev. 4 classification at the basic price.[2] It should be noted that foreign-owned firms are defined as foreign affiliates who have at least 50% foreign ownership and that domestic-owned firms include domestic multinationals (domestic firms with foreign affiliates) and domestic firms not involved in international investment. The layout of this table with N sectors (N=34), G economies (G=60), and 2 types of firms is shown in Table 1.

Table 1. The layout of the OECD inter-country input–output tables with firm ownership information included

Outputs / Inputs		Intermediate Use							Final Demand				Total Output
		1		2		⋯	G		1	2	⋯	G	
Intermediate Inputs	1	Z_{DD}^{11}	Z_{DF}^{11}	Z_{DD}^{12}	Z_{DF}^{12}	⋯	Z_{DD}^{1g}	Z_{DF}^{1g}	Y_{D}^{11}	Y_{D}^{12}	⋯	Y_{D}^{1g}	X_{D}^{1}
		Z_{FD}^{11}	Z_{FF}^{11}	Z_{FD}^{12}	Z_{FF}^{12}	⋯	Z_{FD}^{1g}	Z_{FF}^{1g}	Y_{F}^{11}	Y_{F}^{12}	⋯	Y_{F}^{1g}	X_{F}^{1}
	2	Z_{DD}^{21}	Z_{DF}^{21}	Z_{DD}^{22}	Z_{DF}^{22}	⋯	Z_{DD}^{2g}	Z_{DF}^{2g}	Y_{D}^{21}	Y_{D}^{22}	⋯	Y_{D}^{2g}	X_{D}^{2}
		Z_{FD}^{21}	Z_{FF}^{21}	Z_{FD}^{22}	Z_{FF}^{22}	⋯	Z_{FD}^{2g}	Z_{FF}^{2g}	Y_{F}^{21}	Y_{F}^{22}	⋯	Y_{F}^{2g}	X_{F}^{2}
	⋮	⋮	⋮	⋮	⋮	⋱	⋮	⋮	⋮	⋮	⋱	⋮	⋮
	G	Z_{DD}^{g1}	Z_{DF}^{g1}	Z_{DD}^{g2}	Z_{DF}^{g2}	⋯	Z_{DD}^{gg}	Z_{DF}^{gg}	Y_{D}^{g1}	Y_{D}^{g2}	⋯	Y_{D}^{gg}	X_{D}^{g}
		Z_{FD}^{g1}	Z_{FF}^{g1}	Z_{FD}^{g2}	Z_{FF}^{g2}	⋯	Z_{FD}^{gg}	Z_{FF}^{gg}	Y_{F}^{g1}	Y_{F}^{g2}	⋯	Y_{F}^{gg}	X_{F}^{g}
Value-added		Va_{D}^{1}	Va_{F}^{1}	Va_{D}^{2}	Va_{F}^{2}	⋯	Va_{D}^{g}	Va_{F}^{g}					
Total input		$(X_{D}^{1})'$	$(X_{F}^{1})'$	$(X_{D}^{2})'$	$(X_{F}^{2})'$	⋯	$(X_{D}^{g})'$	$(X_{F}^{g})'$					

Note: $\mathbf{Z}_{FD}^{12}$ is the $N \times N$ matrix representing the exports of intermediates produced by foreign-owned firms located in Country 1 used by Country 2's domestic firms; $\mathbf{Y}_{F}^{12}$ is the $N \times 1$ vector representing the exports of final products produced by foreign-owned firms located in country 1, used by Country 2. $\mathbf{X}$: the $2NG \times 1$ column vector of output; $\mathbf{Va}$: the $1 \times 2NG$ row vector of value-added. For detailed information about country or regional sector classification, one can refer to Appendices 1 and 2. For data explanation, see Cadestin *et al.* (2018a).

[2] Main data sources used in compiling the OECD AMNE–ICIO tables include the OECD–ICIO tables, OECD–AMNE statistics, National accounts, and other National sources, Trade by Enterprise Characteristics and Services Trade by Enterprise Characteristics (TEC), Micro-level databases.

3. Empirical Results

3.1 How to map the geometry of GVCs

By first employing the yearly AMNE–ICIO data to derive binomial regression and then labeling the most important participants (country-sector-firm) with value-added gain (represented by the size of circles) above a threshold percentage (e.g., 0.1% of the total induced value-added in the whole value chain) in both upstream and downstream stages, a map of the ICT exports-related GVCs can be created. As shown in the figures of the next section, the Y-axis denotes the value-added ratio (value-added gained by producing one unit US$ worth of output). The X-axis denotes position, measured by the value-added propagation length between global consumers of ICT products and a specific participating firm in a specific industry along the corresponding value chain (a kind of normalized distance to consumers[3]). The smooth line is fitted by binomial regression smoothing, and the shadowed area represents the confidence interval around the smooth line (for detailed robustness check on the GVC position index and the shape of smile curves, one can refer to Appendices 3 and 4). This GVC mapping can help us identify whether the so-called "smile curve" exists, and if so, what the participants (countries, sectors, and firms) of a specific value chain, as well as their positions and gains, look like.

3.2 Value-added gains in Chinese domestic ICT firms' export-related value chain

As shown in Figures 1-a and 1-b, the value chain for Chinese domestic ICT firms' exports to the world market clearly appears as a "smile curve" (to save space here, we show only 2005 and 2016). Several stylized facts can be observed from these curves.

1) Chinese domestic ICT firms (CHN_D13) were located at the middle–bottom (low-end) of the smile curve although they constituted the largest beneficiary in terms of value-added gain, the reasons for which are several. First, the participation pattern of Chinese domestic ICT firms in GVCs at the early stage of China's economic development was to export labor-intensive assembly products, partly including the acceptance of foreign outsourcing tasks, because of cheap labor costs and abundant labor supply inside China and the lack of industrial capital and technology. When compared with the traditional production process, the assembly process depends on a greater amount of parts and components, including imported intermediates. This makes the value-added ratio of Chinese domestic ICT firms very low, thus explaining their location at the lowest position in this smile curve. This is also the reason for which many other domestic firms as well as foreign countries that directly and

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[3] Our position measure as shown in Equation 2 represents the distance from a specific industry to consumers who consume a specific final product. In other words, the bigger this measure the further the industry from the consumers. Therefore, when putting this industry along the X-axis (the bigger its X-axis figure the closer the industry to the consumers), we need to make an inverse transformation for the distance D_{sk}, such as by using a specific value (e.g., the maximum value of all industries' distances to industry k upstream: max $(D_{\cdot k})$) minus the D_{sk} value.

