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Sustainable development through structural transformation: a pathway to economic, social, and environmental progress

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Abstract
Over the last several decades, environmental sustainability along with social as well as economic growth has been given key importance due to the pressure it imposes on an economy. Therefore, to achieve these three goals together, the world now advances toward attaining sustainable development agenda signed in 2015. The objective of this study is to scrutinize the impact of structural transformation (STR) on socioeconomic and environmental progress captured by sustainable development (SDI) for a global sample of 122 countries. We consider the period from 2000 to 2019 and employ two-step system GMM methodology to take endogeneity into account which might exist between STR and SDI. In line with the literature of economic growth and STR, we include other variables such as corruption, population growth, government consumption and investment. The results from the two-step system GMM suggest that STR positively affects socioeconomic and environmental progress. We also consider the countries according to World Bank income classifications and K means clustering based on the value of STR. For low, upper middle-income and high-income sample, we find that STR positively affects socioeconomic and environmental progress, while it has no significant impact on such progress for lower middle-income category. Having stable structural transformation benefits the economy, society and environment, while unstable structural transformation is not beneficial. Based on the results, policy directions are suggested for the full sample as well as for the subsamples in order to achieve sustainability in all the sectors.

Keywords Structural transformation · Sustainable development · System GMM · Corruption · Population

Abbreviations

ARDL	Autoregressive distributed lag
BCI	Bayesian corruption index
DEVI	Development index

Extended author information available on the last page of the article

DSK	Driscoll–Kraay estimator
ECF	Ecological footprint
ECX	Economic complexity
EII	Ecological impact index
FAO	Food and Agriculture Organization
GDP	Gross domestic product
GMM	Generalized method of moment
GOVC	Government consumption
GR	Growth
HDI	Human development index
INV	Investment
MDG	Millennium development goals
MG	Mean group
MLE	Maximum likelihood estimation
NARDL	Nonlinear autoregressive distributed lag
NICs	Newly industrialized countries
OECD	Organization for economic cooperation and development
OLS	Ordinary least square
PM2.5	Particulate matter 2.5
PMG	Pooled mean group
POLS	Pooled OLS
POPG	Population growth
SDG	Sustainable development goal
SDI	Sustainable development
STR	Structural transformation
TFP	Total factor productivity
UN	United Nations
WDI	World development indicators

1 Introduction

In 2015, the UN's member nations decided to adopt the new set of 17 SDI Goals (SDG) in place of the previous set of Millennium Development Goals (MDG). The SDG is made up of 17 significant goals or targets that nations must achieve to implement the 2030 global agenda. According to the Initiative Global Reporting (IGR, 2013), the SDGs should be adopted in order to combat inequality, end poverty, and advance inclusive development for all. The SDG agenda also places strong emphasis on environmental and resource management since by pursuing economic growth, many nations have hampered their environmental goals. Therefore, sustainable development has placed greater emphasis on the prosperity of economic system, social system as well as that of environmental system. All the nations that have signed up for SDG in 2015 are expected to achieve these goals within 2030 and it has been determined that there will be severe consequences if the goals are not achieved within this target date. However, the latest estimate from the United Nations (2023) shows that achievement of agenda 2030 is now in jeopardy since the progress has been very slow because of the economic fluctuations and climate crisis. Over 50% of the SDGs targets are insufficient and weak and it went reverse or stalled on 30%. Therefore, there is an urgent need to accelerate the SDG achievement across the different regions, especially in the developing countries. With the advancement of digital era brought on by the digital technologies, the SDG achievements have become more convenient compared to the past (Chen et al. 2023; Tu et al. 2022).

Structural transformation (STR), which is the main subject of this study, has numerous roles for the achievement of sustainable development or SDG agenda. According to the working definition by FAO (2017) and Fox et al. (2015), it is a relatively continuous process that involves—increases in output and changes to the economic structure; redistributing labor among different economic sectors; and boosting productivity across the board. The STR differs across countries which can be seen from the map depicted in Fig. 1. The STR in this study is measured using Lilien index of structural transformation which shows sectoral employment shift (from agriculture to services) over time. Since different countries have different forms of STR, it would be interesting to how these different levels of STR affect sustainable development in these nations.

Empirical literatures have demonstrated different effects of STR on sustainable development, which includes economic as well as social and environmental dimensions, over time as the world economy shifts away from industry and toward the provision of services. The effect of structural change on economic growth (GR) has been hotly contested in literature (Hartwig 2012). Even though the majority of researchers believed that long-term structural changes in the areas of demand and invention lead to greater economic growth, some researchers chose to exclude this demand side of the economy in their justification. On the basis of Baumol's (1967)

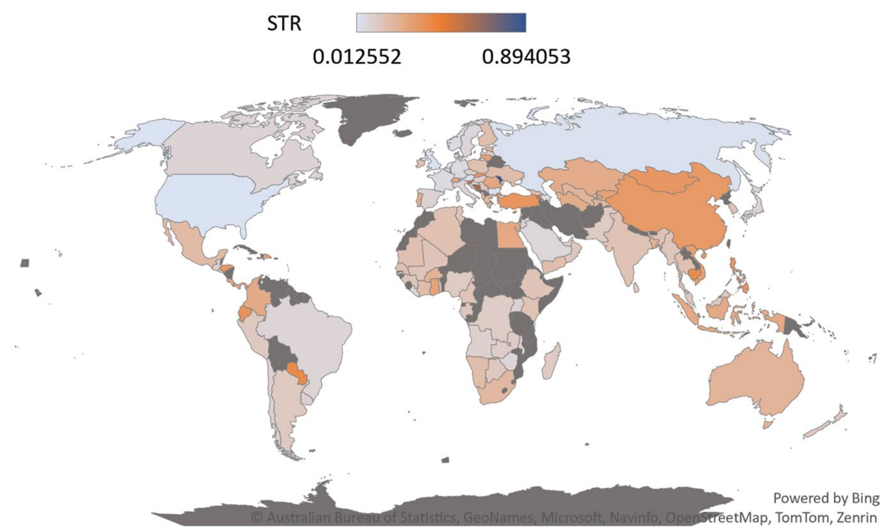

Fig. 1 Structural Transformation across the study sample

cost illness, supply-side research typically claims that structural change results in a drop in aggregate growth illness (Nordhaus 2008; Hartwig 2012, 2015). The mixed results observed in literature with regard to structural change and economic growth may depend on the type of structural change that occurs. On the other hand, several studies such as López et al. (2007) have shown that structural transformation has the capability to make an economy grow with the sustainability of natural resources, thus supporting the environmentally sustained economic growth. Structural transformation, where service sector remains to the main contributor of an economy, can provide sufficient support for carbon neutrality achievement since service sector is less carbon intensive (Ibrahim et al. 2022). Moreover, several studies such as Ghosh et al. (2023) have also demonstrated that there is wide range of heterogeneity across the different income groups when it comes to the effect of structural transformation on social system such as income distribution. Given these scenarios, it can be said that structural transformation can affect sustainable development by influencing economic, environmental and social sustainability in numerous ways.

Against the above background, the purpose of this research is to identify the impact of STR on sustainability of society, economy and environment while accounting for other factors that have been identified in the literature. In this paper, we use an SDI index which is a performance indicator created to measure a country's development and ecological effectiveness. This SDI index created by Hickel and Kallis (2020) is a comprehensive indicator supporting the economic, environmental, and social system sustainability simultaneously. While previous research has analyzed the impacts of structural change or structural transformation on growth, environmental quality and several measures of social sustainability such as human development or income inequality, to the best of these authors' knowledge, no research has yet identified the impacts of STR on sustainable development which encompasses all the three dimensions of sustainability and captures the SDG agenda in an appropriate manner. The income component in the SDI Index is given a sufficiency threshold over which more money is no longer required to achieve high levels of human development. This enables us to fix an issue with the Human Development Index that has existed for a while. Due to the close relationship between income and emissions and material footprint, achieving income levels required for "very high" HDI locks in extremely high ecological impact. Although we are aware that it is conceivable to decouple wealth from CO_2 emissions, current empirical evidence suggests that high-income nations are unable to do so at a rate adequate to significantly reduce the ecological effect (Hickel and Kallis 2020). The SDI celebrates nations that accomplish high levels of human development with little negative influence on the environment rather than pushing very high levels of income (and consequently consumption).

