Competitio 2024. XXIII. évfolyam
doi: 10.21845/comp/2024/1-2/3

A non-stationary panel data approach for examining convergence in South Africa

STACEY-LEE MARAIS
PhD candidate, University of Szeged Faculty of Economics and Business Administration,
marais.stacey-lee@o365.u-szeged.hu

Economic convergence has received much attention since the 1980s when researchers tried to ascertain whether low-income countries would stay that way in the long run, or they would gain 'developmental traction' and become the affluent nations of the future. This article gives fresh insight on this topic from an African perspective by comparing 39 countries—South Africa, 32 Organisation for Economic Cooperation and Development (OECD) members and 6 Latin American countries. The author investigated their average steady-state equilibria and tested convergence trends from 1980 to 2019. The Solow–Swan model was tested. Furthermore, this study applies panel econometric modelling to determine the relationship between the variables analysed in the convergence analysis. This commenced with the Levin–Lin–Chu and Im–Pesaran–Shin panel unit root tests. Then, the Kao test and the vector error correction model were used to evaluate the cointegration and relationships between variables. The findings revealed that South Africa's economic performance is significantly lower than the OECD average gross domestic product per capita with an annual growth rate of 0.54%, which falls below the 'iron law of convergence' hypothesis.
Keywords: convergence, economic development, emerging economies, endogenous growth theory
JEL classifications: C01, C32, C33, E13, F62, F63

1. Introduction

The neoclassical convergence debate gained attention in mainstream econometrician circles during the 1980s (Sala-i-Martin, 1996)—first by Baumol (1986), then by Barro (1991) and Mankiw et al. (1992) and thereafter by Barro and

Sala-i-Martin (1995). Moreover, further investigation stems from the need for economists to answer several questions, one of which is whether poor countries will continue to be poor in the long term or whether they will catch up and be the rich nations of tomorrow. Sala-i-Martin (1996) posited two reasons for the increase in popularity of investigating this issue. First, it was put forward to test the validity of modern theories of economic growth and enabled the calculation of time estimates for convergence across economies. Second, macroeconomic data became more widely available, allowing international comparability across many nations and the plotting of the evolution of growth levels over a period (Sala-i-Martin, 1996). The investigation into the evolution of these growth levels gives impetus to the convergence hypothesis, assuming that the only difference between them is the initial levels of capital (Sala-i-Martin, 1996). Researchers (Barro & Sala-i-Martin, 1991; Mankiw et al., 1992; Sala-i-Martin, 1996; Sahoo et al., 2010; Zeng, 2015; Lengyel & Kotosz, 2018; Monfort & Nicolini, 2000; and Kanó & Lengyel, 2021) have extensively investigated convergence patterns of developed economies in Europe and North America. Only a few have extended the investigation to cover developing economies, focusing largely on Asia (Dissou & Didic, 2013; Zeng, 2015; Ouattra & Zhang, 2019).

There appears to be a sparsity of empirical studies on the phenomena in an African context (McCoskey, 2002; Fedderke et al., 2006; Saba & Ngepah, 2020). Thus, the Republic of South Africa (hereafter referred to as South Africa), recognised as the continent's most structurally advanced economy according to the World Bank (2018), was chosen to investigate this phenomenon and contribute new knowledge to the current discourse. This study comparatively examines the economic development of South Africa with that of the Organisation for Economic Cooperation and Development (OECD) countries through the lens of the convergence theory and its hypothesis. It investigates to what extent a steady-state long-term relationship in GDP per capita can be observed between South Africa and the OECD group of countries from 1980 to 2019. The study period ends in 2019 to exclude the exogenous shock of the COVID-19 pandemic. The remainder of the paper is structured as follows: Section 2 reviews relevant theoretical literature, while Section 3 presents the econometric methods. Section 4 summarises the empirical results. Section 5 discusses the findings and conclusions.

2. Theoretical background

Regional studies have long explored whether GDP per capita converges or diverges across areas. Neoclassical economics holds that the free movement of factors of production and comparative advantage lead to long-term convergence of labour and capital flows in inverse directions. Less developed nations and regions experiencing rapid growth converge approaching the prosperity levels of more developed regions. Testing this theory, South Africa was chosen to conduct a comparative analysis with more developed nations. As it is the African continent's most structurally advanced economy, a comparative analysis with its neighbours would not adequately contribute to the convergence discourse. South Africa is a lesser developed nation than several of its intercontinental peers; therefore, it was decided to investigate its developmental performance by comparing it to that of the OECD through the perspective of convergence theory. According to the World Bank (2018), South Africa is classified as an upper-middle-income country and an emerging economy. As the OECD has four members in the same category (Columbia, Costa Rica, Mexico and Turkey), it is justifiable to comparatively analyse South Africa's economic performance with these four countries and the rest of the collective. Furthermore, the members of the group represent the continents of Asia, Australasia, Central Eastern Europe, Western Europe, North America and South America, as summarised in Table 1 in section 3.1. This diversity enables an analysis of South Africa's economic performance at the global scale.

The regional economic growth theory and the interregional convergence hypothesis were illustrated by Hecksher, Ohlin and Samuelson's (1919, 1933, 1953) model, which is an augmentation of David Ricardo's (1817) theory of comparative advantage. According to the model, specialisation in factor-abundant production, combined with free interregional trade, results in equivalent per capita incomes across areas for people with comparable skills (Dawkins, 2003). The idea of dynamic or static interregional convergence has apparent implications for the regional development theory and trade and investment will eventually result in wage equality across areas. However, this does not necessarily mean equalisation of per capita incomes as per capita incomes are affected by other factors such as population skill level and labour force participation rate (Dawkins, 2003).

Neoclassical growth models are dynamic by design and their convergence hypotheses refer to the convergence of growth rates rather than the static convergence of factor prices, which is similar to its predecessor. Solow (1956) and Swan (1956) developed two types of convergence. First, convergence towards a steady-state growth rate that results in stable per capita incomes, consumption levels and capital/labour ratios is referred to as conditional convergence. This is referred to as conditional as savings rates, depreciation rates and population growth rates vary among countries. Conditional convergence may not always imply similar per capita income levels across countries. Second, absolute convergence arises when all countries' growth model parameters are equal, implying that richer countries would develop slower than poorer countries and per capita incomes will eventually equalise between countries, as in the Herckshe–Ohlin–Samuelson model of international trade (Solow & Swan, 1956). Although both models predict long-run convergence of per capita incomes across regions, the mechanism in which this occurs differs between the neoclassical trade and growth models.

Most neoclassical growth models ignore trade by stimulating growth within closed economies, where convergence occurs by diminishing returns on capital investment rather than through trade or factor mobility. The neoclassical growth theory predicts that locations with lower levels of capital per worker will have higher rates of return and higher initial growth rates than regions with higher levels of capital per person (Barro & Sala-i-Martin, 1999). Moreover, Sala-i-Martin (1996) applied beta (β), alpha (α) and conditional convergence as measurements to test the convergence of regions and countries. The neoclassical growth model further predicts that the growth rate of an economy will be positively related to the distance that separates it from its own steady state. This is the concept known in the classical literature as conditional β-convergence. There is absolute β-convergence if poor countries tend to grow faster than rich ones' (Sala-i-Martin, 1996:1020). Sala-i-Martin (1996:1020) further elaborated that α-convergence can be defined as 'a group of economies are converging in the sense of α if the dispersion of their GDP per capita levels tends to decrease over time'. The aforementioned scholars are the most referenced in this area and have been the theoretical foundation of numerous studies (Saba & Ngepah, 2020).

Sala-i-Martin and Barro (1992) analysed the convergence of gross incomes in 92 countries, finding convergence only if the factors influencing steady-state income remain stable. They observed a convergence rate of approximately 2% annually, which is known as the 'iron rate' (Barro & Sala-i-Martin, 1992). Mankiw et al. (1992) employed a cross-sectional technique based on the Solow growth model, examining the income convergence of 98 nations. The authors observed that conditional convergence occurs when population growth and capital accumulation do not change. McCoskey (2002) highlights a limitation of earlier convergence studies is the manner in which time was dealt with. The author further elaborates that the use of cross-section data sets is "constructed from observations averaged over time" (McCoskey, 2002:819).

Islam (1995) was at the forefront in the use of non-stationary panel data estimating techniques to assess convergence in terms of per capita real income. The study also concluded that there is conditional convergence in per capita real income. Using non-stationary time series tools provides a better understanding of the series' course, which is important for analysing probable convergence over time as stated by McCoskey (2002). Several researchers namely Quah (1996a, 1996b, 1996c), Lee et al. (1997), Pedroni (1997), St Aubyn (1999) and McCoskey and Kao (1999) have applied these sophisticated time series econometric tools. Time series tools can prevent the possibility of misleading regressions since incomes have frequently tested nonstationary, or I(1). While not directly addressing the convergence axiom, Pedroni (1997) and McCoskey and Kao (1999) employed heterogeneous panel data methodologies to examine the effects of urbanisation and human capital on development, respectively.

