MEASURING CONTRIBUTIONS OF TECHNOLOGY CHANGES IN GVCs ON THE ECONOMIC GROWTH OF EMEs

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The objective of this study is to explore the relationship between technology changes in global value chains (GVCs) and economic growth of emerging market economies (EMEs). The key findings are that EMEs have a higher economic growth rate than all countries analyzed, with the manufacturing sector being the major contributor to economic growth. Simple GVCs make a larger positive contribution than complex GVCs, while the non-GVCs component shows different patterns. The study's findings contribute to the field by providing evidence on the relationship between GVCs and economic growth in EMEs. The study's findings suggest that policymakers should focus on promoting the manufacturing sector in EMEs, particularly in medium-high and high technology industries, and adopt a balanced approach to GVC participation.

KEYWORDS

Global value chains, emerging market economies, technology change, structural decomposition analysis

1 INTRODUCTION

EMEs typically integrate more into the global economy as they grow [IMF 2020]. GVCs referred to production sharing across countries have had a significant impact on the economic growth of EMEs [World Bank 2020]. GVCs participating countries, particularly EMEs, can easily pitch into the global market by devoting to specialized production tasks and components and attain the gains from trade without having to independently establish the competitive entire production networks and relevant industries as a prerequisite. Participating in GVCs has been acknowledged as one of the primary incentives for stimulating and promoting sustainable economic growth of EMEs [Gereffi 2019].

It is a well-known fact in the economic literature that technology development is essential for sustainable economic growth [Xing 2021, World Bank 2020]. It is especially pertinent for EMEs where greater challenges for not only rapid but sustainable economic growth as latecomers have to be confronted with. EMEs are keen on coming up with feasible and effective solutions for improving social and economic conditions. Obviously, GVCs plays a pivotal role to EMEs for this issue by providing an opportunity to access technologies of the advanced economies as well as other GVCs participants. EMEs can learn from and collaborate with GVCs partners to obtain knowledge and technology and eventually upgrade their own capabilities. Since the most of EMEs hardly develop their own state-of-the-art and internationally competitive technologies, the substantial portion of technologies in EMEs are transferred or imported from the advanced economies through GVCs. However, the core technology used in GVCs primarily is not a cutting-edge technology but rather a standard technology. In this respect, technology development through GVCs has inherent limits to EMEs to some extent [Xing 2021].

Individual GVCs participating domestic firms and relevant industries in EMEs may benefit from technology changes – which do not necessarily entail technology development – attributed by GVCs activities. Nevertheless, there is an ongoing debate regarding whether it leads to benefit in the aggregated level. It is apparent that gains associated with technology changes do not accrue uniformly to GVCs participants, known as the "Smile Curse" [Shih 1996, Meng 2020]. Overall economic consequences of technology changes from GVCs may rely on countries' domestic capabilities and interactions of firms and relevant industries. Recent researches have acknowledged that various local or domestic systems and capabilities result in divergent economic outcomes unevenly dispersed across and within countries [Marchi 2018, Lee 2018, Rodrik 2018, Raei 2019]. The economic impacts of technology changes stemmed from GVCs still remains an unresolved puzzle to EMEs.

This study aims to shed light on the aggregate level impact of GVCs technology changes by categorizing them into three underlying components: domestic non-GVCs, simple GVCs, and complex GVCs. To analyze the relationship between GVCs technology changes and economic growth in EMEs, the study will use the structural decomposition analysis (SDA). The study's findings will provide additional insights into the relationship between GVC technology changes and economic growth in EMEs, contributing to the ongoing debate on this topic. Policymakers will be able to use these insights to address the challenges and opportunities that EMEs face and to develop policies that promote sustainable economic growth.

The paper is organized as follows: Section 2 outlines the theoretical framework for analysis, followed by Section 3, which describes the materials and methodology used in the study. Section 4 will present the results and discussion, while the final section will provide a summary of the findings and draw conclusions based on the analysis.

2 THEORETICAL FRAMEWORK

The impact of technology changes in GVCs on the overall economic growth of EMEs has been a subject of debate in the literature. The approaches to address this issue in the aggregate level can be broadly grouped into two categories: (1) focusing on how GVCs participation might affect economic performance, and the relationship between various measures of GVCs and related outcomes are examined, and (2) analyzing the change of economic variables using SDA.

The trade accounting framework proposed by [Koopman 2014] and extended by [Wang 2017, Borin 2019] provides a comprehensive mathematical framework for decomposing gross exports into various underlying GVCs components. This can be used to measure GVCs-related activities such as forward and backward GVCs participation and GVCs production length [Wang 2017, Li 2019, Meng 2020]. The trade accounting framework has focused on how the decomposition of underlying GVCs components has boosted the competitiveness of local economic systems and relevant industries in EMEs through increased productivity, innovation and upgrading. For examples, [Jangam 2021] conclude that GVCs participation of 24 EMEs eventually enhances the economic upgrading through increases in domestic value added enclosed in exports. [Lee 2018] highlight the importance of GVCs measured by foreign value added embodied in the domestic final product, which successfully stimulates the formation of local innovation systems in latecomers of EMEs, such as Korea, Taiwan and Brazil. [Tajoli

2018] analyze the positive relationship between GVCs participation and developing countries' innovation performance proxied by patent per capita, which is enabled by international knowledge spillovers through GVCs.