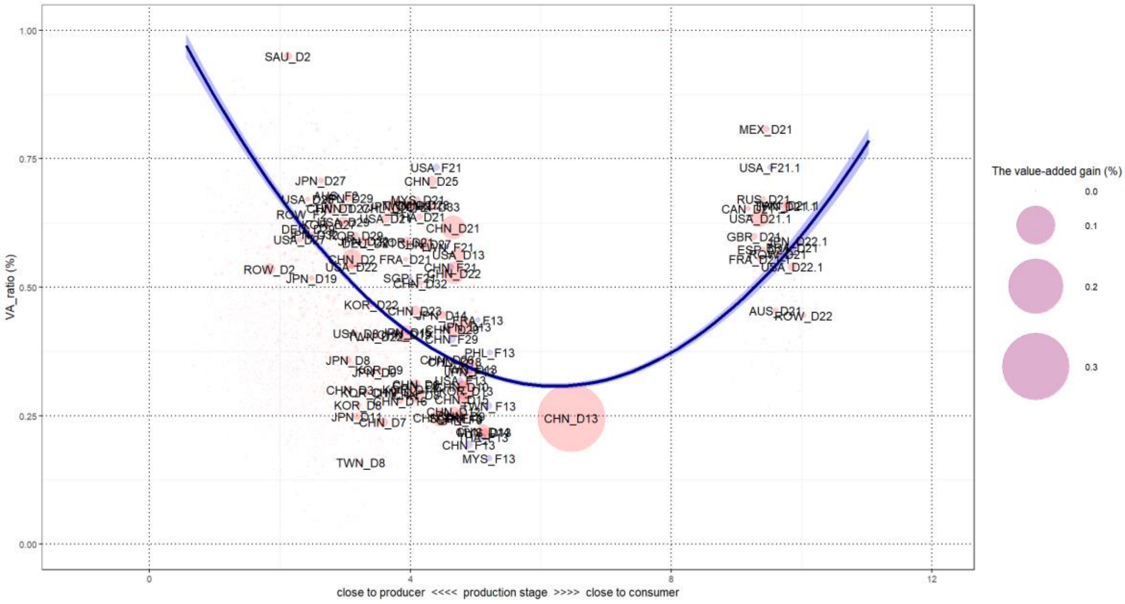

Figure 1a. Chinese domestic ICT firms' export-related value chain (2005)

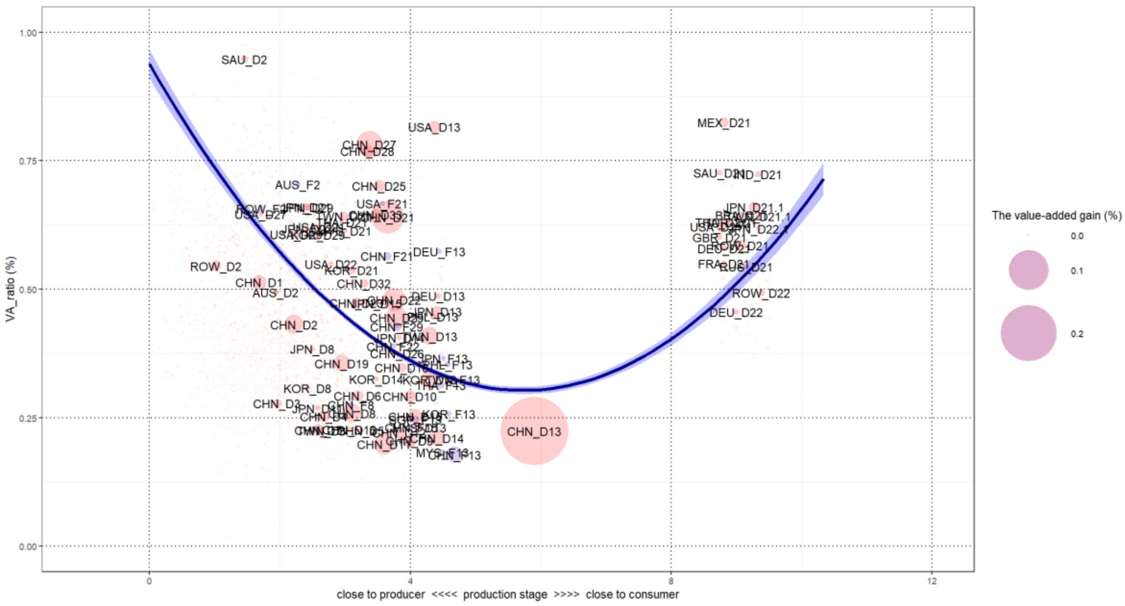

Figure 1b. Chinese domestic ICT firms' export-related value chain (2016)

indirectly provide intermediate products to Chinese domestic ICT firms have been involved in the upstream segment of this value chain. In addition, to deliver those assembly ICT products to users around the world, foreign after-services industries are also needed. Thus, more foreign countries are involved in the downstream stages of this value chain. Therefore, Chinese domestic ICT firms are naturally located in the middle–bottom of this smile curve. The value-added gain, then, is self-evident, as Chinese domestic ICT firms were the most direct player in the production of ICT exports.

2) Many other Chinese domestic firms in different sectors (e.g., in the 2005 case, CNH_D21: Wholesale and retail; CHN_D22: Transportation; CHN_D2: Mining; CHN_D11: Basic Metals; CHN_19: Electricity; CHN_8: Chemicals) also benefited by participating in the upstream stages of this value chain. This was because most of the intermediate inputs directly and indirectly needed by the Chinese domestic ICT firms to produce exports were presumed to come from other Chinese domestic firms.
3) Other countries' (regions) domestic firms located in the upstream position of this value chain also obtained a relatively large portion of value-added gain, particularly their ICT firms (TWN_D13, KOR_D13, JPN_D13, USA_D13, for the 2005 case). This clearly shows the strong cross-border, intra-industrial linkages between China and the US as well as linkages with other East Asian economies. This is partly because of the relatively broad industry classification of ICT in the AMNE (broader classification used, more intra-industrial transaction appears). In addition, we can also see that other countries' domestic non-ICT firms located in much higher upstream stages could also enjoy value-added gains by joining this value chain. They include many business services providers (USA_D29, JPN_D29, KOR_D29), as well as some manufacturing intermediate suppliers (JPN_D14: Electrical equipment, JPN_D11: Basic metals, JPN_D8: Chemicals). This reflects the level of inter-industrial linkages between China and foreign economies.
4) Although the value-added gain was not substantial, it can still be easily identified in the upstream stage of this value chain for 2005, with the existence of beneficiaries, including both multinationals located in China (CHN_F29: Business services, CHN_F13: ICT) and abroad (SGP_F13: ICT; TWN_F13: ICT; THA_F13: ICT, USA_F21: Business Services). This reflects the fact that multinationals, both inside and outside China, have also been involved in Chinese domestic ICT firm value chains through the provision of intermediate goods directly and indirectly although their presence was not substantial when compared with that of domestic firms. This is likely because most of those multinationals located in China focus on the production of final products rather than intermediates.
5) The main beneficiaries in the downstream stage of this value chain include service industries, such as Wholesale and Retail (21) and Transportation (22) in the U.S., Japan, the UK, Mexico, and France. This can be explained by the fact that China's domestic firms' ICT products were mainly exported to these countries, which had to be delivered to their countries' domestic consumers mainly through the use of domestic and international wholesale and transportation services provided by both their domestic and multinational firms.

Upon examining the evolution of Chinese domestic ICT firms' exports-related smile curves over time, no significant change in the shape of this curve is seen, but some remarkable structural changes concerning the participating countries and firms can be observed.