In a more recent study McCoskey (2002) investigated income convergence among 37 Sub-Saharan African countries from 1960 to 1990, testing the hypothesis of club convergence using a nonstationary panel data approach but did not detect any convergence in real GDP. Moreover, a study by Fedderke et al. (2006) examined the link between investment in economic infrastructure and long-run economic growth. By evaluating the experience of South Africa in a time-series setting from 1875 to 2001 through the vector error correction model (VECM) approach. Ouattara and Zhang (2019) investigated the long-run steady-state relationships between 29 Chinese provinces. Moreover, it studies the impact of infrastructure investment on output elasticities by applying causality tests by Dumitrescu and Hurlin (2012).

Lengyel and Kotosz (2018) compared the catching-up success of NUTS3 areas in the four Visegrad Group countries (Czechia, Hungary, Poland and Slovakia) to the average of the 15 founding member states of the European Union (EU) from 2000 to 2014. This was done by examining their respective real GDP per capita based on purchasing power parity. These countries acceded to the EU in 2004. The integration of these economies into the EU began before this and was bolstered by monies from the Structural Fund following the accession. The goal was to help less developed areas catch up and converge to the average of the more senior member states. The authors observed that all four nations were catching up, albeit at different rates. The Czech and Hungarian economies declined from 2006 to 2008, but the Slovakian and Polish economies grew steadily throughout the period.

Kanó and Lengyel (2021) further explored this group and investigated the club convergence phenomenon among the Visegrad Group (Czechia, Poland, Hungary and Slovakia) from 2000 to 2016. The authors examined whether convergence can be observed among the group given that they have a shared socioeconomic historical context. Their analysis revealed that despite the substantial cohesion subsidies provided by the EU, there was no convergence among these countries.

Kung (2009) took a nonstationary panel data approach by examining the interaction between economic growth and the financial system and assessing whether convergence could be detected. The panel comprised 57 countries and was divided into three groups categorised as top, middle and bottom based on their real GDP per capita from 1967 to 2001. The findings give strong support for conditional convergence. Middle- and high-income countries have comparable growth paths in terms of per capita GDP and the development of their financial systems Kung (2009). The mutually reinforcing relationship between financial development and economic growth is highest in the early phases of economic development, but it lessens when sustained economic growth occurs. As a result, low-income countries with a moderately established financial sector are more likely to catch up with their middle- and high-income counterparts, whereas those with a less developed financial sector are more likely to remain impoverished. Moreover, this result accounts for the observed significant divergence between impoverished and rich countries Kung (2009). Saba and Ngepah (2020) investigated the hypothesis of club convergence in military spending and economic growth (real GDP per capita) of 35 African countries from 1990 to 2015, applying the Phillips and Sul (2009) methodology. The analysis demonstrated that little to no income convergence can be observed between the countries.

The literature review comprised of studies investigating the formation of convergence clubs and convergence between countries. Mixed results were observed, with some studies supporting and others contradicting the convergence hypothesis and the hypothesis of club convergence. One of the reasons for this is the use of varying approaches and testing methods that could not account for heterogeneous series. Building on the work of McCoskey (2002) this study applied heterogenous panel data econometric modelling. Firstly, the enumeration of the β-convergence, α-convergence and the steady state equilibrium was conducted. Moreover, the estimation of the β-coefficient, resulted in an approximation of the speed of convergence that would take place. The analysis sought to answer the research question of to what extent convergence can be observed over the same period for South Africa and the OECD from 1980–2021. The OECD collective average income per capita was used as the international benchmark.

Secondly, the examination of the long-term interaction between real GDP per capita and total investment from 1980–2019. The novelty of this investigation stems from its analysis of an African country applying both classical and contemporary sophisticated methods and tests examining the convergence hypothesis.

H_1: The per income per capita convergence disparity between South Africa and the OECD has narrowed.

2.1. Theoretical model

Poor nations initially start farther away from their steady-state equilibrium level; however, as levels of capital increase, the economy grows rapidly; then, the growth rate starts to decline as it reaches its steady-state (Sala-i-Martin, 1996). The Solow-Swan model (1956) is the basis framework for enquiries into economic development and convergence when determining nations' steady-state equilibria. The Solow-Swan model centres around four variables: output *(Y),* capital *(K),* labour *(L)* and 'knowledge' or the 'effectiveness of labour' *(A)*. Output changes over time *(t)* only if inputs into the production process changes. If output increases over time with the given levels of capital and labour, this is seen as technological progress in terms of improvements in the effectiveness of labour (labour augmenting or Harrod-neutral). Meaning that improved allocation of resources in the production process has resultant in increases in output. This study employs the same foundational theory, contributing to the existing discourse on convergence by applying both classical and panel econometrics to analyse the economic development of South Africa. Analysis of a growth equation with the Solow–Swan model (1956) is 'derived as a log-linear approximation, from the transition path of the neoclassical growth model for closed economies' (Barro & Sala-i-Martin, 1991:108). Equation 1 illustrates the Cobb–Douglas production function, is applied and the 'convergence coefficient, β, depends on the productivity of capital and the willingness to save.

$$Y_t = A_t K_t^{\alpha} L_t^{1-\alpha} \tag{1}$$

The steady-state equilibrium levels of each country have been calculated following the Solow-Swan model (1956). Sala-i-Martin (1996:1020) extrapolates the classical methodology in his work and describes "$\gamma_{i,t,t+T} \equiv \log(y_{i,t+T} \;/\; y_{i,t}) \;/\; T$ be economy *i*'s annualised growth rate of GDP between *t* and *t* + *T*, and let $\log(y_{i,t})$ be the logarithm of economy 's GDP per capita at time *t*". Equation 2 is the model's regression estimation.

$$\gamma_{\,i,t,t+\mathrm{T}} = \alpha \;-\; \beta log\left(\gamma_{i,t}\right) + \epsilon_{i,t} \tag{2}$$

The Sala-i-Martin (1996) derivative of β-convergence and α — convergence was applied as a measurement to test the convergence of regions and countries. The neoclassical growth model predicts "that the growth rate of an economy will be positively related to the distance that separates it from its own steady-state. This is the concept known in the classical literature as conditional β-convergence. The data demonstrates "absolute β-convergence if poor countries tend to grow faster than rich ones" when $\beta > 0$ (Sala-i-Martin, 1996:1020-1027).

In particular, the source of convergence in the neoclassical growth model is the assumed diminishing returns to capital. If the ratio of capital (and hence output) to effective labour declines relative to the steady-state ratio, then the marginal product of capital rises. Therefore, for a given saving behaviour, an economy grows faster the further it is below the steady-state' (Barro & Sala-i-Martin, 1991:109). Steady-state GDP per capita is the constant amount of production per person achieved by an economy when capital investment equals capital depreciation, population increase, and technical advancement are all taken into consideration. In the steady state, the economy's capital stock is constant, implying that the quantity of new capital added via investment matches the amount lost through depreciation. At this point, the economy reaches a growth plateau represented by Equation A1 in the Appendix. GDP per effective work is another concept crucial to grasping the multifaceted nature of economic growth in the Solow-Swan convergence model. This metric aids in analysing how economies may expand through capital accumulation, labour growth, and technological advancement as descripted by Equation A2 in the Appendix.

Using the aforementioned as a theoretical base, the contemporary economic growth theory has employed aggregated models to measure economic growth with these approaches. Focusing on whether there has been an increase in equilibrium gross domestic product (GDP) per capita over a period and identifying the economic factors that exert an influence (Ascani, et al., 2012). Moreover, the neoclassical Solow–Swan growth model of the 1950s has been the blueprint for the furtherance of economic theory and the drafting of policies for institutions worldwide, where economic development was viewed as a linear process that can be influenced by adjusting certain factors. This simplified view pays no attention to the multiplex social, institutional or historical elements, which are qualitative and contribute to the advancement of an economy. Endogenous growth theorists, such as Solow in the late 1980s and Romer in the 1990s, asserted that technological innovation was at the core of economic growth processes in the long-term (Ascani, et al., 2012). This study applies the principles and assumptions established in the endogenous growth theory.