Second approach on the impact of technology changes associated with GVCs is to employ SDA. Variation of technology coefficients accrued by, for example, adopting a different mix of inputs and substituting foreign inputs in production, indicates the altered attributes of technology structure, resulting in technology change. This ultimately leads to change in *Leontief* inverse [Miller 2009]. As a result, the primary research strategy in SDA for assessing technology change is to investigate the change of *Leontief* inverse. [Sousa Filho 2021] examine the effect of technology changes of Brazil incurred by substituting imported inputs for domestically produced inputs which are considered as essential factors in the path of Brazilian economic growth. [Pereira-López 2022] explore the technology change in six EU countries from 2010 to 2015 by decomposing the *Leontief* inverse into three components: change induced by final demand, direct and indirect requirements by normalization of the *Leontief* inverse. Using the Chinese extended input output tables, which distinguish processing trade from conventional exports, [Pei 2012] apply SDA to address the overestimated contribution of 'high-tech', mainly mechanical and electrical products on value added growth.

Two input output (IO) analysis-based approaches stated above have developed independently, each with its own unique technique and advantage. SDA has the notable advantage directly quantifying the inherent underlying components of variable by decomposition rather than indirectly exploring implications through relationship between variables. On the other hand, using the trade accounting framework, it is possible to identify the diverse underlying GVCs related components, such as domestic, traditional trade, 'simple' GVCs and 'complex' GVCs components [Wang 2017, Li 2019, Xing 2021]. It is beneficial to integrate two approaches in order to take advantage of each, yet there is a major bottleneck. In SDA, the change in variable - for example, gross output or value added - is factorized into underlying components commonly in additive terms, illustrating total changes as the sum of the underlying several decomposed components. However, while components in the trade accounting framework are displayed in level as additive terms, they cannot be converted to additive terms when converting to change. As a result, it is not feasible to integrate these two approaches.

This study attempts to formulate underlying components in SDA that are compatible with those in the trade accounting framework, allowing for a direct comparison and examination of the outcomes and implications of two approaches. To do so, following [Miller 2009], the *Leontief* inverse matrix is partitioned to three components in multiplicative terms, making components compatible after converting to change: (1) intra-regional or domestic components without GVCs activities involved in production, (2) spillover or 'simple' GVCs, and (3) feedback or 'complex' GVCs components in production.

In SDA, the decomposed components should be independent each other in order to correctly isolate the impacts of underlying components of changes, usually under the *ceteris paribus* condition. However, the value added coefficients and technology coefficients are not independent. Since gross output is the column sum of the IO table, the sum of technology coefficients and value added coefficients along the column side should be equal to one per se. As a result, when technology coefficients are changed as a result of the technology change, the value-add coefficients vary accordingly [Ghosh 2018]. [Dietzenbacher 2000] propose the method to take care of the dependencies of components by RAS type of normalization of technology coefficients. This study follows the methodology proposed by [Pei 2012] and [Koppany 2017], which is consistent with [Dietzenbacher 2000].

The recent trend of GVCs may be split up into two distinct periods. The rapid expansion of GVCs from 1995 to 2008 led to rises in GVCs participation of all countries including EMEs. The GVCs expansion has been considerably lowered since the global financial crisis – albeit lately recovered to some extent [Li 2019, World Bank 2020, Xing 2021]. The global financial crisis has greater impact on EMEs in particular [Li 2019]. In line with this, this study separates the time span into 2000-2008 and 2008-2019, and focuses on EMEs, which have played key roles in GVCs. This study measures the contributions to value added growth of EMEs from underlying technology changes of GVCs components using SDA, which vary depending on sectors and technology levels.

This paper makes several contributions in the GVCs literature. First, the paper takes a first step to integrate SDA approach and the trade accounting framework in analyzing contributions of various GVCs components to economic growth of EMEs. Second, the paper expands the existing empirical analyses by addressing the dependency of components in SDA, allowing theoretically consistent estimates. Third, this study covers the period from 2000 to 2019. The period from 2000 to 2019 is an important time frame to analyze the relationship between GVCs and economic growth, as it includes the global financial crisis of 2008. This enables a comprehensive understanding of the role of GVCs in promoting economic growth and how the impact of GVCs-related technology changes on economic growth has evolved over time, particularly in the aftermath of a major global economic crisis such as COVID-19. Forth, this study undertakes an analysis of the contribution of GVCs to the economic growth of EMEs by the technology levels of industries, which provides a better understanding of how GVCs related technology changes affects economic growth to EMEs at the sectoral level.

3 MATERIALS AND METHODOLOGY

3.1 Materials

One of the challenging issues in the GVCs study is to accurately quantify GVCs components from intimately interconnected firms, industries and countries. Furthermore, traditional trade statistics are inadequate for assessing GVCs activities due to the fact that data reported in gross terms rather than value added terms [Koopman 2014, Johnson 2018]. Attempt to measure GVCs activities using IO database, in particular MRIO, has gained popularity since it provides extensive information on interdependences at sectoral and country levels as well as value added [Antras 2021].

In this study, the ADB MRIO at constant 2010 US dollars is utilized, which expands the world input output database (WIOD) by adding 19 Asian countries. It covers 62 countries, including the rest of the world, which totals to 63 countries, ranging from 2000 to 2019. The classification of countries used in this study follows the [IMF 2020], which consists of advanced economies (AEs), EMEs, and low-income and developing economies (LEs). According to the [IMF 2020], there are 39 countries in the AEs group, while 96 countries belong to the EMEs group, of which 21 are included in the ADB MRIO. Furthermore, the ADB MRIO contains 35 industries that conform to the International Standard Industrial Classification Revision 3 (ISIC Rev. 3).

