Article

The Causality between Participation in GVCs, Renewable Energy Consumption and CO₂ Emissions

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Abstract: Using the panel vector autoregressive (PVAR) model accompanied by the system-generalized method of moment (System-GMM) approach, this paper investigates the dynamic causality between participation in global value chains (GVCs), renewable energy consumption and carbon dioxide (CO₂) emissions throughout 1990–2015 for 172 countries. The results show that participation in GVCs negatively causes renewable energy consumption except for the Middle East and North America (MENA) and sub-Saharan Africa. Second, except for the Asia–Pacific region and globally, participation in GVCs has no causal impact on CO₂ emissions, and participation in GVCs has a positive effect on CO₂ emissions in the Asia–Pacific region and globally. Third, except for globally and sub-Saharan Africa, CO₂ emissions have no causal impact on participation in GVCs; however, CO₂ emissions hurt participation in GVCs globally and in the sub-Saharan African region. Forth, renewable energy consumption positively causes participation in GVCs in MENA, while renewable energy consumption does not cause participation in GVCs globally and in other regions. Fifth, there is no causality between CO₂ emissions and renewable energy consumption both at the global and regional levels. Several policy implications are proposed and discussed for promoting participation in GVCs and improving the environment.

Keywords: participation; GVCs; renewable energy consumption; CO₂ emissions; PVAR

1. Introduction

Global climate warming and energy scarcity are consensually regarded as the most challenging and threatening global environmental issues, which will severely affect all aspects of human life and health [1–4]. To ensure the energy security and sustainable development of human society, the relevant international organizations, policymakers and researchers have highlighted the significance of governing global warming and reducing greenhouse gas (GHG) emissions. In particular, as production sharing becomes the significant characteristic of today's global economy [5], much debate about the environmental consequences of participation in global value chains (GVCs) has emerged [6]. According to the recent report of the United Nations' Sustainable Development Goals, "Global supply chains play a critical role in many of the most pressing environmental stresses and social struggles" [7], which clearly emphasizes the effect of GVCs on the environment.

As carbon dioxide (CO₂) emissions are the primary source of climate warming, mitigating CO₂ emissions is the key to solving the problem of global climate change [8–11]. There is strong agreement among researchers that renewable energy provides a promising solution to stimulate CO₂ emission reduction [12,13]. Widespread use of renewable energy and further technological advancement of renewable energy technologies are all conducive to decreasing CO₂ emissions [14,15]. At the same time, it is widely accepted that integration in GVCs plays a growing role in accessing knowledge and enhancing learning and innovation ability [16], which is vital to the development of eco-technology

and the use of renewable energy. However, participation in GVCs might increase CO₂ emissions in turn [17]. These contradictory views make it a challenge for policymakers to make reasonable and consistent industrial development policies aiming at increasing the share of participation in GVCs while concurrently protecting the environment and saving energy.

Two parallel literatures on the relationship between participation in GVCs and the environment have emerged. The first group of studies shows that participation in GVCs is environmentally beneficial [18–20]. The increase of participation in GVCs can prevent environmental deterioration and save energy due to several channels. First, technology spillovers and labor transfer through participation in GVCs contribute to the transfer of environmental technology and new energy technology [6,21–24]. Second, participation in GVCs contributes to the process of technology diffusion and the sharing of technical information, reducing the emissions and increasing the use of renewable energy use [25–28]. Besides, participation in GVCs also means that the firms face differentiated and co-evolving environmental constraints and standards [29,30]. Supplier firms must comply with global standards and environmental certifications, which can cut down their carbon footprints, to avoid being excluded from GVCs [31–34]. Furthermore, participation in GVCs can lead to less raw material consumption and waste by extending product life [35,36].

While some scholars have claimed that participation in GVCs leads to environmental degradation [37], the increase in participation in GVCs can increase energy consumption and CO₂ emissions due to several channels. First, participation in GVCs is associated with greater distance between nodes in the distribution network, and greater distances translate into higher CO₂ emissions of lorries [38,39]. The emergence and expansion of GVCs have increased the importance of logistics and transport (including maritime shipping) [40,41], which are regarded as significant emitters of air pollutants [42]. Second, participation in global value chains further accelerates the growth of the global energy footprint, in which stronger backward linkages can increase the energy use [43]. Third, international carbon leakage and CO₂ emissions traded internationally through GVCs lead to emissions burden-shifting and threaten mitigation targets [44–46].

However, with the extensive literature on the impacts of participation in GVCs on renewable energy consumption and CO₂ emissions, few studies have been done on the causal relationship among participation in GVCs, renewable energy consumption and CO₂ emissions. In addition, only a few studies have simultaneously focused on renewable energy consumption and CO₂ emissions to verify the relationship between them and participation in GVCs. This paper, therefore, aims to fill these gaps by employing a multivariate panel approach, which also includes variables of economic growth and labor force, since economic growth and labor force have significant impacts on these variables.

As fewer empirical results have addressed the issue of the causality between participation in GVCs, renewable energy consumption and CO₂ emissions, we contribute to the literature in three ways. First, we employ the panel vector auto-regression (PVAR) to fill the gap in the empirical literature by examining the causality between participation in GVCs, renewable energy consumption and CO₂ emissions from the global and region levels. Second, to best of our knowledge, this is the first study that applies large samples of 172 countries over the period of 1995–2015 to explore the causality of participation in GVCs, renewable energy consumption and CO₂ emissions. Finally, we put forward several sound policy recommendations designed to improve the environment while enhancing participation in GVCs.

The remainder of the paper is organized in the following manner: Section 2 reviews the literature and is followed by Section 3, which describes the methodology and data. Section 4 introduces the empirical results and provides discussions. Section 5 concludes the main results and puts forward the policy implications in terms of global and regional levels.

2. Literature Review

This section mainly reviews the literatures that have measured the participation in GVCs and examined the relationship among participation in GVCs, energy consumption and CO₂ emissions, as well as the causality between CO₂ emissions and renewable energy consumption.

2.1. Measurement of Participation in GVCs

From the perspective of international production networks, Gereffi [47,48] initially defined GVCs as the configuration of coordinated activities, which contain design, production, marketing, transport, retail and disposal or recycling that are "divided among firms and that have a global geographical scale". As GVCs become the new trend of global production division, many literatures have put forward methods to measure the participation in GVCs. Hummels et al. [49] proposed the concept of "Vertical specialization" (VS), which was defined as the use of imported intermediate goods in producing goods that are exported, indicating that fragmentation, outsourcing and slicing the value chain cause the vertical trading chain to stretch across countries. They then developed the HIY (Hummels, Ishii and Yi) method, which uses the ratio of imported input content of exports to measure the VS. It is understood that the HIY method has some shortcomings, which turn out to be accurate only under two special assumptions that do not hold in general. First, the intensity of the use of imported intermediates inputs is assumed to be the same whether production is for export or production is for domestic final consumption. Second, imported inputs for production should be 100% foreign sourced. Liu et al. [37] claims that the HIY method fails to capture all value-added sources in gross exports in multi-country production networks. For overcoming these limitations, Daudin et al. [50] and Johnson and Noguera [51] improved the HIY method from the value-added trade perspective. Daudin et al. [50] defined value-added trade as the standard trade minus vertical trade and put forward the method for measuring part of VS1, which refers to the value of a country's exports that are used as imported intermediate inputs by other countries of the world to produce exports back to home. Johnson and Noguera [51] defined value-added exports as value-added produced in the country of origin and absorbed in another destination country and proposed value-added to gross export ratio (VAX ratio) for measuring the intensity of production sharing. However, these two methods are more closely related to the factor content discussions in the trade instead of HIY's original concepts [52]. Koopman et al. [53,54] provided the KPWW (Koopman, Powers, Wang and Wei) method to measure country's participation in global production chains by completely decomposing gross exports into various value-added components by source, containing exports of value added, domestic gross exports that return home, foreign value added and other additional double counted terms. The KPWW technique provides an accounting formula quantifying all kinds of double counted items and establishes a precise relationship between value-added measures of trade and official trade statistics, which allow us to gauge the depth and the pattern of one country's participation in GVCs. Moreover, relying on the literature of the KPWW method, some recent studies computed the participation in GVCs by calculating the indirect domestic value added (DVX) share and foreign value added (FVA) share of total exports [55–58].

