GROWTH THROUGH INNOVATION AND PRODUCTIVITY: THE CASE OF SOUTH AFRICA

by

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DEDICATION

I dedicate this dissertation to my mother Julia Ledwaba and my late grandparents Mr David Ledwaba and Mrs Martha Ledwaba.

DECLARATION

I declare that "GROWTH THROUGH INNOVATION AND PRODUCTIVITY: THE CASE OF SOUTH AFRICA" is my work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references and that this work has not been submitted before for any other degree at any other institution.

________________________ 29 AUGUST 2022

Full names Date

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ABSTRACT

The purpose of this study was to investigate growth through innovation and productivity in the South African economy. The study employed the Autoregressive Distributed Lag (ARDL) approach to analyse the annual time series data from the period 1994 to 2018. The data of the study is quantitative and was collected from the South African Reserve Bank and the World Bank. Due to a decline in investment in innovation in South Africa as compared to Brazil, Russia, India and China, the study recommends increased investment in innovation, which may yield positive results on economic growth given the Fourth Industrial Revolution (4IR) presence. The results of the study indicate that there is a long-run relationship between the variables furthermore, in the short-run research and development (R&D), several patents and manufacturing: Labour productivity has a positive and is statistically significant on GDP. However, labour productivity in the non-agricultural sector is positive but statistically insignificant on GDP. Moreover, the findings, in the long run, reveal that R&D, number of patents, and manufacturing: labour productivity is positive and statistically significant on the economic growth in South Africa while labour productivity in the non-agricultural sector has a negative impact on economic growth. This study recommends that policymakers should aim at increasing government-funded R&D, education and human capital to induce productivity and eventually drive up economic growth in South Africa.

KEY CONCEPTS: Innovation, Labour productivity, South Africa, Autoregressive Distributed Lag, Patents, Research and development.

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ACRONYMS

GDP	Gross Domestic Product
ILO	International Labour Organisation
R&D	Research and Development
4IR	Fourth Industrial Revolution
CeSTII	Centre for Science, Innovation Indicators
BRICS	Brazil, Russia, India, China and South Africa
HSRC	The Human Sciences Research Council
OECD	Organisation for Economic Cooperation and Development
ARDL	Autoregressive Distributed Lag
OLS	Ordinary Least Squares
EU	European Union
TFP	Total Factor Productivity
ECM	Error Correction Model
NoP	Number of Patents
LPNas	Labour Productivity in Non-agricultural sector
LPman	Manufacturing: Labour Productivity
KPSS	Kwiatkowski-Phillips-Schimidt-Shin
DF-GLS	Dickey-Fuller Generalised Least Squares
AIC	Akaike Information Criterion
SBC	Scwarz Bayesian Criterion
HQC	Hannan-Quinn Criterion
CUSUMsq	Cumulative Sum of Squares

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CHAPTER 1

ORIENTATION TO THE STUDY

1.1 INTRODUCTION AND BACKGROUND

The forces of the Fourth Industrial Revolution (4IR) have ushered in a new economy and a new form of globalisation (World Economic Forum, 2019). Xu, David and Kim (2018) argued that although each industrial revolution is often considered a separate event, together they can be better understood as a series of events building upon innovations of the previous revolution, leading to more advanced forms of production. The International Labor Organization (ILO) (2018) estimated that by 2030, about 60% of occupations, or at least one-third of constituent activities could be automated. In addition, between 3 and 14% of the global workforce would need to switch occupational categories. Furthermore, Schwab (2016) posited that when compared to previous industrial revolutions, the Fourth Industrial Revolution is evolving at an exponential rather than a linear pace. It is disrupting almost every industry in every country. The breadth and depth of these changes herald the transformation of entire systems of production, management and governance. He also noted that technological innovation will also lead to a supply-side miracle, with long-term gains in efficiency and productivity. Transportation and communication costs will drop, logistics and global supply chains will become more effective, and the cost of trade will diminish, all of which will open new markets and drive economic growth.

The issue of the industrial revolution is well linked to the Creative Destruction theory coined by Schumpeter (1942). According to Pfarrer and Smith (2015), creative destruction refers to an evolutionary process within capitalism that revolutionises the economic structure from within, incessantly destroying the old one, and creating the new one. Likewise, Blau (2002) stated that creative destruction refers to the ceaseless product and process innovation mechanism by which new production units replace outdated ones. This restructuring process permeates major aspects of macroeconomic performance, not only long-run growth but also economic fluctuations, structural adjustment, and the functioning of factor markets.

Blau (2002) also indicated that over the long run, the process of creative destruction accounts for over 50% of productivity growth. At business cycle frequency, restructuring typically declines during recessions, adding a significant cost to downturns. Obstacles to the process of creative destruction can have severe short and long-run macroeconomic consequences. Aghion, Fedderke, Howitt and Viegi (2013) also stated that according to the theory, the process of destruction and the process of technological catching up are positively correlated, because only firms that can compete internationally would be able to survive in the new competitive environment. According to Grobbelaar and Buys (2001), it is almost universally accepted that technological change and other kinds of innovations are the most important sources of productivity growth and increased material welfare and this has been the case for centuries. Furthermore, Pece, Simona and Salisteanu (2015) and Maradana, Pradan, Dash, Gaurav, Jayakumar and Chartejee (2017) found that there is a positive and a long-run relationship between economic growth and innovation in countries such as Indonesia, Thailand and Malaysia,

Obstacles to the process of creative destruction can have severe short and long-run macroeconomic consequences (Blau, 2002). Moreover, technological discontinuities can lead to intensified technological competition or even to a complete breakdown of competitive patterns. Consequently, a process of 'creative destruction' may unfold, which eventually leads to the demise of established firms, resulting in poor economic growth (Bergek *et al*., 2013). Furthermore, Schlesinger and Doyle (2015) stated that the value of large, dominant firms that fail to transform themselves in the process of creative destruction eventually becomes destroyed.

Given all these, Sokolov-Mladenović, Cvetanović and Mladenović (2016) argued that the only way to effectively increase economic growth in the long term is through productivity improvements. At present, developed countries largely base their economic growth on the creation and use of knowledge. Knowledge, objectified in technological changes, has become a fundamental creator of the competitive advantage of companies and countries in the world. Sokolov-Mladenović *et al*. (2016) also noted that the expected growth rate of the economy depends upon the economy-wide amount of research. What drives individuals to engage in research and development (R&D) activities is their perception that such activity will ensure extra profit. It is unsurprising then that policymakers and researchers widely acknowledge that investment in innovation is one of the major drivers of productivity growth, and is therefore of critical importance. The importance of knowledge in production was further captured by Hausmann, Hidalgo, Bustos, Coscia, Simoes and Yildirim (2013), who concluded that product knowledge to create new products or services is key to the economic success and wealth of a country.

There are many channels through which societies accumulate knowledge, including formal education, on-the-job training, basic scientific research, learning by doing, process innovations, and product innovations (Blanchard *et al*., 2010). According to Walwyn and Cloete (2016), in the most recent survey, it is apparent that South Africa's expenditure on R&D has grown in real terms by 52% between 2001 and 2012. This increase was driven by government funding, which rose from 34% of total R&D funding in 2003 to 45% by 2012. Much of the additional funding has been granted to universities, with government support of R&D in this sector rising 450% in nominal terms and 250% in real terms over the same period. The survey also reveals a decline in the average cost of research, as expressed by expenditure per full-time equivalent researcher.

It is shown in the next section that this argument also holds for the South African economy since it has become increasingly dependent on technology and technological progress. The section also explores the pivotal role that technological progress has played in South Africa's economic growth performance over the past decades.

1.2 STATEMENT OF THE PROBLEM

South Africa faces key challenges such as poverty, low levels of education and employment, as well as an urgent need for economic growth. This occurs although the country has all the resources required to solve humanity's biggest challenges. However, the activating ingredient is the ability to innovate (Mzimba, 2019). Innovation is widely acknowledged as being vital to economic growth and progress (Blankley & Moses, 2009). Given the importance and the inevitable presence of the 4IR, the problem is that channels through which societies accumulate knowledge in South Africa are of great concern. A decline in investment into R&D impedes development and economic growth in South Africa.