A commonly used method for classifying industries is based on their level of technological intensity. The OECD and the United Nations Industrial Development Organization (UNIDO) have established two main industry classifications, but for this study, the UNIDO classification is used because the OECD classification is better suited for highly industrialized economies [UNIDO 2010]. The Industrial Statistics Guidelines by the [UNIDO 2010] follows the earlier system of grouping industries by technological intensity, which includes low technology, medium technology, and medium-high and high technology. The list and classification of industries is provided in Table 1.

Technology classification	Industries
Low	Food, beverages, and tobacco Textiles and textile products Leather, leather products, and footwear Wood and products of wood and cork Pulp, paper, paper products, printing, and publishing Coke, refined petroleum, and nuclear fuel Manufacturing, nec; recycling
Medium	Rubber and plastics Other nonmetallic minerals Basic metals and fabricated metal
Medium-high and High	Chemicals and chemical products Machinery, nec Electrical and optical equipment Transport equipment

Source: [UNIDO 2010]

Table 1 Technology Classification by Sector

3.2 *Methodology*

The MRIO provides a comprehensive framework to examine the economic consequences of inter-related industries and countries. Let $\mathbf{X}$ denote a column vector of gross output, composed of intermediates ($\mathbf{Z}$) and final demand ($\mathbf{y}$) along the row-wise of the MRIO, which represents the demand side of economy. For supply side, let denote $\mathbf{V}'$ as a row vector of value added, which make up the gross output along the column-wise with $\mathbf{Z}$. In each country denoted by G, there are N industries or sectors. Therefore, $\mathbf{Z}$ is a total GN $\times$ GN intermediate matrix. Each of $\mathbf{y}$ contains a N $\times$ K final demand matrix, where K represents categories of final demand. $\mathbf{y}$ is a total final demand matrix with GN $\times$ NK dimension.

The MRIO can be expressed as: $\mathbf{X} = \mathbf{Zi} + \mathbf{Y}$, where $\mathbf{i}$ represents the unit column vector and $\mathbf{Y} = \mathbf{yi}$. Solving for $\mathbf{X}$ provides the solution of entire economic systems as:

$$\mathbf{X} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{Y} = \mathbf{LY} \tag{1}$$

where, $\mathbf{A}$ is a matrix of technology coefficients calculated by $\mathbf{A} = \mathbf{Z}\widehat{\mathbf{X}}^{-1}$, in which $\widehat{\mathbf{X}}$ is a block diagonal matrix with elements of gross output vector $\mathbf{X}$. The *Leontief* inverse denoted by $\mathbf{L}$ can be interpreted as the total output required directly and indirectly to produce one unit of final demand, simply the requirement matrix or the multiplier of whole economic system.

In order to drive the compatible GVCs related components in SDA, factorizing $\mathbf{L}$ to the underlying GVCs relevant components is necessary as in the trade accounting framework. This study follows the formulation of [Miller 2009]. The first step is to split $\mathbf{A}$ into domestic and foreign technology coefficients as follows:

$$\mathbf{A} = \begin{bmatrix} \mathbf{A}_{11} & \cdots & \mathbf{0} \\ \vdots & \ddots & \vdots \\ \mathbf{0} & \cdots & \mathbf{A}_{GG} \end{bmatrix} + \begin{bmatrix} \mathbf{0} & \cdots & \mathbf{A}_{1G} \\ \vdots & \ddots & \vdots \\ \mathbf{A}_{G1} & \cdots & \mathbf{0} \end{bmatrix} \equiv \mathbf{A}^{\mathbf{D}} + \mathbf{A}^{\mathbf{F}} \tag{2}$$

Note that the diagonal block matrix of $\mathbf{A}^{\mathbf{D}}$ with elements of $\mathbf{A}_{11}, \ldots \mathbf{A}_{GG}$ represents the domestic technology coefficients of each corresponding country for domestic production using domestic inputs from its own or other domestic industries. On the other hand, in the off-diagonal block matrix denoted by $\mathbf{A}^{\mathbf{F}}$, the elements of $\mathbf{A}^{\mathbf{F}}$ along the row-side illustrate the technology coefficients of intermediates export from source country to G foreign countries and industries for production: the elements of $\mathbf{A}^{\mathbf{F}}$ along the column-side indicate the technology coefficients of imported inputs from G foreign countries and industries to destination county.

Equation (1) can be modified as:

$$\mathbf{X} = \mathbf{AX} + \mathbf{A}^{\mathbf{D}}\mathbf{X} - \mathbf{A}^{\mathbf{D}}\mathbf{X} + \mathbf{Y} \tag{3}$$

Then, by re-arranging equation (3), the following equations are obtained:

$$(\mathbf{I} - \mathbf{A}^{\mathbf{D}})\mathbf{X} = (\mathbf{A} - \mathbf{A}^{\mathbf{D}})\mathbf{X} + \mathbf{Y} \tag{4}$$

and,

$$\mathbf{X} = (\mathbf{I} - \mathbf{A}^{\mathbf{D}})^{-1}(\mathbf{A} - \mathbf{A}^{\mathbf{D}})\mathbf{X} + (\mathbf{I} - \mathbf{A}^{\mathbf{D}})^{-1}\mathbf{Y} \qquad 5)$$

