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# Global Value Chains Embeddedness for the Energy Efficiency: A Panel Data Approach with Country-Level Decomposition

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**Abstract:** This study examines the link between a firm's energy efficiency and their participation in global value chains (GVCs). Both countries' GVCs participation and positioning indices are designed to define the features of countries' participation in global value chains. We begin with a theoretical approach of how GVC participation influences energy efficiency. The sample size of 54 nations from 2000 to 2019 is then investigated for empirical analysis using FE and 2SLS methods. The results show that the impact of countries' participation in GVCs is unknown and the development of global value chains positioning increases the energy efficiency in selected countries. Further, it is found that the expansion of GVCs positioning index increases energy efficiency and the effect of forward GVCs positioning on energy efficiency is larger than the effect of backward GVCs positioning. Furthermore, increasing GVC participation in wealthy nations reduces the energy efficiency of the manufacturing industries, but increasing GVC participation in developing countries raises the energy efficiency of manufacturing industries, somewhat opposing the pollution haven approach. A key policy recommendation is that countries actively participate in GVCs to encourage energy efficiency at the macro-level.

**Keywords:** energy efficiency; global value chains; 2SLS

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## 1. Introduction

Climate change and energy constraint are often regarded as the most complex and dangerous global environmental challenges, with major implications for all aspects of people's lives and health [1,2]. Global value chains (GVCs) are extensive processes and institutional frameworks for profit generation and distribution. They are a value generation and provision process that is thought to be influenced by a number of actors from many nations and their inputs activities and resources that run both upstream and downstream [3]. GVCs, which are frequently led by big multinational businesses (MNEs), are widely acknowledged to have a considerable impact on the environment of both emerging and established economies [4,5]. As a result, research on the environmental effects of GVCs has emerged, including ecological responsibility, defined as "the scenario in which important environmental processes are preserved for posterity" [6].

Despite the growing systematic interest in GVCs and the ecological obligation of GVC participants, investigation on the connections between firms operating in developing and developed markets and the GVCs participation, in which they participate in terms of environmental protection, remains patchy and classified [7]. Despite several researches on value chains and ecological concerns, empirical evidence on the impact of GVCs on energy efficiency is severely lacking. Most research focused on the effects of FDDM green initiatives on GVC environmental sustainability [8] or the role of GVCs in ensuring sustainability initiatives in developing markets [9].

There are two different established literatures on the link between GVC participation and energy use. The first set of studies shows that participation in GVCs is beneficial to the environment [10–12]. Increased participation in GVCs can help to prevent environmental degradation and conserve energy in a variety of ways. First, engagement in GVCs helps to spread environmental and new energy technology via technological spillover effects and labor mobility [13–15]. Second, participation in GVCs aids in the diffusion of technology and the sharing of technical information, cutting emissions and promoting the use of renewable energy. Furthermore, participation in GVCs indicates that businesses must deal with a variety of changing environmental constraints and requirements [16,17]. Supplier firms must comply with global rules and environmental standards that can minimize their carbon footprints in order to avoid being removed from GVCs [18,19]. Furthermore, through extending product life, participation in GVCs may result in lower raw material consumption and waste [20]. Although the preceding research made some advances, each study examines several GVCs participation indicators independently and only considers one country, throwing doubt on the conclusions' application to other nations. There has not been much research on how countries' GVCs participation impacts their energy efficiency, and no definitive results have been obtained.

This paper is unique in three ways. To correctly determine the features of countries' participation in GVCs, we first build a comprehensive index. We then provide a creative reason for how the various methods in which countries participate in GVCs affect their energy efficiency, notably their placement or positioning within the GVCs ladder. Only a few papers that we are aware of have presented such a conceptual mechanism examination. Second, this is the first study to analyze the link between GVC participation and energy efficiency using a global dataset spanning 48 countries from 2000 to 2019. It allows us to differentiate between the varying effects on developed and developing countries, offering empirical proof for the trading relationship and environmental policy. Lastly, we created a useful tool for GVC positioning that could have implications for future research.