Walwyn and Cloete (2016) showed that it is apparent that South Africa's expenditure on R&D has grown in real terms. On the contrary, Grobbelaar and Buys (2001) indicated that there is evidence of disinvestments and decay of the country's R&D capacity. Furthermore, Grobbelaar and Buys (2001) argued that South Africa's position as a knowledge creator is declining. In support of this notion, the Centre for Science, Innovation Indicators (CeSTII) noted that both government-funded R&D and the injection of funds from the business sector have been showing signs of slowing down in 2013/14. Grobbelaar and Buys' (2001) notion was also corroborated by Schaffer, Steenkamp, Flowerday and Goddard (2017), who also noted that R&D expenditure relative to GDP declined marginally over the period 2004 to 2012, but increased in other emerging market peers, including China, the Russian Federation and Brazil. The ratio of R&D expenditure to GDP in South Africa was 0.73 % in 2012 and was the lowest among Brazil, Russia, India, China and South Africa (BRICS countries) (e.g. China 1.93%, Brazil 1.15%). The Human Sciences Research Council (HSRC) estimated that South Africa spent 0.73 % of its GDP on R&D in 2013/14, which compares unfavourably to an Organisation for Economic Cooperation and Development (OECD) average of 2.4 % of GDP. Similarly, Arnoldi (2019) highlighted that government funding of R&D for the business sector continued to decrease, having dropped from a share of 9.6% in 2008/9 to 2.8% in 2016/17.

In light of the above, it is evident that a decline in investment in R&D within South Africa has a negative effect on knowledge creation. As a result, productivity might be compromised and may be coupled with negative repercussions on economic growth. In addition, technological discontinuities indicated by a decline in R&D over the past years in South Africa can lead to diminishing technological competitiveness of firms' levels of production, and eventually to a complete breakdown of competitiveness. Consequently, this may lead to the downfall of established firms and poor economic growth. Thus, the study seeks to examine the impact of innovation and productivity on economic growth in South Africa.

1.3 RESEARCH AIM AND OBJECTIVES

1.3.1 Aim

This study aims to investigate growth through innovation and productivity in South Africa.

1.3.2 Objectives

To realise the above-mentioned aim, the objectives of the study are organised as follows:

- To determine the impact of innovation on economic growth.
- To investigate the relationship between productivity and economic growth.
- To examine long-run and short-run relationships between innovation, productivity and economic growth.
- To determine the direction of causality between innovation, productivity and economic growth.

1.4 RESEARCH QUESTIONS

- What is the impact of innovation on economic growth?
- What is the nature of the relationship between productivity and economic growth?
- Is there a long-run and short-run relationship between innovation, productivity and economic growth?
- What is the direction of causality between innovation, productivity and economic growth?

1.5 DEFINITION OF CONCEPTS

The following concepts are adopted and defined:

- Economic growth

An increase of the national income per capita, and involves the analysis, especially in quantitative terms, of this process, with a focus on the functional relations between endogenous variables. In a wider sense, economic growth involves an increase in the GDP, GNP and NI, therefore of the national wealth, including the production capacity, expressed in both absolute and relative size, per capita, encompassing also the structural modifications of the economy (Haller, 2012).

- Innovation

Innovation is an economic process that occurs as a response to perceived profit opportunities, through an act of foresight of the capitalist entrepreneurs who create or realise these opportunities through innovations (Grobbelaar & Buys, 2001). Since it is not possible to quantify innovation in line with Manzini (2015), the following are used as proxies for innovation in the model:

- Research and Development

Research and Development (R&D) is the term commonly used to describe activities undertaken by firms and other entities such as individual entrepreneurs to create new or improved products and processes. The broadest meaning of the term covers activities from basic scientific research performed in universities and laboratories to testing and refining products before a commercial sale or use (Hall, 2007).

- Number of patents

Patent output is used in current surveys as a proxy for knowledge intensity. It is proposed here that the licensing of patents and other intellectual property for industrial application is perhaps the most appropriate indicator. This is because it indicates the intellectual property that is engaged productively in the economy. This is in stark contrast to patents that are filed and never put to practical use (Manzini, 2015). Additionally, patent data are the most widely used indicators of technology output. They are used, for instance, to assess the rate of technological change, to gauge firms' competitive positions, to measure industrial structure, or to evaluate scientific progress and knowledge spillovers (Rassenfosse & Potterie, 2009).

- Productivity

A country's ability to improve its standard of living over time depends almost entirely on its ability to raise its output per worker. Productivity is commonly defined as a ratio between the output volume and the volume of inputs. In other words, it measures how efficiently production inputs, such as labour and capital, are being used in an economy to produce a given level of output (Krugman, 1994).

1.6 ETHICAL CONSIDERATIONS

The study made use of secondary data which was sourced from the South African Reserve Bank and the World Bank. All the sources used were acknowledged and the rules of the University of Limpopo of researching Master of Commerce degree requirements were also considered. The study referenced all sources to maintain and uphold academic standards.

1.7 SIGNIFICANCE OF THE STUDY

The study investigates growth through innovation and productivity on economic growth in South Africa. The rationale for employing the ARDL approach is that it has various econometric advantages that gained greater acceptance over well-known residual-based approaches such as Engle and Granger (1987) furthermore, the ARDL approach is able to distinguish between the dependent and explanatory variables (Mongale, 2019).

According to Nicolaides (2014), the overall finding was that a sustained investment in R&D is very important for the future of South Africa's R&D capacity. The government needs to realise both the importance of an R&D capacity as well as the necessity of investing in it. Constant investment should be made in the development of young researchers to ensure the rejuvenation of the R&D systems. R&D incentives could also make South Africa a more attractive location for multinational enterprises to base their R&D activities.

The study will play an important role in assisting policymakers in implementing policies that will achieve inclusive growth. From the results of the study, it is expected that the ARDL model and the Granger causality test will provide results that will add to the body of knowledge and provide more understanding of the topic in question. Furthermore, the study can be used by society to close the knowledge gap and to better their understanding of how growth through innovation and productivity impacts the South African economy.

1.8 STRUCTURE OF THE STUDY

This study consists of five chapters organised in the following manner:

Chapter 1 is the orientation of the study and the introductory chapter. It provides the general background of the study, the problem statement, research aim and objectives, research questions, the definition of concepts, ethical consideration, the significance of the study and finally the structure of the dissertation. Chapter 2 reviews the relevant theoretical framework and a large area of empirical literature regarding Growth through Innovation and productivity: the case of South Africa.

Chapter 3 includes the research methodology, where a detailed explanation of the estimation techniques implemented in this study has been provided. This chapter also outlines the model specification and how data collection was done.

Chapter 4 presents the interpretation of the results and findings of different tests conducted in the previous chapter. Chapter 5 provides the summary, recommendations and conclusions. The List of references contains all articles, books and other sources used throughout the dissertation. Appendices include the data and results that could not be added in the chapters.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This section provides the conceptual review, both the theoretical and empirical literature of growth through creative destruction. The section is divided into subsections. The first subsection discusses the conceptual review followed by the theoretical framework of the study and the third subsection focuses on the theoretical review and lastly the empirical literature of the study as well as the analysis of trends of the variables employed in the study.

2.2 Conceptual review

According to Frederiksen, Phelps and Kimmons (2018), a conceptual review refers to describing relevant concepts of the study and also to outlining the relationship between them which includes relevant theory. International Monetary Fund- (IMF) (2021), defined economic growth as the increase in the market value of goods and services produced by an economy over time and is usually measured as the percent rate of increase in the real gross domestic product (GDP) annually. Furthermore, it measures how countries develop over time and also measure human well-being and progress. In the context of the study, innovation is referred to as the abundance of large firms and state of the art technology in urban areas and it is measured by research and development which shows the amount of money spent on applying different R&D circulating in the country (Allgurin, 2017). Moreover, for there to be economic growth in the country it is worth noting that innovation lies in a country's shape of settlement structure, availability of knowledge sources like universities and public research institutions and finance to induce productivity levels and output (Fritsch and Wyrwich, 2020).