Moreover, this research uses a unique measure of structural transformation as opposed to the measure of economic complexity used in recent literature (Nathaniel 2021; Cui et al. 2022; Ghosh et al. 2023). To measure the structural transformation or structural change of an economy, this study uses Lilien index of structural transformation following Lilien (1982). This index is able to capture the structural shift of demand of employment between different sectors of a country. As a result, this measure provides a way to examine which economic sector is experiencing low or high dispersion in growth of employment over time, providing a way for structural change of that country. It provides insights into the dynamics of economic growth, resource allocation, technology adoption, skill development, and policy effectiveness, all of which are essential components of a country's development journey. To this end, the study considers dual classification approach, dividing the full sample according to the income group as well as according to the cluster samples. For example, according to World Bank classification, the study considers low-income sample, lower middle-income sample, upper middle-income and high-income sample. On the other hand, it also considers stable and unstable cluster defined through the Lilien index values. The study uses k means clustering to divide the whole sample into two groups of high and low structural transformation. However, since there are some countries which move between clusters, the study considers division of stable and unstable cluster. Thus, the study provides policy directions with regard to the benefits of a stable and consistent structural transformation process.

As for the methodology, generalized method of moment (GMM) is used in this study because of its conceptual concepts to incorporate more extremum estimators (such OLS and MLE) into the omnibus system as well as its flexibility regarding model constructs. This method is superior since it can provide efficient feasible estimation. Moreover, this method takes the endogeneity that might exist between structural transformation and sustainable development into account because there is possibility of reverse causality. Furthermore, this method allows us to use internal instruments instead of external instruments which are difficult to find.

The rest of the paper is organized as follows: the second section provides an overview of previous studies; third section provides data and method, and fourth section presents results and final section concludes.

2 Literature review

2.1 STR and economic development

Given the importance of STR on economic GR, it was once thought that STR had two effects on economic development. The industrialization process, often known as the structural transition from agrarian to industrial output, creates greater production scales and more pollutants as an economy grows (Cherniwchan 2012; Antoci et al. 2014; Nejat et al. 2015). Second, the structural shift toward the service industry, or "tertiarization," promotes the GR of less polluting economic sectors and reduces pollution. Vu (2017) explored the association between GR and STR in Asian countries. They introduced a new effective STR in their study. In their research, they used the data for 42 years and for the 19 countries of Asia. They found that this type of STR can cause a significant effect on GDP per person, GDP, wage as well as productivity. However, Erumban et al. (2019) examine how STR affects India's rise in total productivity. They used data collected over a period of 31 years in India for their study. They discovered that capital was allocated across sectors in a way that aided TFP GR in the 1990s thanks to pro-market changes. For a sample of Asian nations, Foster-McGregor and Verspagen (2016) investigate this STR process and its relationship to productivity development. They used data for 21 years and the 17 Asian countries in their study. In contrast to the overall Asian environment, they found that the dynamic structural effect had a negative impact on Asian productivity GR, whereas the static structural effect is particularly strong in nations with intermediate levels of productivity GR. However, when they converge to employment arrangements that are typical of middle- and low-income countries worldwide, the non-high-income Asian nations in their sample see a productivity GR boost.

Innovation is considered to be a key endogenous factor and imposes positive effect on GR (Xu et al. 2023). In this regard, to propel China's economic GR, Zhou et al. (2021) look at the direction of technological innovation and STR utilizing a nonlinear econometric model and 14-year-old Chinese provincial data. A need to change the technical progress strategy from imitation to innovation is revealed by the inverted U-shaped relationship between technological advancement and economic GR from a national perspective. When the turning point is reached, structural improvement spurs economic expansion in China.

2.2 STR and environmental quality

In recent years, greenhouse gas emissions have increased significantly (Shang and Luo 2021). The dynamic effects of urbanization, economic structure, technological advancement, and population density on ecological footprint (ECF) and air quality (PM2.5) in Newly Industrialized Countries (NICs) over a 27-year period are examined by Sahoo and Sethi (2022). They use methods such as MG and PMG to determine the relationships between the variables. The findings show that NICs' ECF grows as economies develop over time. Similarly, the industrialization coefficient is favorable and highly correlated with ecological impact. Similar to population density, urbanization significantly and positively contribute to PM2.5.

Several studies have used economic complexity (ECX) as a measure of structural transformation in order to determine its relationship with environmental quality. For example, in 20 nations, Cui et al. (2022) looked at how human capital, renewable energy, urbanization, economic GR, and ECF are related to economic complexity (ECX). For a period of 37 years, they found that ECF is positively connected with ECX in both panels. Also, along with income per capita and the use of fossil fuels, Neagu (2020) adds ECX to the list of explanatory variables for changes in ecological footprint. An examination of the relationship between the ECF and ECX is conducted over a 19-year period in a panel of 48 countries which are complex. He confirmed long-run positive correlation between the ECX index, GDP per person, and consumption of energy from non-renewable and the ECF of production as the dependent variable. Similarly, Yilanci and Pata (2020) explored correlations between GR, the ECX index, energy use, and ECF for the period 1965–2016 using a new method. The results of the Fourier ARDL technique demonstrate that the series are co-integrated. The overall findings show that environmental problems in China cannot be solved by GR, and ECF gets an increase because of ECX.

As identified by Nathaniel (2021), the effect of ECX on environmental footprint and CO_2 emissions in the ASEAN area is investigated. According to the research, ECX, energy use, and economic expansion all lead to higher ECF and CO_2 emissions. Although globalization lowers EF, its effect on CO_2 emissions is still unknown. Globalization, ECF, and energy use all have a feedback causal relationship that contributes to CO2 emissions. Ikram et al. (2021) investigate how economic activity and STR affect Japan's environment. It uses the recently created Quantile ARDL (QARDL) model. According to the Quantile Granger-causality results, there is a bidirectional causal relationship between ecological footprint, ECX, and GR in both low and high quantiles. Similarly, QARDL results show that economic GR and environment have an asymmetrically favorable relationship in both the short- and long term.

Kazemzadeh et al. (2022) showed that the ECF is favorably influenced by the ECX in the two initial quantiles and POLS, but not in the 75th and 90th quantiles. The 10th, 25th, 50th, 75th, and 90th quantiles of gross domestic product have a favorable impact on ecological footprint. The relationship between the ECX Index, Human Development Index (HDI), and the mediating impacts of income inequality among emerging nations is examined by Le Caous and Huarng (2020). Eighty-seven developing nations were examined using hierarchical linear modeling over a 27-year period, and the effects of gender inequality and energy use were also examined at the country level. For greater sturdiness, various year lags were applied. The findings indicate that human development grew as ECX increased. However, income inequality served as a partly mediating factor in this association. Gender inequality, energy use, and country-level predictors all have an effect on SDI.

As a result of the analysis conducted by various researchers which contend that as income rises, the economy will shift from the primary sector (based on agriculture) to the secondary sector (based on industry), and pollution levels would rise, providing most of the evidence from the literature evaluation for this study. Then, as a nation's economy shifts to the tertiary sector, environmental damage should be reduced (based on services). In contrast, Hamilton's early research refuted the aforementioned claim since he does not think that a change in the structure of production leads to an increase in pollution.

In a new empirical study, Li et al. (2023) utilized dynamic ARDL approach to investigate the way structural change affects the sustainability of environment. The authors considered Pakistan and considered sample period of 49 years. The authors found that environmental sustainability is affected negatively via structural change. However, this statement is only true in the short run but not for the long run.