An examination of the causal relationship between the variables in Table 1 is valuable, as it would enhance the understanding of the levers within an economy. This is commonly performed through long- and short-term analysis. The preferred techniques for this purpose are the fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS). Long-run studies are carried out utilising series-level values. The model for long-term analysis is presented in Equations A5 and A6 in the Appendix. Stock and Watson (1993) proposed that the lags and leads of independent variable differences, as well as the level values of explanatory variables, should be added to the model to eliminate the OLS estimator's deviation and endogeneity problems. The relationship of this investigation is described by Equation 3. Thereafter the VECM approach was applied to examine the long-term equilibrium correlation among variables, as well as short-run departures from that equilibrium. A prerequisite to VECM approach is to conduct VAR analysis, the results of which shown in Table 9 is that the optimal lag for the regression analysis was VAR(8).

$$LnGDP_{t-8} = \beta_0 + \beta_1 EMP_{t-8} + \beta_2 LnCap\_stock_{t-8} + \beta_3 LnGFCF_{t-8} + \beta_4 LnLab_{t-8} + \beta_5 LnForex_{t-8} + \beta_6 LnBrent_{t-8} + \beta_7 D_{ex\_regime} + \beta_8 D_{USrecession} + \beta_9 ECT_{t-8} + u_t \quad (3)$$

The choice of variables was guided by the literature and is deemed the most appropriate to test the Solow–Swan model (1956) and calculate convergence (Monfort & Nicolini, 2000; Blonigen, 2005; Head & Rise, 2008; Grigoras, 2015; Egri & Tánczos, 2018; Lengyel, & Kotosz, 2018; Kanó & Lengyel, 2021; Bolganbayev, et al., 2022 and Gbadamosi, et al., 2022). Sala-i-Martin (1996) illustrated that to enumerate economic convergence, it is necessary to include the GDP per capita for a cross-section of economies. All national economies depend on petroleum, which is the primary weighted input of energy daily. Changes in petroleum prices impact input costs, which affects price and production levels in a country (Gülay & Pazarlioğlu, 2016). Simultaneously, variations in the real and nominal exchange rates have a significant impact on the national economies. Increasing the effective use of a nation's economic resources is crucial to its economic development. To stabilise the economy, positive and immediate improvements in economic growth are required when considering the law of supply and demand. Therefore, economic research places a great deal of emphasis on how oil prices and currency rates affect economic growth (Gülay & Pazarlioğlu, 2016). Thus, independent variables Brent crude oil and nominal exchange rate were introduced into the analysis in an attempt to counter its influence as an asymmetric shock in exchange rate volatility (Gülay & Pazarlioğlu, 2016). As the dollar is the currency denomination used in this analysis, the nominal exchange rate was included as it is the unit of measure that displays two currencies' respective prices.

Table 1. Macroeconomic variables of study

Macroeconomic variable	EViews reference	Measurement	Source
Capital stock at current PPPs	Cap_stock	Millions in USD	Penn World Table 10.0
Number of persons engaged	EMP	Millions of persons	Penn World Table 10.0
Output-side real GDP at chained PPPs	GDP	Millions in USD	Penn World Table 10.0
Share of gross capital formation at current PPPs	GFCF	Millions in USD	Penn World Table 10.0
Share of labour compensation in GDP at current national prices	Lab	Millions in USD	Penn World Table 10.0
Foreign exchange rate to USD (annual average price)	Forex	Tens in USD	LSEG Data & Analytics
Brent crude oil price (annual average price)	Brent	Tens in USD	LSEG Data & Analytics

Source: Author's construction

The sources of the secondary data for this analysis are the Penn World Tables 10.0 and LSEG data and analytics. Annual data for 6 variables of the 39 countries from 1980 to 2019 were extracted and converted into a balanced panel dataset that comprises 1,560 observations. This macroeconomic phenomenon was investigated by analysing real GDP as the dependent variable along with total investment, capital stock, employment, labour share of compensation, Brent crude oil and foreign exchange rate to USD (forex) as the independent variables.

3. Data and methods

3.1. Data

Among the current OECD members are 6 post-socialist countries (PSCs) namely, Czechia, Estonia, Latvia, Lithuania, Slovenia and Slovakia, all of which have a 10-year gap in their available data from 1980 to 1990, amounting to a loss of 360 observations for the 6 variables. This posed difficulties for the stability and reliability of the analysis of the unbalanced panel dataset. This was solved by removing the six PSCs and introducing six control Latin American countries (Argentina, Bahamas, Barbados, Panama, Trinidad and Tobago and Uruguay) that have similar World Bank classifications, thereby restoring balance in the panel dataset.

Table 2. Study population

32 OECD member countries				
Australia	Denmark	Ireland	New Zealand	Switzerland
Austria	Finland	Israel	Norway	Turkey
Belgium	France	Italy	Poland	United Kingdom
Canada	Germany	Japan	Portugal	United States
Chile	Greece	Luxembourg	South Korea	
Columbia	Hungary	Mexico	Spain	
Costa Rica	Iceland	Netherlands	Sweden	
6 Control countries				
Argentina	Bahamas	Barbados	Panama	Trinidad and Tobago
Uruguay				
1 Comparative analysis country				
South Africa				

Source: Author's construction

This study sheds new light on this area from an African perspective as it comparatively analyses 39 countries—South Africa, 6 Latin American countries and the 32 OECD members. It investigates their respective average steady-state equilibria and tests convergence patterns from 1980 to 2019. This allows South Africa's developmental performance to be plotted against an international benchmark.

3.2. Methods

The purpose of this research is to contribute to the current conversation by using econometrics to examine South Africa's economic progress. This study is done throughout the thirty-nine-year period 1980–2019, where the economic progress of South Africa is compared to the OECD and the Latin American control group of nations. Firstly, the enumeration of the β-convergence, α-convergence and the steady state equilibrium was conducted. Through the estimation of the β-coefficient, the speed of convergence was calculated, which is the amount of time in years that it will take South Africa to reach the OECD average GDP per capita.

Half-life is defined as the 'time required to cover half the road leading to full convergence within the study region if the speed of convergence remains unchanged' (Egri & Tánczos, 2018:53) and was calculated using Equation 4.

$$\pi = \frac{ln2}{\beta} \tag{4}$$

Secondly, an examination into the causal relationship between the variables was conducted by applying sophisticated panel data econometric methods and tests. Table 3 presents the explanatory statistics on the 39 countries from 1980 to 2019. The table summarises the descriptive data for central tendency and variability. The mean values represent the average value of the variables in the overall model. The standard deviation represents the dispersion of data around the mean value. It also indicates the data's proximity to the average value throughout the specified period. The range of data can be assessed by the highest and minimum values in each model. The range indicates the amount of variance in variables. Variables with broader range values exhibit more variance and vice versa. This study conducts panel data econometric analysis using EViews 12 software.

Table 3. Descriptive statistics

Variable	N	Mean	Median	Maximum	Minimum	Std. Dev
real GDP per capita	1560	5,435431	5,476747	7,31378	3,480623	0,771461
Capital stock	1560	6,014458	6,116556	7,839221	3,681969	0,836371
Labour share	1560	0,560347	0,5755	0,7506	0,2677	0,091415
Forex	1560	93,28729	1,305102	3281,622	0	331,9472
Brent crude	1560	1,543505	1,467404	2,049084	1,104369	0,282272
Employment	1560	14,14289	4,5837	158,2996	0,0716	23,6868
Total investment	1560	0,247069	0,24845	0,5699	0,042	0,067986

Source: Authors construction from EViews 12 output

First, the panel data unit root tests focus on the income and capital indicators. These tests adhere to the technique of Im et al. (1997, 2003), often known as Im–Pesaran–Shin (IPS). Panel data tests for the cointegration of Engel–Granger (1987) and Kao (1999) have been performed, both of which test the null hypothesis of no cointegration acquiesce heterogeneous cointegrating vectors. It is necessary to test the stationarity of each of the variables under investigation when conducting an econometric analysis. This ensures that the appropriate methods and tests are applied to increase the probability of achieving reliable results.

Panel unit root tests: As estimation issues are caused by the non-stationarity of data, this section applies a unit root test and cointegration methods. The Levin, Lin and Chu (LLC) unit root test works under the assumption of homogeneity of the unit root coefficient $\boldsymbol{p_i = p}$ and involves fitting an augmented Dickey–Fuller (ADF) regression for each panel. Individual intercepts and temporal trends can be analysed using the panel-based unit root test. Furthermore, the error variance and pattern of higher-order serial correlation can vary widely between subjects under investigation. The model operates under the main assumption of homogeneity of the unit root coefficients, where $\boldsymbol{p_i = p}$. The null hypothesis $\boldsymbol{(H_0)}$ states that if $\gamma = 0$, the series has a unit root, meaning it is non-stationary as the p-value equals one $\boldsymbol{(p = 1)}$. The alternative hypothesis $\boldsymbol{(H_1)}$ states that no unit root is present, and the series is stationary when its p-value is less than one ($\rho < 1$). An advantage of this technique is that it accounts for looming cross-sectional dependencies and does not directly pool the autoregressive parameter in the unit root regression, also known as the AR(1) process (Levin, et al., 2002). The test analyses how much the value of the series in the current (t) period is affected by its value in the previous (t-1) period. To further test the results of the LLC, the IPS test was conducted. McCoskey (2002) investigated income convergence in 37 Sub-Saharan African countries from 1960 to 1990 and applied the IPS to test the stationarity of the series. Im, Pesaran and Shin (2003) developed a unit root test for dynamic heterogeneous panels based on the mean of individual unit root statistics in which the standardised t-bar test statistic based on the ADF statistics averaged across the groups. The model operates under the main assumption of heterogeneity of the unit root coefficients $\boldsymbol{(p_i)}$. The null hypothesis $\boldsymbol{(H_0)}$ states that if $\gamma = 0$, the series has a unit root, meaning it is non-stationary as the p-value equals one ($\rho = 1$). The alternative hypothesis $\boldsymbol{(H_1)}$ states that no unit root is present, and the series is stationary when its p-value is less than one ($\rho < 1$).