Therefore, one can presume that R&D expenditure helps improve ways of living and working in a country and makes it easier and more efficient and productive when creating goods and services which will potentially result in economic growth.

2.3 Theoretical Framework

This part of the literature review presents economic theories relevant to this study. The study of knowledge as a key determinant of economic growth is especially present in the so-called new growth theory. The most important direction is the Schumpeterian model of growth, which presents the complexity of technological change as a source of economic growth. The study focused on the Cobb–Douglas production function, which explains the impact of productivity on growth.

2.3.1. Schumpeterian model

Over the past 25 years, the Schumpeterian growth theory has developed into an integrated framework for understanding not only the macroeconomic structure of growth but also the many microeconomic issues regarding incentives, policies and organisations that interact with growth (Aghion & Howitt, 2006). This model is regarded as Schumpeterian in that it is about growth generated by innovations, which result from entrepreneurial investments that are themselves motivated by the prospects of monopoly rents. Innovations replace old technologies, in other words, growth involves creative destruction (Aghion, Akcigit & Howitt, 2014). According to Islam, Ghani, Kusuma and Theseira (2016), the modern growth theory begins with Joseph Schumpeter where it states that human resources are an important factor of production than natural resources as well as the role of entrepreneurship and also determined that capital will grow faster or slower or involve innovation and changes.

This is an alternative model of endogenous growth, which is generated by a random sequence of quality-improving (or “vertical”) innovations. The model grew out of modern industrial organisation theory, which portrays innovation as an important dimension of industrial competition. It is called Schumpeterian because it embodies the force that Schumpeter (1942) called “creative destruction”; that is, the innovations that drive growth by creating new technologies also destroy the results of previous innovations by making them obsolete (Aghion *et al*., 2013). Onyimadu (2015) further emphasises that the Schumpeterian growth model is about innovations and research spillovers as drivers of economic growth, additionally, this model shows that the researcher can successfully innovate or become unsuccessful making innovation uncertain as a result of technology advancing. Likewise, Petrovic and Nikolic (2018), views Schumpeterian as a theory of economic growth and innovation whereby there is a generation of new technology replacing previous technology and finally leads to the economy growing as well as increased productivity levels.

According to Henrekson, Johansson and Karlsson (2021), posits that under the Schumpeterian model new ideas are economically relevant if they are put to economic use since the entrepreneur is perceived as the link between new ideas and their market introduction. In addition, they indicated a three-step process that translates new combinations into economic growth, the first step involving the inception of an idea (invention) followed by an identification of the potential use of the idea to realise its economic value and lastly it leads to dissemination into the economy. Aghion, Akcigit and Howitt (2015), further explored the Schumpeterian as a model that analyses the relationship between inequality and economic growth as well as innovation-led growth. On the other hand, Cozzi (2022) is of the view that the Schumpeterian growth model relies on capital as an important factor of production. The Schumpeterian growth model provides similar projections as the neoclassical growth model with regards to the capital inflows when there is no friction on the domestic financial market (Koch and Zongo, 2018).

The Schumpeterian paradigm has proved to be a useful framework for extending consideration of economic growth beyond the impact of innovation on economic development. Since the endogenisation of innovation requires an explicit treatment of the source of efficiency gains, Schumpeterian frameworks, such as those originally advanced by Aghion and Howitt (1992), are useful in analysing the interaction between institutions and economic growth (Aghion *et al*., 2013). A simple one-sector Schumpeterian model is presented; in which it is always the same product that is improved by innovation. This one-sector model contains the essential ideas of the Schumpeterian approach. For most empirical purposes, however, the one-sector model is too simple. A multisector Schumpeterian model is also developed and presented, in which many different products are improved by innovation each year (Aghion *et a*l., 2013). After adopting this model, the economy will either in the present or future be expected to be in a position whereby growth is positively significant from the associated investment in the development of new and advanced technology and investment in the capital as a factor of production increasing productivity levels.

2.3.2. Cobb–Douglas production function

In economics and management research, the Cobb-Douglas functional form of production function is widely used to represent the quantitative link between outputs and inputs. The form of production functions was proposed by Knut Wicksell (1851-1926) and was tested against statistical evidence by Cobb and Douglas (Yiadom-boakye *et al*., 2008). According to Mack and Faggian (2013), it is arguably the most common function for studying the impact of productivity. The production function is presented in the form of Q_{it} = ($K^{\alpha}{}_{it}$ L $^{\beta}{}_{it}$) where Q represents the labour productivity per employee, *K* is the level of capital stock and L is the total labour force in the countries *i* at time *t*. Furthermore, Khatun and Afroze (2016), states that the Cobb-Douglas production function is easy in its computation and interpretation of estimated parameters. Moreover, the objectives of applying this production function include estimating the coefficients of inputs, marginal productivities and factor shares in total output and degree of returns to scale.

Chowdhury and Islam (2015) are of the view that the Cobb-Douglas production function is still the ever-present form of theoretical and empirical analysis of growth and productivity because it is central to plentiful of the work related to growth, technological evolution, productivity and labour. According to Husain and Islam (2016), economists prefer to use Cobb Douglas functional form *Y = f (K, L) = AkαL β*,

Where *Y* is the output

K is the capital and

L is the Labour

Therefore, *α + β = 1 α, β>0 K, L>0* because it provides a relatively accurate description of the economy and is very easy to work with algebraically. Additionally, Dritsaki and Stamatiou (2018) posit that this function presents the quantity produced from labour and capital as the factors of production and that this production function focuses on productivity measurement, determination of marginal product and determination of less costly combination of factors in the production for a specific quantity of product as some of its basic goals. Kleyn, Arashi, Bekker and Millard (2017) provide an example of the Cobb Douglas production function whereby a loss or cost of overestimating production response to both capital and labour as inputs is more serious than when underestimating production which results in penalisation of an overestimate. Upon the application of the Cobb Douglas production function, production can be achieved by utilising the required factors of production which are capital and labour as inputs to induce productivity yielding positive output as production levels increase.

2.4 Theoretical review

This section focuses on the theoretical review of the Lucas growth theory, the Solow growth model and Romer's endogenous growth theory.

2.4.1. Lucas's growth theory

Human capital accumulation is regarded as the first model of Lucas and labour accumulation of human capital as the second model (Islam, Ghani, Kusuma and Theseira 2016). Moreover, Islam *et al,* (2016), believes that Lucas's model function indicates that higher productivity in education increases marginal product of labour, wage rate and brings an increase in economic growth. According to Puaschunder (2019), the idea of externalities and spillover effects arising from learning by doing and knowledge spillover that positively affect labour productivity on the aggregate level of the economy was picked by Lucas in the late 1980s as the endogenization of knowledge and technology was about the growth that occurred in Asian countries in the 1980s. Likewise, Jovovic (2017), posits that Lucas made an important contribution to the theory of endogenous growth because the higher level of human capital suggests a faster process of accumulation hence he is of the view that the interaction between individuals in the process of creation of knowledge directly influenced the transfer of knowledge. Additionally, Islam (2016) indicates that in order to gain and have increased economic growth there needs to be government expenditure (investment) in human capital that merges training and skills as well as knowledge to enhance a country's human resources. Therefore the Lucas growth model can assist policymakers in advising the government to increase expenditure and invest more into human capital to enhance knowledge as it is important in improving productivity in a country.

2.4.2. Solow growth model

The Solow growth model emphasises the importance of capital investment for economic growth and the model also assumes that technology exogenously determines the rate of growth to increase the productivity of labour Islam *et al.* (2016). According to Sredojevic, Cvetanovic and Boskovic (2016), the starting point of Solow's model is the production function whereby *Y= TF (K, L)*, where *Y* denotes the production, *T* being technology, *K* for physical capital and *L* is the amount of work. Gardonova (2016) is of the view that the Solow model is about economic growth through neoclassical production function similar to the Cobb-Douglas type. The Solow model aims to explain the long-run economic growth through capital accumulation, labour and by increases in productivity which are referred to as technological progress.