Defining $\mathbf{A}^{*} = (\mathbf{I} - \mathbf{A}^{\mathbf{D}})^{-1}(\mathbf{A} - \mathbf{A}^{\mathbf{D}})$, solving for $\mathbf{X}$ gives the solution. Then the *Leontief* inverse can be partitioned to three components in multiplicative formulae as:

$$\mathbf{X} = (\mathbf{I} - \mathbf{A}^{*2})(\mathbf{A}^{*} + \mathbf{I})(\mathbf{I} - \mathbf{A}^{\mathbf{D}})^{-1}\mathbf{Y} \tag{6}$$

It is necessary to look at each term in equation (6) in order to explore the economic implications. First, the elements of the third term in equation (6) are:

$$(\mathbf{I} - \mathbf{A}^{\mathbf{D}})^{-1} \equiv \mathbf{M}^{1} = \begin{bmatrix} (\mathbf{I} - \mathbf{A}_{11})^{-1} & \cdots & \mathbf{0} \\ \vdots & \ddots & \vdots \\ \mathbf{0} & \cdots & (\mathbf{I} - \mathbf{A}_{GG})^{-1} \end{bmatrix} \tag{7}$$

The elements in the diagonal block matrix of $\mathbf{M}^{1}$ indicate, in the context of production and absorbing of output, that domestically produced outputs using domestic inputs either absorb domestically or export to foreign countries as final products. Therefore, in $\mathbf{M}^{1}$, there are no GVCs activities involved; only domestic productions are engaged.

The elements of the second term are:

$$\mathbf{A}^{*} + \mathbf{I} \equiv \mathbf{M}^{2} = \begin{bmatrix} \mathbf{I} & \cdots & (\mathbf{I} - \mathbf{A}^{11})^{-1}\mathbf{A}^{1G} \\ \vdots & \ddots & \vdots \\ (\mathbf{I} - \mathbf{A}^{GG})^{-1}\mathbf{A}^{G1} & \cdots & \mathbf{I} \end{bmatrix} \tag{8}$$

The diagonal elements of $\mathbf{M}^{2}$ are block identity diagonal matrices, which don't have any meaningful roles in multiplicative formulae. In the meantime, the elements in the off-diagonal block matrices of $\mathbf{M}^{2}$ stipulate that domestically produced outputs using domestic inputs export to foreign countries as intermediates for foreign countries' production and finally absorb in foreign countries. In this sense, the elements of $\mathbf{M}^{2}$ as intermediates cross the border once from source country to absorbing foreign countries, which can be characterized as the 'simple' GVCs components [Koopman 2014, Wang 2017, Li 2019, Xing 2021].

Furthermore, the elements in the first term are:

$$[\mathbf{I} - (\mathbf{A}^{*})^{2}]^{-1} \equiv \mathbf{M}^{3} = \tag{9}$$

$$\begin{bmatrix} [\mathbf{I} - (\mathbf{I} - \mathbf{A}^{11})^{-1}\mathbf{A}^{1S}(\mathbf{I} - \mathbf{A}^{SS})^{-1}\mathbf{A}^{S1}]^{-1} & \cdots & \mathbf{0} \\ \vdots & \ddots & \vdots \\ \mathbf{0} & \cdots & [\mathbf{I} - (\mathbf{I} - \mathbf{A}^{GG})^{-1}\mathbf{A}^{GR}(\mathbf{I} - \mathbf{A}^{RR})^{-1}\mathbf{A}^{RG}]^{-1} \end{bmatrix}$$

for $S \neq 1$ and R≠ G. The elements of $\mathbf{M^3}$ imply once domestically produced outputs in the source country export to foreign country *S* as intermediates for production in country S: outputs produced in county S export to other third countries as intermediates used in production. Then, outputs produced in the 3rd countries are re-exported to source country as intermediates for production in the source country and finally absorbed in the source country. Consequently, the elements of $\mathbf{M^3}$ cross the border at least two times, which are characterized as "complex" GVCs components [Koopman 2014, Wang 2017, Li 2019, Xing 2021].

To match SDA to GVCs analysis, it is required to convert equation (1) to value added by pre-multiply the vector of value added coefficients calculated from $\mathbf{v} = \mathbf{V}\widehat{\mathbf{X}}^{-1}$, where V is a column vector of value added. Value added is obtained as:

$$\mathbf{V} = \hat{\mathbf{v}}\mathbf{X} = \hat{\mathbf{v}}\mathbf{L}\mathbf{Y} \tag{10}$$

where, $\hat{\mathbf{v}}$ is a block diagonal matrix of value added coefficients. From equation (10), the change of value added can be decomposed as follows:

$$\Delta\mathbf{V} = \frac{1}{2}\Delta\hat{\mathbf{v}}(\mathbf{L_1Y_1} + \mathbf{L_0Y_0}) + \frac{1}{2}(\hat{\mathbf{v}}_1 + \hat{\mathbf{v}}_0)\Delta\mathbf{L}(\mathbf{Y_1} + \mathbf{Y_0}) + \frac{1}{2}(\hat{\mathbf{v}}_1 + \hat{\mathbf{v}}_0)(\mathbf{L_1} + \mathbf{L_0})\Delta\mathbf{Y} \tag{11}$$

where, subscripts of 1 and 0 represent two different time periods for examining the changes of value added. As a result, the changes in value added are broken down into the relevant underlying three components as in equation (11): changes in value added coefficients, changes in the *Leontief* inverse or technology change, and changes in final demand, respectively.