1) More Chinese domestic manufacturing firms have been involved in the upstream stage of this value chain. Their share of value-added gain in the whole chain increased from 26.3% to 38.9% over time (note the change in the corresponding circle size between 2005 and 2016). This is mainly because Chinese domestic manufacturing firms experienced a relatively quick industrial upgrading over this period and can thus provide more complex intermediate inputs to Chinese domestic ICT firms as a replacement for foreign imports. For instance, JPN_D14, JPN_D11, JPN_D8 appeared in 2005 and were largely replaced by the corresponding Chinese domestic firms (CHN_D14, CHN_D11, CHN_D8) in 2016.
2) More Chinese domestic service firms have been involved in the upstream stage of this value chain; meanwhile, their value-added gains account for a much larger portion than those of other manufacturing firms do. In addition, in 2005, the largest upstream beneficiaries were the traditional service providers, domestic wholesale and retail (CHN_D22), and transportation firms (CHN_D21), while in 2016, domestic financial and insurance firms (CHN_D27) and other business services firms (CNH_29) showed a remarkable increasing presence, which took over the share provided by the U.S., Japan, and Korea's domestic services firms (USA_D29, JPN_D29, KOR_D29). This clearly reflects the ongoing domestic-oriented servitization of the whole ICT value chain in China since the time increasingly modern domestic services have been embodied in China's ICT exports.
3) The value-added ratio of the U.S. domestic ICT firms (USA_D13) that were the most important foreign suppliers of intermediate goods in the upstream of this value chain increased from 56.4% in 2005 to 81.6% in 2016, while the figure for China's domestic ICT firms (CHN_D13) declined slightly, from 24.6% in 2005, to 22.4% in 2016. This reflects the fact that the U.S. domestic ICT firms increasingly concentrated on high-tech production of more complex intermediate goods (e.g., computer processors), whereas Chinese domestic ICT firms even then took on more tasks, such as assembling final products using low-skilled labor. This result is very consistent with the existing literature (Ye *et a*l., 2015 and Meng *et al.*, 2020).
4) Multinational ICT firms in China (CHN_F13) enhanced their participation in the upstream of this value chain by providing intermediate goods to Chinese domestic ICT firms directly and indirectly as a means of realizing more value-added gain. This is probably because, increasingly, Japanese, Korean, and Taiwanese domestic ICT firms (JPN_D13, KOR_D13, TWN_D13) located upstream as intermediate goods providers to Chinese domestic ICT firms moved their production capacity to China to be much closer to their consumer. This can be confirmed by the shrinking share of value-added gain for JPA_D13 (66.7% down), KOR_D13 (75.9% down), and TWN_D13 (76.2% down) and the increasing share of CHN_F13 (5.8 times greater) in the 2016 figure when compared with the corresponding value-added gains in the 2005 figure.
5) Some developing countries' services firms (ROW_D21, MEX_D21, ROW_D22, BRA_D21, RUS_D21, IND_D21) enhanced their participation at the downstream stage of this value chain. This reflects the fact that those countries imported more

Chinese ICT products, including both intermediate goods and final products, which need to be shipped to their domestic users. Thus, their domestic services firms (wholesale, retail, and transportation) are able to enjoy more value-added gain.

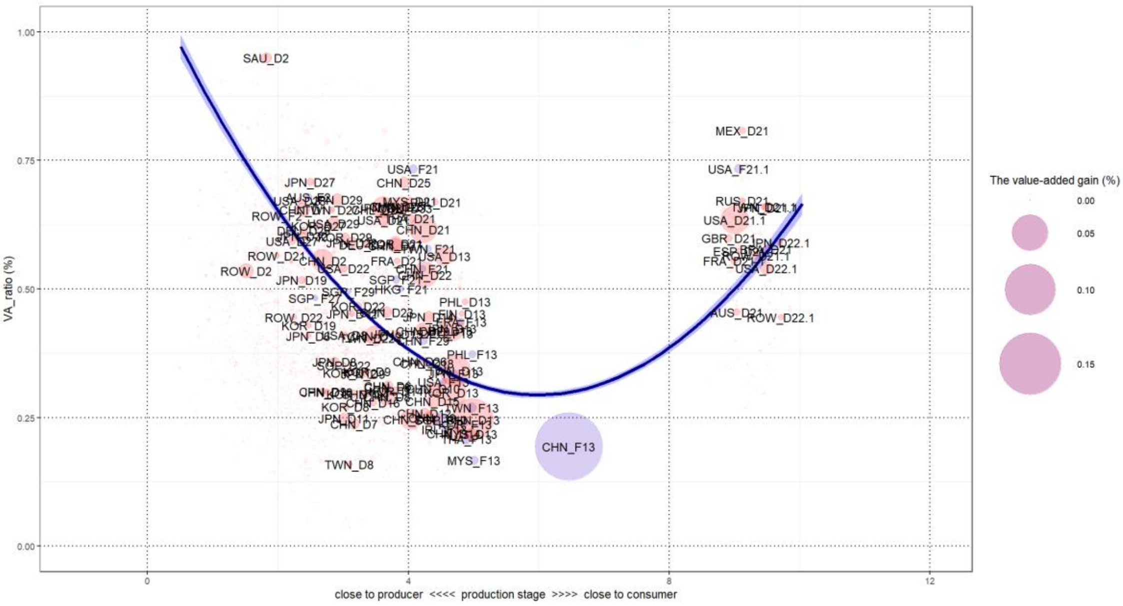

Figure 2a. China-based multinational ICT firms' export-related value chain (2005)

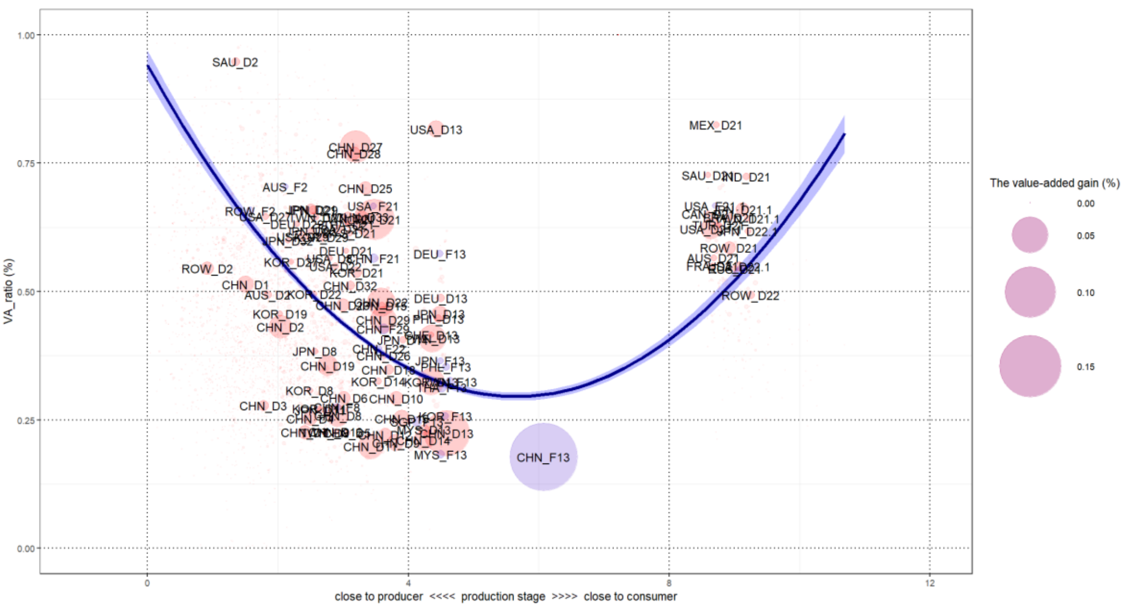

Figure 2b. China-based multinational ICT firms' export-related value chain (2016)