In addition, Nikolaos and Tsaliki (2021) state that the Solow model is regarded as the stepping stone in formulating a stable neoclassical theory of economic growth and this growth model has managed to formulate a model of economic growth based on neoclassical premises. Following this, Solow posits that with increased savings rate the economy can achieve high growth rates in assets from investment needed to obtain the total output. Another reason is that in developing countries where there is a struggle for attaining required savings for the development of technology, they can resort to the influence of debt on productivity and deploy technology, labour and capital to enhance the economic growth of a country provided these funds are properly invested in productive economic activities (Linhartova, 2021). As observed, the policymakers need to use this growth model to advise the government on public expenditure in human capital development since this is the investment with the highest return in the form of higher economic performance.

2.4.3 Romer's endogenous growth theory

According to Sredojevic *et al.* (2016), Romer's endogenous growth theory is based on R&D. The growth process is driven by technological progress which results from companies that seek to maximise profits from taking investment decisions. This is why Romer prioritises technology over other goods due to that it is a non-competitive and exclusive good. Islam *et al.* (2016), believe that Romer determined that education which is the investment of new knowledge could lead to an increase in human capital by rising productivity through the labour force which will result in greater output growth. Puaschunder (2019) further stated that the Lucas-Romer models are dynamic competitive general equilibrium models that are underpinned by explicit specifications of preferences and technology.

Romer's model is considered the first and most significant to the endogenous growth theory. It is stated that the neoclassical theory did not manage to determine the importance of technological change in Romer's opinion and that his view symbolises the established knowledge or ideas. Moreover, Jovovic (2017) believes that knowledge has an endogenous influence on the economy. Furthermore, Apostol, Enriquez and Suaway (2022) believe that Romer's endogenous growth theory point out the significance of intentional actions and efforts made by firms to pursue a culture of ideas that bring about innovation and eventually result in economic growth. Similarly, the endogenous growth theory can help policymakers to be in a position to advise the government that in order for the economy to grow there needs to be an increase in investment in the factor inputs such as physical capital, labour, human capital and technology to induce the production and eventually lead to growth.

2.5. Empirical literature

This section presents a summary of previous empirical studies on how growth through creative destruction affects economic growth. For the sake of aspiring to remain relevant to the purpose, the section is aligned with the objectives of the study.

2.5.1. Innovation and economic growth

Aghion and Howitt (1990) begin from the belief supported by many empirical studies starting with Solow (1957) that a large proportion of economic growth in developed countries is attributable to improvement in technology rather than the accumulation of capital. They model technological progress as occurring in the form of innovations, which in turn result from the activities of research firms. As a result, they examine a channel that has received little attention in the endogenous growth literature, namely that of industrial innovations which improve the quality of products.

R&D and economic growth

Haq (2018) states that a country with a high foreign direct investment, R&D, patent rights and high technology exports will be highly developed and the economy of that country will be highly developed. Furthermore, Haq (2018) examined the impact of innovation on economic growth in Canada, South Korea and Pakistan. The data indicate that the growth in the real GDP of South Korea is due to high investment in R&D and human capital. The GDP of Pakistan is higher than that of South Korea but Pakistan is a less developed country. There are other factors like an equal distribution of income, gender equality, political stability and social justice, which contribute to the development of a country significantly.

According to Adak (2015), the economic structure of Turkey has changed dramatically over the last three and a half decades during which technology has become a crucial endogenous variable in the aggregate production function. The new technology investments brought with them high productivity rates and rapid, positive economic growth. The interrelation between technological progress and economic growth is summarised and analysed using quantitative methods. The econometric results show a significant effect of technological progress and innovation on economic growth. Firstly, technological progress and innovation relation was tested by the Ordinary Least Squares (OLS) method. A significant relation was found between technological imports and the number of total patent applications. Total patent applications and GDP relation was tested in the next step. Consequently, a long-run relation can be seen between the two variables by the Granger and Error Correction Models.

Sokolov-Mladenović, *et al* (2016) investigated the influence of R&D expenditure on economic growth in the 28 European Union (EU) member countries during the period of 2002–2012. For this purpose, a multiple regression model was constructed, which showed that ceteris paribus, an increase in R&D expenditure as a percentage of GDP by 1% would cause an increase in real GDP growth rate by 2.2%.

Furthermore, Sokolov-Mladenović, *et al*, (2016) investigated a set of research questions on whether the investment in R&D from 2002 to 2012 in the EU had a positive effect on economic growth. For this purpose, a multiple regression model was constructed in which the dependent variable was the real rate of economic growth, and the independent variable was the value of research and development expenditure as a percentage of GDP. To have a better model, in addition to the independent variable, control variables were introduced with a significant impact on the real rate of economic growth. The control variables used include gross fixed capital formation as a percentage of GDP, general government final consumption expenditure as a percentage of GDP, fertility rate, as well as financial crisis as the dummy variable. Their results unambiguously confirmed that, under conditions of the financial crisis, investment in R&D has a positive effect on the real economic growth rate. The constructed multiple regression model with fixed effects showed that with the application of the clause ceteris paribus, an increase in the share of R&D expenditure in GDP by 1% causes GDP growth of 2.2% in 28 countries of the EU in the period 2002 to 2012 (Sokolov-Mladenović *et al*., 2016).

According to Schaffer, Steenkamp, Flowerda and Goddard (2017), most OECD countries are operating at the world technological frontier, where the scope for rapid growth through technology diffusion and catching-up is mostly gone. On the contrary, South Africa should be growing faster than the OECD area and more in line with its emerging market peers as it industrialises and grows, in part through the adoption of the world-best technology. South Africa, however, is caught in a cycle of declining total factor productivity (TFP) growth and stagnant GDP growth at around 1 %.

According to Manzini (2015), the innovation that has an economic impact is likely to result in social benefit through improved wealth. Pece, *et al* (2015) found that foreign direct investments have a major impact on economic growth through knowledge transfer and improvement of technological processes. Moreover, the results indicated that education and human capital have a positive and strong impact on economic growth. This confirms a positive relationship between innovation and economic growth.

Innovation is regarded as an essential determinant of economic growth and development, which can only be achieved by countries with a high level of human and social capital (Hassanin, 2014). Additionally, Maradana, *et al*. (2017) emphasise that the level and structure of innovation should not be ignored because it plays an imperative role in stimulating economic growth. It is also suggested that government should play a pivotal role to foster innovation such as actions to increase innovation and then integrate it with per capita economic growth. Similarly, Broughel and Thierer (2019) are of the view that technological innovation is a fundamental driver of economic growth and human progress. This includes fostering innovation by encouraging R&D. For this reason, the study employed the Solow growth model for theoretical support and to also determine how the variables representing innovation affect economic growth in South Africa.

In relation to innovation, there several factors that result in economic growth. According to Johansson and Malm (2017), policymakers regard entrepreneurship as an important topic and a driving force behind job creation and economic growth. Furthermore, an entrepreneur is defined as the economic actor who engages in innovation, which is the introduction of new ways of employing existing productive means. It is noted that Schumpeter differentiates innovation from financing and classified innovation into broad categories which are the introduction of a new good, the introduction of a new method of production, the opening of a new market, the overpowering of a new source of supply of raw materials and the carrying out of a new organisation. On the contrary, Hessels and Naude (2019) state that policymakers find it difficult to promote economic development through entrepreneurship and they also argue that the reason is that the positive impact of entrepreneurship is overestimated and its negative impact is underestimated moreover, that there is no blended approach towards the role of entrepreneurship in economic development.

An increase in entrepreneurial ability was made possible in two ways, the first being that parents transfer human capital specifically tacit knowledge to their children and secondly parents transfer financial capital to children which is to support their entrepreneurial ventures. Ehrlich, Li and Liu (2017) believe that entrepreneurship is not only the generator but also the outcome of knowledge spillover. Coad and Karlsson (2022) found that research has focused on the effects of entrepreneurship on innovation, economic growth and welfare in addition to its effects on job creation. It also showed that it is mainly young firms rather than small firms that are responsible for job creation and that the quality of jobs created is sometimes poor. Furthermore, Coad *et al*. (2022) noted that establishing the effects of entrepreneurship on macroeconomic outcomes is technically challenging because entrepreneurship may not only affect innovation but in turn, innovation may affect entrepreneurship outcomes. Additionally, there is a positive relationship between entrepreneurial activity and innovation in developed countries suggesting that by increasing the level of entrepreneurial activity developed countries can improve their ability to produce commercially relevant innovations and eventually lead to growth. Weli, Okereke and Nnamdi (2022) posit that credit creation by financial systems has the potential to grow production resulting in economic growth and this can happen when the financial sector is allowed to expand and efficiently allocate resources. Furthermore, they highlighted the possibility that financial institutions could actively motivate innovation and growth by funding productive investments.