Cointegration test: To ascertain if a group of non-stationary time series are cointegrated in the context of panel data, a statistical method known as the Kao (1999) cointegration test was utilised, as in a study by McCoskey (2002). This methodology is based on Engle and Granger's (1987) cointegration test and should be applied when the variables are integrated in the order of I(1). The test assumes that the number of periods (t) remains constant, while the number of cross-sectional units (n) rises. It also presupposes that the errors are not serially associated in each cross-sectional unit. The Granger methodology is based on the ADF regression, which adds lagged values for the variables under consideration. It examines the relevance of the lagged variables to determine the presence of cointegration.

Moreover, the Kao test uses the Fully Modified Ordinary Least Squares (FMOLS) estimator and adds Error Correction Model (ECM) into the model design. The system of Equations A3 and A4 is listed in the Appendix.

Regression tests: As cointegration amongst the variables in both the provincial and convergence parts of the study were detected through the application of the Kao cointegration test, we then went on to perform regression analysis. Following the same methodological approach, FMOLS and DOLS were performed by the authors. Yahyaoui and Bouchoucha (2021) applied the FMOLS and DOLS approaches to investigate the link between foreign aid, economic growth and governance in a panel of 48 African countries from 1996 to 2014. Phillips and Hansen (1990) developed the FMOLS method, which corrects biases in the OLS estimator (caused by problems such as autocorrelation and heteroskedasticity) by considering the possible correlation between the constant term, error term and independent variable differences. The short-run analysis should use the same methodology as the long-run analysis.

Short-term analysis is performed using the error correction model (ECM). In this analysis, the initial differences of the series and one-lagged values of the error correction term (ECT) are employed. ECT is a collection of error terms (residuals) derived from the long-term analysis. The model for the short-run analysis is depicted in Equations A5 and A6 (see Appendix). If the ECT coefficient ($\propto_1$) is negative and statistically significant, the short-term divergence between the series is removed and the series returns to the long-run convergence relationship. In each period, a 1% divergence of the ECT coefficient vanishes.

Vector Autoregressive (VAR) model developed by Christopher Sims (1980) which gained popularity and have been widely applied to determine the relationships between variables that have concurrent interactions. Wu (2021) applied the panel VAR approach investigating the impact that FDI has on economic growth to panel data of the 11 cities in the Yangtze River Economic Belt between 2000–2008. Panel VAR models are straightforward mathematical models in which the value of a variable at a given moment is represented by a (linear) weighted sum of its own history (often across a number of discrete time-steps) and the past of a set of additional variables. Each variable is a vector stochastic process that denotes a time series. Fitting a VAR model entails determining the best weights such that estimation errors are minimised; numerous common strategies exist to do this. There is no distinction between dependent and independent variables in VAR models and is explained by the simultaneous Equations 9 and 10 in the Appendix. The VAR lag criterion must be determined depending on the variables. Additional diagnostic tests are run to ensure the stability and robustness of the study and its findings. The results are visualised and interpreted using impulse response functions and variance decomposition.

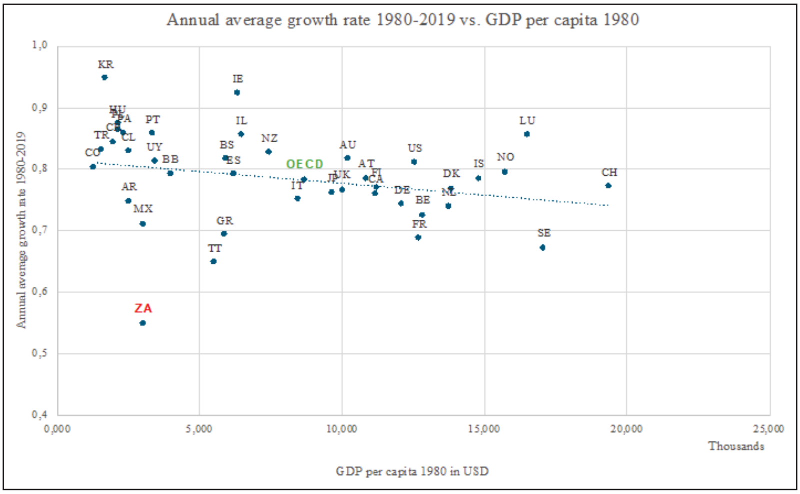
Causality tests: Pradhan and Bagchi (2013) applied the VECM approach to examine the interaction between transport infrastructure and economic growth in India from 1970 to 2010. Causality tests identify the existence of and direction of interaction between variables, based on which the theoretical foundations of this test were developed by Granger (1969) and were further expanded by Dumitrescu and Hurlin (2012). The variables are not treated as independent and dependent but analysed simultaneously, as depicted by Equations A5 and A6 in the Appendix. The null hypothesis for this test is that there is no causality relationship from $\boldsymbol{Y}$ to $\boldsymbol{X}$ $(\boldsymbol{H_0} : \forall \boldsymbol{\beta_j} = \mathbf{0})$. If a cointegration link is identified between the variables, the causation relationship is further evaluated using the vector ECM (VECM) approach. Equations A11 and A12 are used for this procedure (see Appendix), where the $\boldsymbol{\gamma_i}$ coefficient tests short-run causality and the $\boldsymbol{\varphi_1}$ coefficient tests long-run causality. If $\boldsymbol{\gamma_i} \neq \mathbf{0}$, it indicates short-run causality, whereas $\boldsymbol{\varphi_1} \neq \mathbf{0}$, indicates long-run causality from $\boldsymbol{X}$ to $\boldsymbol{Y}$.

4. Results

The enumeration of the β-convergence, α-convergence and the steady state equilibrium was conducted, and the results are presented in the paragraphs that follow.

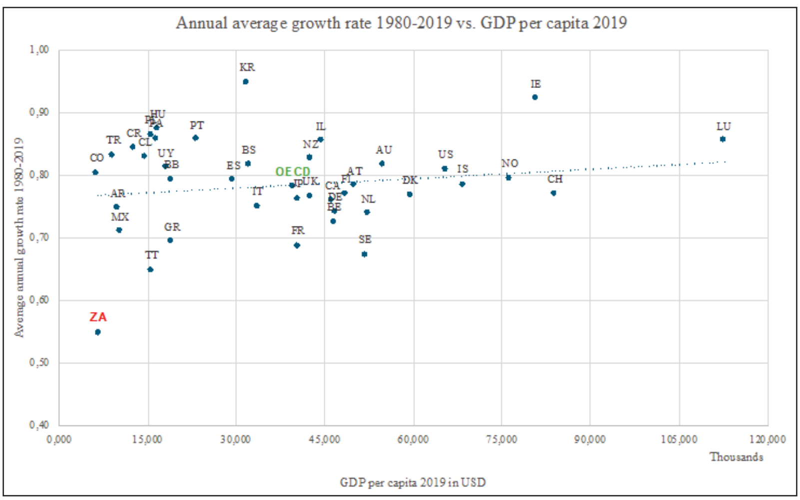
Convergence: The enumeration of the β-convergence, α-convergence and the steady state equilibrium was conducted to examine to what extent convergence can be observed between South Africa and the OECD over the period 1980–2019. Figures 1 and 2 illustrate the GDP per capita 1980 and 2019 versus the annual average growth rate 1980-2019 respectively, for the population of 39 countries including the OECD average (in green). In 1980 the average GDP per capita for the OECD is \$8708 with an annual growth rate for the thirty-nine-year period of 0.78. This is considered as the benchmark for the convergence analysis and is positioned on the onward sloping trendline showing a negative relationship between the initial income in 1980 and the growth rate of member states. The data reveals that several member states are positioned in close proximity to the benchmark, either above with higher a GDP per capita and growth rate (AU, AT, CA, FI, US, LU, NO) or below with a lower GDP per capita and growth rate (IT, GR, TT, MX, AR, ZA) than the OECD average. South Africa (in red) finds itself in the latter group with its GDP per capita at \$3035 and a growth rate of 0.55. No members are in an overlap position with the benchmark. Another observation of the data reveals is that a number of members have a lower GDP per capita but a higher growth rate than the benchmark (TR, NZ, BS, IL, IE, PT, UY, CL, HU, KR). Moreover, there are members that have lower growth rate but a higher GDP per capita than the benchmark (CH, JP, UK, DE, BE, FR, NL, SE).