3.2 Value-added gains in the China-based multinational ICT firms' export-related value chain

Figures 2-a and 2-b show the participants' value-added gains as well as their positions in the value chain related to China-based multinational ICT firms' exports. Both clearly appear in the form of "smile curves." When compared with the smile curves related to Chinese domestic ICT firm exports (Figures 1-a and 1-b) over time, a few findings can be gleaned:

1) The position of China-based multinational ICT firms' exports (CHN_F13) was at the middle–bottom of the value chain, which is similar to the position of Chinese domestic ICT-exporting firms (CHN_D13) in Figures 1a and 1b. However, the share of CHN_F13's value-added gain and its position in Figures 2a and 2b were smaller and lower than those of CHN_D13 were in Figures 1a and 1b, respectively. This is mainly because almost half of China-based multinational ICT firms are doing processing trade, which is more labor-intensive and requires more imported intermediate input when compared with Chinese domestic ICT-exporting firms.
2) When compared with Figure 1a, more foreign domestic firms were involved in the upstream stage of the value chain (Figure 2a). The share of value-added gain for these firms in the upstream stage of the value chain was 36.9% in Figure 2a, which was much greater than that in Figure 1a (27.6%). On the one hand, this is consistent with the fact that many China-based multinational ICT firms are doing processing exports, which need a more substantial amount of intermediate inputs from other countries. On the other hand, this also reflects the fact that multinational ICT value chains have more variation in arranging intermediate inputs from different locations and types of firms.
3) There is no significant change in the shape of this value chain between 2005 and 2016, but a similar structural change concerning the participating members upstream can be clearly observed. To be precise, Chinese domestic firms, including those involved in both manufacturing and services, enhanced their industrial upgrading, thus replacing foreign firms as suppliers of intermediate goods and services to China-based multinational ICT firms (the share of value-added gain by Chinese domestic firms upstream increased from 28.2% to 44.6% over the period). This fact can also be partly confirmed by a recent case study having to do with the iPhone X (Xing, 2020): Chinese companies "contributed 25% of the value-added to the iPhone X."

3.3 Value-added gains in the U.S. domestic ICT firms' export-related value chain

Figures 3-a and 3-b show the mapping result for the value chain in terms of the U.S. domestic ICT firms' exports. A U-shaped smile curve cannot be clearly identified. Value chains may not always look like a smile curve, particularly for the U.S.' domestic ICT firms. The main features of these figures and their changes over time are summarized as follows:

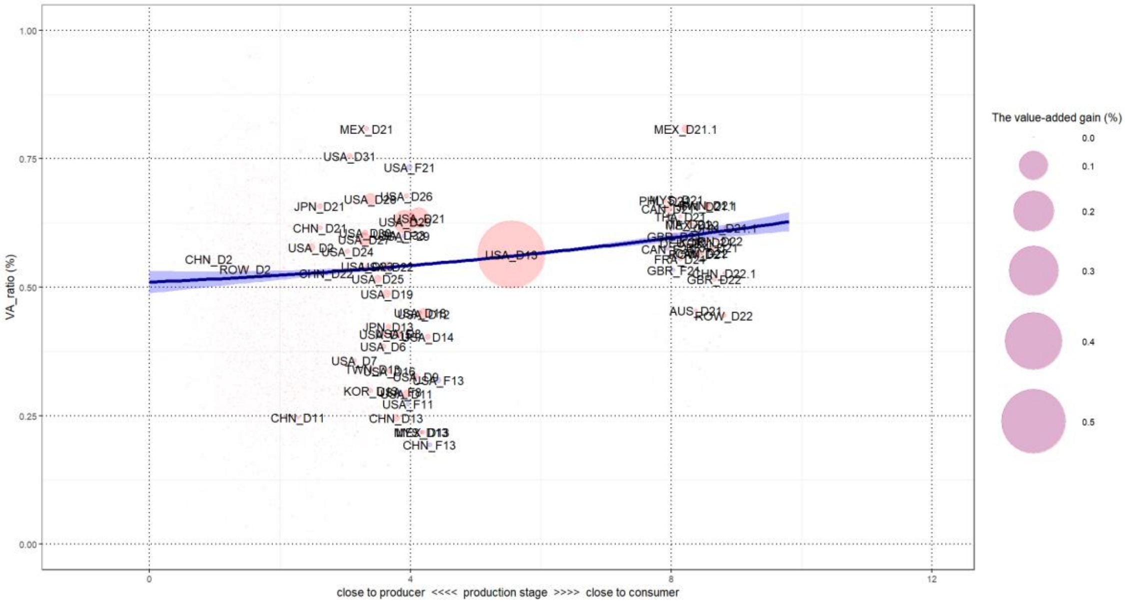

Figure 3a. The U.S. domestic ICT firms' export-related value chain (2005)

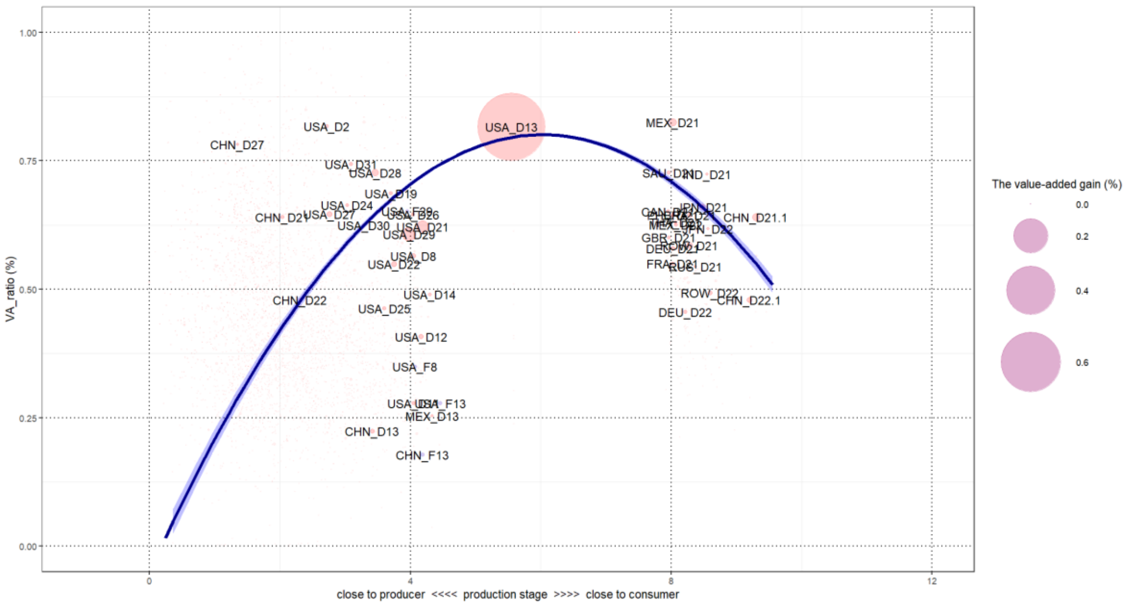

Figure 3b. The U.S. domestic ICT firms' export-related value chain (2016)

1) The relatively higher value-added ratio of the U.S.' domestic ICT firms when compared with that of other participants upstream and downstream along this value chain is the main reason that it does not look like a smile curve. This ratio even increased from 56.4% to 81.6% between 2005 and 2016, which made the curve assume a somewhat inverted-U shape. This clearly reflects the fact that producing

one unit of output by the U.S.' domestic ICT firms can create more value-added. This is probably due to the fact that more high-skilled laborers with higher wages, and more sophisticated capital with higher rent are used in these firms.