2.5.2. Productivity and economic growth

According to Chang, Wang and Liu (2016), knowledge spillovers in the form of human capital are regarded as the engine of sustained growth and development. Furthermore, by using the ratio of higher-educated employees, it is found that a 1% increase in the proportion of higher-educated employees will increase productivity by 0.93-1.15%, which also indicates that human capital spillovers are stronger under greater technology intensities. Productivity growth (or output growth, which is net of input growth) is a key to the long-run sustainability of growth as well as development because with rapid productivity growth proportionately, fewer resources will be required to raise the growth by one unit, and the scarce resources can be released from the growth process to be utilised for the overall development of the economy (Mitra, 2016). Samaniego and Sun (2016) present evidence that countries shift resources towards manufacturing industries with rapid productivity growth.

According to Brighton, Gibbon, Brown and Ni Luanigh (2016), the recent poor productivity of the UK economy, especially since the end of the recession of 2008-09, has become a major concern for economists and policymakers. Unlike previous recessions, job losses were not as high as might have been expected but real wages have declined, falling by an average of 1.7 % per year between 2008 and 2014. Productivity growth too has been very modest: this has become known as the 'productivity puzzle. As a consequence, the UK, which was already some way behind many other major developed economies on this measure, has fallen back even further. The overall level of productivity in the United States economy is now 31 % higher than that of the UK, while that of Germany is 28 % higher.

Within the results, it has been argued that inefficiency in the allocation of resources in the economy, and an absence of the 'innovation' processes cannot help drive up productivity. Mitra (2016) is of the view that it is international trade and export in particular, which improves the productivity of firms, finally leading to economic growth. Similarly, Jajri (2007) found that openness to foreign companies and the world economy, and the presence of foreign companies in Malaysia could be major contributing factors to total factor productivity growth.

According to Jajri (2007), the results of the study examining the determinants of total factor productivity growth in Malaysia revealed that the economy was able to cause a shift due to innovation. Furthermore, the economy needs an improvement of productivity to catch up, specifically the effective use of human capital in the labour market, increasing the number of skilled labours to operate more advanced technology and the adoption of new technology to stimulate economic growth. There are areas where improvement would bring an increasing growth rate, which includes increasing the quality of education and skills training, stimulating innovation, the adoption of information technology more widely, and fostering a well-functioning competition policy framework and the regulatory framework of small and medium-sized enterprises (Asada, Nixon & Koen, 2017). Basri, Karim and Sulaim (2020) found that shocks in production factors are positively and significantly transitional in impacting productivity growth, and the overall effects are positive over time. Moreover, these findings yield further insights into assisting policymakers in expanding the current labour market policy for sustainable economic growth.

Friedenthal (2016) states that a generally accepted expenditure ratio for an active science and innovation ecosystem is around 1.5% of GDP. Furthermore, other nations will become more competitive in creating economic and social value relative to South Africa. This has been recognised as a major concern quantified by the relatively low percentage of GDP spent on R&D and innovation at 0.75% of GDP. In comparison to other BRICS countries - Brazil, Russia, India and China spend approximately 1.24%, 1.13%, 0.85%, and 2.01% of GDP spent on R&D. The situation is still the same of late, Cleary (2019) also revealed that the gross expenditure on R&D (GERD) remains low at 0.8% of GDP. Additionally, Mongale (2019) used the Ordinary Least Square based ARDL approach and analysed the quarterly time series data from 1998 to 2018 to examine the implications of labour productivity and labour costs in South Africa and results has shown that labour productivity growth has been slowing down in South Africa. On the other hand, Hye & Lau (2015), employed a new endogenous growth model for theoretical support and ARDL model and rolling window regression method to determine the long-run and short-run relationship between trade openness and economic growth and results reveal that human capital and physical capital are positively related to economic growth in the long-run. Similarly, CEIC Data (2019) also revealed that labour productivity dropped by 1.13% year on year in December 2018 compared to a growth of 0.10% in the previous quarter.

Additionally, labour productivity in major advanced countries like Japan has been experiencing a slow-down in recent years. This is affected by a slowdown in total factor productivity as a result of technology and ideas through research and development and management resources not being utilised appropriately (Nakamura, Kaihatsu & Yagi, 2018). Recent trends of labour productivity and economic growth were analysed in Latvia, Lithuania and Estonia in the post-crisis as compared to the pre-crisis and crisis periods. The findings of this study suggest that there are no relations between labour productivity and economic growth in the pre-crisis period. However, the increase in labour productivity during the crisis is a significant driver of economic growth. These are key factors to maintain and improve the competitiveness of nations in the global market (Auzina-Emsina, 2014).

Korkmaz and Korkmaz (2017) have noted that labour productivity of developed countries is always higher than that of developing countries for the reason that developed countries have a strong economy, education and health infrastructure, and engage in technological innovations. For this reason, the study employed the ARDL approach and employed R&D, the number of patents, labour productivity in non-agricultural sector and manufacturing: labour productivity to determine their impact economic growth in South Africa. Whereas others studies have used various other macroeconomic variables such as exports, imports, interest rate, exchange rate, inflation rate, national income and unemployment rate to examine their impact on economic growth in South Africa. Furthermore, in explaining how productivity leads to economic growth the study employed various growth theories such as the Solow growth model by means of capital accumulation and labour which increase productivity and eventually leads to economic growth.

Furthermore, there are numerous non-economic factors that result in output productivity and economic growth. Human capital measured by the level of education is commonly considered one of the essential variables supporting economic growth.

One of the most important types of investment providing the highest return in terms of output is an investment in human capital (Linhartova, 2021). Human capital is regarded as an essential factor in developing countries to benefit from foreign technology furthermore, human capital accumulation is regarded as an engine of economic growth by the new endogenous growth models. Hye, *et al* (2015) found that human capital and physical capital are positively related to economic growth in the long run. Furthermore, in a study by Linhartova (2021), the panel data analysis was done of the 28 European Union (EU) countries and the results showed that some areas of public expenditure encourage human expenditure while some areas may have the opposite effect. Again, a negative and statistically significant impact on human capital development was shown for public spending on health, social protection and housing and community.

According to Kwendo and Muturi (2015), in demonstrating the impact of public spending on economic growth they did an analysis using panel data and Hausman test on the following countries Burundi, Rwanda, Kenya, Portugal and Tanzania and they found that public health expenditure has a positive impact on economic growth in these countries. Using the OLS method to investigate the impact of government spending on economic growth in Nigeria Musa and Jelilov (2016) found that government spending significantly and positively affects economic growth. In addition to this, Omodero (2018) focused on how government spending on education, health and defence affect GDP and from the findings of the study it is suggested to focus on investing towards education and health to boost the country's economy. Education and health care are regarded as the basis of economic growth and development in that they are regarded as important factors of economic performance and are a form of human capital that influence human productivity growth. Let, Hamzah, Yusop and Mazlan (2018) believe that technological progress is an essential factor to drive and sustain long-run growth and labour productivity Furthermore, the rapid growth of output and labour productivity across countries has largely been driven by technological advancement. Following this, it is evident that ICT has become a new source for improving labour productivity.