Figure 1. Growth rate 1980–2019 vs. GDP per capita 1980



Source: Author’s construction

Figure 2. Growth rate 1980–2019 vs. GDP per capita 2019

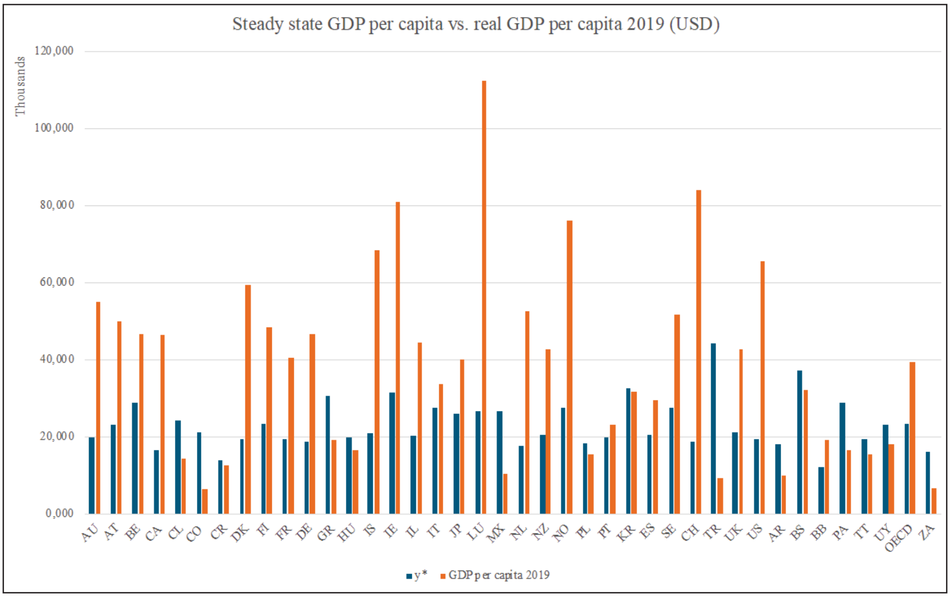


Source: Author’s construction

Pointing to the data in 2019 in Figure 2, it is observable that each of the 39 countries have experienced considerable increases in their GDP per capita. The upward sloping regression trend line indicates that now a positive relationship can be observed between the income in 2019 and the growth rate. The average GDP per capita for the OECD jumps to $39,685, which becomes the new benchmark of comparison. The data reveals that several member states are positioned in close proximity to the benchmark, either above with higher a GDP per capita and growth rate (NZ, IL, AU, AU, IE, LU) or below with a lower GDP per capita and growth rate (IT, GR, TT, MX, AR, ZA the same countries as in 1980) than the OECD average. South Africa still finds itself in the latter group with its GDP per capita now reaching $6073, which is more than double that of 1980. This illustrates conditional β-convergence where the country's GDP has dramatically increased, slightly narrowing the per capita income gap with developed nations of the OECD. Repeatedly, no members are in an overlap position with the benchmark. Observation of the data reveals is that a number of members have a lower GDP per capita but a higher growth rate than the benchmark (BS, ES, PT, UY, CL, HU, KR, TR etc.). Moreover, some members have lower growth rates but a higher GDP per capita than the benchmark (CA, JP, UK, DE, BE, FR, NL, NO, SE).

The steady-state GDP per capita in Figure 3, represents the per capita income level that an economy can maintain in the long run when its equilibrium is attained. At this stage, capital investment equals capital depreciation, with population increase and technical development factored in. Steady-state GDP per capita is the constant amount of production achieved per person by an economy when capital investment equals capital depreciation, population increase, and technological advancement are all considered. In the steady state, the capital stock in the economy does not shift, implying that the quantity of new capital added via investment matches the amount lost through depreciation. The model predicts that poorer countries would expand faster than affluent ones because they have more space to amass capital. This process is referred to as convergence. As these economies invest and thrive, GDP per capita approaches its steady-state level.

Figure 3. Steady-state GDP per capita vs. real GDP per capita 2019

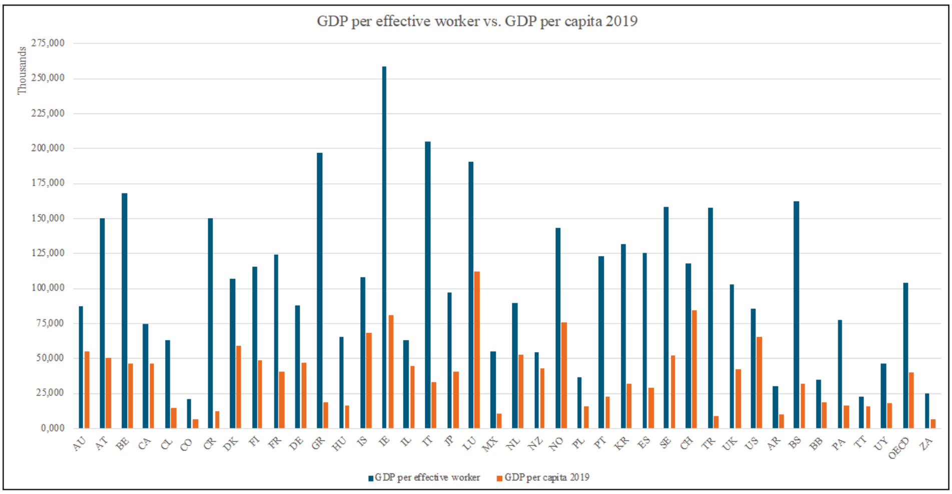


Source: Author's construction

Figure 3 demonstrates the modelled steady state equilibrium level (y* in blue) and the real GDP per capita in 2019 of the 39 countries including the OECD average (in orange). This is approximated income per capital level than can be sustained in the long term by each of these economies when equilibrium has been achieved. It is evident that the vast majority of the OECD members have attained a GDP per capita in 2019 that exceeds their steady state equilibrium levels including the blocks average. These are developed nations with mature capital markets enabling efficient capital accumulation. This approximation is a static view, and it is important to note that new steady state equilibrium levels are continually identified as economies are dynamic. The data reveals that the Latin American countries (TT, PA, AR, MX, CO) and South Africa ($16,282) are largely the countries with a GDP per capita in 2019 that is below the steady-state equilibrium level. Based on the parameters of the model, potentially the South African economy has the capacity to enhance its economic performance by technological amelioration in labour or gains in capital accumulation, and eventually reducing dispersion and attaining the OECD average steady-state equilibrium level ($23,417). Moreover, conditional β-convergence is inferred whereby South Africa is diverging from its low initial GDP toward a higher GDP level potentially at a faster rate therefore closing the per capita income gap between itself and the OECD average.

Figure 4 illustrates the modelled GDP per effective worker (blue) versus the GDP per capita in 2019 (orange). An effective worker is described as one whose productivity is enhanced by technology. This indicates that a worker's production is determined by not just the amount of labour but also the level of technology accessible in the economy. This is determined as the total production (GDP) divided by the number of productive workers. It reflects labour productivity while considering technology advancements. The modelled GDP per effective worker value is greater than the actual GDP per capita in 2019 for each of the 39 countries. Highlighting that advances in technology could catapult these economies to attain greater levels of GDP per capita. The Solow-Swan model states that economies will gravitate to a steady state in which GDP per effective worker remains fixed over time unless technology adjustments occur.

Figure 4. GDP per effective worker vs. real GDP per capita 2019



Source: Author's construction

The model emphasises that increasing capital per effective worker results in increased production per effective worker. However, due to decreasing returns to capital, the growth rate of production per effective worker will ultimately stabilise unless technological advancement is made. The model predicts that poorer nations would expand faster than wealthy ones as they catch up on capital accumulation and productivity. Poorer nations frequently enjoy better returns on investment due to lower initial levels of capital per effective worker, which facilitates the convergence process. Continuous technological advancements are required for long-term GDP growth per effective worker. In the long term, technological breakthroughs raise the steady-state level of GDP per effective worker, allowing for continuous improvements in the standards of living. Through the estimation of the β-coefficient it approximates that it will take South Africa 34.11 years to reach the OECD average GDP per capita of 2019 ($39,686).

After the convergence analysis was completed an examination into the causal relationship between the variables was conducted by applying sophisticated panel data econometric methods and tests. The results of which are presented commencing with the unit root tests.

Panel unit root tests: The results summarised in Table 4, the LLC test reveals that all the variables in the panel are stationary at the first difference, thus concluding that variables have been integrated in the order of I(1) at the 1% significance level. The results of the IPS test are consistent with those of the LLC in that variables of each of the 39 countries are stationary at first difference and thus integrated in the order of I(1).

Table 4. Panel unit root test results

Variable	Test method	Order of integration	t-statistics	p-value	Cross sections
rGDP	LLC	I(1)	-22,4275	0.00	39
	IPS	I(1)	-26,6564	0.00	39
Cap stock	LLC	I(1)	-6,63611	0.00	39
	IPS	I(1)	-11,5569	0.00	39
Labs	LLC	I(1)	-27,6298	0.00	39
	IPS	I(1)	-26,6564	0.00	39
Forex	LLC	I(1)	-17,663	0.00	39
	IPS	I(1)	-16,8929	0.00	39
Brent crude	LLC	I(1)	-34,4822	0.00	39
	IPS	I(1)	-30,1974	0.00	39
Emp	LLC	I(1)	-17,7923	0.00	39
	IPS	I(1)	-18,067	0.00	39
GFCF	LLC	I(1)	-17,4977	0.00	39
	IPS	I(1)	-19,6711	0.00	39

Source: Author's construction

Cointegration test: The result of the panel Kao test in Table 5 detects cointegration among the variables for all 39 countries; as the p-value is 0.0001 ($p < 0.10$), the null hypothesis of no cointegration can be rejected. This enables the application of the FMOLS regression analysis, which has the same methodological logic as the Kao test.