2.3 STR and human capital development

In this section, we review previous literature which examines the relationship between structural transformation and human capital development. According to Musambira and Matusitz (2015), the Human Development Index (HDI) measures the overall progress in fundamental aspects of human development, encompassing education, health, life expectancy, technological access, and a satisfactory living standard. A study by Mostolizadeh and Salimi (2021) indicate that in developing countries, ECX and political stability have a long-term, significant negative impact on the human development index, while the long-term, significant positive impact of the rule of law and the economic freedom index on the index is observed. Similarly, in a subset of 24 OECD nations, Arica and Kurt (2021) look into how the Human Development Index (HDI) affects economic complexity index (ECI) utilizing panel data methods during a 23-year period. The study's findings indicate that while human development has a Granger causal relationship with ECX in six nations, it has a unidirectional causal relationship with ECX in five industrialized countries. Additionally, the 5% threshold of significance shows that there is a feedback effect between human development and ECX in Spain, demonstrating that both factors are impacting one another.

The impact of sectoral changes and structural restructuring on Latin America's current productivity trajectory is examined by Ferreira and da Silva (2015). They employ a general equilibrium model with four sectors and discovered that productivity reduction seen after mid-1970s was typically caused by the traditional services sector's poor performance and is a fundamental explanation for the divergence during this time.

The importance of STR on productivity GR in Denmark is examined by Holm (2014). Price's equation is a tool he uses from theoretical evolutionary biology, based on Danish data over an 18-year span using panel data methodologies. The results of decomposition studies are found to be significantly influenced by the economy's STR, not least in terms of the size of the inter-firm selection effect. The old technique is biased downward in its assessment of economic selection because of the structural shift away from capital-intensive and hence high labor productivity manufacturing and toward labor-intensive and therefore low labor productivity services. Similarly, using a STR theory that takes into account an unrestricted number of sectors as well as long-run income and price impacts, Buiatti et al. (2022) study the disparity in labor productivity GR between Europe and the USA in the services sector. They do numerical experiments using the scenario in which the sectoral labor productivity in Europe grows counterfactually at the same rate as that in America. They show that accounting for two-thirds of the difference since 1995, the wholesale and retail trade, business, and financial services sectors were primarily responsible for the loss in aggregate labor productivity and lack of catch-up.

3 Data and methodology

3.1 Data description

In this study, we consider the effect of STR on sustainable development for 122 countries for the period from 2000 to 2019. Different countries have different income and development levels (Luo et al. 2022). Therefore, we divide our whole sample into the low-income category, lower middle-income, upper middle-income and high-income category in line with the classification provided by World Bank. Table 29 in appendix provides the list of these countries. The income in the World Bank classification is measured by per capita gross national income (USD). The currency is converted from local currency to USD using the Atlas method of World

Bank. According to the latest estimates from World Bank Atlas Method, countries having per capita GNI of 1135 USD or less are low-income countries, those having per capita GNI between 1136 and 4465 USD are lower middle income, per capita GNI between 4466 and 13,845 USD are upper middle income and per capita GNI of 13,846 USD or more are considered high-income countries. This study also considers stable and unstable cluster samples based on the Lilien index value. Since high or low value of structural transformation can affect SDI in different ways, the study first uses K means clustering to divide countries into two clusters. The study first considers the initial year 2000 and end year 2019 and then selects these two clusters. However, since there are several countries which move between clusters within these 20-year period, this study considers stable and unstable cluster. The stable cluster is the one where countries remain in the same cluster throughout the period. This indicates that stable cluster countries have either high or low structural transformation. The unstable cluster is the one where countries move from high to low or low to high structural transformation throughout the period. Among the total sample, there are 13 countries which fall within unstable cluster and 109 countries which are within the stable cluster. Table 29 also provides the countries using the cluster classification.

Our dependent variable is sustainable development. This variable comes from Hickel and Kallis (2020). It is an index calculated by the following formula:

$$\mathrm{SDI} = \frac{\mathrm{DEV}I}{\mathrm{EII}}$$

Here, SDI refers to the sustainable development index, DEVI refers to the index of development and EII is ecological impact index. The DEVI is again an index based on education, income as well as life expectancy. For calculating ecological impact index, two variables are used such as CO2 emission and material footprint.

The main independent variable is the structural transformation which is measured by Lilien index. The data for sectoral employment to calculate this index, as described in Lilien (1982), come from World Development Indicators (WDI). The Lilien index is generally accepted as an important indicator of structural transformation. This index expresses specialization, which is one of the main factors that plays a role in the reshaping of sectoral employment by structural transformations (Goschin et al. 2008). Many studies in the literature use the Lilien index to represent structural transformation (Garonna and Sica 2000; Zulkhibri et al. 2015; Chen et al. 2023). The following formula is used for constructing the Lilien index:

$$\mathrm{LI} = \left[\sum_{i=1}^{n} \frac{\mathrm{SE}_{it}}{\mathrm{SE}_{t}} \left(\Delta \ln \mathrm{SE}_{it} - \Delta \ln \mathrm{SE}_{t}\right)^{2}\right]^{1/2}$$

Here, LI implies Lilien index, SE is sectoral employment, sector is donated by i, whereas t denotes time dimension.

This study follows the economic model derived by Teixeira and Queirós (2016) where the authors modeled the effect of structural change on economic growth by incorporating other control variables such as population growth, investment, public consumption, and institutional quality variables. For institutional quality, we use Bayesian Corruption Index (BCI) variable which comes from the QOG database. The data for population growth is extracted from WDI. Population growth has a significant impact on society, the economy and the environment, and this increase poses some difficulties in achieving the SDGs (Lu et al. 2015). The data for government consumption comes from PWT, while the data for investment come from WDI. Based on this theoretical background, we expect that structural transformation, investment and government consumption will positively affect sustainable development. However, corruption and population are expected to have a detrimental impact on sustainable development.

The basic equation can be specified as follows:

$$\mathrm{SDI} = f(\mathrm{STR},\ \mathrm{BCI},\ \mathrm{POPG}, \mathrm{GOVC},\ \mathrm{INV})$$

Here, SDI, STR, BCI, POPG, GOVC and INV refer to sustainable development index, structural transformation, Bayesian corruption index, population growth, government consumption and investment, respectively. For country i at time t, Eq. 1 can be specified as:

$$\mathrm{SDI}_{it} = a_0 + a_1\mathrm{STR}_{it} + a_2\mathrm{BCI}_{it} + a_3\mathrm{POPG}_{it} + a_4\mathrm{GC}_{it} + a_5\mathrm{INV}_{it} + \in_{it} \tag{1}$$

All the variables have been logged to take care of heteroscedasticity.

3.2 Methodology

This study utilizes two-step system GMM estimation technique as opposed to standard panel data model such as fixed or random effect (Hu et al. 2022). In the GMM method introduced by Arellano and Bond (1991), a nonlinear dynamic panel model is estimated with first differenced series. However, the first difference transform is still weak when time dimension is smaller and using unbalanced panel data. For this reason, system GMM developed by Arellano and Bover (1995) is recommended instead of using first differenced data. Blundell and Bond (1998) argued that the tools of the GMM model revealed by Arellano and Bond (1991) do not solve the endogeneity problem. A system-based approach has been suggested to overcome this problem. In the GMM and System GMM models, single-stage error conditions are assumed to be homoscedastic and independent in terms of observations and time. However, in the second phase, obtained residues are used to create a consistent variance–covariance matrix estimation. Thus, the two-stage estimator becomes much more asymptotic and efficient as it smooths the assumptions of independence and homoscedasticity (Baltagi 2005; Khadraoui and Smida 2012). With the improvements made by Bun and Windmeijer (2010), a finite sample correction is provided to the two-stage covariance matrix and it was proved that the two-stage estimator will give more robust results than the one-stage estimator. Arellano (2003) illustrated the GMM model as in Eq. 2.

$$Y_{it} = Y_{i(t-1)} + x_{it}\beta + n_i + u_{it} \quad \text{and} \quad E(u_{it}|x_{i1}, \ldots\ldots, x_{iT}n_i) = 0(t = 1, \ldots\ldots, T) \tag{2}$$

Equation 2 shows the lagged values of X and Y. One-stage estimation (GMM1) accepts that error terms have constant variance between groups and time, while two-stage estimation (GMM2) considers that error terms can have varying variance (Windmeijer 2005). Arellano and Bond (1991) show a dynamic panel data model analyzed via GMM approach as seen in Eq. 3.

$$Y_{it} = Y_{i(t-1)}a_1 + Y_{i(t-p)}a_p + x_{it}b_1 + w_{it}b_2 + v_1 + e_{it} \quad \text{and} \quad i = [1, \dots, N], t = [1, \dots, N] \tag{3}$$

In Eq. (3), $a_1 \cdots a_p$ shows the parameters to be estimated. x_{it} represents exogenous variables in the $(1{*}k1)$ vector. b_1 represents the parameters to be estimated in the $(k1{*}1)$ vector. w_{it} represents the predicted variables in the vector $(1{*}k2)$. b_2 represents the parameters to be estimated in the vector $(k2{*}1)$. Finally, v_1 shows random effects.