The remainder of the essay is structured as follows: Section 2 describes the literature review and hypotheses development in more detail and suggests the main argument of this study. The econometric models, variables' description, and data sources are described in Section 3. In Section 4, the empirical findings and discussion are provided, and the paper is concluded in Section 5.

## 2. Review of Literature and Hypotheses Development

Here, we examine how country–industry participation in GVCs affects energy efficiency and develop three hypotheses that have to be proved.

### *2.1. Relationship between GVCs Positioning and Energy Efficiency*

The GVCs position can be used to estimate a country's predicted position in the downstream or upstream of global production networks [21]. The impact of GVCs positioning on energy efficiency is divided into two parts: first, enhancing an industry's GVC positioning results in the transition and enhancement of its internal core; second, the new tech ripple effects affiliated with GVC up-gradation will greatly increase its energy efficiency. Examining the GVCs positioning can estimate a country's predicted position in the downstream or upstream of global industrial chains. Furthermore, as countries advance up the GVCs ladder, economies in lower places can gain from the transfer of knowledge and spillover from established economies by developing strong economic partnerships with them. To reach a more effective and resource production design, further improve the energy resource use efficiency, and maximize the energy utilization framework, it is necessary to acquire more modern manufacturing and management techniques, improve production processes, adjust product structures, and so forth [22]. Based on this process, this study suggests testing the following hypothesis:

**Hypothesis 1.** *An improvement in the industry's GVCs positioning will considerably improve the energy efficiency by improving internal industry structure and advance technologies.*

The GVCs position for an industry is often divided into two categories: the forward linkages GVCs positioning and the backward linkages GVCs positioning. The two different GVCs positioning indices demonstrate the numerous ways that various industries have improved their GVCs, which has a varying effect on how much energy they use. Sectors with greater forward linkages GVCs positioning index, in particular, make strong competitiveness and cutting-edge technology. They contribute by manufacturing inputs for others, either producing intermediate or raw materials, or both [23]. While downstream industries have higher backward GVCs, those engaged in the refining and assembling of imported components have lower backward GVCs [24]. As a result, an increase in the forward GVCs positioning index indicates a change in the industry's inner structure toward high-tech levels throughout the value chain, which can greatly enhance energy efficiency. While the decrease in the backward GVCs positioning index represents an increase in the integrity of the internal industry value chain, it also predicts that the chain's energy efficiency will continue to diminish due to scale effects and technology spillovers. Given the previous, this essay suggests a second hypothesis to be evaluated:

**Hypothesis 2.** *Industrial modernization and technical improvement, which go hand in hand with the expansion of the forward GVCs positioning, can successfully increase energy efficiency. Technology spillover and scale effect generated by the reduction in the positioning of the backward GVCs positioning would significantly lower the efficiency of energy.*

### *2.2. Relationship between GVCs Participation Degree and Energy Efficiency*

Global value chains participation measures the extent to which a country or firms participate in the global production network. The effects of globalization on the transfer of cash and technology across borders provide nations with new opportunities to join the international market and increase their own efficiency in energy use. Nonetheless, because of the diversity of technology across nations, and depending on their level of development, there will be considerable discrepancies in how industrial structure affects the participation in GVCs [25]. More developed countries, in particular, often dominate the upstream of the ladder of global production chains across the industries. By creating product standards and limiting technology spillovers, advanced countries maintain influence over the export of essential intermediary items with high value-added and lesser energy use. Similarly, wealthy countries' domestic energy consumption continues to fall [26], supporting the pollution haven idea, as high energy use and polluting product production shifts to comparatively underdeveloped regions. In general, the energy efficiency of industrialized countries continues to fall as a result of their participation in GVCs, particularly in areas where outsourcing is frequent.