As noted in the previous section, the dependency between the decomposed underlying components in equation (11) needs to be resolved for the theoretically consistent measurement. The first and second terms in equation (11) are intrinsically dependent each other [Dietzenbacher 2000, Pei 2012, Koppány 2017, Ghosh 2018]. From the basic macroeconomic identity of IO table, $\mathbf{Y} = \mathbf{V}$, the relationship between two components can be derived as: $\mathbf{Y} = \mathbf{V} = \mathbf{v}'\mathbf{X} = \mathbf{v}'(\mathbf{I} - \mathbf{A})^{-1}\mathbf{Y}$, so that $\mathbf{v}'(\mathbf{I} - \mathbf{A})^{-1} = \mathbf{i}$. It stipulates that any changes in $\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-1}$ from variations in technology coefficients should be balanced by changes in $\mathbf{v}'$, illustrating these two components are not independent each other per se.

In eliminating the dependency, there are possible solutions proposed by [Dietzenbacher 2000], [Pei 2012] and [Koppány 2017]. This study follows the method suggested by [Pei 2012, Koppany 2017]. With time dimension, equation (10) can be expressed at time *t*, usually two different time periods of *i* and *j* as follows:

$$\mathbf{V_t} = \hat{\mathbf{v}}_\mathbf{t}\mathbf{L_t}\mathbf{Y_t} = \hat{\mathbf{v}}_\mathbf{t}\left(\mathbf{I} - \mathbf{A_t}(\mathbf{I} - \hat{\mathbf{v}}_\mathbf{t})^{-1}(\mathbf{I} - \hat{\mathbf{v}}_\mathbf{t})\right)^{-1}\mathbf{Y_t} = \hat{\mathbf{v}}_\mathbf{t}\,(\mathbf{I} - \widetilde{\mathbf{A}}_\mathbf{t})^{-1}\mathbf{Y_t}, \quad \text{for } t=i, j \tag{12}$$

where, $\widetilde{\mathbf{A}}_\mathbf{t} = \mathbf{A_t}(\mathbf{I} - \hat{\mathbf{v}}_\mathbf{t})^{-1}(\mathbf{I} - \hat{\mathbf{v}}_\mathbf{t})$. The key determinant of eliminating dependency is $(\mathbf{I} - \hat{\mathbf{v}}_\mathbf{t})^{-1}(\mathbf{I} - \hat{\mathbf{v}}_\mathbf{t})$. When the value added coefficients vary due to the technology changes, $(\mathbf{I} - \hat{\mathbf{v}}_\mathbf{i})^{-1}(\mathbf{I} - \hat{\mathbf{v}}_\mathbf{j})$, for t = i and j, is changed accordingly. In the case of *i* = *j*, then $(\mathbf{I} - \hat{\mathbf{v}}_\mathbf{i})^{-1}(\mathbf{I} - \hat{\mathbf{v}}_\mathbf{j}) = 1$, indicating $\widetilde{\mathbf{A}}_\mathbf{t} = \mathbf{A_t}$. Meanwhile, when $i \neq j$, $\widetilde{\mathbf{A}}_{\boldsymbol{ij}} = \mathbf{A_i}(\mathbf{I} - \hat{\mathbf{v}}_\mathbf{i})^{-1}(\mathbf{I} - \hat{\mathbf{v}}_\mathbf{j})$. In fact, the elements in $(\mathbf{I} - \hat{\mathbf{v}}_{\boldsymbol{t}})$ are the column sum of technology coefficients. Therefore, $(\mathbf{I} - \hat{\mathbf{v}}_\mathbf{i})^{-1}(\mathbf{I} - \hat{\mathbf{v}}_\mathbf{j})$ implies the ratio of column sums of two technology coefficients at different time periods, which reflects the changes in value added coefficients affecting the technology coefficients uniformly for all industries. The ratio indicates the substitution between total intermediates and value added known as the fabrication effects [Dietzenbacher 2000]. By assuming that variations in value added coefficients associated with technology changes have a uniform impact on the technology coefficients, the change in $\widetilde{\mathbf{A}}_{\boldsymbol{ij}} = \mathbf{A_i}(\mathbf{I} - \hat{\mathbf{v}}_\mathbf{i})^{-1}(\mathbf{I} - \hat{\mathbf{v}}_\mathbf{j})$ alludes to the mixture of inputs resulting from the changes of technology coefficients after taking dependency into account [Pei 2012, Koppany 2017].

The change of value added of two different time periods can be expressed as:

$$\Delta\mathbf{V} = \mathbf{V_1} - \mathbf{V_0} = \hat{\mathbf{v}}_\mathbf{1}\mathbf{L}(\widetilde{\mathbf{A}}_\mathbf{11})\mathbf{Y_1} - \hat{\mathbf{v}}_\mathbf{0}\mathbf{L}(\widetilde{\mathbf{A}}_\mathbf{00})\mathbf{Y_0} \tag{13}$$

where, $\mathbf{L}(\widetilde{\mathbf{A}}_\mathbf{11}) = (\mathbf{I} - \widetilde{\mathbf{A}}_\mathbf{11})^{-1}$ and $\mathbf{L}(\widetilde{\mathbf{A}}_\mathbf{00}) = (\mathbf{I} - \widetilde{\mathbf{A}}_\mathbf{00})^{-1}$, respectively. In the same manner, $\mathbf{L}(\widetilde{\mathbf{A}}_\mathbf{t})$ can be replaced by $\widetilde{\mathbf{M}}_{\boldsymbol{t}}^\mathbf{3}\widetilde{\mathbf{M}}_{\boldsymbol{t}}^\mathbf{2}\widetilde{\mathbf{M}}_{\boldsymbol{t}}^\mathbf{1}$ as in equation (6), where $\widetilde{\mathbf{M}}_\mathbf{t}^\mathbf{3} = \left(\mathbf{I} - \widetilde{\mathbf{A}_\mathbf{t}}^{*\mathbf{2}}\right)$, $\widetilde{\mathbf{M}}_\mathbf{t}^\mathbf{2} = \left(\widetilde{\mathbf{A}_\mathbf{t}}^{*} + \mathbf{I}\right)$, and $\widetilde{\mathbf{M}}_\mathbf{t}^\mathbf{1} = \left(\mathbf{I} - \widetilde{\mathbf{A}_\mathbf{t}}^{\mathbf{D}}\right)^{-1}$, respectively.