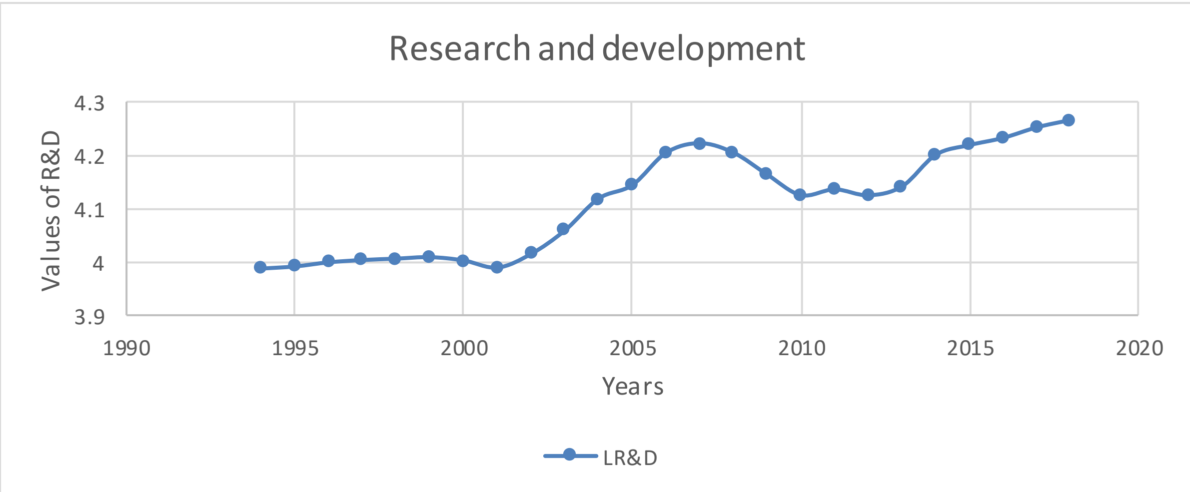
According to Dedrick, Kraemer and Shih (2013), other factors such as human capital, trade openness and cost of telecommunications relatively affect production. On the other hand, Najarzadeh, Rahimzadeh and Reed (2014) have in their study examined the impact of the internet as another factor on labour productivity and employed the generalised method of moments regression through panel data and their findings were that the internet has a positive and is statistically significant on labour productivity.

2.6. The overview of trends

This section focuses mainly on the analysis of trends of all the variables employed in the study for the period 1994 - 2018. The focus is largely on the main variables, starting by the trends of the variables that represent innovation which are R&D and a number of patents followed by variables that represent productivity which are labour productivity in the non-agricultural sector and manufacturing: labour productivity and lastly the comparison of economic growth represented by gross domestic product between the BRICS countries.

2.6.1. Trends for research and development

Figure 2. 1: Research and development

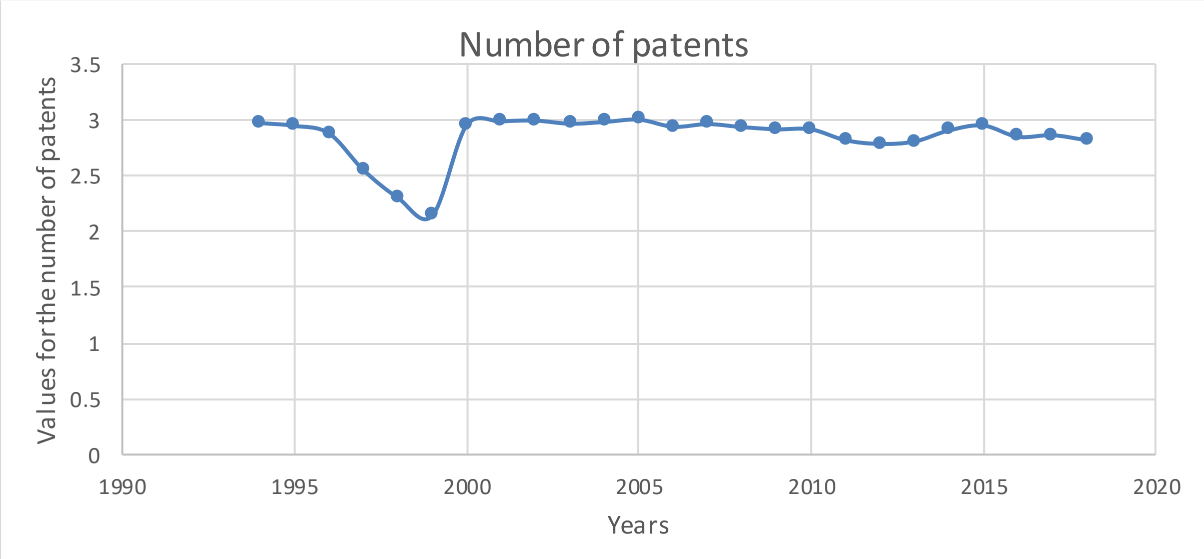


Source: Author’s compilation

Figure 2.1 depicts the number of patents annual data for South Africa for the period 1994 – 2018. The trend shows that the lowest R&D was at 4% between the 1990s and 2000s. Moreover, the highest recorded was post-2015 to 2018 with higher investment in R&D expenditure.

2.6.2. Trends for number of patents

Figure 2. 2 : Number of patents

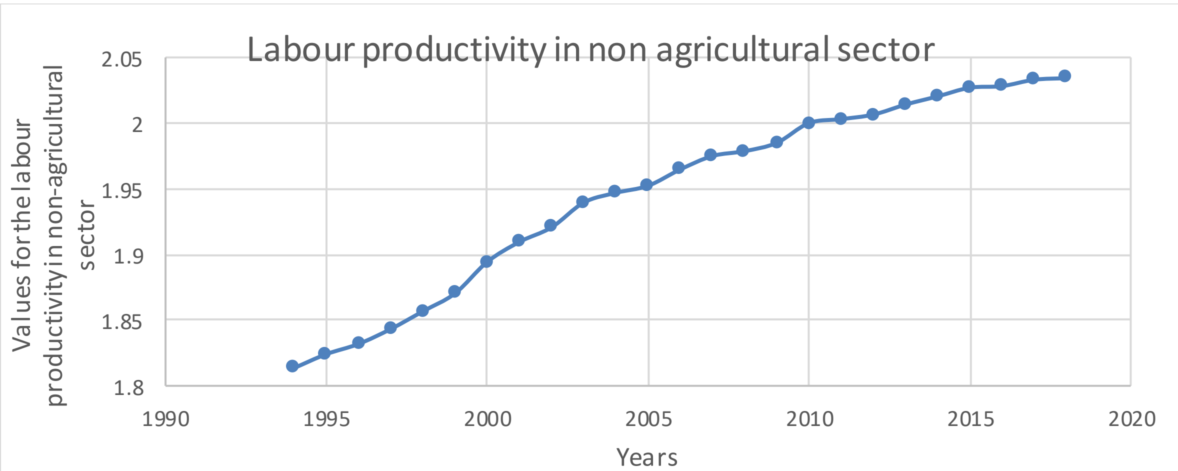


Source: Author's compilation

Figure 2.2 above shows the number of patents as a proxy for innovation for the period 1994 – 2018. The trend shows that South Africa recorded the lowest number of patents at 2.1%. Additionally, there was an increase in the number of patents from the year 2000 where it can be observed that the values ranged around 3% until 2018.

2.6.3. Trends for Labour productivity in the non-agricultural sector

Figure 2. 3 : Labour productivity in the non-agricultural sector



Source: Author's compilation

Figure 2.3 shows a graphical illustration of the labour productivity in the non-agricultural sector. From the observation of the trend the lowest value of between 1.8 and 1.85% has been recorded in 1994 and further increased from 1995 to 2018 and reached between 2 and 2.5% value.