2.2. Impacts of Participation in GVCs on Environment and Energy Consumption

Participation in GVCs has a variety of impacts on energy consumption and CO₂ emissions. Chiou et al. [59] concluded that working closely with supply chain partners promotes environmentally friendly product innovations, thereby creating advantages (e.g., better product quality) over rivals. Khattak et al. [19] considered that GVCs represent both the drivers of environmental upgrading and the means by which to obtain the knowledge needed to upgrade, particularly for firms in relational networks. Khattak and Stringer [31] examined the impact of GVCs on the environment and claimed that through regular interaction, knowledge is created and transferred across the GVCs, resulting in environmental upgrading. Pathikonda and Farole [60] suggested that GVCs have altered the nature of

global trade, and offer significant opportunities for developing countries to expand exports, access technology and raise productivity.

However, not all impacts of participation in GVCs are equally helpful for energy conservation and environmental protection. Davis and Caldeira [46] pointed out that consumption-based accounting of CO₂ emissions demonstrates the potential for international carbon leakage, and CO₂ emissions traded internationally primarily export from China and other emerging markets to consumers in developed countries. Besides, Spaiser et al. [44] and Meng et al. [61] all considered that most developing countries, such as China, join GVCs by exporting relatively large amounts of final products in their early stage of development, which produce a large amount of CO₂ emissions, which makes the poorer countries bear the natural depletion costs.

2.3. Relationship between CO₂ Emissions and Renewable Energy

A wealth of empirical studies has emerged examining the possible causality between CO₂ emissions and renewable energy, mainly divided into two categories, namely single country analysis and cross-country analysis. Findings of both categories have been mixed. More details about relevant studies are shown in Table 1. Since in this paper we examined the case of countries at global and regional levels, previous research with cross-country data is discussed in detail below. A majority of studies have found evidence for a bidirectional causal relationship between CO₂ emissions and renewable energy (see Salim and Rafiq [62] for six emerging countries, Liu et al. [63] for ASEAN-4 countries, Jebli et al. [64] for 25 OECD countries, Dogan and Seker [65] for 15 EU countries and Dong et al. [66,67] for BRICS countries and 14 Asia–Pacific countries). Some previous studies have shown evidence for a unidirectional causal relationship between CO₂ emissions and renewable energy, such as Al-mulali and Ozturk [68], who examined this for 27 advanced economies, and Balsalobre-Lorente et al. [69], who studied this for 5 EU countries. Furthermore, Bölük and Mert [70], Zoundi [71] and Bhattacharya et al. [72] demonstrates that renewable energy consumption has a significant negative effect on CO₂ emissions, and renewable energy consumption is an efficient tool for protecting the environment.

Table 1. Summary of studies on the relationship between renewable energy (RE) and CO₂ emissions.

Author(s)	Country(ies)	Period	Methodology	Results
Menyah and Wolde-Rufael [73]	US	1960–2007	Granger causality test	There is no causality running from RE to CO ₂ emissions.
Pata [74]	Turkey	1974–2014	ARDL/FMOLS/CCR	RE has no effect on CO ₂ emissions.
Dong et al. [75]	China	1995–2014	Panel FMOLS/DOLS	Natural gas consumption → CO ₂ Natural gas consumption has a significant negative impact on CO ₂ emissions
Ben Jebli and Ben Youssef [76]	Tunisia	1980–2009	ARDL/VECM Granger causality approach	CO ₂ → RE (short run) In the long-run, RE impacts weakly and negatively CO ₂ emissions when using the model with exports, and this impact is statistically insignificant when using the model with imports.
Dong et al. [77]	China	1993–2016	ARDL/VECM Granger causality test	In both the short and long run, nuclear energy and renewable energy play important roles in mitigating CO ₂ emissions
Sinha and Shahbaz [78]	India	1971–2015	ARDL	RE was found to have significant negative impacts on CO ₂ emissions

Table 1. Cont.

Author(s)	Country(ies)	Period	Methodology	Results
Salim and Rafiq [62]	Brazil, China, Philippines, India, Turkey, Indonesia	1980-2006	FMOLS/DOLS/Granger causality methods	RE↔ income; (short run) RE↔ pollutant emission (short run)
Balsalobre-Lorente et al. [69]	EU-5 countries	1985-2016	EKC model	Renewable electricity consumption→CO ₂ ; Renewable electricity consumption improves environmental quality. RE contributes around 1/2 less per unit of energy consumed than fossil energy consumption in terms of GHG emissions in EU countries.
Bölük and Mert [70]	16 EU countries	1990-2008	Panel fixed effect model	Gas consumption↔ CO ₂ RE↔ CO ₂
Dong et al. [66]	BRICS countries ASEAN-4 countries (Malaysia, Thailand, Indonesia, Philippines,)	1985-2016	VECM panel Granger causality tests	RE↔ CO ₂ (long run) The increasing RE decreases CO ₂ emissions.
Liu et al. [63]	27 advanced economies	1990-2012	Panel OLS/FMOLS/DOLS/ VECM Granger causality test	RE→CO ₂ Renewable energy can reduce the CO ₂ emissions.
Al-mulali and Ozturk [68]	14 Asia-Pacific countries	1970-2016	Panel FMOLS/ VECM Granger causality method	Natural gas consumption↔ CO ₂ (short run and long run) Natural gas consumption has a significantly negative effect on CO ₂ emissions.
Dong et al. [77]	25 African countries	1980-2012	DOLS/FMOLS	Renewable energy has a negative effect on CO ₂ emissions, coupled with an increasing long run effect. RE↔ CO ₂
Zoundi [71]	EU-15 countries	1980-2012	DOLS	RE mitigates the CO ₂ emissions.
Dogan and Seker [65]	85 developing and developed countries	1992-2012	System-GMM/FMOLS	Growth of RE has a significant negative impact on CO ₂ emissions.
Bhattacharya et al. [72]	OECD-25 countries	1980-2010	FMOLS/DOLS	RE↔ CO ₂ (long run) RE reduces CO ₂ emissions.
Jebli et al. [64]				

Notes: ARDL (Autoregressive distributed lagged); FMOLS (Fully modified ordinary least square); CCR (Canonical cointegrating regression); DOLS (Dynamic ordinary least square); VECM (Vector Error-Correction Model); EKC (Environmental Kuznets curve); OLS (Ordinary least square); System-GMM (System generalized method of moments)

3. Methodology and Data

3.1. Methodology

In order to comprehensively analyze the endogenous dependent relationship between participation in GVCs, renewable energy consumption and CO₂ emissions, the PVAR model proposed by Love and Zicchino [79] was adopted in this paper. As a powerful analysis tool of macroeconomic dynamics, the PVAR model treats all the variables as endogenous and interdependent and allows for the existence of unobserved individual heterogeneity. The PVAR model is given as

$$Y_{i,t} = \mu_i + \phi(I)Y_{i,t} + \alpha_i + \delta_t + \varepsilon_{i,t}, \quad (1)$$

where $Y_{i,t}$ is the vector of endogenous variables, and μ_i refers to the matrix of country-specific fixed effects; $i = 1, 2, \dots, N$ and $t = 1, 2, \dots, T$ represent the country and time, respectively. $\phi(I)$ is the lag

operator of the matrix polynomial, α_i is the individual specific effects, δ_t is the time effects and ε_{it} is the random error vector.