Finally, the change of value added can be derived as follows:

$$\begin{aligned}
\Delta\mathbf{V} = {} & \hat{\mathbf{v}}_\mathbf{1}\widetilde{\mathbf{M}}_\mathbf{11}^\mathbf{3}\widetilde{\mathbf{M}}_\mathbf{11}^\mathbf{2}\widetilde{\mathbf{M}}_\mathbf{11}^\mathbf{1}\mathbf{Y_1} - \hat{\mathbf{v}}_\mathbf{0}\widetilde{\mathbf{M}}_\mathbf{00}^\mathbf{3}\widetilde{\mathbf{M}}_\mathbf{00}^\mathbf{2}\widetilde{\mathbf{M}}_\mathbf{00}^\mathbf{1}\mathbf{Y_0} \\
= {} & \left(\frac{\mathbf{1}}{\mathbf{2}}\right)\{[\hat{\mathbf{v}}_\mathbf{1}(\widetilde{\mathbf{M}}_\mathbf{11}^\mathbf{3}\widetilde{\mathbf{M}}_\mathbf{11}^\mathbf{2}\widetilde{\mathbf{M}}_\mathbf{11}^\mathbf{1}) - \hat{\mathbf{v}}_\mathbf{0}(\widetilde{\mathbf{M}}_\mathbf{00}^\mathbf{3}\widetilde{\mathbf{M}}_\mathbf{00}^\mathbf{2}\widetilde{\mathbf{M}}_\mathbf{00}^\mathbf{1})]\mathbf{Y_1} \\
& \quad + [\hat{\mathbf{v}}_\mathbf{1}(\widetilde{\mathbf{M}}_\mathbf{11}^\mathbf{3}\widetilde{\mathbf{M}}_\mathbf{11}^\mathbf{2}\widetilde{\mathbf{M}}_\mathbf{11}^\mathbf{1}) - \hat{\mathbf{v}}_\mathbf{0}(\widetilde{\mathbf{M}}_\mathbf{00}^\mathbf{3}\widetilde{\mathbf{M}}_\mathbf{00}^\mathbf{2}\widetilde{\mathbf{M}}_\mathbf{00}^\mathbf{1})]\mathbf{Y_0}\} \\
& + (\tfrac{1}{2})[\hat{\mathbf{v}}_\mathbf{0}(\widetilde{\mathbf{M}}_\mathbf{10}^\mathbf{3}\text{-}\widetilde{\mathbf{M}}_\mathbf{00}^\mathbf{3})\,\widetilde{\mathbf{M}}_\mathbf{10}^\mathbf{2}\widetilde{\mathbf{M}}_\mathbf{10}^\mathbf{1}\mathbf{Y_1} \\
& \quad + \hat{\mathbf{v}}_\mathbf{1}(\widetilde{\mathbf{M}}_\mathbf{11}^\mathbf{3}\text{-}\,\widetilde{\mathbf{M}}_\mathbf{01}^\mathbf{3})\,\widetilde{\mathbf{M}}_\mathbf{01}^\mathbf{2}\widetilde{\mathbf{M}}_\mathbf{01}^\mathbf{1}\mathbf{Y_0}] \\
& + (\tfrac{1}{2})[\,\hat{\mathbf{v}}_\mathbf{0}\widetilde{\mathbf{M}}_\mathbf{00}^\mathbf{3}(\widetilde{\mathbf{M}}_\mathbf{10}^\mathbf{2}\text{-}\widetilde{\mathbf{M}}_\mathbf{00}^\mathbf{2})\widetilde{\mathbf{M}}_\mathbf{10}^\mathbf{1}\mathbf{Y_1} + \hat{\mathbf{v}}_\mathbf{1}\widetilde{\mathbf{M}}_\mathbf{11}^\mathbf{3}(\widetilde{\mathbf{M}}_\mathbf{11}^\mathbf{2}\text{-} \\
& \quad \widetilde{\mathbf{M}}_\mathbf{01}^\mathbf{2})\widetilde{\mathbf{M}}_\mathbf{01}^\mathbf{1}\mathbf{Y_1}] \\
& + (\tfrac{1}{2})[\hat{\mathbf{v}}_\mathbf{0}\widetilde{\mathbf{M}}_\mathbf{00}^\mathbf{3}\widetilde{\mathbf{M}}_\mathbf{00}^\mathbf{2}(\widetilde{\mathbf{M}}_\mathbf{10}^\mathbf{1}\text{-}\widetilde{\mathbf{M}}_\mathbf{00}^\mathbf{1})\mathbf{Y_1} + \hat{\mathbf{v}}_\mathbf{1}\widetilde{\mathbf{M}}_\mathbf{11}^\mathbf{3}\widetilde{\mathbf{M}}_\mathbf{11}^\mathbf{2}(\widetilde{\mathbf{M}}_\mathbf{11}^\mathbf{1}\text{-} \\
& \quad \widetilde{\mathbf{M}}_\mathbf{01}^\mathbf{1})\mathbf{Y_0}] \\
& + (\frac{\mathbf{1}}{\mathbf{2}})(\hat{\mathbf{v}}_\mathbf{1} + \hat{\mathbf{v}}_\mathbf{0})(\mathbf{L_1} + \mathbf{L_0})\Delta\mathbf{Y}
\end{aligned} \tag{14}$$