Table 5. Panel Kao (1999) test result

	t-statistic	p-value
ADF	-3,80402	0,0001

Source: Author's construction

Regression tests: The panel FMOL and DOLS regression results are summarised in Tables 6 and 7. In the FMOLS test, employment (0.928) and forex (0.142) exert the least effect on the dependent variable. However, total investment (0.00) and capital stock (0.00) have the highest significant effect on real GDP. The DOLS test confirms the insignificant effect that employment (0.269) has on real GDP per capita across the panel.

Table 6. Panel FMOLS regression results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
Labs	-0,36954	0,104892	-3,523057	0,0004
GFCF	-0,484194	0,082293	-5,883811	0
Forex	3,00E-05	2,04E-05	1,468013	0,1423
Emp	-0,000159	0,001767	-0,09026	0,9281
Cap stock	0,710139	0,025003	28,4024	0
Brent crude	0,028614	0,016675	1,715958	0,0864

Source: Author's construction

Table 7. Panel DOLS regression results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
Labs	-0,458613	0,119962	-3,822971	0,0001
GFCF	-0,600526	0,092108	-6,519811	0
Forex	5,54E-05	1,87E-05	2,964822	0,0031
Emp	0,001729	0,001565	1,104444	0,2698
Cap stock	0,65458	0,026317	24,87334	0
Brent crude	0,029636	0,017846	1,660638	0,0973

Source: Author's construction

Causality test: The Granger test detected three bi-directional causality relationships, which are between total investment and real GDP, labour share and Brent crude, as well as capital stock and total investment, as listed in Table 8. Furthermore, uni-directional causality relationships were detected from labour share to real GDP, employment to labour share, labour share to capital stock, forex to employment, Brent crude to forex, Brent crude to employment and capital stock to Brent crude. As there is a cointegration connection, there should be at least one directional causation link between the variables (Engle & Granger, 1987; Granger, 1988).

Table 8. Granger causality results.

Relationship	F-Statistic	Prob.
Labour_share does not Granger Cause real_GDP	3,9532	0,0003
GFCF does not Granger Cause real_GDP	2,58595	0,0119
real_GDP does not Granger Cause GFCF	2,46687	0,0162
Employment does not Granger Cause Labour_share	2,73482	0,0081
Labour_share does not Granger Cause Cap_stock	3,59916	0,0008
Brent_crude does not Granger Cause Labour_share	1,91941	0,0631
Labour_share does not Granger Cause Brent_crude	1,86297	0,0721
Cap_stock does not Granger Cause GFCF	2,62278	0,0108
GFCF does not Granger Cause Cap_stock	2,93291	0,0048
Forex does not Granger Cause Employment	1,84608	0,075
Brent_crude does not Granger Cause Forex	1,77869	0,0877
Brent_crude does not Granger Cause Employment	2,72988	0,0082
Cap_stock does not Granger Cause Brent_crude	3,55328	0,0009

Source: Author's construction

Vector autoregressive (VAR) model: the results show that VAR(8) model is the optimal choice as it has the greatest number of asterisk symbols (*) shown in Table 9.

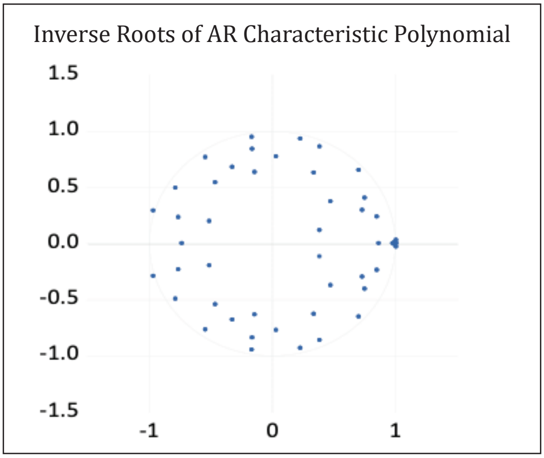
Table 9. Panel VAR lag length criteria result

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-12269,1	NA	0,844052	19,6956	19,78191	19,72805
1	6976,158	38182,01	3,68E-14	-11,06756	-10,7799	-10,9594
2	7524,942	1082,617	1,65E-14	-11,8685	-11.37940*	-11.68462*
3	7585,381	118,5535	1,62E-14	-11,88683	-11,1964	-11,6272
4	7673,069	171,0195	1,53E-14	-11,94883	-11,057	-11,6135
5	7738,185	126,2666	1,49E-14	-11,97465	-10,8814	-11,5636
6	7817,11	152,1596	1,42E-14	-12,02261	-10,728	-11,5359
7	7932,208	220,6038	1,27E-14	-12,12854	-10,6325	-11,5661
8	8022,722	172.4690*	1.19e-14*	-12.19507*	-10,4976	-11,5569

Source: Author's construction. LR: sequential modified LR test statistic (each test at 5% level), FPE: Final prediction error, AIC: Akaike information criterion, SC: Schwarz information criterion, HQ: Hannan-Quinn information criterion

Running the VAR(8) model produced an output that is more meaningful when visualised and interpreted through impulse-response functions and variance decomposition. However, the reliability of the VAR model was first tested and plotted in the inverse roots of AR characteristic polynomial graph, Figure 5, which shows that all the roots are located inside the unit circle, therefore we can conclude that the VAR(8) model satisfies the stability condition, and its results are reliable.

Figure 5. Inverse roots of AR characteristic polynomial



Source: Author's construction

The primary goal of a VAR model's impulse response analysis is to explain how the variables in the model change in response to a shock in one or more variables. This feature enables the tracking of the propagation of a single shock inside a chaotic system of equations, making them extremely helpful instruments in the evaluation of economic strategies. The generalised impulse response (GIR) function test is independent of variable order since it removes the effects of other shocks from the response, revealing the variables' adjustment paths. GIR is beneficial in big systems where structural links are difficult to uncover (Koop et al., 1996). Forecast error variance decompositions (FEVD) measure the contribution of each type of shock to the forecast error variance, it and the GIR both assess the extent to which the shocks reverberate through a system.

The results of which are summarised in Table 10 where the 1st and 8th focus variance periods are interpreted. GDP has a strongly endogenous influence on itself of 100% in the 1st focus period ceteris paribus, in the 8th this percentage drops to 92.7% and LABS has the highest influence on GDP at approximately 3.1%. LABS has a strongly endogenous influence on itself of 91.1% in the 1st period ceteris paribus, where the other variables are weakly endogenous with GDP at 8.8%. In the 8th period, this LABS endogenous influence increases to 96.1% and GDP drops to 1.9%. GFCF has a strongly endogenous influence on itself of 95.3% in the 1st focus period ceteris paribus, followed by LABS at 3.2%, in the 8th this decreases GFCF endogenous influence on itself decreases to 89.2%. GDP's influence on GFCF in the 1st focus period is 1.33% and increases to 6.4% in the 8th focus period. EMP has a strongly endogenous influence on itself of 96.8% in the 1st focus period ceteris paribus, where the other variables are weakly endogenous with GDP at 1.3%, in the 8th focus period this influence raised to 2.4%, and EMP still has a strong influence on itself at 95.5%. Lastly, CAPS has a strongly endogenous influence on itself of 88.6% in the 1st period ceteris paribus, where the other variables are weakly endogenous, of which GFCF exerts 7.05% influence and GDP exerts 4.0% influence. During the 8th focus period, the influence of CAPS on itself decreases to 62.8%, the remainder of the variance is largely influenced by GDP (19.8%) and GFCF (14.2%).

Table 10. Variance decomposition

	Period	S.E.	GDP	LABS	GFCF	FOREX	EMP	BRENT	CAPS
GDP	1	0.020457	100	0	0	0	0	0	0
	8	0.078643	92.7269	3.151782	1.055347	0.366827	0.007644	0.983555	1.707948
LABS	1	0.012292	8.897947	91.10205	0	0	0	0	0
	8	0.036757	1.933472	96.19361	0.50419	0.082131	0.975894	0.039299	0.271401
GFCF	1	0.022553	1.338433	3.263703	95.39786	0	0	0	0
	8	0.053284	6.459204	1.900283	89.26798	0.179988	0.109735	0.634314	1.448494
FOREX	1	37.86825	0.935452	0.410346	0.411589	98.24261	0	0	0
	8	165.9197	0.872874	0.102032	0.43692	98.29002	0.027743	0.213939	0.056472
EMP	1	0.29821	1.342575	0.525918	1.100097	0.135931	96.89548	0	0
	8	1.492498	2.471233	0.188121	0.886009	0.05519	95.53288	0.837045	0.029518
BRENT	1	0.091147	2.644093	0.005689	0.936214	0.625306	0.295103	95.4936	0
	8	0.223153	1.897099	0.693504	1.235275	0.700998	0.707662	92.76851	1.996952
CAPS	1	0.019011	4.087011	0.051445	7.055886	0.01161	0.009112	0.050446	88.73449
	8	0.101419	19.86175	0.543526	14.29145	0.079598	0.144666	2.194384	62.88462

Source: Own construction

Causality tests: Table 11 summarises the short-run causality relationship between the variables, while Table 12 presents the long-run relationship each has on the dependent variable, real GDP. These results support the findings of the Granger test.