We employ the Driscoll–Kraay estimator (DSK) for robustness check to strengthen the empirical analysis. In the model estimated by the fixed effects panel data method, the existence of autocorrelation and heteroscedasticity issues could emerge. In this direction, the Driscoll–Kraay estimator, which gives robust results in the presence of heteroscedasticity, autocorrelation and inter-unit correlation. This approach provides a Newey–West-type correction for the series of cross-section means (Tatoğlu 2012). The fixed effect technique can also control for the time invariant characteristics (Gao and Petrova 2022; Gao et al. 2023; Wang and Tao 2023).

4 Results and discussion

Table 1 depicts the descriptive statistics of all the parameters. We can see that the highest mean is observed in case of BCI, followed by population growth and SDI. Table 2 provides a correlation matrix for the full sample. While the dependent variable has correlation with independent variables, there is no high degree of correlation (above 0.9) between the independent variables. It can be seen that BCI has a negative correlation with GOVC and INV, meaning that there are negative association between corruption and government consumption and between corruption and investment. This indicates that institutional quality factors can provide significant influences on both government consumption and investment (Table 2).

Table 3 shows two-step GMM and Driscoll–Kraay Standard Errors results for all countries in the panel. According to the findings, while lnGOVC, lnBCI and lnINV have a negative impact on lnSDI, lnSTR and lnPOP affect LNSDI positively. The

Table 1 Descriptive statistics of full sample

Variable	Mean	SD	Min	Max
lnSDI	− 0.62338	0.406759	− 2.53831	− 0.159
lnSTR	− 1.74682	0.803822	− 5.3544	0.736184
lnBCI	3.762252	0.494516	1.86413	4.30573
lnPOPG	1.745904	0.238991	− 0.36769	3.09341
lnINV	− 1.4122	0.337364	− 6.66324	− 0.13778
lnGOVC	− 1.81205	0.415487	− 5.25762	− 0.61907

Table 2 Correlation matrix of full sample

	lnSDI	lnSTR	lnBCI	lnPOPG	lnINV	lnGOVC
lnSDI	1					
lnSTR	0.1853	1				
lnBCI	0.5757	0.1708	1			
lnPOPG	− 0.174	− 0.054	0.1021	1		
lnINV	− 0.2507	− 0.057	− 0.3494	0.0259	1	
lnGOVC	0.1367	0.009	− 0.0208	− 0.3492	0.0065	1

Table 3 Two-step system GMM and Driscoll–Kraay standard errors results of full sample

Variables	Two-step system GMM	DSK fixed effects regression
	Coefficient	Coefficient
L. lnSDI	1.126*** (− 0.0166)	–
lnSTR	0.00802*** (− 0.0016)	0.0638*** (0.019564)
lnBCI	− 0.0452*** (− 0.00806)	− 0.664*** (0.224799)
lnPOPG	0.0801*** (− 0.00691)	0.0703** (0.028207)
lnINV	− 0.00262** (− 0.00108)	− 0.0168* (0.009509)
lnGOVC	− 0.0119*** (− 0.00269)	0.0228** (0.010051)
Constant	0.110*** (− 0.0299)	2.658*** (0.816558)
AR(2) *P* value	0.951	
Hansen test *P* value	0.415	
Sargan test *P* value	0.673	
Wald χ^2	668,635.81***	
F statistics		31.36***
R^2		0.342

***, **, * implies significance at 1%, 5% and 10% respectively. Standard errors are in parenthesis

DSK regression result also agrees with most of the findings except for the government consumption variable which depicts positive influence for sustainable development. However, our main focus is the two-step system GMM regression since it can take care of endogenous relationship between structural transformation and sustainable development. Table 3 also shows the p value for several post diagnostic tests of system GMM which prove that the performance of two-step system GMM model is robust and satisfactory. AR(2) *p* value shows no rejection of the null hypothesis of no second order serial correlation and Hansen test can also not reject the null of exogenous instruments proving that instruments used are valid. From Table 4, it can also be deducted that model does not suffer from multicollinearity as VIF value is less than 10.

These results have some economic implications. The effect of structural transformation on sustainable development is positive. This finding indicates that structural transformation is an efficient tool for achieving the SDGs since it creates positive

Table 4 VIF and tolerance values for full sample

Variable	VIF	1/VIF
lnSTR	1.05	0.956864
lnBCI	1.27	0.788216
lnPOPG	1.23	0.809929
lnINV	1.12	0.889581
lnGOVC	1.12	0.88921
Mean VIF	1.16	

environmental consequences. Firstly, the positive impact of lnSTR will decrease environmental pollution and help achieve SDGs and combat climate change (Goal 7 and Goal 13). It will also support sustainable growth through productivity. This assumption supports our empirical finding. Especially in developed countries, high level of knowledge, skills and technology, triggers structural transformation and environmental quality (Mealy and Teytelboym 2020). This basically means productivity and increase in per capita output. The positive impact of structural transformation refers to high productivity (Vu 2017; Erumban et al. 2019), energy efficiency and environmental quality (Wing and Eckaus 2007; Xu et al. 2007; Zhou et al. 2021) which are promoters of the sustainable development. In an empirical study, Mulder et al. (2014) have found that OECD countries' shift toward the service sector has reduced overall trend of energy intensity, which implies the improvement in environmental quality and consequently sustainable development. Erumban et al. (2019), on the other hand, supported the proposition that structural change or structural shift boosts productivity development, and Mostolizadeh and Salimi (2021) and Le Caous and Huarng (2020) found that structural change supports human development significantly. According to theoretical arguments as proposed in Avenyo and Tregenna (2022), reduction in manufacturing sector share and expansion of the service industry will provide less emissions. Further, Zhang et al. (2014) and Zhu et al. (2017) have found that structural change which favors the service sector can bring down carbon emission and thereby promote sustainable development.

Corruption has a negative effect on sustainable development as we expected since it is one of the important barriers that hinder the achievement of sustainable development. Because it undermines institutional indicators such as democracy, law and order, accountability, and political stability. Furthermore, corruption negatively affects economic development, especially by damping national income (Reinikka and Smith 2004). Therefore, it is essential to fight against corruption. A decrease in corruption can decrease child and infant mortality rates (Gupta et al. 2001) which can pave the way for reaching Goal 3. In addition, anti-corruption policies can contribute to increasing environmental sustainability (Liao et al. 2017; Zandi et al. 2019; Haseeb and Azam 2021; Akalin et al. 2021). In conclusion, anti-corruption policies can be an effective tool for achieving Goal 16 which refers to accountable and inclusive institutions. The findings also bear a resemblance to those studies (Frolova et al. 2019; Fanea-Ivanovici et al. 2019; Syaifudin et al. 2021). Moreover, corruption hampers human development by negatively affecting the spending of government on health and education and it also has negative impact on private investment, growth, human capital and equality. Corruption also has negative outcomes for environmental quality as it can weaken the stringency of energy and environmental policies, attracting dirty firms which pollute the environment. The existence of corrupt officials may weaken environmental regulations, and as a result, these non-stringent environmental regulations can produce higher pollutant emissions. An increase in corruption can also significantly increase the carbon emissions level of a country.