At the earlier point of their participation in GVCs, developing nations are mostly involved at the most downstream stage of the global value chain via the use of cheap labor and economical resource components [27]. Although participation has increased, the intensity of the energy has stayed consistent. On the other side, when rich countries outsourced downstream industrial chains, emerging countries boosted their domestic energy use and emissions [28,29]. As they continue to upgrade to advance technology and experience and understanding production lines, less developed countries have begun to absorb cutting-edge technologies and greatly boos their locus in the GVCs through technological spillover effects and learning effects. The impacts of value-added trade on emerging countries' energy efficiency are now complicated. Moreover, issues such as lower value chains participation make it difficult for some organizations to increase their energy efficiency by eliminating their hurdles in value-added trade. Similarly, as a result of the application of modern technologies and environmental protection laws, emerging nations' design of the product has improved, resulting in a gradual decrease in their energy efficiency. We offer the third hypothesis, which will be tested in this study based on the aforementioned method:

**Hypothesis 3.** *GVCs participation has unknown effects on energy efficiency and there are various techniques through which firms in different nations participate in GVCs have a varied effect on energy efficiency.*

## 3. Econometric Model and Variables' Description

This section discusses the econometric model's design, the development of the GVCs positioning index and participation index, as well as the data sources.

### *3.1. Econometric Model*

The main goal of the present study is to empirically examine, on a worldwide scale, how a particular industry's GVCs participation influences its energy intensity. Following theoretical analysis is used to develop the regression model:

$$\mathrm{lnEE_{ijt}} = \mathrm{a_0} + \mathrm{a_1 GVCsP_{ijt}} + \mathrm{a_2 GVCsPt_{ijt}} + \mathrm{Z_\beta} + \mu + \varepsilon_{\mathrm{ijt}} \quad (1)$$

In above Equation (1), the subscripts t, j and i stand for year, country and industry, respectively; EE stands for each industry's energy efficiency per unit of value added; GVCSP and GVCSPT stand for the country-industry positioning and level of GVC participation, respectively; Z denotes the control variables, while $\varepsilon_{\mathrm{ijt}}$ is the error term and describes the fixed effects. Following in the footsteps of [28], this study employs the country and industry fixed effect to control the particular industry features and deals with the temporal impact in light of the large variations between industries in various nations.

According to the current study, we included control variables for industry-level in Equation (1) to exclude the impact of other determinants on the outcomes: (1) the industrial scale is defined as the gross industrial production value at current prices (lnY). (2) Nominal capital stock is described as capital stock (lnK). (3) The number of individuals employed or the labor intensity (lnL). (4) The percentage of exports to total output, which is an indicator of foreign trade dependency (FTD).

### *3.2. Variables' Description*

#### 3.2.1. GVCs Positioning Index (GVCSP)

The country-industry level GVCs participation in this work is defined by [29] as the log percentage of country-production industries of intermediate goods used in exports to the use of intermediate imports into manufacturing. As stated in Section 2, the GVCs positioning index consists of two components: forwards linkage based GVCs positioning (GVCSPF) and backward linkages based GVCs positioning (GVCSPB). The numerical formula is as follows:

$$\mathrm{GVCSP_{ijt}} = \mathrm{GVCSPF_{ijt}} + \mathrm{GVCSPB_{ijt}} = \ln(1 + \frac{\mathrm{IV_{ijt}}}{\mathrm{uE_{ijt}}}) + \ln(1 + \frac{\mathrm{FV_{ijt}}}{\mathrm{uE_{ijt}}}) \quad (2)$$

Because the measure given by Koopman et al. [29] has a double-counting problem, this study uses their value-added fragmentation approach, which divides a nation's total value-added exports as follows:

$$\begin{aligned} uE_{i^*} = V_i \sum_{j \neq i} B_{ii} Y_{ij} \quad & + V_i \sum_{j \neq i} B_{ij} Y_{jj} + V_i \sum_{j \neq i} \sum_{t \neq ij} B_{ij} Y_{ji} + V_i \sum_{j \neq i} B_{ii} Y_{ji} \\ & + V_i \sum_{j \neq i} B_{ii} A_{ji} (I - A_{ii})^{-1} Y_{ii} + V_i \sum_{j \neq i} B_{ii} A_{ji} (I - A_{jj})^{-1} E_{i^*} \\ & + \sum_{t \neq i} \sum_{j \neq i} V_i B_{ii} Y_{ij} + \sum_{t \neq i} \sum_{j \neq i} V_i B_{ii} A_{ij} (I - A_{jj})^{-1} Y_{jj} \\ & + \sum_{i \neq j} V_t B_{ti} A_{ij} \sum_{j \neq i} (I - A_{jj})^{-1} E^{j^*} \end{aligned} \quad (3)$$