The first term in equation (14) illustrates the effect of the change in value added (VA) coefficients after accounting for the dependency of technology coefficients. The change of *Leontief* inverse after resolving dependency is factorized into the second, third and fourth terms, which, respectively, indicate the underlying effects of changes in non-GVCs, simple GVCs, and complex GVCs components. The final term represents the effect of change in final demand. This term can be further decomposed into various sub-components. However, since the main purpose of this study is to examine the contributions of technology changes, it is no longer decomposed.

4 RESULTS AND DISCUSSION

4.1 Results

Table 2 presents the contributions of the fundamental components to the economic growth of all 63 countries including the rest of the world, and EMEs during three periods: 2000-2019, 2008-2019, and 2000-2008. The calculations are done using equation (14). The study considers the two phases of globalization between 2000 and 2019, as mentioned in [Xing 2021, World Bank 2020]. The first phase was characterized by a surge in globalization from the 1990s to around 2008. However, during the second phase, trade decreased following the global financial crisis, resulting in a considerable slowdown in globalization. Therefore, the contributions to economic growth are analyzed while taking into account these two phases.

The table shows the compound annual growth rate (CAGR) of each component's contribution to economic growth. It is noted that the sum of changes in the *Leontief* Inverse, final demand, and value added ratio should be equal the overall economic growth, because these three factors are directly derived from the economic growth rate through decomposition. The calculations for all the measures in this study are conducted at the sectoral level. To obtain the aggregate measures at the country and economies' levels, the sector-level measures are weighted according to each sector's share in the total value added.

As shown in Table 2, it indicates that EMEs had a significantly higher economic growth rate than all countries throughout the examined period. In particular, EMEs had an average growth rate of 7.164% from 2000 to 2019, while all countries had an average growth rate of 2.425%. However, it should be pointed out that during the period spanning from 2008 to 2019, EMEs encountered a slight decline in their economic growth rate, with an average rate of 6.525%. The primary cause of this decline was the global financial crisis of 2008, which had a noteworthy impact on EMEs. As a result, the crisis exerted a greater influence on the economic growth rate of EMEs during the period under consideration.

(Unit: CAGR%)

Period	Coun-tries	Economic Growth	Change in VA Ratio	Change in Final Demand	Change in *Leontief* Inverse
2000 ~ 2019	All	2.425	0.030	2.393	0.001
	EMEs	7.164	0.105	6.931	0.128
2008 ~ 2019	All	2.174	0.166	1.962	0.046
	EMEs	6.525	-0.055	6.093	0.486
2000 ~ 2008	All	2.487	-0.241	2.773	-0.044
	EMEs	7.335	0.082	7.224	0.029

Source: Author's calculation

Table 2. Contribution of Components to Economic Growth

It is evident that final demand played the most significant role to economic growth during the entire period of 2000-2019, with a contribution of 2.393% and 6.931%, respectively, compared to the changes in the *Leontief* Inverse (0.001 and 0.128%) and value added ratio (0.03 and 0.105%). This finding aligns with previous literatures on SDA, such as [Hosseinzadeh 2018, Bertulfo 2019]. The *Leontief* Inverse, which is an indicator of the contribution of technological changes, showed mixed results for all countries, with both negative and positive changes. The negative value of change means a decrease in the importance of its effect on economic growth as in [Pereira-Lopez 2022, Hosseinzadeh 2018]. However, despite these fluctuations, it ultimately had a positive but small contribution to economic growth. Meanwhile, EMEs are experiencing a noticeable increase in their contribution from the changes of the *Leontief* Inverse, which has risen from 0.029% to 0.486% over the period. This indicates that technological changes are playing a crucial role in driving economic growth. This ongoing trend demonstrates their ability to continue capitalizing on technological changes and leveraging them for further economic growth.

(Unit: CAGR%)

Period	Classification of Industries	Change in Complex GVCs	Change in Simple GVCs	Change in non-GVCs
2000 ~ 2019	EMEs	0.070	0.220	-0.162
	Manufacturing	0.208	0.631	0.253
	Low	0.093	0.361	0.875
	Medium	0.202	0.645	-0.598
	Medium-high & High	0.287	0.806	0.244
2008 ~ 2019	EMEs	0.014	0.125	0.347
	Manufacturing	0.094	0.384	0.397
	Low	0.060	0.261	0.467
	Medium	0.103	0.422	-0.442
	Medium-high & High	0.112	0.444	0.769
2000 ~ 2008	EMEs	0.165	0.417	-0.554
	Manufacturing	0.501	1.374	0.029
	Low	0.167	0.590	1.032
	Medium	0.587	1.606	-0.069
	Medium-high & High	0.634	1.666	-0.481

Source: Author's calculation

Table 3. Decomposition of Technology Changes by Technology Classification in EMEs

Table 3 displays the contribution of technological changes on the economic growth of EMEs from all of 35 industries and their manufacturing industries, decomposed into three underlying components: complex GVCs, simple GVCs, and non-GVCs. Manufacturing industries are further categorized as Low, Medium, and Medium-high & High, based on [UNIDO 2010] as presented in Table 1.