Based on the selection criteria of AIC (Akaike information criterion), HQIC (Hannan-Quinn information criterion) and BIC (Bayesian information criterion), the optimal lag of this model was confirmed as the first-order PVAR model. Therefore, Equation (1) can also be rewritten as

$$d\ln gdp_{it} = \mu_{1i} + a_{11}d\ln gdp_{it-1} + a_{12}d\ln gvc_{it-1} + a_{13}d\ln rec_{it-1} + a_{14}d\ln co_2_{it-1} + a_{15}d\ln labor_{it-1} + \alpha_{1t} + \delta_{1t} + \varepsilon_{1it}, \quad (2)$$

$$d\ln gvc_{it} = \mu_{2i} + a_{21}d\ln gdp_{it-1} + a_{22}d\ln gvc_{it-1} + a_{23}d\ln rec_{it-1} + a_{24}d\ln co_2_{it-1} + a_{25}d\ln labor_{it-1} + \alpha_{2t} + \delta_{2t} + \varepsilon_{2it}, \quad (3)$$

$$d\ln rec_{it} = \mu_{3i} + a_{31}d\ln gdp_{it-1} + a_{32}d\ln gvc_{it-1} + a_{33}d\ln rec_{it-1} + a_{34}d\ln co_2_{it-1} + a_{35}d\ln labor_{it-1} + \alpha_{3t} + \delta_{3t} + \varepsilon_{3it}, \quad (4)$$

$$d\ln co_2_{it} = \mu_{4i} + a_{41}d\ln gdp_{it-1} + a_{42}d\ln gvc_{it-1} + a_{43}d\ln rec_{it-1} + a_{44}d\ln co_2_{it-1} + a_{45}d\ln labor_{it-1} + \alpha_{4t} + \delta_{4t} + \varepsilon_{4it}, \quad (5)$$

$$d\ln cap_2_{it} = \mu_{5i} + a_{51}d\ln gdp_{it-1} + a_{52}d\ln gvc_{it-1} + a_{53}d\ln rec_{it-1} + a_{54}d\ln co_2_{it-1} + a_{55}d\ln labor_{it-1} + \alpha_{5t} + \delta_{5t} + \varepsilon_{5it}. \quad (6)$$

During the process of estimation of the PVAR model, to eliminate the individual specific effect and fixed time effect, the mean-difference method and forward mean-difference (known as “Helmert procedure”) method were applied. Then, the lagged independent variables were used as the tool variables to estimate the parameters of the model using the system-generalized method of moment.

3.2. Data Selection and Description

Annual data over the period of 1990–2015 for a total of 172 countries (see Appendix A for the countries used in this study) comes from the World Bank Development Indicators databases (WDI) and Euro database [56,80]. Economic growth was proxied using per capita GDP in current US dollars. Renewable energy consumption was represented by the percentage of renewable energy consumption of the total final energy consumption. CO₂ emissions were measured by carbon dioxide emissions (kg) per PPP (purchasing-power-parity) US dollars as a percent of GDP. The percentage of total labor force participation on total population ages 15–64 was used as a proxy for labor force. There are no direct statistics data on the participation in GVCs for all of the countries; thus, the relevant data was obtained by the formula as follows:

$$GVC\ Participation_{it} = \frac{FVA_{it} + DVX_{it}}{Total\ Exports_{it}}, \quad (7)$$

where FVA_{it} is the foreign value added, and DVX_{it} is the indirect domestic value added in country i at time t . FVA share identifies the share of a country’s exports, which consists of inputs produced in other countries, and it captures the extent of GVC participation for downstream firms and industries. It is considered a measure of backward GVC participation. DVX share captures the contribution of the domestic sector of a country to the exports of other countries, thus indicating the extent of GVC participation for relatively upstream sectors. It is considered as a measure of forward GVC participation. The FVA and the DVX components of a single country/area gives us a comprehensive description of GVC participation [57,58,81]. Total exports is measured by the exports of goods and services (BOP) in current US dollars. The larger the ratio, the greater the intensity of involvement of a particular country in GVCs. All the variables in this paper were converted to natural logarithm to eliminate heteroscedasticity and increase the reliability and consistency of the results.

4. Empirical Results and Discussion

This section discusses the main results of the estimation of the system-generalized method of moment (System-GMM) PVAR model and presents the results of variance decomposition and impulse response function analysis.

4.1. System-GMM PVAR Causality Results

For the global level, the causal relationship between participation in GVCs, renewable energy consumption and CO₂ emissions is shown in Panel A of Table 2. The results show that the participation in GVCs negatively causes renewable energy consumption at the 1% level of significance, which indicates that renewable energy consumption decreases 0.0637% when participation in GVCs increases by 1%. Additionally, participation in GVCs positively causes CO₂ emissions, which implies that a 1% increase in participation in GVCs increases the CO₂ emissions by 0.0313%. This result supports the finding of De Vries and Ferrarini [82], who found that a substantial share of CO₂ emissions growth in emerging countries accounted for increasing participation in GVCs, and contradicts the findings of Sun et al. [83], who found that the promotion of participation in GVCs could reduce CO₂ emissions significantly in developing countries compared with those in developed countries. Panel A of Table 2 also shows that renewable energy consumption does not cause the participation in GVCs and the CO₂ emissions. CO₂ emissions cause the participation in GVCs and the relationship is negative at the 10% level of significance. This suggests that a 1% increase in CO₂ emissions will decrease the participation in GVCs by 0.0620%. Additionally, CO₂ emissions do not cause renewable energy consumption. This evidence is inconsistent with the finding of Bhattacharya et al. [72] who found that the growth of renewable energy consumption had a significant negative effect on CO₂ emissions in 85 developed and developing countries.

Table 2. Estimated causality results from the dynamic panel System-GMM.