Equation (3) divides a country's gross value-added exports into nine parts. $uE_i$ denotes the value-added exports in country $i$ at time $t$. Here $IV_{ij} = V_i \sum_{j \neq i} B_{ii} Y_{ij}$ denotes the domestic value added in intermediate products re-exported from country $i$ to third countries. $FV_{ij} = \sum_{t \neq i} \sum_{j \neq i} V_i B_{ii} Y_{ij} + \sum_{t \neq i} \sum_{j \neq i} V_i B_{ii} A_{ij} (I - A_{jj})^{-1} Y_{jj}$ refers to foreign value added embodied in country $i$, $r$ industry.

3.2.2. GVCs Participation Index (GVCSPT)

This study uses a most recent index given by Wang et al. [30] to examine how much a country's industry participates in global value chains. They created the following GVC participation degree indices:

$$\mathrm{GVCSPT_F} = \frac{\mathrm{VA\_GVCS_{ij}}}{\mathrm{VA_{ij}}} = \frac{\mathrm{VA\_GVCS\_S_{ij}}}{\mathrm{VA_{ij}}} + \frac{\mathrm{VA\_GVCS\_C_{ij}}}{\mathrm{VA_{ij}}} \tag{4}$$

VA denotes total value added of a nation's industry, VA_GVCS_C and VA_GVCS_S imply the value contributed in the manufacture of intermediate exports absorbed by a direct importer or re-export, accordingly. A second participation index can be represented as follows:

$$\mathrm{GVCSPT_B} = \frac{\mathrm{Y\_GVCS_{ij}}}{\mathrm{Y_{ij}}} = \frac{\mathrm{Y\_GVCS\_S_{ij}}}{\mathrm{Y_{ij}}} + \frac{\mathrm{Y\_GVCS\_C_{ij}}}{\mathrm{Y_{ij}}} \tag{5}$$

Y denotes a country's total output of final products and services. Y_GVCS_C and Y_GVCS_S represent the internal and external value added in intermediary imports used for domestic and exporting products, respectively. In this study, the total of these indexes is termed as the GVCs participation level index of a nation's industry:

$$GVCSPT_{ij} = GVCSPT_F + GVCSPT_B = \frac{VA\_GVCS_{ij}}{VA_{ij}} + \frac{Y\_GVCS_{ij}}{Y_{ij}} \tag{6}$$

### *3.3. Sample Period and Data Sources*

The energy efficiency statistics utilized in this study were derived from the European Commission's World Input-Output Database (WIOD) climate reports. From 2000 to 2019, the database covered 28 EU countries as well as 20 additional significant nations and contained data on overall energy usage, emissions relevant energy use, and $CO_2$ emissions by 64 sectors and households for 12 different types of energy commodities.

The data for GVCs participation is derived from the 2020 World Input-Output database (WIOD), which covers the Socio Economic Account (SEA) and World Input-Output Table (World IO Tables), two sub-databases that cover 56 sectors in 28 EU countries and 20 other major global economies between 2000 and 2019. The World WIOD Tables are mainly used to compute data for the GVCs' relevant indices. World Bank provides the majority of the relevant information for control variables. In additional to the datasets described above, we collected over 30,000 samples across 56 industries from 48 major nations between 2000 and 2019.

## **4. Results and Discussions**

### *4.1. Benchmark Estimation Results*

Using a sample of 56 industries from 48 countries and a three-dimensional panel data technique, we examine the impacts of GVCs positioning and GVCs participation on the energy efficiency of industries from 2000 to 2019. Descriptive statistics of the variables is given in Table 1.

This estimating method controls the fixed effects of both the year and the country*industry. Table 2 shows the empirical results. The findings in column (1) and column (2) show the outcomes where the GVCs positioning is the only explanatory variable. Column (3) and column (4) show the results when the GVCs participation is used as the sole explanatory variable. Column (5) and column (6) present further findings that use the GVCs' positioning and participation in GVCs as explanatory variables.