2) In 2005, there were still many domestic manufacturing firms involved in the upstream stage of this value chain, but in 2016, many of them disappeared, with only Fabricated Metals (USA_12) and Chemicals (USA_D8) showing a presence as a supplier of intermediates. The share of value-added gain of these firms was 23.6% in 2005 but shrunk to 9.3% in 2016. Something similar happened to foreign domestic manufacturing firms located upstream in this value chain (the share of their value-added gain declined from 8.4% to 3.4% over the period). In 2016, only ICT firms located in China (CHN_D13 and CHN_F13) enjoyed a value-added gain by joining the upstream stage of this value chain. The change is also reflected by the expanding share of value-added gain by USA_D13 in this value chain, from 55.9% in 2005 to 77.9% in 2016. Therefore, we can conclude that the US domestic ICT firms' value chain has experienced significant technological upgrading, which has transitioned to the production of very high value-added products (depending on the availability of high-skilled labor and high-tech capital) without relying on more domestic and foreign intermediate input. Those products (being traced at a more detailed product level by trade statistics) include units of automatic data processing machines (HS847150, accounting for about 6.3% of their ICT exports), surgical instruments and appliances, and electro-diagnostic apparatus (HS901819, accounting for about 2.9% of their ICT exports).

3.4 Value-added gains in the U.S.-based multinational ICT firms' export-related value chain

Figures 4-a and 4-b show the mapping results for the value chain in terms of the U.S.-based multinational ICT firms' exports, which clearly appear as "smile curves." When compared with previous figures, the main findings can be presented as follows:

1) The pattern of value chains shown in Figures 4a and 4b is very similar to that in Figures 2a and 2b. To be precise, the production of multinational ICT firms' exports in both China and the U.S. depended highly on a large amount of intermediate input provided by both domestic and foreign suppliers at the upstream stages of the value chain. This is probably because the U.S. economy is big enough with a relatively large differential of primary costs across states; thus, multinational ICT firms can still arrange their value chains to produce assembly products and export them to the world market. Another factor possibly contributing to this phenomenon is that most U.S.-based multinational ICT firms' exports are final goods although they might be different from those made by China-based multinational ICT firms in terms of quality and function (we cannot identify the difference because of the broad classification of sectors used in the data).
2) As mentioned earlier, China has experienced relatively rapid industrial upgrading, which has also enabled more Chinese domestic manufacturing firms (CHN_D13: ICT,

CHN_D11: Basic metals, CHN_D14: Electrical equipment, CHN_D8: Chemicals) with lower value-added ratios to be suppliers of intermediate goods in a position that is upstream of U.S.-based multinational firms in the value chain. This also makes this smile curve much flatter. Simultaneously, Chinese domestic financial and insurance (CHN_D27) and business services (CHN_D29) firms could also get value-added gain from this value chain. This is mainly because more services are embodied in Chinese domestic firm-produced intermediate goods used directly and indirectly by U.S.-based multinational ICT firms.

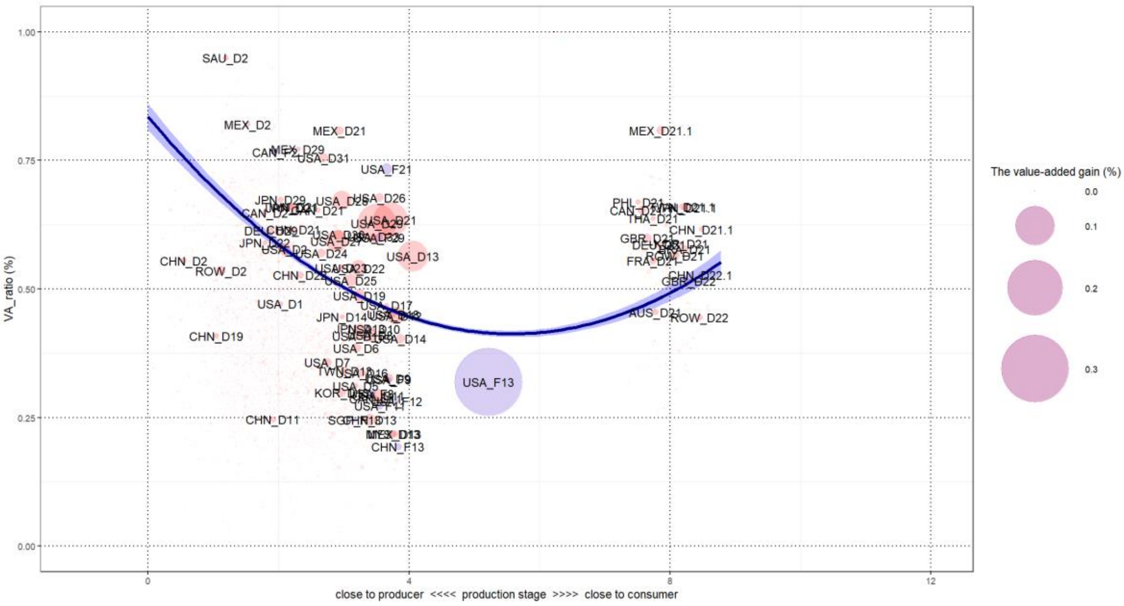

Figure 4a. The U.S.-based multinational ICT firms' export-related value chain (2005)