Dependent Variables					
Independent variables		Panel A: Global			
		dlngdp	dlngvcs	dlnrec	dlncO ₂
L.dlngdp			−0.0854 ** (−2.39)	−0.0598 *** (−3.40)	−0.0120 (−0.55)
L.dlngvcs	0.0368 ** (2.15)			−0.0637 *** (−3.99)	0.0313 * (1.85)
L.dlnrec	−0.0204 (−1.49)	0.00723 (0.50)		−0.0107 (−0.81)	−0.00288 (−1.57)
L.dlncO ₂	−0.0796 *** (−2.67)	−0.0620 * (−1.78)	0.00823 (0.37)		−0.00259 * (−1.86)
L.dlnlabor	−0.653 (−1.12)	−0.133 (−0.57)	0.0264 (0.05)	0.821 ** (1.98)	
Independent variables		Panel B: Asia-Pacific			
		A_dlngdp	A_dlngvcs	A_dlnrec	A_dlnlabor
A_L.dlngdp			−0.194 ** (−1.99)	−0.0837 ** (−2.37)	0.0449 (1.04)
A_L.dlngvcs	0.0373 ** (2.00)			−0.0507 *** (−5.65)	0.0333 *** (2.64)
A_L.dlnrec	−0.103 ** (−2.46)	−0.0749 (−0.97)		−0.0272 (−0.68)	0.000979 (0.38)
A_L.dlncO ₂	−0.131 *** (−3.16)	−0.0861 (−0.84)	0.0487 (1.08)		−0.00356 (−1.32)
A_L.dlnlabor	−0.980 * (−1.89)	−1.075 (−1.11)	1.271 ** (2.54)	−0.563 (−1.05)	

Notes: t-statistics are given in parentheses. *, **, *** show significance at the 10%, 5% and 1% levels, respectively.

Panel B of Table 2 shows the causal relationship between participation in GVCs, renewable energy consumption and CO₂ emissions for the Asia–Pacific region. First, the results show that the participation in GVCs negatively causes renewable energy consumption and the relationship is significant at the 1% level. This suggests that a 1% increase in participation in GVCs will decrease renewable energy consumption by 0.0507% in Asia–Pacific region. In addition, the results also show that participation in GVCs positively causes CO₂ emissions, and the relationship is significant at the 1% level. This indicates that 1% increase in participation in GVCs will increase CO₂ emissions by 0.0333% in the Asia–Pacific region. Besides, renewable energy consumption does not cause the participation in GVCs and CO₂ emissions. This implies that there are not causal effects of renewable energy consumption on participation in GVCs and CO₂ emissions. Furthermore, the results also show that CO₂ emissions do not cause the participation in GVCs. This suggests that an increase in CO₂ emissions does not influence the participation in GVCs of countries in the Asia–Pacific region. CO₂ emissions also do not cause renewable energy consumption. This empirical result contradicts the finding of Dong et al. [66] and Liu et al. [63] who proposed that renewable energy consumption has a negative impact on CO₂ emissions, and that there is a feedback causalities between CO₂ emissions and renewable energy consumption in four selected countries of the Association of Southeast Asian Nations.

Panel A of Table 3 presents the causality between participation in GVCs, renewable energy consumption and CO₂ emissions in the Caribbean–Latin America. The results show that the participation in GVCs causes renewable energy consumption and the relationship is negative at the level of 10% significance. This indicates that renewable energy consumption will decrease by 0.0698% when participation in GVCs increases by one percent. However, participation in GVCs does not cause CO₂ emissions. From Panel A of Table 3, renewable energy consumption does not cause participation in GVCs. This implies that there is no causal effect of renewable energy consumption on participation in GVCs in Caribbean–Latin America. Renewable energy consumption also does not cause the CO₂ emissions. In addition, Panel A of Table 3 also shows that CO₂ emissions do not cause the participation in GVCs and renewable energy consumption. This suggests that CO₂ emissions do not have casual effects on participation in GVCs and renewable energy consumption.

Panel B of Table 3 presents the causal relationship between participation in GVCs, renewable energy consumption and CO₂ emissions in the Middle East and North America (MENA). The estimated results show that the participation in GVCs does not cause renewable energy consumption and CO₂ emissions. Renewable energy consumption causes the participation in GVCs and the relationship is positive at the level of 1% significance. This indicates that one percent increase in renewable energy consumption would increase the participation in GVCs of countries in MENA by 0.0551%. However, renewable energy consumption does not cause CO₂ emissions. Panel B of Table 3 also shows that CO₂ emissions do not cause participation in GVCs and renewable energy consumption. Thus, CO₂ emissions have no causal effects on participation in GVCs and renewable energy consumption in MENA. This empirical evidence collaborates the findings of Charfeddine and Kahia [4] who found that renewable energy consumption has a slight influence on CO₂ emissions in MENA.

Panel C of Table 3 describes the causal relationship between participation in GVCs, renewable energy consumption and CO₂ emissions in sub-Saharan Africa. The empirical results show that the participation in GVCs does not cause renewable energy consumption and CO₂ emissions. That suggests that an increase in participation in GVCs would not affect renewable energy consumption and the CO₂ emissions in sub-Saharan Africa. From Panel C of Table 3, renewable energy consumption does not cause the participation in GVCs and CO₂ emissions, which implies that renewable energy consumption has no causal effects on participation in GVCs and CO₂ emissions in sub-Saharan Africa. In addition, the result also shows that CO₂ emissions cause the participation in GVCs and the relationship is negative at the level of 5%. Thus, one percent increase in CO₂ emissions will decrease the participation in GVCs by 0.139%. On the contrary, CO₂ emissions do not cause renewable energy consumption, which implies that an increase in CO₂ emissions would not influence renewable energy consumption.

This result is inconsistent with the finding of Zoundi [71] who found that renewable energy had a negative effect on CO₂ emissions in 25 selected African countries.

Table 3. Estimated causality results from the dynamic panel System-GMM.

Dependent Variables					
Panel A: Caribbean–Latin America					
Independent variables	C_dlnGdp	C_dlnGvcs	C_dlnrec	C_dlnco ₂	C_dlnlabor
C_L.dlnGdp		−0.0822 * (−1.90)	−0.0441 * (−1.78)	0.0509 (1.24)	0.00435 (0.87)
C_L.dlnGvcs	0.0349 (0.80)		−0.0698 * (−1.88)	−0.00824 (−0.21)	0.000585 (0.15)
C_L.dlnrec	0.0244 (0.64)	−0.0406 (−1.18)		−0.00827 (−0.19)	−0.000917 (−0.28)
C_L.dlnco ₂	−0.0922 *** (−3.39)	−0.0439 (−1.15)	0.0431 (1.38)		−0.0108 *** (−2.85)
C_L.dlnlabor	−1.226 ** (−2.08)	0.178 (0.70)	−0.458 (−1.62)	1.634 ** (2.44)	
Panel B: Middle East North Africa (MENA)					
Independent variables	M_dlnGdp	M_dlnGvcs	M_dlnrec	M_dlnco ₂	M_dlnlabor
M_L.dlnGdp		−0.439 *** (−7.23)	−0.0206 (−0.14)	−0.191 *** (−2.85)	−0.00603 (−1.13)
M_L.dlnGvcs	0.0609 (1.41)		−0.133 (−1.00)	0.00221 (0.04)	−0.00168 (−0.35)
M_L.dlnrec	0.0113 (0.50)	0.0551 *** (2.64)		0.00458 (0.12)	0.00272 (1.57)
M_L.dlnco ₂	−0.273 *** (−5.29)	0.0412 (0.66)	0.250 (1.59)		0.00241 (0.46)
M_L.dlnlabor	−0.268 (−0.35)	−2.384 *** (−2.83)	−5.742 *** (−2.66)	−3.773 *** (−3.46)	
Panel C: Sub-Saharan Africa					
Independent variables	S_dlnGdp	S_dlnGvcs	S_dlnrec	S_dlnco ₂	S_dlnlabor
S_L.dlnGdp		0.00277 (0.05)	−0.0114 (−1.28)	−0.0690 ** (−1.99)	0.000317 (0.26)
S_L.dlnGvcs	0.00520 (0.20)		0.00473 (0.76)	−0.0147 (−0.52)	0.0000974 (0.12)
S_L.dlnrec	0.0628 (0.61)	−0.0812 (−0.48)		0.000732 (0.01)	0.00935 (1.50)
S_L.dlnco ₂	0.0355 (0.80)	−0.139 ** (−2.48)	0.00720 (0.52)		0.000487 (0.45)
S_L.dlnlabor	1.556 (1.63)	10.82 *** (2.97)	1.266 *** (3.02)	−5.069 *** (−2.64)	

Notes: t-statistics are given in parentheses. *, **, *** show significance at the 10%, 5% and 1% levels, respectively.