Population growth has been studied as an important variable in many environmental sustainability studies (Liddle and Lung 2010; Wang et al. 2013; Uddin et al. 2016). According to the findings of this study, population growth affects sustainable development positively, therefore it might be a tool to achieve the SDG agenda. Population growth promotes technological innovation, which decouples the negative impact on the environment (Boserup 1981). The positive correlation between population and sustainable growth is also supported by (Yang et al. 2021). Population growth can enable a country to have better health, better performance of human capital as well as better education, which can enhance sustainable development. The increase in population can help drive the environmental degradation down via the expansion of natural resources in a country for indefinite periods. Moreover, it can help sustainable development through savings of energy and decreased carbon emissions (Meng et al. 2023). According to Herrmann (2012), the growth of population has the capacity to increase the stakes of the global efforts toward decreasing poverty, providing energy and food security, creating employment as well as safeguarding the environmental quality. The fact that population growth has a positive impact on sustainable development can also be explained by the theory of Kuznets (1960). According to Kuznets (1960), growth of population may induce higher technological innovation. He argued that if there is constant proportion of geniuses in a population, this will result in larger number of geniuses in an economy as the population continues to increase. With human innovation supported by the geniuses, many economies can stretch their resources for an indefinite period and foster their social, economic and environmental progress.

The other significant findings are the negative impact of government or public consumption and investments on sustainable development. The negative impact of public consumption on sustainable development can be explained by the fact that high level of public sector consumption can produce inefficiencies, crowding our effect and market distortions, which in turn negatively affect the sustainable development and growth (Teixeira and Queirós 2016). This result matches the findings of a seminal work by Barro (1991) and recent works such as Dreher (2006), Batten and Vo (2009), Afonso and Jalles (2014) and Teixeira and Queirós (2016). We can also conclude that the government expenditures are not environmentally friendly and do not support environmental sustainability which inhibits Goal 7 and Goal 13. The negative relationship between government consumption and environmental quality is also confirmed for Malaysia (Samah et al. 2021), the Emerging Market and Developing Economies (Le and Ozturk 2020), the top 40 CO_2 emitting countries

Table 5 Descriptive statistics of low-income sample

Variable	Mean	SD	Min	Max
lnSDI	− 0.71143	0.182315	− 1.23787	− 0.27312
lnSTR	− 1.8739	0.743014	− 4.20155	0.2066
lnBCI	4.06384	0.138697	3.72429	4.28193
lnPOPG	1.929672	0.220636	0.824849	2.29284
lnINV	− 1.64999	0.346903	− 2.56277	− 0.61676
lnGOVC	− 1.9358	0.449582	− 3.90215	− 1.05338

Table 6 Correlation matrix of low-income sample

Variables	lnSDI	lnSTR	lnBCI	lnPOPG	lnINV	lnGOVC
lnSDI	1					
lnSTR	0.2647	1				
lnBCI	0.0059	− 0.075	1			
lnPOPG	0.0843	− 0.2202	0.4496	1		
lnINV	− 0.0768	0.0308	− 0.1279	− 0.0488	1	
lnGOVC	0.1564	0.2318	− 0.1434	− 0.3994	0.0002	1

(Adewuyi 2016), Venezuela (Mohammed Saud et al. 2019) and China (Yuelan et al. 2019).

The result also shows that public investment (physical capital formation) in these countries is not efficient in terms of sustainability. This is expected since investments require energy consumption and lead to environmental degradation. The result does not match with the seminal finding of Barro (1991) where the author concluded that high level of capital formation can positively result in the productivity of production frontiers. However, our result is in line with the study of Mehrara and Musai (2013) where the authors discovered that investment does not drive growth rate in either the long or short run. Aslan and Altinoz (2021) have also concluded in their study that capital formation or investment has negative effect on growth, and as a result, it hinders sustainable development. The negative relationship between corruption and government consumption and between corruption and investment can also be explained by the correlation matrix presented in Table 2. The correlation matrix demonstrates that corruption has a negative association with both government consumption and investment. Therefore, it can be concluded that corruption can hinder sustainable development directly and also indirectly through its effects on government consumption and investment.

Now, we divide the full sample into low, lower middle, upper middle and high-income countries. First, we specifically reported the system GMM results for each income group. Tables 5, 6, 7 and 8 present the descriptive statistics, correlation matrix, system GMM result and DSK result, and VIF and tolerance values, respectively. From the descriptive statistics, the highest mean value is observed for lnBCI followed by lnPOPG. The correlation matrix also shows no high correlation between

Table 7 Two-step system GMM and Driscoll–Kraay standard errors results of low-income sample

Variables	Two-step system GMM	DSK fixed effects regression
L. lnSDI	1.101*** (0.0212)	–
lnSTR	0.0135** (0.00679)	0.204*** (0.0572)
lnBCI	− 1.384*** (0.0628)	− 1.747*** (0.211)
lnPOPG	0.325*** (0.0318)	0.241 (0.165)
lnINV	− 0.0161 (0.0161)	− 0.0416 (0.0366)
lnGOVC	0.0189 (0.0185)	0.108*** (0.0225)
Constant	4.688*** (0.198)	6.728*** (0.752)
AR(2) P value	0.289	
Hansen test P value	1	
Sargan test P value	0.7	
Wald chi2	8599.33***	
		23.19***
R-squared		0.3268

***, ** imply significance at 1% and 5% respectively. Standard errors are in parenthesis

Table 8 VIF and tolerance values for low-income sample

Variable	VIF	1/VIF
lnSTR	1.07	0.933375
lnBCI	1.26	0.791573
lnPOPG	1.44	0.694313
lnINV	1.02	0.982263
lnGOVC	1.21	0.829532
Mean VIF	1.2	

the independent variables. The mean value of VIF being 1.2 also proves that there is no presence of multicollinearity issue.

According to the results of system GMM in Table 7, the results of lnSTR, lnBCI and lnPOPG in low-income category match the finding of the full sample. However, for the low-income category, both the lnINV and lnGOVC have insignificant impact on lnSTR. The results are further validated by the DSK estimation as the signs are similar across both estimation techniques, although significance levels vary. The results of lnINV and lnGOVC prove that they do not have any significant effects on sustainable development of low-income countries, and it could be because of the low level of governmental consumption and investment in these economies.

Now, the descriptive statistics, correlation matrix, two-step system GMM and DSK results as well as VIF results are presented for lower middle-income category in Tables 9, 10, 11 and 12, respectively. The correlation matrix shows no evidence of high correlation between the independent variables. The results of VIF and tolerance prove no issues of multicollinearity. Now, the results of system GMM suggest that the effects of lnSTR and lnBCI match the finding of the full sample except for

Table 9 Descriptive statistics of lower middle-income sample

Variable	Mean	SD	Min	Max
lnSDI	– 0.48825	0.182474	– 1.15201	– 0.17079
lnSTR	– 1.59948	0.852126	– 5.3544	0.528438
lnBCI	4.058675	0.131067	3.45182	4.25891
lnPOPG	1.827103	0.169613	1.03725	2.11028
lnINV	– 1.5411	0.365589	– 2.91663	– 0.13778
lnGOVC	– 1.92422	0.526545	– 5.25762	– 0.61907

Table 10 Correlation matrix of lower middle-income sample

Variables	lnSDI	lnSTR	lnBCI	lnPOPG	lnINV	lnGOVC
lnSDI	1					
lnSTR	0.0326	1				
lnBCI	– 0.3148	– 0.0046	1			
lnPOPG	– 0.5597	– 0.0965	0.1994	1		
lnINV	0.0326	– 0.0676	– 0.0926	0.1612	1	
lnGOVC	0.3361	– 0.0373	– 0.0941	– 0.2122	– 0.0967	1

Table 11 Two-step system GMM and Driscoll–Kraay standard errors results of lower middle-income sample