2.6.4. Trends for Manufacturing: Labour productivity

Figure 2. 4 : Manufacturing: Labour productivity

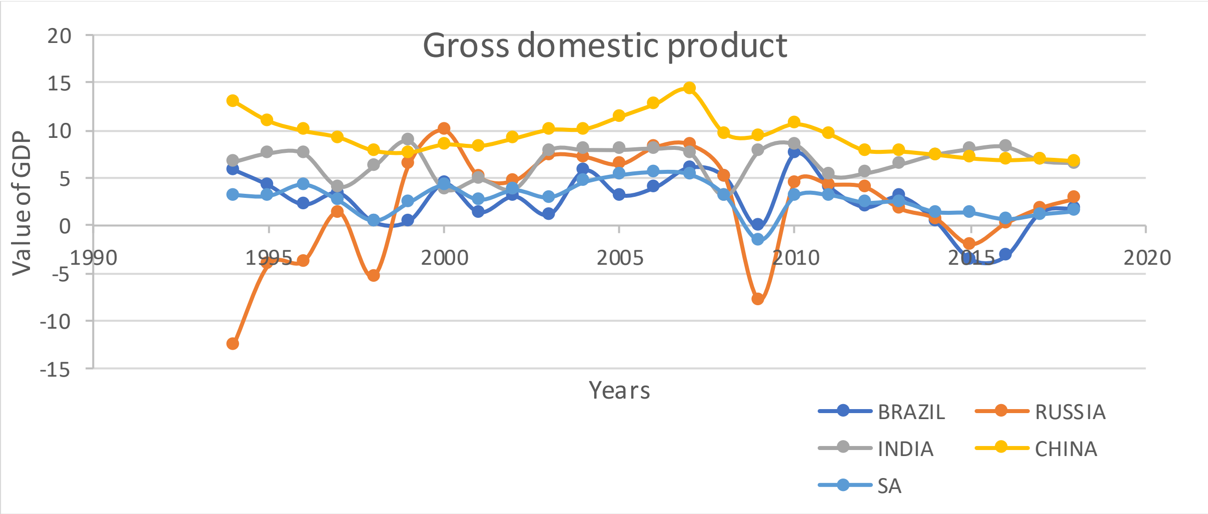
Source: Author's compilation

Figure 2.4 depicts the trend for manufacturing: labour productivity over the period 1994 – 2018. The trend shows the lowest value at 1.75% for the year 1994. The highest was realised in 2019 and shows a record of 2.05%.

2.6.5. Trends for the gross domestic product

To better understand these trends, the study focuses on the BRICS countries from the period 1994-2018. This is an analysis of trends of the gross domestic product between the BRICS countries.

Figure 2. 5 : Gross domestic product



Source: Author's compilation

Figure 2.5 depicts the annual gross domestic product trends of the BRICS countries. According to Menon (2017), economic growth plays an important role in restructuring the economic and social attributes of countries around the world, particularly the less developed countries. It is clear from figure 2.5 that South Africa's GDP rate as compared to Brazil, Russia, India and China has been the lowest between 0 and 5% and rarely plunges above the 5% mark. China has been the best-performing country with an average of between 5 and 10% value in GDP. Brazil is the tenth-largest economy in the world and the services sector is the most important and accounts for 63% of total GDP the biggest segment within services are government, education and health with 15% of total GDP which helps stimulate production and as a result increasing economic growth. On the other hand, Russia has a continually strong oil sector that is forecast at 2.4% in 2022 before slowing down to 1.8% in 2023. For South Africa, agriculture had contributed 2.53% to the GDP in South Africa whereas industry services had contributed 23.42% and 64.57% of total value added respectively. Moreover, the combined GDP of the BRICS reached US$17 trillion representing just under 22% of the global economy additionally, the economies of the BRICS have sustained strong growth and enjoy GDPs exceeding US$1trillion (Lowe, 2016).

2.7. Summary

The main focus of this chapter was to look at the conceptual review of the study, the two theoretical frameworks linked to Innovation and productivity as variables of the study. Firstly, the study focused on the Schumpeterian model of growth, which represents a change in technology as a result of innovation and replacement of old with new technology concerning objective one of the study. The second focus was on the Cobb-Douglas production function, which mainly focuses on the impact of production on economic growth followed by the review of theories of the study which are the Lucas growth theory, the Solow growth model and Romer's endogenous growth theory. Lastly, the focus was on the previous empirical studies on innovation and economic growth as well as productivity on how it affects economic growth in other parts of the world as well as an overview of trends for the variables employed in the study.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This chapter discusses the methodology of the study. It commences by outlining the data sources, model specification and estimation techniques. The study employed the Autoregressive Distributed Lag (ARDL) technique to determine the long-run relationship between the series that are non-stationary, as well as reparameterising them to the Error Correction Model (ECM).

3.2 Data

To investigate the relationship between creative destruction, productivity and economic growth, the econometric analysis was performed by using the annual time series data from 1994 to 2018. Following studies such as Adak (2015), Sokolov-Mladenović *et al*. (2016), Pradhan, Arvin and Bahmani (2018) and Morris (2018), R&D and number of patents are used as proxies to capture the impact of creative destruction. On the other hand, labour productivity in the non-agricultural sector and manufacturing labour productivity are proxies for productivity. Meanwhile, GDP is the dependent variable as a measure of economic growth. Data on productivity was sourced from the South African Reserve Bank whereas data on creative destruction is obtainable from the World Bank website in percentages.

3.3 Model specification

The study estimates the growth model which can be expressed in its functional form as follows:

GDP = *f* (innovation, productivity) (3.1)

Equation 3.1 can be expressed in a linear function as follows:

$$GDP_t = \boldsymbol{\alpha_0} + \boldsymbol{\beta_1 R\&D_t} + \boldsymbol{\beta_2 NoP_t} + \boldsymbol{\beta_3 LPNas_t} + \boldsymbol{\beta_4 LPman_t} + \boldsymbol{\mu_t} \quad (3.2)$$

Where

GDP	=	Gross domestic product
R&D	=	Research and Development
NoP	=	Number of patents

LPNas	=	Labour productivity in non- agricultural sector
LPman	=	Manufacturing: Labour productivity
µ	=	stochastic or random error term (which means properties of zero mean and non- serial correlation)
β1 – β4	=	Coefficients of associated variables
$\boldsymbol{\alpha_0}$	=	constant interception

3.4 Estimation techniques

The proposed study adopted the Auto Regressive Distribution Lag (ARDL) approach established by Perasan and Shin 1999 and Perasan *et al*. (2001). This method captures the cointegration between a set of variables, the long run and the short run simultaneously. In the ARDL, the following techniques are employed: graphical analysis of visual inspection, unit root test, lag length selection, cointegration and ARDL estimates both in the short and long run. The Granger method was used to find the causal relationship between the variables (Granger, 1969) and the diagnostic tests.

3.4.1 Visual inspection

Visual inspection is a method used to test for stationarity. According to Mah (2012), a visual inspection can be in the form of graphical analysis or the correlogram test. Therefore, the graphical analysis is the preferred form because it provides a plot of the time series of the variables. Furthermore, it provides a clue about the nature of the time series, and shows how the log of variables throughout the study is increasing, decreasing, or constant. Guajarati and Porter (2009) state that when it is increasing or decreasing, it means that the mean of the log of the variables has been changing over time. For this reason, the log variables are not stationary, whereas when it is constant, fluctuating around the trend line, the variables are stationary.

3.4.2 Stationarity/Unit root test

One of the first steps in the econometric analysis is to test for the unit-roots of the series to deal with the issue of stationarity. The presence of a unit root implies that a time series under consideration is non-stationary while the absence of it entails that a time series is stationary. In the case where the time series data is non-stationary, the regression would only generate spurious results (Gujarati, 2004). When the data is stationary at level form, it may be described as integrated of order zero, denoted as I(0). If after running the default unit root tests, the researcher finds that their data is non-stationary, it must be differenced n-times to become stationary, denoted as I(n).

According to Mushtaq (2011), testing for stationarity is very important because the results of the regression might be fabricated. When testing for stationarity, the trended series is called non-stationary and with unit root. On the other hand, non-trended series is a stationary series characterised by without unit root. In a formal way, the series is called stationarity if it satisfies three conditions, otherwise, it will be a non-stationary series.

i. The mean of Yt (E(Yt) remains the same over time or time-invariant. i.e.
   E(Yt) = u, ∀ t
   Where the symbol ∀, is used for all and (u) is any scalar
ii. The variance of Yt (V (Yt) is time-invariant. i.e.
   V (Yt) = $\boldsymbol{\sigma}^2$, ∀ t
iii. Cov of Yt and Yt-s (cov (Yr-s) is time-invariant, but can depend upon the lag length. i.e. Cov (Yt, Yt, Yt-s) = ϒs

If the above conditions do not hold, the series is non-stationary. Certain formal tests are used to test the data for unit root. In this study, the focus is on Dickey and Fuller (1979), the standard version of Kwiatkowski-Phillips-Schmidt-Shin (KPSS) (1992) and a Dickey-Fuller test statistic using a generalised least squares (GLS) rationale, which was employed to test for the non-stationary assumption.