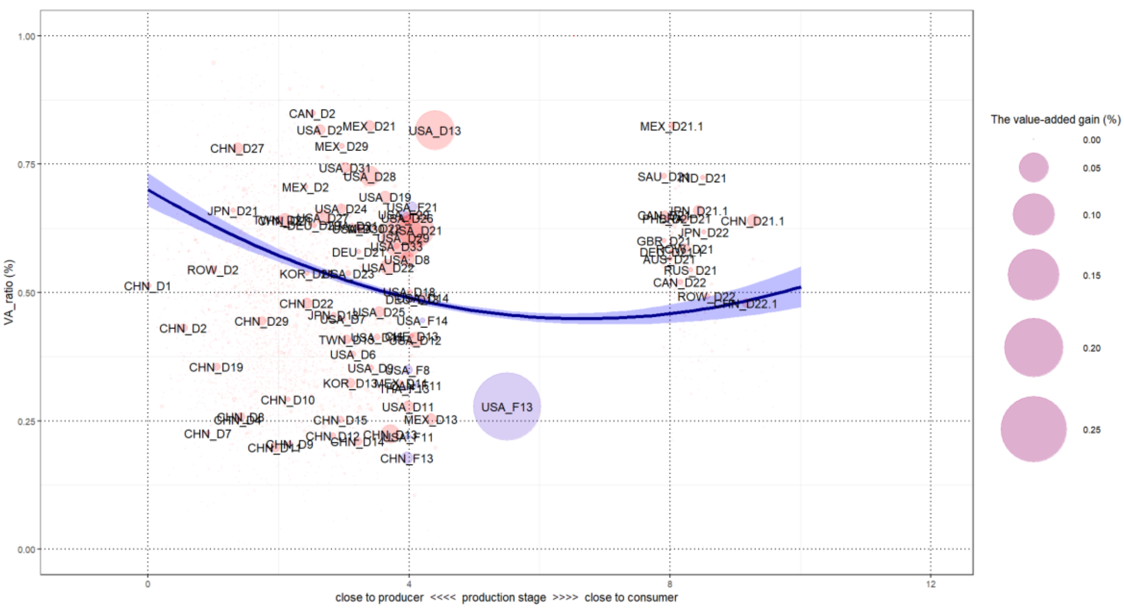

Figure 4b. The U.S.-based multinational ICT firms' export-related value chain (2016)

4. Conclusion

With U.S.-based and China-based multinational ICT firms' exporting activities over the period 2005–2016 as our analytical target, our empirical results show that the value chains in terms of China-based multinational ICT firm exports clearly appear as "smile curves," wherein the ICT-exporting firms take the largest portion of value-added gain but only obtain very low value-added per unit exported. Thus, they are located at the low-end along these curves. This result is very evident for China-based multinational ICT firms in much the same way as the findings from the case study on iPhone's supply chain. The value chain, as it relates to the U.S. domestic ICT firms' exports, shows a much steeper inverted-U-shaped smile curve over time, in which the U.S. domestic ICT firms take the majority of value-added gain with much less usage of intermediate inputs provided by both domestic and foreign firms over time. This result clearly reflects the quick technology upgrading and specialization of U.S. domestic ICT firms, which can create more value-added per unit of output, relying on more domestic, high-skilled labor and sophisticated capital. The value chains in terms of U.S.-based multinational ICT firms' exports also clearly appear as "smile curves," implying that multinationals can still find opportunities in the U.S. to arrange value chains as they do in China because the U.S. economy is big enough with large differentials of primary costs across states as well as the ease of importing cheaper intermediate goods with lower import tariff rates from the world market. Our results also show that more Chinese domestic firms including both manufacturing and services suppliers have been increasingly involved at the upstream stage of almost all smile curves identified. This clearly reflects the quick industrial upgrading happening in China, which has enabled more Chinese domestic firms to replace other suppliers in GVCs.

On the basis of the foregoing findings, we can discuss several highly important policy implications on the recent bilateral trade conflicts between the U.S. and China. First, the recent U.S.–China trade conflicts are due to very complex political, economic, institutional, and cultural factors, which are clearly beyond the scope of our smile curve analyses. However, on the basis of our results, at least from the economic perspective, we can say that GVCs could play a very important role as an automatic stabilizer of those trade conflicts. This is mainly because the development of GVCs is an irreversible process of the ongoing globalization, which is mainly based on each country's comparative advantages dominated by firms rather than governments; thus, the whole economic efficiency could be guaranteed in the long run. Any exogenous nonmarket shock might tentatively impact GVCs but cannot change the fact that GVCs do follow market mechanisms. Further, the context of the current U.S.-China trade conflicts is totally different from those of previous U.S.–Japan trade conflicts, which occurred during 1970–1980. For example, the U.S. and Japan were competitors in exporting cars during 1970–1980, but the U.S. and China are both competitors and collaborators in producing ICT products (e.g., smart phones) in the era of GVCs. Without the existence of a competition–collaboration dynamic, nobody can imagine how such high-quality and cheap (referring to its function) smart phones can be produced (assembled) in China and exported all over the world, while bringing substantial benefits to our lives, as well as how the massive investment in R&D for innovation in the U.S. could be paid off. This relationship can be clearly recognized in almost all ICT smile curves visualized in the paper.

On the other hand, the value creation along GVCs mainly follows the market mechanism although there is no guarantee that the distribution of value-added gain across countries, sectors, firms, or individuals has been accepted by individuals as income could always remain equal. This relates not only to the income distribution and redistribution systems adopted domestically, for example, the growing wage gap across sectors with different levels of GVC involvement or between high-skilled and low-skilled labor inside some high-level GVC-participating sectors (for further discussion on the U.S., see Meng *et al.*, 2020; on European countries, see Parteka and Wolszczak-Derlacz, 2019) but also to the global income distribution pattern in terms of income shifts among multinationals. Examples of this include: "U.S. companies have become more active at shifting income out of the United States…" (see Klassen and Laplante, 2012), "…multinational firms alter the distribution of reported profits to take advantage of losses…" (Simone *et al.*, 2017). This fact has, at least in part, been a driver of the backlash against globalization and the breaking out of trade conflicts between the U.S. and China.

Finally, there is a sticky interdependency between the U.S. and China. As both competitors and collaborators along almost all ICT value chains, the so-called "Paradoxical Pair of Concerns" (Baldwin *et al.*, 2014) has been widely recognized by both sides. China would not want to be locked in at the low-end of GVCs (tangible activities) led by multinationals and would thus be likely to adopt very aggressive (somehow radical) innovation strategies to support their firms on more intangible activities (R&D, design, finance, and marketing) (see Cheng *et al.*, 2020). Therefore, as shown in our paper, more Chinese domestic firms, especially high value-added services suppliers have been able to climb up the ladder to the high-end and enjoy more value-added gains directly and indirectly upstream in GVCs. In other words, the quickly increasing presence (or value-added gain) of Chinese firms in GVCs (meaning the relatively shrinking influencing power of the U.S.) might be another possible trigger for the U.S.–China trade conflicts. Therefore, the nature of the current U.S.–China trade conflicts may be similar to judgments coming from international politics literature: "relative gains are more important than absolute gains" (Waltz, 1959); "the first concern of states is not to maximize power but to maintain their position in the system" (Waltz, 1979).