4.2. Variance Decomposition

In order to specify the degree of mutual dynamic effects between variables, in this section we use the forecast error variance decomposition method of the PVAR model to present the first 10 years of variance decomposition (see Appendix B for the variance decomposition). However, before the analysis of forecast error variance decomposition and impulse response functions, the stability of the PVAR model must be test. Referring to the studies of Hamilton [84], Lütkepohl [85] and Abrigo and Love [86], the model is stable only when the modulus of all eigenvalues of the adjoint matrix is less than one. The stability graphs (see Appendix C for the stability graphs) show that the characteristic roots are all less than one and all fall within the unit circle at both global and regional levels, which indicates that the PVAR models in this paper are all stable.

For the global level, only 0.020% of the forecast error variance of participation in GVCs after ten periods can be explained by shocks in renewable energy consumption, while 0.174% of the forecast error

variance of participation in GVCs is explained by shocks in CO₂ emissions. After ten years forecast, around 0.482% of the forecast error variance of renewable energy consumption can be explained by disturbances in participation in GVCs, while around 0.006% can be explained by shocks in CO₂ emissions. Shocks in participation in GVCs appear to have minimal effect (only 0.262%) in forecasting CO₂ emissions, while shocks in renewable energy consumption appear to have a more important impact (3.187%) in forecasting CO₂ emissions.

In the Asia–Pacific region, the variance contribution of renewable energy consumption and CO₂ emissions to participation in GVC shocks are 0.028% and 0.135%. A shock to participation in GVCs accounts for 2.644% of the variance in energy consumption, and it accounts for 0.262% of the variance in CO₂ emissions. This result indicates that renewable energy consumption and CO₂ emissions appear to have insignificant or minor effects on participation in GVCs, while the participation in GVCs seems to have some impact in renewable energy consumption.

In the Caribbean–Latin America region, around 0.094% of the variance of participation in GVCs is explained by shocks in renewable energy consumption, and around 0.250% can be explained by shocks in CO₂ emissions; 0.835% of the variance of renewable energy consumption is attributed to shocks in participation in GVCs, and 0.194% of the variance of renewable energy consumption is attributed to shocks in CO₂ emissions. The variance contribution of participation in GVCs and renewable energy consumption and to CO₂ emission shocks are 1.138% and 5.881%, respectively.

In the MENA region, a disturbance to renewable energy consumption accounts for only 0.653% of forecast error variance in participation in GVCs, and a disturbance to CO₂ emissions accounts for only 0.730% of the variance in participation in GVCs. This means that renewable energy, renewable consumption and CO₂ emissions appear to have insignificant or minor effects on participation in GVCs in the short and long run. In contrast, 3.181% of variance of renewable energy consumption after ten periods can be explained by the disturbances in participation in GVCs.

In the sub-Saharan Africa region, a shock to renewable energy consumption accounts for 0.169% of the forecast error variance in participation in GVCs, and a shock to CO₂ emissions accounts for 1.164% of the variance in participation in GVCs. Additionally, around 0.976% of the variance of renewable energy consumption is explained by disturbances in participation in GVCs and 0.016% from disturbances in CO₂ emissions, while the variance contribution of participation in GVCs and renewable energy consumption and to CO₂ emissions' shocks are 1.649% and 14.783%.

4.3. Impulse-Response Function (IRF) Analysis

This section portrays the results of impulse response functions (IRFs) of economic growth, participation in GVCs, renewable energy consumption, CO₂ emissions and labor force, and we focus on the three variables of participation in GVCs, renewable energy consumption and CO₂ emissions using the Monte Carlo method to simulate the process 200 times. The IRFs proposed by Love and Zicchino [79] characterize the impact of adding a standard deviation to the error term on the current and future values of other endogenous variables while holding other variables unchanged. However, due to the uncertainty of variance–covariance of errors orthogonality, it is important to ensure the orthogonalization of shocks based on the Cholesky decomposition of variance–covariance matrix residues [87]. Thus, it is necessary to determine the order of variables on the basis of their endogeneity. Sims [87] considered that more exogenous and affect the following variables simultaneously or even with a lag should come out earlier; nevertheless, the variables coming out later are more endogenous and affect foregoing variables only with a lag. According to this and preceding studies, we ensured the order of variables in this paper as follows: economic growth, participation in GVCs, renewable energy consumption, CO₂ emissions and labor force. Economic growth may affect participation in GVCs, renewable energy consumption and CO₂ emissions contemporaneously or even with a lag, whereas renewable energy consumption and CO₂ emissions may affect the economic growth and participation in GVCs only with a lag.

Figure 1 shows the global impulse response functions, which reports that the responses of participation in GVCs to one standard deviation shock of renewable energy consumption is positive, which initially increases and then decreases and stabilizes in the long run from year 2 to 10. More precisely, the maximum positive effect occurs in the first year with the value equal to about 0.002. On the contrary, a shock in CO₂ emissions will decrease participation in GVCs firstly and then increase it and eventually stabilize. The maximum negative effect also occurs in the first year. The responses of CO₂ emissions as the result of one standard deviation shock to participation in GVCs initially increase and then decrease and stabilize in the long run, while the responses of renewable energy consumption as the result of one standard deviation shock to participation in GVCs initially decrease and then increase and stabilize in the long run from year 2 to 10.

Figure 1. Global impulse response functions.

In Figure 2, participation in GVCs will have a negative response to a standard deviation shock in renewable energy consumption and CO₂ emissions in the Asia–Pacific region in period 0 and 1 but the response is equal to zero from 2 to 10. More precisely, the maximum negative effects all occur in the first year with the value equal to about 0.005 and 0.01, respectively. This is consistent with the PVAR estimation that the contributions of renewable energy consumption and CO₂ emissions to participation in GVCs are very weak in Asia–Pacific. In addition, the response of CO₂ emissions to one standard deviation shock in participation in GVCs is positive and it is strongly positive in the first year. The response of renewable energy consumption to one standard deviation shock in participation in GVCs is positive at 0 and negative in the first year and stabilizes in the long run from 2 to 10.

Figure 3 presents the Caribbean–Latin America impulse response functions, in which a positive shock to renewable energy consumption has a negative effect on the participation in GVCs at the first year and then positive in the second year, and the effects of shocks entirely die after three years. The maximum effect occurs in the first year. Similarly, the impact of a one standard deviation shock in CO₂ emissions on participation in GVCs is negative in the first year and positive in the second. Furthermore, the maximum impact also appears in the first year. The response of renewable energy consumption to a one standard deviation shock of participation in GVCs initially decreases and then increases and stabilizes in the long run from 3 to 10. The response of CO₂ emissions to one standard

deviation shock in the participation in GVCs is instantaneously negative but positive in the first year and equal to 0 from year 2 to 10.