**Table 1.** Descriptive statistics.

| Variables | No of Obs. | Mean | Std. Deviation | Minimum | Maximum |
|---|---|---|---|---|---|
| lnEE | 32,740 | 0.062 | 2.700 | −12.843 | 10.411 |
| GVCSP | 35,282 | −0.155 | 0.167 | −1.285 | 4.063 |
| GVCSPF | 35,281 | 0.068 | 0.036 | 0 | 0.291 |
| GVCSPB | 35,281 | 0.227 | 0.140 | 0 | 1.015 |
| GVCSPT | 33,262 | 0.457 | 0.337 | 0 | 12.625 |
| lnGDP | 33,247 | 9.796 | 3.2 | −2.302 | 21.833 |
| lnCapital | 32,798 | 9.586 | 3.440 | −2.302 | 22.427 |
| lnLabor | 33,245 | 4.079 | 2.4 | −4.606 | 12.490 |
| FTD | 33,248 | 0.238 | 0.273 | 0 | 1.432 |

Source: Authors' own calculation.

**Table 2.** Benchmark estimation results.

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| GVCSPT | −3.047 *** (0.176) | −2.447 *** (0.190) | | | −3.025 *** (0.185) | −2.427 *** (0.192) |
| GVCSP | | | 0.220 (0.230) | 0.256 (0.344) | 0.224 (0.196) | 0.218 (0.283) |
| ln(GDP) | | 0.445 *** (0.052) | | 0.435 *** (0.055) | | 0.453 *** (0.053) |
| ln(capital) | | 0.255 *** (0.037) | | 0.283 *** (0.032) | | 0.243 *** (0.032) |
| ln(labor) | | −0.533 *** (0.055) | | −0.399 *** (0.053) | | −0.552 *** (0.052) |
| ln(labor productivity) | | −0.279 *** (0.43) | | −0.196 *** (0.042) | | −0.239 *** (0.043) |
| Foreign trade dependency (FTD) | | 0.143 (0.084) | | 0.381 (0.218) | | 0.195 (0.187) |
| Constant | 0.364 *** (0.024) | 3.119 *** (0.293) | 0.042 (0.106) | 4.537 *** (0.285) | 0.446 *** (0.085) | 2.959 *** (0.273) |
| Country and Industry Dummy | Yes | Yes | Yes | Yes | Yes | Yes |
| Year Dummy | Yes | Yes | Yes | Yes | Yes | Yes |
| No of Obs. | 32,739 | 32,475 | 32,744 | 32,473 | 32,745 | 32,476 |
| $R^2$(Adjusted) | 0.976 | 0.978 | 0.972 | 0.977 | 0.974 | 0.978 |

Notes: Parentheses indicate robust standard errors. All regressions are grouped by country*industry. *** $p < 0.01$.

As demonstrated in column (1) and column (2) of Table 2, the coefficients of GVCs positioning are consistent and significant at the 1% level of significance, revealing a strong negative association between an industry's GVCs positioning and its energy efficiency. After accounting for the control factors, most of the assessed parameters except labor remain positive and significant at the 1% level of significance. Sectors with higher GVCs ranks are likely to have better levels of technology and capability for value addition, resulting in improved energy efficiency [31]. This lends credibility to Hypothesis 1, which was strongly supported in Section 2.

The estimated GVCs participation index parameters, displayed in Table 2 column (3) and column (4), are not statistically significant, suggesting the existence of insufficient evidence to imply a meaningful relationship between GVCs participation and firms' energy efficiency. This is aligned with Hypothesis 3, which asserts that the various methods used by different countries to participate in GVCs have diverse effects on energy intensity. Furthermore, as seen in column (5) and column (6), our prior findings hold true when both GVC positioning and GVC participation degree are considered as explanatory factors.

While the projected factors of GVCs participation are still insignificant at the 10% statistical threshold, the GVCs position coefficients are still significantly negative.

### *4.2. Robustness Check*

Control for Endogeneity with 2SLS Regression

For the three-dimensional panel data technique to achieve estimation consistency, all estimated coefficients of explanatory variables must be exogenous. However, the study's primary explanatory variables (GVCSP and GVCSPT) and dependent variable (EE) may have a bidirectional causal link, causing endogeneity issues and failing to meet the estimation reliability requirements. To update the model, we generate the instrumental variables for GVCs positioning and GVC participation, correspondingly, and estimate them using two-stage least squares (2SLS).