There are noteworthy empirical findings to highlight. First, the manufacturing sector in EMEs consistently makes a greater contribution than all other industries during the entire period of analysis. Furthermore, simple GVCs persistently have a larger positive contribution than complex GVCs. For the periods of 2000-2008 and 2008-2019, the contribution of simple GVCs to economic growth decreased significantly in the latter period compared to the former as well as that of complex GVCs. The non-GVCs component showed different patterns between the two periods, with a negative contribution in the earlier period and a positive contribution in the latter period.

Industries with low levels of technology have experienced a greater contribution to growth from non-GVCs related technological changes compared to the combined contribution from simple and complex GVCs. In contrast, industries classified as medium and medium-high and high have benefited from technological changes, with both simple and complex GVCs consistently making positive contributions to economic growth throughout the analyzed period. Additionally, the manufacturing sectors in EMEs, especially those categorized as medium-high and high, benefit from technological changes, with simple GVCs having a larger impact on economic growth than complex GVCs. The results support the importance of enhancing technology through participation in GVCs, as demonstrated in Table 2. However, the mixed results of the non-GVCs component indicate the need for a more nuanced understanding of the role of different types of technological changes in achieving better economic growth.

4.2 Discussion

The findings of this study have important policy implications for policymakers in EMEs. As revealed in this study, EMEs had a significantly higher economic growth rate than all countries throughout the examined period. However, during the period from 2008 to 2019, EMEs encountered a slight decline in their economic growth rate, primarily attributed to the global financial crisis of 2008, which had a noteworthy impact on EMEs as in [Li 2019, Xing 2021]. This suggests that EMEs may be more vulnerable to economic crisis such as the COVID-19 pandemic. In the meantime, this study reaffirms that the persistent and substantial role played by the manufacturing sector in deriving economic growth underscores the significance of prioritizing policies aimed at promoting this sector in EMEs, particularly in the medium-high and high technology industries.

To promote technological development efficiently with limited resources, policymakers in EMEs should focus on industries that demonstrate high growth potential and make significant contribution to economic growth. It should be noted that complex GVC activities are more common in higher technology intensive sectors [Li 2019], and that they involve more slicing the production process into highly fragmented tasks and crossing national borders several times. Based on our findings, the characteristic of complex GVCs activities presents challenges to technological development in EMEs, resulting in a lower contribution to economic growth compared to that of simple GVCs.

While simple GVCs have significantly contributed to economic growth, recent trends indicate a decline in their level of contribution. Therefore, from a long-term perspective, policymakers should focus on promoting technological development through diversified ways, including both complex and simple GVCs, in high technology-intensive industries. By participating in GVCs, EMEs can acquire advanced technological capabilities through knowledge spillovers and collaboration with technologically advanced countries. This can enable them to move up the value chain and enhance their technological capabilities, leading to sustained economic growth in the long run. Thus, policymakers should adopt a balanced approach that considers the advantages and disadvantages of both complex and simple GVCs to promote technological development and ensure sustainable economic growth in EMEs.

5 CONCUSIONS

Technology development is crucial for sustainable economic growth, particularly for EMEs that face challenges in rapid and sustainable economic growth. GVCs play a vital role in providing access to technologies of advanced economies and other GVCs participants, allowing EMEs to learn from and collaborate with their partners to upgrade their own capabilities. However, the impact of GVCs-related technology changes on economic growth remains an unresolved puzzle, and the gains associated with technology changes do not accrue uniformly to GVCs participants.

The study examined the contributions of technological changes to the economic growth of EMEs. The empirical findings of the study are that technological changes have a significant impact on the economic growth of EMEs. The manufacturing sector has consistently contributed more to economic growth than other industries. Simple GVCs have consistently had a larger positive impact on economic growth than complex GVCs. On the other hand, the non-GVCs component showed different patterns between the two periods, with industries with low technology intensity contributing more to economic growth through non-GVCs related technological changes than through simple and complex GVCs combined. In contrast, industries with medium and medium-high to high technology intensity have benefited from both simple and complex GVCs, which have consistently made positive contributions to economic growth throughout the analyzed period.

The study emphasizes the importance of prioritizing policies to promote the manufacturing sector in EMEs, especially in medium-high and high technology industries, as it plays a significant role in deriving economic growth. The study suggests that policymakers in EMEs should focus on industries with high growth potential that make a significant contribution to economic growth for efficient technological development with limited resources. While simple GVCs have significantly contributed to economic growth, recent trends indicate a decline in their contribution. Therefore, policymakers should adopt a balanced approach that considers the advantages and disadvantages of both complex and simple GVCs. By participating in GVCs, EMEs can create an environment that supports innovation and growth, enabling them to take advantage of the benefits of GVCs-related technological changes and achieve sustainable economic growth.

It is recommended that, to effectively participate in GVCs, EMEs should adopt a strategic approach that takes into account their development stage. As an example, the electronics industry, which has high potential for growth, should follow a strategic approach that focuses on low and medium-skilled labor with process innovation in the initial stage. In the middle stage, the focus should shift to high-skilled labor, while the advanced stage should include product, process, and organizational innovation. On the other hand, it is important for EMEs to be aware of the potential risks associated with excessive reliance on GVCs, including those associated with global risks such as the COVID-19 pandemic, protectionism, and the Ukraine war. Such risks could lead to supply chain disruptions and affect GVC participation. Therefore, EMEs should consider diversifying their supply chains, promoting domestic production, and building resilience to external shocks to mitigate these risks.

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