Figure 2. Asia-Pacific impulse response function.

Figure 3. Caribbean-Latin America impulse response function.

The MENA impulse response functions are shown in the Figure 4. Figure 4 shows that the response of the participation in GVCs to a one standard deviation shock in the growth of renewable energy consumption initially increases and then decreases and later increases and equals zero from year 3 to 10. The response of participation in GVCs to a one standard deviation shock of CO₂ emissions is positive in the first two years and then negative in the third year and later equal to 0 from year 5 to 10. Additionally, the responses of renewable energy consumption to a one standard deviation shock in participation in GVCs are instantaneously positive but negative at the first year and equal to 0 from year 3 to 10. The response of CO₂ emissions to a one standard deviation shock in participation in GVCs is positive in the first year and weakly negative in the second year, and the effect dies after a weakly positive response in the third year.

Figure 4. MENA impulse response functions.

From the sub-Saharan Africa impulse response functions in Figure 5, the reaction of participation in GVCs to one standard shock in renewable energy consumption is positive for the whole period (up to ten years), and the maximum positive impact occurs in the first year with the value approximately equal to 0.01. The reaction of participation in GVCs to a one standard deviation shock in CO₂ emissions is strongly negative in the first year with a value of about 0.02. The impact dies after three years after a weakly positive response in the second year. The response of CO₂ emissions to one standard deviation shock in participation in GVCs is negative from year 0 to 1 and equal to zero from year 1 to 10. The reaction of renewable energy consumption to a one standard deviation shock in participation in GVCs is positive for the whole period and then stabilizes from the first year.

Figure 5. Sub-Saharan Africa impulse response functions.

4.4. Robustness Check

In order to check the robustness of the previous analysis, we conducted the panel Granger causality test. The results from the test revealed the same direction of causal relationships between participation in GVCs, renewable energy consumption and CO₂ emissions.

From Tables 4 and 5 the participation in GVCs granger causes renewable energy consumption at the global level and in the Asia–Pacific, Caribbean–Latin America region, whereas all were without feedback. Renewable energy consumption causes the participation in GVCs in MENA region without feedback inversely. There is a bidirectional causality between participation in GVCs and CO₂ emissions at the global level. However, there is only a unidirectional causal relationship running from CO₂ emissions to participation in GVCs in selected sub-Saharan Africa countries and from participation in GVCs to CO₂ emissions in Asia–Pacific region. Additionally, there is no causality between renewable energy consumption and CO₂ emissions at global and regional levels.

Table 4. Panel Granger causality tests.

Dependent Variables					
Independent variables	dlnngdp	Global			
		dlnngvcs	dlnrec	dlnco2	dlnlabor
L.dlnngdp		5.725 ** (0.017)	11.532 *** (0.001)	0.299 (0.585)	0.060 (0.806) **
L.dlnngvcs	4.602 ** (0.032)		15.902 *** (0.000)	3.418 * (0.064)	0.041 (0.839)
L.dlnrec	2.216 (0.137)	0.247 (0.619)		0.659 (0.417)	2.453 (0.117)
L.dlnco2	7.111 *** (0.008)	3.163 * (0.075)	0.137 (0.711)		3.462 * (0.063)
L.dlnlabor	1.259 (0.262)	0.325 (0.569)	0.003 (0.959)	3.904 ** (0.048)	

Table 4. Cont.

Dependent Variables					
Asia-Pacific					
Independent variables	A_dlngdp	A_dlngvcs	A_dlnrec	A_dlnco ₂	A_dlnlabor
L.A_dlngdp		3.949 ** (0.047)	5.634 ** (0.018)	1.074 (0.300)	0.226 (0.634)
L.A_dlngvcs	3.989 ** (0.046)		31.973 *** (0.000)	6.962 *** (0.008)	1.015 (0.314)
L.A_dlnrec	6.030 ** (0.014)	0.933 (0.334)		0.461 (0.497)	0.144 (0.704)
L.A_dlnco ₂	10.004 *** (0.002)	0.712 (0.399)	1.167 (0.280)		1.730 (0.188)
L.A_dlnlabor	3.566 * (0.059)	1.240 (0.265)	6.432 ** (0.011)	1.111 (0.292)	
Caribbean-Latin America					
Independent variables	C_dlngdp	C_dlngvcs	C_dlnrec	C_dlnco ₂	C_dlnlabor
L.C_dlngdp		3.597 * (0.058)	3.179 * (0.075)	1.535 (0.215)	0.764 (0.382)
L.C_dlngvcs	0.647 (0.421)		3.544 * (0.060)	0.043 (0.836)	0.023 (0.879)
L.C_dlnrec	0.405 (0.524)	1.403 (0.236)		0.037 (0.847)	0.077 (0.781)
L.C_dlnco ₂	11.509 *** (0.001)	1.325 (0.250)	1.896 (0.168)		8.151 *** (0.004)
L.C_dlnlabor	4.313 ** (0.038)	0.484 (0.487)	2.629 (0.105)	5.943 ** (0.015)	

Notes: Probability values are given in parentheses. *, **, *** show significance at the 10%, 5% and 1% levels, respectively.

Table 5. Panel Granger causality tests.

Dependent Variables					
MENA					
Independent variables	M_dlngdp	M_dlngvcs	M_dlnrec	M_dlnco ₂	M_dlnlabor
L.M_dlngdp		52.334 *** (0.000)	0.019 (0.892)	8.123 *** (0.004)	1.278 (0.258)
L.M_dlngvcs	1.980 (0.159)		1.000 (0.317)	0.001 (0.972)	0.120 (0.729)
L.M_dlnrec	0.253 (0.615)	6.985 *** (0.008)		0.014 (0.905)	2.449 (0.118)
L.M_dlnco ₂	27.992 *** (0.000)	0.433 (0.510)	2.529 (0.112)		0.212 (0.645)
L.M_dlnlabor	0.120 (0.729)	8.010 *** (0.005)	7.068 *** (0.008)	11.945 *** (0.001)	
Sub-Saharan Africa					
Independent variables	S_dlngdp	S_dlngvcs	S_dlnrec	S_dlnco ₂	S_dlnlabor
L.S_dlngdp		0.002 (0.960)	1.640 (0.200)	3.950 ** (0.047)	0.069 (0.792)
L.S_dlngvcs	0.040 (0.842)		0.573 (0.449)	0.268 (0.605)	0.015 (0.904)
L.S_dlnrec	0.373 (0.541)	0.230 (0.631)		0.000 (0.996)	2.263 (0.132)
L.S_dlnco ₂	0.638 (0.424)	6.130 ** (0.013)	0.267 (0.605)		0.207 (0.649)
L.S_dlnlabor	2.660 (0.103)	8.825 *** (0.003)	9.147 *** (0.002)	6.993 *** (0.008)	

Notes: Probability values are given in parentheses. *, **, *** show significance at the 10%, 5% and 1% levels, respectively.

5. Conclusions

Based on the previous studies about participation in GVCs, renewable energy consumption and CO₂ emissions, this paper firstly employs the PVAR model with the System-GMM approach to examine the causality between participation in GVCs, renewable energy consumption and CO₂ emissions, while taking into account the variables of economic growth and labor force using the panel data of 172 countries throughout 1990–2015.