Variables	Two-step system GMM	DSK fixed effects regression
L. lnSDI	0.853*** (0.00706)	–
lnSTR	0.00182 (0.00182)	0.00624 (0.0205)
lnBCI	– 0.307*** (0.0161)	– 2.188*** (0.126)
lnPOPG	– 0.189*** (0.0127)	– 0.365*** (0.0374)
lnINV	0.00688*** (0.000948)	0.0551** (0.0248)
lnGOVC	0.0101*** (0.000959)	0.110*** (0.00693)
Constant	1.598*** (0.0834)	9.101*** (0.537)
AR(2) *P* value	0.695	
Hansen test *P* value	0.112	
Sargan test *P* value	0.403	
Wald χ^2	353,394.77***	
F stat		64.69***
R^2		0.2107

***, ** imply significance at 1% and 5% respectively. Standard errors are in parenthesis

the fact that the role of structural transformation is insignificant. However, the population growth's impact is negative, while the effects of investment and government consumption are positive on sustainable development. The results of the population growth can be explained by the Harrod Domar model and Solow model. According

Table 12 VIF and tolerance values for lower middle-income sample

Variable	VIF	1/VIF
lnSTR	1.02	0.984111
lnBCI	1.05	0.950726
lnPOPG	1.11	0.904742
lnINV	1.06	0.943761
lnGOVC	1.05	0.953743
Mean VIF	1.06	

to Harrod Domar model, growth of population negatively affects the per capital income growth when there are no diminishing returns to capital. Moreover, Solow (1956, 1957) explained that per capita income can be lowered when there is increase in growth of population which is exogenous and it would be translated into labor supply growth, which would ultimately outpace the capital formation growth. Moreover, sustainable economic development can be hampered because of the increasing size of population and structure of population such as high child dependency ratios (Das Gupta et al. 2011). Sustainable development can also be undermined by the growth of the population when they start to exert pressure on natural resources and services (Ping and Shah 2023). This finding is in line with Shittu et al. (2021). Regarding the impact of investment, it is seen to increase development since it can contribute positively toward the production factors' productivity in this income category (Barro 1991). Regarding government consumption, our result matches the finding by Azam et al. (2023) where the authors discovered that government consumption can increase sustainability. The DSK regression validates the finding from system GMM.

Tables 13, 14, 15 and 16 present the descriptive statistics, correlation table, regression results and multicollinearity results for upper middle-income category. The correlation table shows that there is no high degree of correlation. The VIF and tolerance values prove the absence of multicollinearity. The signs of system GMM in Table 11 for all the variables except for lnINV match the findings of the full sample. The variable lnINV has a positive yet insignificant impact on sustainable development. This could be due to the existence of insufficient government investment to promote sustainable development in these countries. The signs of DSK regression match with the findings of system GMM except for the lnINV and lnGOVC which are additional control variables in our study. This could be due to the inherent mechanism of the two-step system GMM technique which has the ability to handle endogeneity and is robust and efficient estimation compared to DSK model.

Table 13 Descriptive statistics of upper middle-income sample

Variable	Mean	SD	Min	Max
lnSDI	− 0.37459	0.200401	− 1.38629	− 0.159
lnSTR	− 1.67578	0.714616	− 4.91425	0.578918
lnBCI	3.962963	0.19239	3.37311	4.30573
lnPOPG	1.704527	0.208086	0.862595	2.40687
lnINV	− 1.40981	0.337498	− 6.66324	− 0.65499
lnGOVC	− 1.72676	0.349097	− 3.09869	− 0.77821

Table 14 Correlation matrix of upper middle-income sample

Variables	lnSDI	lnSTR	lnBCI	lnPOPG	lnINV	lnGOVC
lnSDI	1					
lnSTR	− 0.0008	1				
lnBCI	0.1257	0.0362	1			
lnPOPG	− 0.1417	− 0.2041	− 0.0816	1		
lnINV	− 0.2163	− 0.0399	− 0.229	0.2798	1	
lnGOVC	− 0.2947	− 0.1024	− 0.1309	− 0.223	0.0013	1

Table 15 Two-step system GMM and Driscoll–Kraay standard errors results of upper middle-income sample

Variables	Two-step system GMM	DSK fixed effects regression
L. lnSDI	1.226*** (0.0151)	–
lnSTR	0.00656* (0.00367)	0.0186*** (0.00507)
lnBCI	− 1.288*** (0.0181)	− 1.226*** (0.136)
lnPOPG	0.0544*** (0.0198)	0.0717 (0.0422)
lnINV	0.000541 (0.00223)	− 0.0469 (0.0308)
lnGOVC	− 0.00193 (0.0147)	0.119*** (0.0376)
Constant	4.747*** (0.0803)	5.523*** (0.682)
AR(2) *P* value	0.37	
Hansen test *P* value	0.71	
Sargan test *P* value	0.61	
Wald χ^2	228,189.76***	
F stat		565.06***
R^2		0.0849

***, * implies significance at 1% and 10% respectively. Standard errors are in parenthesis

Table 16 VIF and tolerance values for upper middle-income sample

Variable	VIF	1/VIF
lnSTR	1.07	0.930598
lnBCI	1.08	0.928416
lnPOPG	1.23	0.813996
lnINV	1.13	0.887777
lnGOVC	1.13	0.883328
Mean VIF	1.13	

The results for high-income sample are presented in Tables 17, 18, 19 and 20 which provide descriptive statistics, correlation, regression results and multicollinearity results. Correlation matrix shows no evidence of high correlation between the independent variables. The coefficient signs match the findings of the full sample

Table 17 Descriptive statistics of high-income sample

Variable	Mean	SD	Min	Max
lnSDI	− 0.90845	0.512169	− 2.53831	− 0.19723
lnSTR	− 1.88774	0.823065	− 4.93412	0.736184
lnBCI	3.275706	0.544105	1.86413	4.10338
lnPOPG	1.670643	0.258656	− 0.36769	3.09341
lnINV	− 1.24303	0.199703	− 2.21396	− 0.48518
lnGOVC	− 1.76457	0.322622	− 3.10517	− 1.14546

Table 18 Correlation matrix of high-income sample

Variables	lnSDI	lnSTR	lnBCI	lnPOPG	lnINV	lnGOVC
lnSDI	1					
lnSTR	0.2001	1				
lnBCI	0.4848	0.206	1			
lnPOPG	− 0.3423	0.0515	− 0.2364	1		
lnINV	− 0.3318	0.0345	− 0.1747	0.3539	1	
lnGOVC	0.3422	0.0901	0.2643	− 0.4451	− 0.1802	1

Table 19 Two-step system GMM and Driscoll–Kraay standard errors results of high-income sample

Variables	Two-step system GMM	DSK fixed effects regression
L. lnSDI	1.291*** (0.107)	–
lnSTR	0.0254* (0.0132)	0.140*** (0.0409)
lnBCI	− 1.379*** (0.103)	− 0.531*** (0.178)
lnPOPG	0.271** (0.110)	− 0.0412 (0.0796)
lnINV	− 0.0158 (0.0517)	− 0.373*** (0.119)
lnGOVC	− 0.0319 (0.0465)	− 0.271* (0.131)
Constant	4.949*** (0.335)	2.037** (0.898)
AR(2) *P* value	0.415	
Hansen test *P* value	0.605	
Sargan test *P* value	0.194	
Wald χ^2	10,646.22	
F stat		279.31***
R^2		0.1531

***, **, * implies significance at 1%, 5% and 10% respectively. Standard errors are in parenthesis

as lnSTR and lnPOPG have positive impacts while other variables have negative impacts on sustainable development. The coefficients of lnGOVC and lnINV are negative but insignificant. The multicollinearity results also do not provide any evidence of multicollinearity.

Table 20 VIF and tolerance values for high-income sample

Variable	VIF	1/VIF
lnSTR	1.06	0.941984
lnBCI	1.13	0.882657
lnPOPG	1.19	0.841102
lnINV	1.05	0.951905
lnGOVC	1.25	0.800635
Mean VIF	1.14	

Now, Tables 21, 22, 23 and 24 present descriptive statistics, correlation, regression results and multicollinearity results for the stable cluster. The correlation matrix yet again shows no evidence of high collinear relationship between the independent variables, while VIF and tolerance values also provide no evidence of multicollinearity.