First, we devise novel instrumental factors for the GVCs positioning. Koopman et al. [28] discovered that double-counted products, which accounted for approximately 25.6% of all global exports in 2004, were a substantial part of a country's gross export. In contrast, double counting is a statistical anomaly that has no connection with industrial procedures. This leads us to the conclusion that foreign double-counted components should be used as the instrumental variables for the GVCs positioning. The instrumental variable of the GVCs positioning is chosen as the proportion of the double-counting intermediate exports manufactured in other countries to the foreign content. GVCSP-IV ensures two requirements are required use instrumental variables. It all starts with the GVC positioning. The industry's FDC reflects its position in the global manufacturing process; the greater the FDC, the more international intermediate items it imports. [30] There is no link between the overseas double-counted products and the erroneous item because they do not add to domestic production and have no immediate impact on energy efficiency. To validate an exclusive limitation of this instrumental variable, we undertake an empirical evaluation using the method proposed by [32].

The lagged value of GVCs participation is the instrumental variable of GVCs participation. By re-evaluating the 2SLS model with the instrumental variables, the possible endogeneity is effectively controlled.

Empirical findings of the 2SLS estimates are shown in Table 3. Column 1 shows the level of the instrumental variable in the GVCs estimation results. Column 2 displays the regression results for the instrumental variable of the GVCs participation index. Column 3 includes both GVCSP-IV and L.GVCSPT as explanatory variables. The first-stage regression results show that all instrumental variable coefficients are statically significant at the 1% level, indicating that the instrumental variables and explanatory factors have very high connections. Furthermore, because the KP Wald-F statistic surpasses the SY threshold at all level [33], GVCP-IV is a true instrumental variable. The calculated coefficients of GVCs positioning and participation in GVCs differ somewhat from the baseline regression results, but the sign of the coefficients and their significance remain constant, confirming the benchmark regression's robustness.

Fixed Effects with alternatives Variables:

This section includes some additional robustness testing that used a variety of variables with fixed effects. The findings are summarized in Table 4. Energy efficiency (EE) is defined in Column (1) as the ratio of total energy consumption in total output (lnETO). Our key conclusions remain true, albeit with a slightly lower coefficient of the GVCs positioning than the same value reported in the baseline regression. Column (2) displays the outcome when revealed comparative advantage (RCA) is used instead of the GVCs positioning index, because global competition is frequently associated with value rate of growth. Meanwhile, unlike previous studies, we compute revealed comparative advantage with value-added exports rather than total exports. The GVCs position coefficient is lower than in the baseline study, but it stays significant and negative at the 1% critical threshold, indicating that the results are consistent. Third, we adjust the GVCs participation index using the approach presented by Koopman et al. [29]. Even after modifying the computation method, the coefficient of GVCs participation index remains low at the 10% level of significance as shown in column (3).

**Table 3.** 2SLS regression results.

| | (1) | (2) | (3) |
|---|---|---|---|
| GVCSP | −0.445 *** <br>(0.052) | | −2.353 *** <br>(0.0532) |
| GVCSPT | | 0.265 <br>(0.332) | 0.228 <br>(0.262) |
| Control variables | Yes | Yes | Yes |
| Country and Industry Dummy | Yes | Yes | Yes |
| Year Dummy | Yes | Yes | Yes |
| No of Obs. | 32,473 | 30,296 | 30,296 |
| GVCSP-IV | 0.585 *** <br>(0.033) | | 0.598 *** <br>(0.033) |
| L.GVCSPT | | 0.635 *** <br>(0.000) | −0.685 *** <br>(0.107) |
| K-P rk Wald-F-statistic | 241.462 | 38.242 | 113.75 |

Notes: Parentheses indicate robust standard errors. All regressions are grouped by nation and industry dummies. *** $p < 0.01$. Kleibergen–Paap rk Wald F test statistics is used for weak instrumental variable.