Table 11. Panel VECM short run causality results

	Short run causality						
	real GDP	Labour share	GFCF	Forex	Emp	Cap stock	Brent crude
real GDP	-	20.74608 (0.0042)	15.48572 (0.0303)	7.642162 (0.3652)	3.654601 (0.8186)	22.60107 (0.002)	34.43182 (0.00)
Labour share	29.59771 (0.0001)	-	42.24745 (0.00)	3.100874 (0.8755)	10.99938 (0.1386)	26.87619 (0.0004)	10.14833 (0.1803)
GFCF	3.753107 (0.8077)	21.01289 (0.0038)	-	6.159213 (0.5213)	2.211275 (0.9472)	13.6544 (0.0577)	7.916382 (0.34)
Forex	3.1207 (0.8736)	7.132836 (0.4152)	3.980567 (0.782)	-	5.563201 (0.5916)	1.107883 (0.9929)	12.97551 (0.0727)
Emp	2.970252 (0.8877)	6.321342 (0.5028)	5.024613 (0.657)	9.401154 (0.2251)	-	4.226114 (0.7534)	44.31007 (0.00)
Cap stock	37.18751 (0.00)	7.056105 (0.4231)	25.39962 (0.0006)	5.619395 (0.5848)	2.804716 (0.9025)	-	23.06269 (0.0017)
Brent crude	57.60083 (0.00)	14.94361 (0.0367)	14.03069 (0.0506)	12.19698 (0.0943)	7.312481 (0.3971)	64.58804 (0.00)	-

Source: Own construction

Table 12. Panel VECM long run causality results

	Long run causality						
	real GDP	Labour share	GFCF	Forex	Emp	Cap stock	Brent crude
real GDP	1	0,001 [4.57599]	0,000 [0.10291]	1,095 [1.42569]	-0,010042 [1.61621]	0,00 [1.31699]	-0,021 [11.5263]

Source: Own construction

In Table 12, the variables have a significant to relatively significant effect on each other. Labour share, capital stock and Brent crude have a 1% significant effect on real GDP in the short run. In the long-run, these variables, as well as employment, exert a significant impact on the dependent variable.

5. Discussion and conclusion

This investigation delved into the growth patterns of 39 countries—South Africa, 32 OECD countries and 6 Latin American nations—comparing their performance for 39 years, from 1980 to 2019. Convergence analysis is considered to derive absolute and unconditional convergence results when applied between countries in terms of their long-run steady-state characteristics (Sala-i-Martin, 1996). However, studies that have been conducted between cross-sections of countries with heterogeneous economic characteristics detected conditional convergence (Barro, 1991; Barro & Sala-i-Martin, 1992).

The findings indicate that South Africa's economic performance is significantly lower than the OECD average GDP per capita, with an annual average growth rate in real GDP of 0.54% during the research period, which falls below the 2% 'iron law of convergence' hypothesis. As the country's real GDP per capita over the period has increased from \$3,034.66 to \$6,702.53, the divergence gap is reducing, implying that conditional convergence has been observed which supports the findings previous studies (Barro, 1991; Barro & Sala-i-Martin, 1992). Thus, ceteris paribus, it will take South Africa approximately 34.11 years to reach the 2019 OECD's average GDP per capita. To boost economic performance, South Africa should prioritise the effective use of available technologies as theory suggests. This may be accomplished by investing in R&D, innovation programmes and measures to close the technological divide. Additionally, by encouraging collaboration among the commercial sector, academia and government can help with technological transfer and adoption. The results of the FMOLS test support this policy recommendation as it showed that gross fixed capital formation or total investment and capital stock exert the highest and most significant ($p = 0.00$) effect on real GDP per capita in the long run. Furthermore, the Granger causality test detected a bi-directional relationship between total investment and real GDP, implying that changes in one affect changes in the other.

Moreover, the findings highlight the need for policy initiatives to promote convergence between South Africa and OECD nations. These interventions should focus on education and skill development, infrastructure investment and creating a favourable business climate. Implementing policies that encourage equitable growth and eliminate structural hurdles can help to close the development gap. South Africa should look at prospects for regional economic cooperation with other African countries. Collaborative efforts can help with information exchange, trade integration and cooperative infrastructure projects. Regional cooperation can provide synergies and boost South Africa's economic growth potential as suggested by the regional economic growth theory and interregional convergence hypothesis developed by Hecksher, Ohlin and Samuelson (1919, 1933, 1953). Given the scarcity of empirical studies on convergence in Africa, it is advised that further study be conducted in this field. Increased empirical study can shed light on the processes of economic development, convergence trends and policy implications unique to African nations. This study can help to shape evidence-based policy and decision-making processes. A limitation of this study is that it does not take exogenous shocks such as the covid-19 pandemic into account.

6. References

Ascani, A., Crescenzi, R. & Iammarino, S. (2012). *Regional Economic Development: Review*. London: SEARCH Working Paper. https://doi.org/10.4324/9781315143736-9

Barro, R. J. & Sala-i-Martin, X. (1991). Convergence Across States and Regions. Washington D.C.: *Brookings Papers on Economic Activity*, 1991(1), 107–182. https://doi.org/10.2307/2534639

Blonigen BA. (2005). A review of the empirical literature on FDI determinants. *Atlantic Economic Journal*, 33(4), 383-403. https://doi.org/10.1007/s11293-005-2868-9

Dumitrescu, E.I., & Hurlin, C. (2012). Testing for Granger non-causality in heterogeneous panels. *Economic Modelling*, 29 (4), 1450–1460. https://doi.org/10.1016/j.econmod.2012.02.014

Eberts, R. W. (1990). *Public Infrastructure and Regional Economic Development*. Cleveland: Federal Reserve Bank of Cleveland. https://doi.org/10.26509/frbc-wp-199004

Egri, Z. & Tánczos, T. (2018). The spatial peculiarities of economic and social convergence on Central and Eastern Europe. *Regional Statistics*, 8(1), 49–77. https://doi.org/10.15196/rs080108

Feenstra, R.C., Inklaar, R. & Timmer, M.P. (2015). The Next Generation of the Penn World Table. *American Economic Review*, 105(10), 3150-3182. https://doi.org/10.1257/aer.20130954

Fedderke, J. & Garlick, R. (2008). *Infrastructure Development and Economic Growth in South Africa: A review of the accumulated evidence.* Cape Town: University of Cape Town.

Granger, C.W.J. (1969). Investigating causal relations by econometric models and cross-spectral models. *Econometrica,* 37, 424–438. https://doi.org/10.2307/1912791

Gibb, R. (2007). Regional integration in post-apartheid southern Africa. *Tijdschrift voor Economiesche en Sociale Geografie*, 98(4), 421–435. https://doi.org/10.1111/j.1467-9663.2007.00412.x

Grigoras, S. (2015). Public Sector's Influence on Economic Growth and Convergence as Proof of Development. *Economics and Applied Informatics*, 221(3), 36–44.

Im, K.S., Pesaran, M.H. & Shin, Y. (2003). Testing for unit roots in heterogeneous panels. *Journal of Econometrics*, 115, 53–74. https://doi.org/10.1016/s0304-4076(03)00092-7

Islam, N. (1995). Growth empirics: A panel data approach. *The Quarterly Journal of Economics*, 110 (4), 1127–1170. https://doi.org/10.2307/2946651

Kao, C. (1999). Spurious regression and residual-based tests for cointegration in panel data. *Journal of Econometrics*, 90, 1–44. https://doi.org/10.1016/s0304-4076(98)00023-2

Kanó, I. S. & Lengyel, I. (2021). Convergence Clubs of NUTS3 Regions of the V4 Group. *E&M Economics and Management*, 24(4), 22–38. https://doi.org/10.15240/tul/001/2021-4-002

Kurniawati, M. A. (2020). The role of infrastructure, innovation, and globalization on economic growth in OECD countries, 1996–2017. *Journal of Science and Technology Policy Management*, 11(2), 193–215. https://doi.org/10.1108/jstpm-06-2019-0065

Lengyel, I. & Kotosz, B. (2018). The Catching up Processes of the Regions of the Visegrad Group Countries. *Comparative Economic Research*, 21(4), 5–24. https://doi.org/10.2478/cer-2018-0024

LSEG Data & Analytics, 2023. Workspace Refinitiv https://workspace.refinitiv.com/ (accessed: 13/10/2023).