The result of the system GMM shows that STR affects the SDI positively in the stable cluster. It indicates that countries which have stable structural transformation throughout the years can enjoy higher sustainable development. BCI shows negative impact as expected and POPGR shows positive impact while INV and GOVC show no significant impact. Almost of the results of DSK match well with the findings from system GMM technique.

Tables 25, 26, 27 and 28 present descriptive statistics, correlation, regression results and multicollinearity results for the unstable cluster. Once again, there is no high correlation between the independent variables and VIF and tolerance shows no evidence of multicollinearity. The system GMM shows that STR affects the SDI negatively, but no significant impact is detected. This is an indication

Table 21 Descriptive statistics of stable cluster

Variable	Mean	SD	Min	Max
lnSDI	− 0.63034	0.415856	− 2.53831	− 0.159
lnSTR	− 1.81183	0.776369	− 5.3544	0.736184
lnBCI	3.761426	0.489124	1.86413	4.30573
lnPOPG	1.752068	0.233599	− 0.36769	3.09341
lnINV	− 1.41318	0.339006	− 6.66324	− 0.13778
lnGOVC	− 1.82631	0.418159	− 5.25762	− 0.61907

Table 22 Correlation matrix of stable cluster

Variables	lnSDI	lnSTR	lnBCI	lnPOPG	lnINV	lnGOVC
lnSDI	1					
lnSTR	0.1841	1				
lnBCI	0.5903	0.1531	1			
lnPOPG	− 0.1772	− 0.0618	0.1054	1		
lnINV	− 0.2581	− 0.0457	− 0.3445	0.0289	1	
lnGOVC	0.1493	− 0.011	− 0.0016	− 0.3602	− 0.0149	1

Table 23 Two-step system GMM and Driscoll–Kraay standard errors results of stable cluster

Variables	Two-step system GMM	DSK fixed effects regression
L. lnSDI	1.302*** (0.06)	–
lnSTR	0.027*** (0.007)	0.027*** (0.008)
lnBCI	− 1.426*** (0.085)	− 0.731*** (0.076)
lnPOPG	0.245*** (0.071)	0.013 (0.026)
lnINV	− 0.005 (0.006)	− 0.143*** (.025)
lnGOVC	− 0.012 (0.01)	0.012 (0.016)
Constant	5.021*** (0.237)	− 0.140** (0.052)
AR(2) *P* value	0.46	
Hansen test *P* value	0.24	
Sargan test *P* value	0.119	
Wald χ^2	4443.84***	
F stat		35.41
R^2		0.4266

***, ** imply significance at 1% and 5% respectively. Standard errors in parenthesis

Table 24 VIF and tolerance values of stable cluster

Variable	VIF	1/VIF
lnSTR	1.03	0.972216
lnBCI	1.07	0.937505
lnPOPG	1.14	0.877957
lnINV	1.06	0.941967
lnGOVC	1.13	0.885425
Mean VIF	1.09	

Table 25 Descriptive statistics of unstable cluster

Variable	Mean	SD	Min	Max
lnsdi	− 0.56502	0.315133	− 1.60944	− 0.18995
lnli	− 1.20196	0.824531	− 4.18627	0.578918
lnbci	3.769179	0.538567	1.95546	4.28193
lnpopgrowth	1.694224	0.275267	0.899631	2.47566
lninvestment	− 1.40392	0.323776	− 2.38839	− 0.6892
lngovcons	− 1.68172	0.369907	− 2.9333	− 0.98235

that if countries move from high to low or low to high structural transformation throughout the years, it might not be able to benefit from sustainable development. The BCI shows negative impact while POPGR shows positive impact. Moreover, lnINV has a negative influence on SDI while lnGOVC shows no significant effect on SDI. The result of DSK regression for lnSTR and lnBCI match the findings from system GMM regression.

Table 26 Correlation matrix of unstable cluster

Variables	lnSDI	lnSTR	lnBCI	lnPOPG	lnINV	lnGOVC
lnSDI	1					
lnSTR	0.1329	1				
lnBCI	0.4704	0.328	1			
lnPOPG	− 0.1275	0.1239	0.0858	1		
lnINV	− 0.18	− 0.1848	− 0.3924	0.0103	1	
lnGOVC	− 0.0793	− 0.0675	− 0.1938	− 0.2269	0.2091	1

Table 27 Two-step system GMM and Driscoll–Kraay standard errors results of unstable cluster

Variables	Two-step system GMM	DSK fixed effects regression
L. lnSDI	1.281*** (0.045)	–
lnSTR	− 0.019 (0.032)	− 0.013 (0.008)
lnBCI	− 1.361*** (0.047)	− 0.295** (0.069)
lnPOPG	0.278*** (0.071)	− 0.083*** (0.022)
lnINV	− 0.04** (0.02)	0.007 (0.010)
lnGOVC	0.001 (0.012)	0.027** (0.011)
Constant	4.696*** (0.131)	− 0.607*** (0.005)
AR(2) *P* value	0.108	
Hansen test *P* value	1.000	
Sargan test *P* value	0.300	
Wald χ^2	38,683.03***	
F stat		9.44***
R^2		0.3435

***, ** imply significance at 1% and 5% respectively. Standard errors in parenthesis

Table 28 VIF and tolerance values of unstable cluster

Variable	VIF	1/VIF
lnSTR	1.24	0.8085
lnBCI	1.23	0.815471
lnPOPG	1.18	0.849666
lnINV	1.12	0.889532
lnGOVC	1.12	0.890238
Mean VIF	1.18	

5 Conclusion and recommendations

The aim of this study is to examine the relationship between structural transformation and social, economic and environmental progress on a global scale. For this purpose, we examine 122 countries and six sub-groups for the 2000–2019 period by using the two-step system GMM approach. To the best of our knowledge, this study is the most detailed study examining the relationship between structural transformation and the progress of society, environment and economy (captured by sustainable development). First of all, we present empirical findings for the whole sample. Secondly, we divided the full sample into low, lower middle, upper middle and high-income countries and stable and unstable clusters based on the value of structural transformation. In this way, we compare the results by considering countries' development levels and their structural transformation level. Considering 122 countries in the panel, the overall findings show that while corruption, government consumption and investments have a negative impact on the progress of society, environment and economy, structural transformation and population affects such progress positively. Therefore, it can be seen that our main variable, structural transformation, affects sustainable development positively which means global production and consumption patterns are environmentally friendly. Negative impacts of investments government consumption are also in line with the expectations since they promote economic growth and energy consumption. Government spending means more investments and more energy consumption. Secondly, investments are one of the main promotors of economic growth. However, it leads to more energy consumption and environmental pollution. Finally, government spending due to populist policies can lead to environmental pollution, income inequality, corruption and waste of resources, which will undermine realizing SDGs. In addition, a negative relationship between corruption and sustainable growth is consistent with the theoretical expectations since it creates negative externalities and waste of resources. The positive impact of population can be explained as it promotes technological innovation (Boserup 1981) and helps to achieve sustainable growth by creating green production patterns.

For sub-sample groups, the results are reported as below:

(i) While corruption has a negative impact on sustainable development, structural transformation and population affect sustainable development positively in low-income countries.
(ii) Corruption and population growth have a negative impact on sustainable development. However, government consumption, investments, and structural transformation impact sustainable growth positively in lower middle-income countries. However, the impact of structural transformation is insignificant.
(iii) Structural transformation and population growth have a positive impact on sustainable development; however, corruption affects it adversely in upper middle-income countries.
(iv) Structural transformation and population growth have a positive impact on sustainable development in high-income sample. However, corruption affects sustainable development negatively.
(v) Structural transformation and population growth have positive impacts on social, economic and environmental progress while corruption hinders them in stable cluster. In comparison, structural transformation has negative yet insignificant impact on their progress in unstable cluster. Corruption and investment have negative impacts, while population affects progress of society, economy and environment positively.