The main conclusions of the PVAR analysis can be summarized in three important points. Firstly, except for sub-Saharan Africa, there is a unidirectional causality between participation in GVCs and renewable energy consumption. Participation in GVCs negatively causes renewable energy consumption at the global level and in the Asia–Pacific and Caribbean–Latin America regions, which indicates that participation in GVCs aiming at accelerating economic development will not be conducive to the development and utilization of renewable energy. Renewable energy consumption positively causes participation in GVCs in MENA, which suggests that renewable energy policies aiming to increasing the use of renewable energy and reducing traditional energy use will promote the participation in the international division of labor. There is no causality between participation in GVCs and renewable energy consumption in sub-Saharan Africa.

Secondly, we also found that the causality between participation in GVCs and CO₂ emissions has different aspects in global and regional levels. There is a feedback causal relationship between participation in GVCs and CO₂ emissions at the global level. The environmental policies aimed at reducing CO₂ emissions will increase the participation in GVCs while GVCs policies, such as industrial innovation policies, will cause environmental degradation. There is a unidirectional causality running from participation in GVCs to CO₂ emissions, and participation in GVCs positively causes CO₂ emissions in the Asia–Pacific region. This indicates that the GVC policies will lead to environmental damage. There is a unidirectional causality running from CO₂ emissions to participation in GVCs, and CO₂ emissions negatively cause participation in GVCs in sub-Saharan Africa. This suggests that the environmental policies are beneficial for sub-Saharan African countries to participate in GVCs. However, there is no causality between participation in GVCs and CO₂ emissions in Caribbean–Latin America and MENA.

Thirdly, unlike many previous studies, we also found that there is no causal relationship between renewable energy consumption and CO₂ emissions both at global and regional levels. This implies that existing renewable energy policies fail to protect the environment, and environmental policies aimed at reducing CO₂ emissions also have no effect on the development and use of renewable energy.

From the forecast error variance decomposition, renewable energy consumption and CO₂ emissions appear to have a slight effect on participation in GVCs in the short and long run at the global and regional levels. Shocks in participation in GVCs also appear to have minimal effects in forecasting CO₂ emissions and renewable energy consumption. In addition, the impulse response results show that with the exception of the MENA region, the overall effect of a one standard deviation shock of CO₂ emissions on participation in GVCs is negative, while except for Asia–Pacific and Caribbean–Latin America region, the cumulative effect of a one standard deviation shock of renewable energy consumption on participation in GVCs is positive. For the global level and the Asia–Pacific and MENA regions, the cumulative effect of a one standard deviation shock of participation in GVCs on CO₂ emissions is positive, but for the global level and Asia–Pacific and Caribbean–Latin America regions, the overall effect of a one standard deviation shock of participation in GVCs on renewable energy consumption is negative.

Overall, this study demonstrates that there are environmental costs related to GVC policies aiming to participate in the global division of labor. Hence, the implementation of GVCs policies will be a challenge to environment protection. On the contrary, renewable energy policies and environmental protection policies do not have adverse effects on participation in GVCs. To some extent, environmental policies seeking to mitigate CO₂ emissions and to increase the use of renewable energy facilitate participation in GVCs. Thus, this investigation argues that reasonable environmental,

energy and industrial policies should be developed to promote participation in GVCs while protecting the environment. Some of the policy recommendations are as follows.

Firstly, industrial policies aiming to promote participation in GVCs should be executed with care and should consider technological innovation to reduce traditional energy consumption and to accelerate renewable energy consumption. On the one hand, firms should be required to produce intermediate and final products complying with global standards and environmental certifications. On the other hand, since participation in GVCs is an important way to obtain technical information, governments should encourage firms to learn and absorb the environmental knowledge and technology in the process of participation in GVCs.

Besides, given that effective environmental governance can accelerate global competition through GVCs, environmental conservation policies targeting reduction of CO₂ emissions and increasing the use of renewable energy should be exercised rigorously. Sound environmental protection laws and regulations need to be developed to strengthen environmental management. At the same time, governments should provide financial support for environmental projects and facilities and offer tax breaks for companies, projects or products that are in line with environmental standards.

Furthermore, considering that renewable energy consumption does not play a role in alleviating CO₂ emissions currently, governments should continue the process of energy production and consumption reforms by setting mandatory renewable energy targets and development plans. Additionally, governments should raise funds through multiple channels to support renewable energy development to break through the constraints of inadequate inputs of funds.

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Appendix A

Asia–Pacific (29)

Australia; Bangladesh; Bhutan; Brunei Darussalam; Cambodia; China; Fiji; Hong Kong SAR, China; India; Indonesia; Japan; Korea, Dem. People's Rep.; Korea, Rep.; Lao PDR; Malaysia; Maldives; Mongolia; Myanmar; Nepal; New Zealand; Pakistan; Papua New Guinea; Samoa; Philippines; Singapore; Sri Lanka; Thailand; Vanuatu; Vietnam.

Middle East and North Africa (17)

Algeria; Bahrain; Egypt, Arab Rep.; Iran, Islamic Rep.; Iraq; Israel; Jordan; Kuwait; Lebanon; Malta; Morocco; Oman; Qatar; Saudi Arabia; Syrian Arab Republic; Tunisia; United Arab Emirates.

Caribbean–Latin America (27)

Antigua and Barbuda; Argentina; Bahamas; Barbados; Belize; Bolivia; Brazil; Chile; Colombia; Costa Rica; Cuba; Dominican Republic; Ecuador; El Salvador; Guatemala; Haiti; Honduras; Jamaica; Mexico; Nicaragua; Panama; Paraguay; Peru; Suriname; Trinidad and Tobago; Uruguay; Venezuela, RB.

Sub-Saharan Africa (38)

Angola; Botswana; Burundi; Cabo Verde; Cameroon; Central African Republic; Chad; Congo, Dem. Rep.; Cote d'Ivoire; Djibouti; Eswatini; Gabon; Gambia; Ghana; Kenya; Lesotho; Liberia; Madagascar; Malawi; Mali; Mauritania; Mauritius; Mozambique; Namibia; Niger; Nigeria; Rwanda; Sao Tome and Principe; Senegal; Seychelles; Sierra Leone; Somalia; South Africa; South Sudan; Tanzania; Togo; Uganda; Zambia.

Global (172)

Afghanistan; Albania; Andorra; Armenia; Aruba; Austria; Azerbaijan; Belgium; Bermuda; Bosnia and Herzegovina; British Virgin Islands; Bulgaria; Canada; Cayman Islands; Croatia; Cyprus; Czech Republic; Denmark; Estonia; Finland; France; French Polynesia; Georgia; Germany; Greece; Greenland; Hungary; Iceland; Ireland; Italy; Kazakhstan; Kyrgyz Republic; Latvia; Liechtenstein; Lithuania; Luxembourg; Macao SAR, China; Monaco; Montenegro; Netherlands; New Caledonia; North Macedonia; Norway; Poland; Portugal; Romania; Russian Federation; San Marino; Slovak Republic; Slovenia; Spain; Sweden; Switzerland; Tajikistan; Turkey; Turkmenistan; Ukraine; United Kingdom; United States; Uzbekistan; West Bank and Gaza; Asia–Pacific countries; Middle East and North Africa countries; Caribbean–Latin America countries; sub-Saharan Africa countries.