Appendix 1 Country/region code in the OECD, Analytical AMNE Database

OECD code	OECD countries	Non-OECD code	Non-OECD economies
AUS 1	Australia	ARG 37	Argentina
AUT 2	Austria	BRA 38	Brazil
BEL 3	Belgium	BGR 39	Bulgaria
CAN 4	Canada	CHN 40	China (People's Republic of)
CHL 5	Chile	COL 41	Colombia
CZE 6	Czech Republic	CRI 42	Costa Rica
DNK 7	Denmark	HRV 43	Croatia
EST 8	Estonia	CYP 44	Cyprus[4]
FIN 9	Finland	IND 45	India
FRA 10	France	IDN 46	Indonesia
DEU 11	Germany	HKG 47	Hong Kong, China
GRC 12	Greece	MYS 48	Malaysia
HUN 13	Hungary	MLT 49	Malta
ISL 14	Iceland	MAR 50	Morocco
IRL 15	Ireland	PHL 51	Philippines
ISR 16	Israel[5]	ROU 52	Romania
ITA 17	Italy	RUS 53	Russian Federation
JPN 18	Japan	SAU 54	Saudi Arabia
KOR 19	Korea	SGP 55	Singapore
LVA 20	Latvia	ZAF 56	South Africa
LTU 21	Lithuania	TWN 57	Chinese Taipei
LUX 22	Luxembourg	THA 58	Thailand
MEX 23	Mexico	VNM 59	Viet Nam
NLD 24	Netherlands	ROW 60	Rest of the World
NZL 25	New Zealand		
NOR 26	Norway		
POL 27	Poland		
PRT 28	Portugal		
SVK 29	Slovak Republic		
SVN 30	Slovenia		
ESP 31	Spain		
SWE 32	Sweden		
CHE 33	Switzerland		
TUR 34	Turkey		
GBR 35	United Kingdom		
USA 36	United States		

Source: ReadMe_analytical AMNE.xlsx from the OECD (https://www.oecd.org/sti/ind/amne.htm)

4 Footnote by Turkey: The information in this document with reference to "Cyprus" relates to the southern part of the Island. There is no single authority representing both Turkish and Greek Cypriot people on the Island. Turkey recognizes the Turkish Republic of Northern Cyprus (TRNC). Until a lasting and equitable solution is found within the context of the United Nations, Turkey shall preserve its position concerning the "Cyprus issue". Footnote by all the European Union Member States of the OECD and the European Union: The Republic of Cyprus is recognised by all members of the United Nations with the exception of Turkey. The information in this document relates to the area under the effective control of the Government of the Republic of Cyprus.

5 The statistical data for Israel are supplied by and under the responsibility of the relevant Israeli authorities or third party. The use of such data by the OECD is without prejudice to the status of the Golan Heights, East Jerusalem and Israeli settlements in theWest Bank under the terms of international law.

Appendix 2 Industry (sector) code of the OECD AMNE ICIO data

Code 1	Code 2	Industry
A	1	Agriculture, forestry and fishing
B	2	Mining and extraction of energy producing products
C10T12	3	Food products, beverages and tobacco
C13T15	4	Textiles, wearing apparel, leather and related products
C16	5	Wood and products of wood and cork
C17T18	6	Paper products and printing
C19	7	Coke and refined petroleum products
C20T21	8	Chemicals and pharmaceutical products
C22	9	Rubber and plastic products
C23	10	Other non-metallic mineral products
C24	11	Basic metals
C25	12	Fabricated metal products
C26	13	Computer, electronic and optical products
C27	14	Electrical equipment
C28	15	Machinery and equipment, nec.
C29	16	Motor vehicles, trailers and semi-trailers
C30	17	Other transport equipment
C31T33	18	Other manufacturing; repair and installation of machinery and equipment
DTE	19	Electricity, gas, water supply, sewerage, waste and remediation services
F	20	Construction
G	21	Wholesale and retail trade; repair of motor vehicles
H	22	Transportation and storage
I	23	Accommodation and food services
J58T60	24	Publishing, audiovisual and broadcasting activities
J61	25	Telecommunications
J62T63	26	IT and other information services
K	27	Financial and insurance activities
L	28	Real estate activities
MTN	29	Other business sector services
O	30	Public admin. and defence; compulsory social security
P	31	Education
Q	32	Human health and social work
RTS	33	Arts, entertainment, recreation and other service activities
T	34	Private households with employed persons

Source: ReadMe_analytical AMNE.xlsx from the OECD (https://www.oecd.org/sti/ind/amne.htm)

Appendix 3 Robustness check for the GVC position index

To check the robustness of our GVC position index proposed in Section 2.3, we calculate the distance from sectors by firm type to consumers of a specific product for all countries and years covered in the OECD's AMNE–ICIO data. Our conclusion is that although the evolution of industrial and trade structures might impact this position index, the general positions of most industries by firm type are unlikely to change frequently or significantly because the most important determinants of position are the inherent properties of an industry.

Given space limitations, we merely present one example as shown in Figures A1 and A2, which represent the distance of all countries, industries, and firms to consumers of Chinese firm-made ICT products between 2005 and 2016. The larger the position indicator (the darker the color represented on the right side) the more upstream the position of the relevant industry and firm in the value chain.