**Table 4.** Results of alternative measures of variables and fixed effects.

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| GVCSP | −0.518 *** <br>(0.161) | −0.085 *** <br>(0.026) | −2.225 *** <br>(0.302) | −1.071 *** <br>(0.226) | −1.185 *** <br>(0.235) |
| GVCSPT | −0.008 <br>(0.095) | 0.257 <br>(0.336) | 0.265 <br>(0.327) | 0.250 <br>(0.420) | 0.208 <br>(0.411) |
| Control variables | Yes | Yes | Yes | Yes | Yes |
| Country and Industry dummies | Yes | Yes | Yes | No | No |
| Year dummy | Yes | Yes | Yes | Yes | No |
| $\mu_1$ | No | No | No | Yes | No |
| $\mu_2$ | No | No | No | No | Yes |
| No of Obs. | 32,496 | 32,471 | 32,471 | 32,472 | 32,465 |
| $R^2$ Adjusted | 0.959 | 0.977 | 0.977 | 0.890 | 0.894 |

Notes: Robust standard errors are presented in parentheses. The first four regressions were classified by country and industry dummies, while the remaining four regressions were clustered by country*year. $\mu_1$, shows the country and industry fixed effects. $\mu_2$, shows the country*year and industry*year fixed effect. *** $p < 0.01$, are 1%, 5% and 10% level of significance.

Column 5 uses industry fixed effects and time varying (i.e., industry*year and country*year) to adjust for non-observable variables that fluctuate over time at the nation and industry levels, replacing industry*country dummies with industry and country dummies. This successfully reduces mistakes resulting from missing variables and helps in minimizing any endogeneity issues. As shown in results, adjusting the fixed effect has no effect on the benchmark regression results. In conclusion, regardless of how the dependent variable's index, measurement method, or important explanatory factors are changed, the findings are substantially similar to the baseline regression analysis, demonstrating the paper's conclusions' trustworthiness.

### *4.3. First Difference Regression*

Table 5 displays the results of the first difference estimator. Taking into account the likely time patterns of the aforementioned regression, and further investigating the effect of change in GVC positioning and GVC participation on the changing energy efficiency, because the GVCs positioning coefficient increases in absolute value relative to the baseline regression and remains negatively significant at the 1% significance level, the firm's energy efficiency is reduced dramatically. It is worth mentioning that at the 5% level of significance, the coefficient of the GVCs participation turns positive, indicating that a higher GVCs participation results in higher energy intensity. This is similar to the previous findings of the study, which revealed that some businesses in specific countries may only accept labor that requires a substantial amount of energy and very little added value because of fears such as low value addition from the labor. Despite their increased GVCs participation, the energy efficiency cannot be significantly increased.

**Table 5.** Regression results first difference estimator.

| | (1) | (2) | (3) |
|---|---|---|---|
| D.GVCSP | −3.311 *** (0.256) | | −3.28 *** (0.256) |
| D.GVCSPT | | −0.416 *** (0.233) | −0.382 *** (0.181) |
| Controls | Yes | Yes | Yes |
| Country and Industry dummies | Yes | Yes | Yes |
| Year dummy | Yes | Yes | Yes |
| No of Obs. | 30,094 | 30,095 | 30,092 |
| $R^2$ Adjusted | 0.067 | 0.018 | 0.073 |

Notes: Parentheses indicate robust standard errors. All regressions are categorized by country*industry. *** $p < 0.01$.

*4.4. Heterogeneity Analysis*

GVCs participation is a means of pooling resources from several countries and industries. GVCs participation has varying impacts on their energy intensity due to the enormous differences in the growth of diverse firms across various nations. To support Hypothesis 3, we categorized the 42 nations as developing or developed based on their stage of development. We then examined the manufacturing and service sectors individually due to the significant disparity in energy efficiency between these two sectors. Table 6 displays the results.