Appendix B

Table A1. Global variance decomposition.

Forecast Horizon	Impulse Variable				
	dlnGdp	dlnGvcs	dlnrec	dlnco ₂	dlnlabor
dlnGdp					
1	1	0	0	0	0
5	0.9893361	0.0025948	0.0001838	0.0045337	0.0033517
10	0.989336	0.0025948	0.0001838	0.0045337	0.0033517
dlnGvcs					
1	0.032321	0.967679	0	0	0
5	0.034139	0.963852	0.0002032	0.0017404	0.0000654
10	0.034139	0.963852	0.0002032	0.0017404	0.0000654
dlnrec					
1	0.0031008	0.0006187	0.9962805	0	0
5	0.0044322	0.0048201	0.9906688	0.0000601	0.0000188
10	0.0044322	0.0048201	0.9906688	0.0000601	0.0000188
dlnco ₂					
1	0.0098183	0.0005127	0.0324005	0.9572686	0
5	0.0098265	0.0026184	0.0318704	0.95025	0.0054347
10	0.0098265	0.0026184	0.0318704	0.95025	0.0054347
dlnlabor					
1	0.0004509	0.0007894	0.0000475	0.0022884	0.9964238
5	0.000443	0.0008376	0.0015875	0.0035019	0.9936301
10	0.000443	0.0008376	0.0015875	0.0035019	0.9936301

Table A2. Asia-Pacific variance decomposition.

Forecast Horizon	Impulse Variable				
	A_dlnGdp	A_dlnGvcs	A_dlnrec	A_dlnco ₂	A_dlnlabor
A_dlnGdp					
1	1	0	0	0	0
5	0.9685149	0.005721	0.0026714	0.0165631	0.0065297
10	0.9685128	0.005721	0.0026715	0.0165631	0.0065316
A_dlnGvcs					
1	0.0009344	0.9990656	0	0	0
5	0.0055822	0.9917179	0.0002837	0.0013485	0.0010677
10	0.0055822	0.9917179	0.0002837	0.0013486	0.0010677
A_dlnrec					
1	0.0159327	0.0076805	0.9763867	0	0
5	0.0294922	0.0264432	0.9259253	0.0034593	0.0146801
10	0.0294925	0.0264431	0.9259233	0.0034593	0.0146817
A_dlnco ₂					
1	0.0098183	0.0005127	0.0324005	0.9572686	0
5	0.0098265	0.0026184	0.0318704	0.95025	0.0054347
10	0.0098265	0.0026184	0.0318704	0.95025	0.0054347
A_dlnlabor					
1	0.0159275	0.0060485	0.0007268	0.0000284	0.9772688
5	0.0993128	0.0071406	0.0015168	0.0039228	0.8881068
10	0.0993129	0.0071406	0.0015169	0.0039229	0.8881066

Table A3. Caribbean–Latin America variance decomposition.

Forecast Horizon	Impulse Variable				
	C_dlngdp	C_dlngvcs	C_dlnrec	C_dlnco ₂	C_dlnlabor
C_dlngdp					
1	1	0	0	0	0
5	0.9756536	0.0013499	0.0015821	0.0058516	0.0155626
10	0.9756536	0.0013499	0.0015821	0.0058516	0.0155626
C_dlngvcs					
1	0.015681	0.984319	0	0	0
5	0.0186041	0.9775121	0.0009434	0.0025021	0.0004382
10	0.0186041	0.9775121	0.0009434	0.0025022	0.0004383
C_dlnrec					
1	0.0035186	0.0022672	0.9942143	0	0
5	0.0047287	0.0083537	0.9818271	0.0019437	0.0031469
10	0.0047287	0.0083537	0.9818271	0.0019437	0.0031469
C_dlnco ₂					
1	0.0094439	0.0119188	0.0614551	0.9171823	0
5	0.0134228	0.0113824	0.0588137	0.8834816	0.0328995
10	0.0134228	0.0113824	0.0588137	0.8834816	0.0328995
C_dlnlabor					
1	0.0000293	0.0007297	0.0007281	0.0024042	0.9961088
5	0.0027462	0.0008535	0.0008787	0.0104012	0.9851205
10	0.0027462	0.0008535	0.0008787	0.0104012	0.9851205

Table A4. MENA variance decomposition.

Forecast Horizon	Impulse Variable				
	M_dlngdp	M_dlngvcs	M_dlnrec	M_dlnco ₂	M_dlnlabor
M_dlngdp					
1	1	0	0	0	0
5	0.9327897	0.0047878	0.0006104	0.0572782	0.0045341
10	0.9327785	0.0047883	0.0006116	0.0572853	0.0045363
M_dlngvcs					
1	0.0804942	0.9195058	0	0	0
5	0.1397596	0.8098994	0.0065298	0.0072645	0.0365466
10	0.1397675	0.8098409	0.0065295	0.0072955	0.0365665
M_dlnrec					
1	0.000492	0.0324807	0.9670274	0	0
5	0.0007078	0.0318093	0.9002398	0.0067105	0.0605325
10	0.0007092	0.0318093	0.900238	0.0067106	0.0605329
M_dlnco ₂					
1	0.0188852	0.000034	0.0025907	0.9784901	0
5	0.0342636	0.0023953	0.0067691	0.8374305	0.1191416
10	0.0342653	0.0023968	0.006769	0.8374217	0.1191472
M_dlnlabor					
1	4.71e−06	0.0124864	0.0337619	0.0111924	0.9425546
5	0.0038516	0.0126314	0.0406818	0.0126392	0.9301959
10	0.003854	0.0126313	0.0406818	0.0126393	0.9301935

Table A5. Sub-Saharan Africa variance decomposition.

Forecast Horizon	Impulse Variable				
	S_dlngdp	S_dlngvcs	S_dlnrec	S_dlnco ₂	S_dlnlabor
S_dlngdp					
1	1	0	0	0	0
5	0.9939538	0.0000101	0.0001115	0.0008216	0.005103
10	0.9939475	0.0000101	0.0001117	0.0008216	0.0051092
S_dlngvcs					
1	0.0570274	0.9429726	0	0	0
5	0.0493443	0.8210868	0.001686	0.011641	0.116242
10	0.0493382	0.8209726	0.0016901	0.0116396	0.1163596
S_dlnrec					
1	0.0009768	0.0100072	0.989016	0	0
5	0.0040452	0.0097622	0.9534488	0.000163	0.0325808
10	0.0040453	0.0097618	0.9534098	0.0001631	0.0326201
S_dlnco ₂					
1	0.0136769	0.0174686	0.1555864	0.8132681	0
5	0.0142864	0.016486	0.1478383	0.7712708	0.0501184
10	0.0142858	0.016485	0.1478309	0.771222	0.0501763
S_dlnlabor					
1	0.0053845	0.0001842	0.0017887	0.0036807	0.9889619
5	0.0050332	0.0001584	0.0081326	0.0032284	0.9834474
10	0.0050332	0.0001584	0.0081391	0.0032279	0.9834414

Appendix C

Figure A1. Global stability graph.

Figure A2. Asia-Pacific stability graph.

Figure A3. Caribbean-Latin America stability graph.

Figure A4. MENA stability graph.

Figure A5. Sub-Saharan Africa stability graph.

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