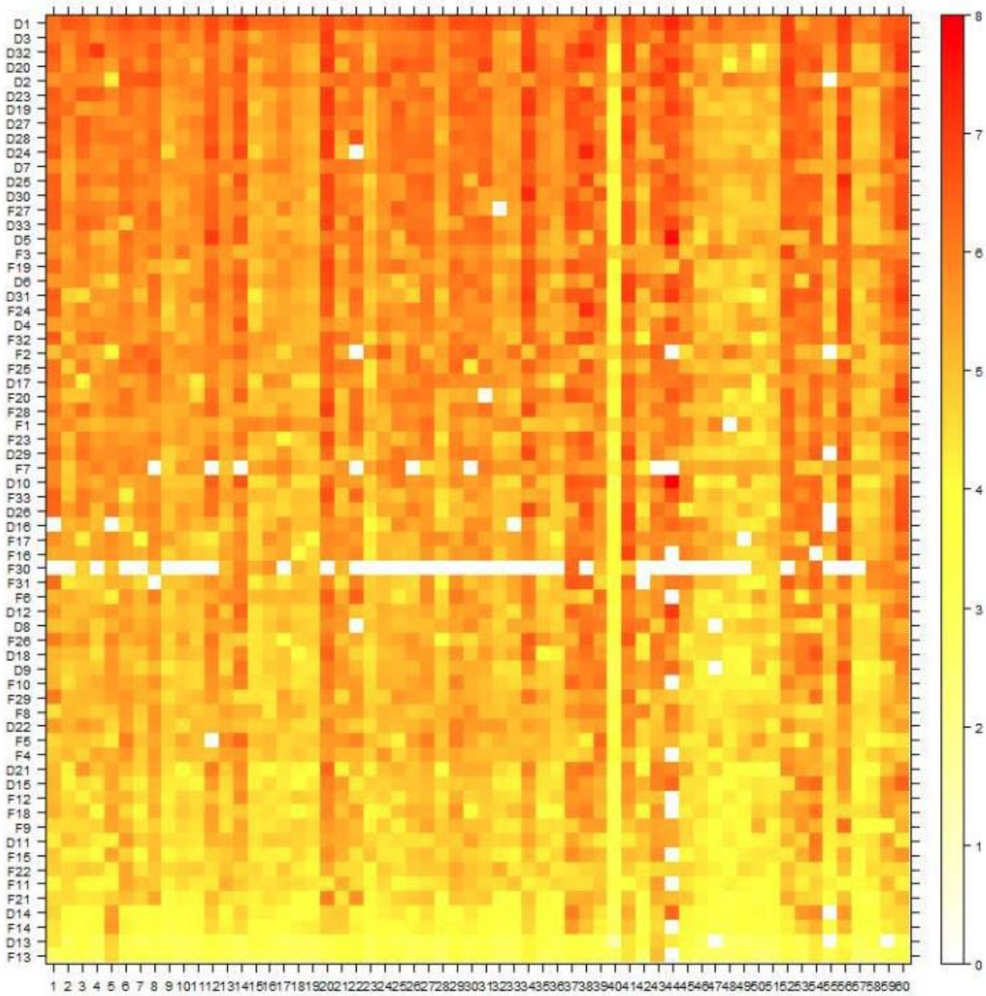

Figure A1. GVC position index for 2005

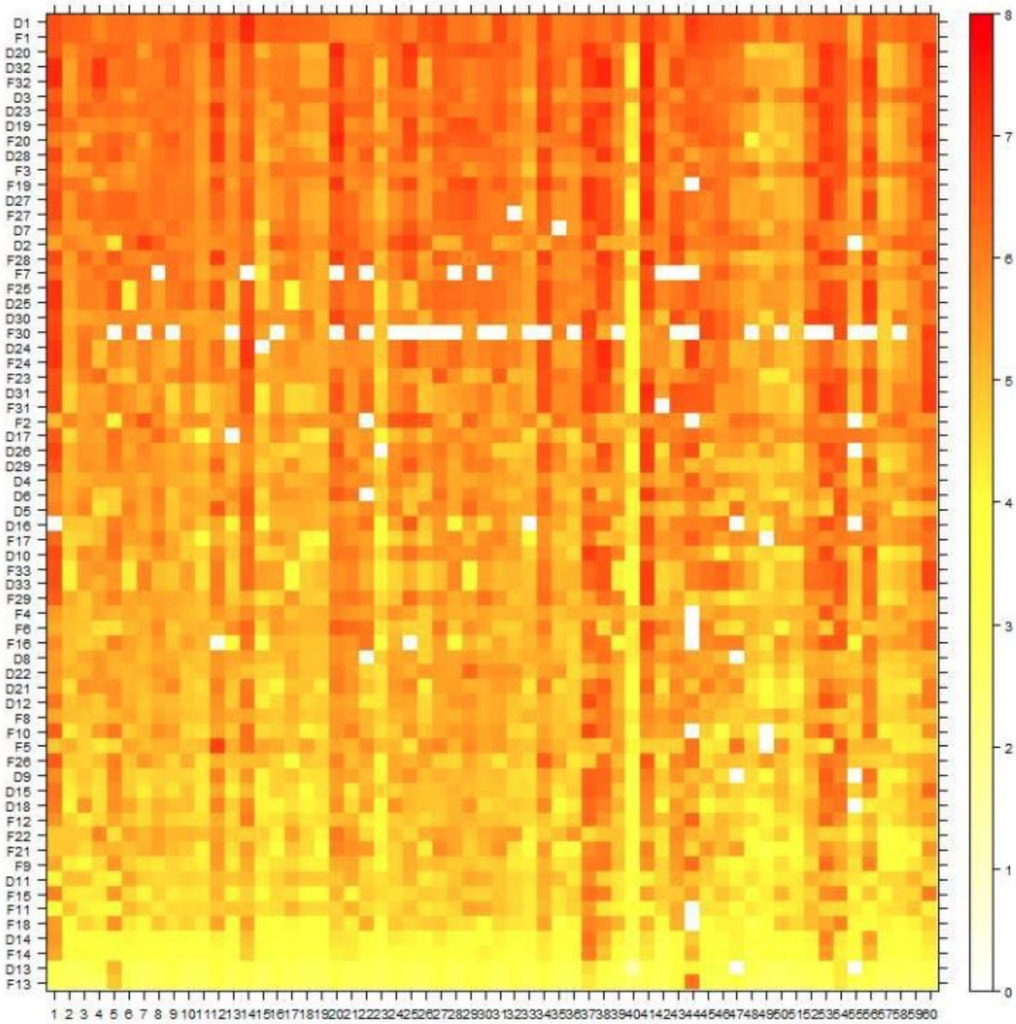

Figure A2. GVC position index for 2016

Appendix 4 Statistical significance of the measured smile curves

We test the significance of smile curves for both China and the U.S. ICT export-related value chains during the entire data period (2005–2016) using a weighted quadratic term regression:

$$v_i = \alpha + \beta_1 D_i + \beta_2 D_i^2 + \epsilon_i$$

where v_i is the value-added ratio (Y-axis) of a participant i who is involved in Chinese- or U.S.-owned firms' ICT value chains, α is the fixed effect, D_i is the position (X-axis) of participant i in the measured value chain (based on a normalized distance measure given in Equation 2) and ϵ_i is an error term. As shown in Tables 1 and 2, most value chains measured appear as U-shaped curves except for the value chain concerning U.S. domestic firms. In the following sections, we provide a detailed explanation. It should be noted that the sample upstream is 4,080 strong (60 economies×34 sectors×2 types of firms); the sample downstream is 240 strong (60 economies×2 sectors (transportation and commerce) ×2 types of firms). However, the number of observations may be smaller than the total sample size. This is because we only count the participants who have enjoyed value-added gains because they joined the corresponding value chain.

Table 2a. Testing the smile curve for ICT export-related value chain (2005)

	USA_D13	USA_F13	CHN_D13	CHN_F13
FE	0.51 ***	0.84 ***	1.11 ***	1.10 ***
	(0.49 – 0.53)	(0.81 – 0.86)	(1.08 – 1.13)	(1.07 – 1.13)
dis	0.01	-0.15 ***	-0.26 ***	-0.27 ***
	(-0.00 – 0.01)	(-0.16 – -0.14)	(-0.27 – -0.25)	(-0.28 – -0.26)
dis^2	0.00	0.01 ***	0.02 ***	0.02 ***
	(-0.00 – 0.00)	(0.01 – 0.01)	(0.02 – 0.02)	(0.02 – 0.02)
Observations	4,087	4,095	4,087	4,095
R^2 / R^2 adjusted	0.037 / 0.036	0.167 / 0.167	0.382 / 0.382	0.369 / 0.369

* p<0.05 ** p<0.01 *** p<0.001

Table 2b. Testing the smile curve for ICT export-related value chain (2016)

	USA_D13	USA_F13	CHN_D13	CHN_F13
FE	-0.05 ***	0.70 ***	0.94 ***	0.94 ***
	(-0.08 – -0.02)	(0.67 – 0.73)	(0.91 – 0.97)	(0.91 – 0.97)
dis	0.28 ***	-0.08 ***	-0.22 ***	-0.23 ***
	(0.27 – 0.29)	(-0.09 – -0.06)	(-0.23 – -0.21)	(-0.24 – -0.22)
dis^2	-0.02 ***	0.01 ***	0.02 ***	0.02 ***
	(-0.02 – -0.02)	(0.00 – 0.01)	(0.02 – 0.02)	(0.02 – 0.02)
Observations	4,115	4,123	4,115	4,123
R^2 / R^2 adjusted	0.466 / 0.466	0.045 / 0.044	0.265 / 0.264	0.255 / 0.255

* p<0.05 ** p<0.01 *** p<0.001

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