Levin, A., Lin, C-F., & Chu, C-S. J. (2002). Unit root tests in panel data: Asymptotic and finite-sample properties. *Journal of Econometrics*, 108, 1–24. https://doi.org/10.1016/s0304-4076(01)00098-7

Mankiw, N. G., Romer, D., & Weil, D. N. (1992). A contribution to the empirics of economic growth. *The Quarterly Journal of Economics*, 107(2), 407–437. https://doi.org/10.2307/2118477

McCoskey, S.K. (2002). Convergence in Sub-Saharan Africa: a nonstationary panel data approach. *Applied Economics*, 34(7), 819–829. https://doi.org/10.1080/00036840110061668

Monfort, P. & Nicolini, R. (2000). Regional convergence and international integration. *Journal of Urban Economics*, 48(1), 286–306. https://doi.org/10.1006/juec.1999.2167

Nagy, B., Lengyel, I. & Udvari, B. (2020). Reindustrialisation patterns in the post-socialist EU members: a comparative study between 2000 and 2017. *The European Journal of Comparative Economics*, 17(2), 253-275.

Ouattara, B. & Zhang, Y.F. (2019). Infrastructure and long-run economic growth: evidence from Chinese provinces. *Empirical Economics*, *57*, pp.263–284. https://doi.org/10.1007/s00181-018-1429-4

Phillips, C.B. & Sul, D. (2009). Economic transition and growth. *Journal of Applied Econometrics*, 24, pp.1153–1185. https://doi.org/10.1002/jae.1080

Phillips, P. & Hansen, B. (1990). Statistical inferences in instrumental variables regression with I(1) processes. *Review of Economic Studies*, 57, 99–125. https://doi.org/10.2307/2297545

Pradhan, R.P. & Bagchi, T.P. (2013). Effect of transportation infrastructure on economic growth in India: The VECM approach. *Research in Transportation Economics*, 38(1), 139-148. https://doi.org/10.1016/j.retrec.2012.05.008

Rogerson, C.M. (1997). Local economic development and post-apartheid reconstruction in South Africa. *Singapore Journal of Tropical Geography*, 18(2), 175–195. https://doi.org/10.1111/1467-9493.00015

Rogerson, C.M. & Rogerson, J. M. (2010). Local economic development in Africa: Global context and research directions. *Development Southern Africa*, 27(4), 465–480. https://doi.org/10.1080/0376835x.2010.508577

Saba, C. S. & Ngepah, N. (2020). Convergence in military expenditure and economic growth in Africa and its regional economic communities: evidence from a club clustering algorithm. *Cogent Economics & Finance*, 8(1), 1–35. https://doi.org/10.1080/23322039.2020.1832344

Sahoo, P., Dash, R. K. & Nataraj, G. (2010). Infrastructure development and growth in China. *Chiba: Institute of Developing Economies*.

Sala-i-Martin, X. (1996). The classical approach to convergence analysis. *The Economic Journal*, 106(437), 1019-1036. https://doi.org/10.2307/2235375

Sala-i-Martin, X. (2006). The world distribution of income: Falling poverty and convergence, period. *The Quarterly Journal of Economics*, 121(2), 351–397. https://doi.org/10.1162/qjec.2006.121.2.351

Sims, C.A. (1980). *Comparison of interwar and postwar business Cycles: Monetarism reconsidered*. https://doi.org/10.3386/w0430

Stock, J.H. & Watson, M.W. (1993). A simple estimator of cointegrating vectors in higher order integrated systems. *Econometrica*, 61(4), 783-820. https://doi.org/10.2307/2951763

Wehner, J. (2000). Development strategies in post-apartheid South Africa. *Afrika Spectrum*, 35(2), 183-192.

Yahyaoui, I. & Bouchoucha, N. (2021). The long-run relationship between ODA, growth and governance: An application of FMOLS and DOLS approaches. *African Development Review*, 33(1), 38–54. https://doi.org/10.1111/1467-8268.12489

Young, J., Watt, A. & van den Hove, S. (2013). Effective interfaces between science, policy, and society: *the SPIRAL project handbook*., Swindon Wiltshire: SPIRAL.

Zeng, D.Z. (2015). *Global experiences with special economic zones: Focus on China and Africa*., Washington D.C.: The World Bank Group. https://doi.org/10.1596/1813-9450-7240

7. Appendix

Steady state GDP per capita equation (Sala-i-Martin, 1996):

$$sY = (n + \delta)K \tag{A1}$$

where:
s represents the savings rate
Y represents the total output, GDP
n represents the population growth rate
δ represents the depreciation rate of capital
K represents capital stock

GDP per effective worker equation (Sala-i-Martin, 1996):

$$GDP\ per\ effective\ worker = \frac{Y}{L \times A} \tag{A2}$$

Where Y is the total output, L is the number of workers, and A represents the level of technology or labour-augmenting technology.

Kao's (1999) equations:
The Kao test uses the FMOLS estimator and adds ECM into the model design.
The Kao test equation's fundamental form is as follows:

$$Y_{it} = \alpha_i + \beta_i + X_{it} + \gamma_i Z_{it} + \varepsilon_{it} \tag{A3}$$

where:
Y_{it} is the dependent variable for cross-sectional unit i at time t.

X_{it} is the set of independent variables for cross-sectional i unit at time t.

Z_{it} is the set of lagged dependent variables for cross-sectional unit i at time t.

α_i, β_i, and γ_i are the coefficients to be estimated.

ε_{it} is the error term."

The ECM equation is added to capture the long-run relationship among the variables. It takes the following form:

$$\Delta Y_{it} = \delta_i + \varphi_i Y_{it-1} + \theta_i Z_{it-1} + \lambda_i \Delta Y_{it-1} + \mu_{it} \quad \text{(A4)}$$

where:
ΔY_{it} is the first difference of the dependent variable for cross-sectional unit *i* at *t* time .

δ_i, φ_i, θ_i, and are the coefficients to be estimated. μ_i is the error term. The Kao test then examines the significance of the coefficient φ_i to determine the presence of cointegration."

FMOLS regression equations:

$$Y_t = \beta_0 + \beta_1 t + \beta_2 X_t + \sum_{i=1}^{r} \alpha_i \Delta X_{t-i} + u_t \quad \text{(A5)}$$

$$\Delta Y_t = \alpha_0 + \alpha_1 ECT_{t-1} + \alpha_2 \Delta X_t + \varepsilon_t \quad \text{(A6)}$$

Panel causality test equations:

$$X_{it} = \sum_{j=1}^{m} \propto_j X_{it-j} + \sum_{j=1}^{m} \beta_j Y_{it-j} + u_{it} \quad \text{(A7)}$$

$$Y_{it} = \sum_{j=1}^{m} \theta_j Y_{it-j} + \sum_{j=1}^{m} \gamma_j X_{it-j} + v_{it} \quad \text{(A8)}$$

Panel VAR model equations:

$$Y_{it} = \propto_0 + \sum_{j=1}^{m} \alpha_j Y_{it-j} + \sum_{j=1}^{m} \beta_j X_{it-j} + u_{it} \quad \text{(A9)}$$

$$X_{it} = \gamma_0 + \sum_{j=1}^{m} \gamma_j X_{it-j} + \sum_{j=1}^{m} \varphi_j X_{it-j} + \vartheta_{it} \quad \text{(A10)}$$

Here m is the optimal lag length and refers to the m−order VAR model and is denoted as VAR(m).

Panel VECM test equations:

$$\Delta Y_{it} = \alpha_1 + \sum_{j=1}^{p} \beta_j \, \Delta Y_{it-j} + \sum_{j=1}^{p} \gamma_j \, \Delta X_{it-j} + \varphi_1 ECT_{it-1} + u_{it} \quad \text{(A11)}$$

$$\Delta X_{it} = \alpha_2 + \sum_{j=1}^{p} \delta_j \, \Delta X_{it-j} + \sum_{j=1}^{p} \theta_j \, \Delta Y_{it-j} + \varphi_2 ECT_{it-1} + v_{it} \quad \text{(A12)}$$

Table A1. Population country codes

Australia	AU	Germany	DE	Netherlands	NL	United Kingdom	UK
Austria	AT	Greece	GR	New Zealand	NZ	United States	US
Belgium	BE	Hungary	HU	Norway	NO	Argentina	AR
Canada	CA	Iceland	IS	Poland	PL	Bahamas	BS
Chile	CL	Ireland	IE	Portugal	PT	Barbados	BB
Colombia	CO	Israel	IL	South Korea	KR	Panama	PA
Costa Rica	CR	Italy	IT	Spain	ES	Trinidad and Tobago	TT
Denmark	DK	Japan	JP	Sweden	SE	Uruguay	UY
Finland	FI	Luxembourg	LU	Switzerland	CH	OECD Average	OECD
France	FR	Mexico	MX	Turkey	TR	South Africa	ZA