Empirical findings on sub-sample clearly show that structural transformation contributes to the progress of society, economy and environment in majority of the groups, while corruption adversely affects such progress. Therefore, regardless of the income and development of a country, policymakers could use long-term structural transformation and anti-corruption strategies to achieve SDGs. Accordingly, while economic growth negatively affects the environment at the beginning of the development process, after reaching a threshold level it affects environmental quality positively (Panayotou 1997). The insignificant negative impact of investments in low-income countries might be attributed to the Pollution Haven Hypothesis. This hypothesis states that developed countries outsource polluted production to less developed and developing countries through foreign direct investment (Copeland and Taylor 1994; Cole 2004; Taylor 2005; Sofuoğlu 2017) since environmental standards are lower in these countries.

Our study shows that structural transformation can be used as a policy tool to achieve SDGs. However, each country group should apply different strategies as empirical findings vary by income group. Low-income countries need to accelerate economic growth. Developing countries have been trying to establish sustainable economic growth. Therefore, these countries will probably utilize cheap fossil fuel resources in the near future. For this reason, low-emission and climate-resilient projects should be supported urgently. In addition, countries should adhere to the Paris Agreement to achieve SDGs. The problem of fair distribution of responsibilities should be resolved in the Paris Agreement. Moreover, the secretariat should follow the developments about nationally determined contributions (NDCs) submitted to the UNFCCC to reduce emissions and tackle climate change (UNFCCC 2015). It is also important to have a smooth structural transformation to realize its benefits on the society, economy and environment as the stable cluster seems to be positively benefiting from such transformation. Therefore, governments should provide incentives for investment in making a smooth transition toward a sustainable structural transformation process. For example, if the economy is already a service-based economy, it should try to maintain this position to achieve its SDG agenda. Therefore, governments should implement policies, build infrastructures, provide incentives for innovation, and facilitate international cooperation to proceed toward smooth and stable structural transformation. They should also monitor and evaluate the progress of such transformation on an annual basis since any deviation from such a system will lead to a decline in its sustainable development progress. Furthermore, the governments must create healthier working conditions so that innovative and creative activities can be promoted to foster real economic sustainable development (Gao et al. 2020).

Developed countries have more advantages in achieving SDGs. However, these countries should solve the outsourcing issues. Therefore, long-term policies should be applied to lower their material footprint. Outsourcing dirty material-intensive productions to less developed and developing countries might be an advantage for developed countries (Stern et al. 1994; Suri and Chapman 1998); however, it is not a real solution to reduce emissions, fight against climate change and achieve SDGs. It is also important that reducing material footprint is directly related to the structural transformation, which considers import/export structure in terms of carbon intensity. Outsourcing could become cleaner thanks to the taxes via the carbon border adjustment mechanism under the framework of the European Green Deal (Karakaya et al. 2021). The key point here is that outsourcing countries should develop various incentives for countries that manage to produce cleaner products. Providing efficient incentives to environmental patents could also help governments (Kirikkaleli et al. 2023) since it triggers structural transformation and provides clean energy. Reducing material footprint and improving structural transformation will pave the way for SDGs (Goal 7, Goal 8, Goal 9, Goal 11, Goal 12., Goal 13 and Goal 15). For a sustainable global temperature, emissions must be net zero by 2050. In this context, the Paris Agreement and the European Green Deal provide guidance for many countries in determining their climate change action policies.

Our finding also asks for the reduction in corruption since it affects sustainable development negatively in all income groups as well as in full sample. Therefore, anti-corruption policies should be strengthened to fight corruption. Moreover, government awareness among the general public should be promoted regarding corrupt activities. Regarding the population, measures such as the one child policy should be promoted in lower middle-income economies since population has a negative impact for development. In this regard, governments in these economies should develop skilled laborers by providing sufficient quality education as well as training to offset the negative impact of population on sustainable development. Universal access to reproductive and sexual health care, family planning, education investment with strong emphasis on gender parity, women empowerment as well as integrating the projections of population in development policies might be some of the tools these lower middle-income economies can use to foster social, economic and environmental welfare in their region (Herrmann 2012).

In the majority of the income samples, public consumption and investments are not sufficient enough for promoting social, economic and environmental progress. Therefore, governments should provide technical and financial support so that public consumption and investments are directed toward the achievement of sustainable development goals (SDGs) and the conditions of society, environment and economy can improve.

This study is not without limitations. Because of the limited data availability, our study could not incorporate more periods and countries. Therefore, future research can incorporate long time series data to examine the relation between structural transformation and sustainable development. Moreover, additional measures of structural transformation such as economic complexity can be used for comparison purposes. The impact of structural transformation on sustainable development may also depend on other institutional factors. These factors can be modeled using threshold regression in future studies. Additionally, the correlation matrix showed that corruption may have negative correlation with consumption and investment. While examining this relationship is out of the scope for this study, future research may examine the relationship of corruption with government consumption and investment and provide crucial policy implications for sustainable development.

Appendix

See Table 29.

Table 29 List of countries included in the sample

Low income	Cluster	Lower middle income	Cluster	Upper middle income	Cluster	High income	Cluster
D.R. of the Congo	Stable	Philippines	Stable	Paraguay	Stable	Poland	Stable
Ethiopia	Stable	Republic of Moldova	Unstable	Peru	Stable	Portugal	Stable
Guinea	Stable	Senegal	Stable	Russian Federation	Stable	Qatar	Stable
Liberia	Stable	Sri Lanka	Stable	Serbia	Stable	Republic of Korea	Stable
Lithuania	Stable	Tunisia	Stable	South Africa	Stable	Saudi Arabia	Stable
Madagascar	Stable	U.R. of Tanzania: Mainland	Stable	Thailand	Stable	Singapore	Stable
Malawi	Stable	Ukraine	Stable	Turkey	Stable	Slovakia	
Mali	Stable	Uzbekistan	Stable	Turkmenistan	Stable	Slovenia	Unstable
Tajikistan	Stable	Viet Nam	Stable	Venezuela (Bolivarian Republic of)	Stable	Spain	
Togo	Stable	Zimbabwe	Stable	**High income**	Stable	Sweden	Stable
Uganda		**Upper middle income**	Stable	Australia	Stable	Switzerland	Stable
Yemen	Unstable	Albania	Stable	Austria	Stable	Trinidad and Tobago	Stable
Zambia	Stable	Argentina	Stable	Belgium	Stable	United Arab Emirates	Stable
Lower middle income	Stable	Armenia	Unstable	Canada	Stable	United Kingdom	Stable
Algeria	Stable	Azerbaijan	Stable	Chile	Stable	United States	Stable
Angola	Stable	Bosnia and Herzegovina	Stable	Croatia	Stable	Uruguay	Stable
Bangladesh	Stable	Botswana	Stable	Cyprus	Stable		
Bolivia (Plurinational State of)	Stable	Brazil	Stable	Czech Republic	Stable		
Burkina Faso	Unstable	Bulgaria	Stable	Denmark	Unstable		
Cambodia	Unstable	China	Stable	Estonia	Unstable		
Cameroon	Stable	Colombia	Stable	Finland	Stable		
Congo	Stable	Costa Rica	Stable	France	Stable		
Côte d'Ivoire	Stable	Dominican Republic	Unstable	Germany	Stable		
Egypt	Stable	Ecuador	Stable	Greece	Stable		

Table 29 (continued)

Low income	Cluster	Lower middle income	Cluster	Upper middle income	Cluster	High income	Cluster
El Salvador	Stable	Gabon	Stable	Hungary	Stable		
Ghana	Stable	Georgia	Stable	Ireland	Stable		
Honduras	Stable	Guatemala	Stable	Israel	Stable		
India	Stable	Indonesia	Stable	Italy	Stable		
Kenya	Stable	Iran (Islamic Republic of)	Stable	Japan	Stable		
Kyrgyzstan	Stable	Jamaica	Stable	Latvia	Unstable		
Lao People's DR	Stable	Jordan	Stable	Mauritius	Stable		
Mauritania	Stable	Kazakhstan	Stable	Netherlands	Stable		
Mongolia	Unstable	Lebanon	Stable	New Zealand	Stable		
Myanmar	Stable	Malaysia	Stable	Norway	Stable		
Nigeria	Stable	Mexico	Stable	Oman	Unstable		
Pakistan	Stable	Namibia	Unstable	Panama	Stable		

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