**Table 6.** Results of grouped regression.

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| | | Developed countries | | | Developing countries | |
| | Entire sample | Manufacturing | Service | Entire sample | Manufacturing | Service |
| GVCSP | 2.580 *** (0.236) | −2.988 *** (0.350) | −1.716 *** (0.266) | 2.255 *** (0.291) | 2.295 *** (0.450) | −2.407 *** (0.415) |
| GVCSPT | 0.087 (0.215) | −0.106 *** (0.060) | 2.377 *** (0.246) | 1.125 *** (0.236) | 0.805 *** (0.261) | −2.265 *** (0.355) |
| Controls | Yes | Yes | Yes | Yes | Yes | Yes |
| Country*Industry dummies | Yes | Yes | Yes | Yes | Yes | Yes |
| Year dummies | Yes | Yes | Yes | Yes | Yes | Yes |
| No of Obs. | 21,377 | 7572 | 10,653 | 11,093 | 4035 | 5375 |
| $R^2$ Adjusted | 0.970 | 0.965 | 0.976 | 0.988 | 0.986 | 0.992 |

Notes: Values in parentheses indicate robust standard errors. All regressions are classified by country*industry. *** $p < 0.01$, level of significance.

The regression findings for developed countries are shown in column (1) through to column (3). Column (1) represents the entire sample of industrialized countries, and Columns (2) and (3) represent the manufacturing and services sectors, respectively. The regression findings for developing countries are shown in columns (4) through to (6). Column (4) represents the entire sample of developing countries, whilst columns (5) and (6) represent the manufacturing and service sectors, respectively.

The value of the coefficient of GVCs positioning is indeed positively significant at the 1% critical threshold, as shown in above Table 6, supporting our prior findings. This shows that there is a consistent positive relationship between GVC positioning and energy efficiency. Manufacturing industries in advanced nations have a strong negative association with GVCs participation at the 10% level of significance, whereas manufacturing industries in developing countries have a significant positive correlation with GVCs participation at the 5% level of significance. While participation in GVCs has increased in developing nations where downstream production links are being built, energy efficiency cannot be lowered without improving manufacturing processes and technology levels.

## 5. Conclusions and Policy Recommendation

As the participation global value chains has had a greater impact on the structure of international trade, the degree and type of industries involved in the global production have experienced major changes, which have had a significant effect on their own energy efficiency. This study examines the various effects of different GVC participation aspects on energy efficiency in depth. The analysis is focused primarily on a detailed design of GVCs participation measures at the country-industry level, such as the GVCs positioning, forward linkage driven GVCs positioning, backward linkage based GVCs positioning, and GVCs participation index. Furthermore, from 2000 to 2019, empirical tests were conducted on a sample of 56 sectors from 42 nations using the three-dimensional panel data approach and the 2SLS method.

The empirical results demonstrate that increasing an industry's GVCs positioning lowers its energy efficiency 2.42 percentage points, which is mostly caused by declining the sector's inner structure and outdated technology. Further, we can say that in terms of the evolution paths of GVCs positioning, it significantly decreases energy efficiency. Moreover the results show that there is a positive relationship between the level of GVC participation and energy efficiency as the coefficient is positively significant across the different regression techniques. It shows that a one percent increase in GVCs participation would increase the energy efficiency by 0.21 percentage points. However, the grouped regression indicates that in the manufacturing sector, increased GVC participation by developed nations reduces energy efficiency, whereas increasing GVC participation by developing countries increases it.

The findings of the paper contain crucial policy recommendations for countries aiming to participate in GVCs while increasing existing energy efficiency. First, countries should seize newly discovered economic benefits in manufacturing distribution networks. They should then aggressively promote innovation to strengthen their basic research and development expenditures and intermediate goods production competence in order to take their industries up a GVCs ladder. It will improve the country's income from global trade while simultaneously increasing environmental quality and energy efficiency. Second, rather than focusing exclusively on the volume of GVC participation, developing nations should stress the quality of participation by continuously refining market procedures, enhancing infrastructure development, and aggressively nurturing an environment that allows domestic industries to be integrated into GVCs. Developing nations must use advanced technologies and investment to increase their ability to develop independently, eliminate the problem of low quality value-added products, and boost industrialization and energy efficiency through scale and the learning effect to the maximum extent possible.

Due to research time and data availability, this work is subject to various limits. Furthermore, this work only compares preliminary categorizations. This study, on the other hand, sheds light on and serves as a source of information about the impact of participation in GVCs on energy utilization. If data are available, future research might look at more countries over a longer time span, contrasting rich and poor countries in depth, or it could focus on just one country for a full investigation.

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