The KPSS test is viewed as complementary to the more commonly employed tests, since it may be used to verify their results. If, say, the DF-GLS test fails to reject its null of a unit root, and the KPSS test rejects, then the evidence from both tests is supportive of a unit root in the series and is deemed to be sufficient to test for stationarity (Fuller, 2000).

Based on this discussion, the following unit root tests were employed to analyse the characteristics of the variables under investigation.

3.4.2.1 *Augmented Dickey-Fuller test*

Dickey-Fuller test (Dickey, Fuller, 1979) is one of the best known and most widely used unit root tests. It is based on the model of the first-order autoregressive process (Box, Jenkins, 1970).

$$y_t = \varnothing_1 y_{t-1} + \varepsilon_t, \qquad t=1, \ldots, T \qquad (3.3)$$

Where $\varnothing_1$ is the autoregression parameter, ε_t is the non-systematic component of the model that meets the characteristics of the white noise process. The null hypothesis is H_0: $\varnothing_1$= 1, i.e. the process contains a unit root and therefore it is non-stationary and is denoted as I(1), an alternative hypothesis is H_1: $| \varnothing_1 |$ <1, i.e. the process does not contain a unit root and is stationary, I(0).

To calculate the test statistic for the DF test, we use an equation that we get if y_{t-1} is subtracted from both sides of the equation (1) :$\Delta y_t = \beta y_{t-1} + \varepsilon_t$,

Where $\beta = \varnothing_1 - 1$. The test statistic is defined as:

$$t_{DF} = \frac{\varnothing_1 - 1}{S_{\varnothing 1}}, \qquad (3.4)$$

Where $\varnothing_1$ is a least-square estimate of $\varnothing_1$, $S_{\varnothing 1}$ is its standard error estimate. Under the null hypothesis, this test statistic follows the Dickey-Fuller distribution. Critical values for this distribution were obtained by a simulation and have been tabulated in Dickey (1976) and Fuller (1976).

Equation 3.3 can be expanded by a constant or a linear trend:

$$Y_t = \beta_0 + \varnothing_1 y_{t-1} + \varepsilon_t, \qquad (3.5)$$

$$Y_t + \beta_0 + \beta_1 t + \varnothing_1 y_{t-1} + \varepsilon_t. \qquad (3.6)$$

In the case where a non-systematic component in DF models is autocorrelated, the so-called Augmented Dickey-Fuller test is constructed (Dickey, Fuller, 1981). Equation 3.3 is then transformed as:

$$Y_t = \varnothing_1 y_{t-1} + \sum_{i=1}^{p-1} y_t \Delta y_{t-i} + \varepsilon_t \qquad (3.7)$$

And the following equation is used to calculate the test statistic of the ADF test:

$$\Delta y_t = (\varnothing_1 - 1) y_{t-1} + \sum_{i=1}^{p-1} y_i \Delta y_{t-I} + \varepsilon_t \qquad (3.8)$$

A practical problem of this test is the choice of lags P. The next steps are the same as in the case of the DF test. Schwert (1989) suggests choosing the maximum lag $P_{max} = 12(T/100)^{1/4}$ because if P is too low, the test will be affected by autocorrelation, and if P is too large, the power of the test will be lower. Equation 3.8 can be expanded by a constant, or linear trend as well. Then tests based on the following equation are used:

$$y_t = d_i + \emptyset_1 y_{t-i} + \sum_{i=1}^{p-1} y_i \Delta y_{t-i} + \varepsilon 1, \qquad (3.9)$$

Where $d_t = \sum_{i=0}^{p} \beta_i t^i$, for p = 0, 1, contains deterministic parts of the models mentioned above.

The limiting distribution of test statistics is identical with the distribution of DF test statistics and for T > ∞ is tabulated in Dickey (1976) and Mckinnon (1991).

3.4.2.2 Dickey-Fuller Generalised Least Squares test

ADF-GLS test, also known as ERS test (Elliot, Rothenberg and Stock, 1996), is another modification of the Augmented Dickey-Fuller test. Before the unit root testing, the ADF- GLS test utilises the detrending transformation (i.e. transformation that removes trend from time series) (Yiadom-boakye *et al*., 2008).

The constant in equation (3.5) is estimated based on the generalised least squares method (GLS) using the transformation:

$$y_1 = y_1, \; y_t = y_t - p y_{t-1}, \qquad t = 2, \ldots, T, \qquad (3.10)$$

$$\chi_1 = 1, \; \chi_t = 1 - p, \qquad t = 2, \ldots, T, \qquad (3.11)$$

Where p = 1 + c/ T and c = -7, 3 based on the equation:

$$y_t = \beta_0 \chi_t = + \varepsilon_t. \qquad (3.12)$$

Subsequently, parameter β_0 is estimated by the least-squares method and is used to remove constant from the time series y_t

$$y_t = y_t - \beta_0 \qquad (3.13)$$

In the last step, the ADF test is calculated based on the transformed time series given by:

$$\Delta y_t = \emptyset_1 y_{t-1} + \sum_{i=1}^{p} y_i \Delta y_{t-i} + \varepsilon_t \qquad (3.14)$$

The trend in models with the linear trend is estimated by GLS. Estimates of parameters are calculated based on equation:

$Y_t = \beta_0 x_t + \beta_1 z_t + \varepsilon_t$ (3.15)

And estimated parameters β_0 and β_1 are then used to remove the trend from the time series y_t

$Y_t = y_t - (\beta_0 + \beta_1 t)$ (3.16)

Finally, the ADF test is applied on the transformed time series, i.e. the test statistic is obtained from the following equation:

$$\Delta y_t = \beta_0 + \phi_1 y_{t-1} + \sum_{i=1}^{p} y_1 \Delta y_{t-l} + \varepsilon_t \quad (3.17)$$

3.4.2.3 *Kwiatkowski-Phillips-Schmidt-Shin test*

All the tests mentioned above are testing the null hypothesis that the time series y_t is integrated of order, I(1). The opposite case, for example, testing the null hypothesis that the time series y_t is I(0), is described by the KPSS test (Kwiatkowski, Phillips, Schmidt & Shin, 1992).

Kwiatkowski, Phillips and Schmidt and Shin built on the idea that the time series is stationary around a deterministic trend and is calculated as the sum of the deterministic trend, random walk and stationary random error. It is based on the model:

$Y_t = d_t + r_t + \varepsilon_t,$

$r_t = r_{t-1} + u_t,$ (3.18)

where $d_t = \sum_{i=0}^{p} \boldsymbol{\beta}_i t^i$, for p = 0, 1, contains deterministic parts of the model (constant or deterministic trend), ε_t are iid N (0, σ c^2), r_t is a random walk with variance σ_u^2 and u_t are iid N (0, u^2).

KPSS test is based on the LM test of the hypothesis that the random walk has a zero variance, i.e. H_0: $\sigma u^2 = 0$, which means that r_t is a constant, against the alternative H_1: $\sigma u^2 > 0$. The test statistic is written as:

$LM = \sum_{i=t}^{T} \boldsymbol{s}_t^2 \mid \sigma^2_{\varepsilon},$ (3.19)

Where $s_t = \sum_{t=1}^{T} \varepsilon_t$, t = 1, 2, …, T, and σ^2 is the estimate of the variance σ^2 of process ε_t from the equation (3.18). Critical values were derived by stimulation and are listed in Kwiatkowski, Phillips, Schimidt and Shin (1992).

3.4.3 Breakpoint test

There are cases where changes in factors outside of the model cause changes in the underlying relationship between the variables in the model. Structural break models capture these cases by incorporating sudden, permanent changes in the parameters of models.

Instability diminishes the ability of a model to meet the objectives of the study and leads to failing to recognise structural breaks which can lead to invalid conclusions and inaccurate forecasts. Identifying structural breaks in models can lead to a better understanding of the true mechanisms driving changes in data. Failing to account for structural changes lead to results in the model having misspecification, which in turn leads to poor forecast performance. Including structural breaks in asset allocation models can improve long-horizon forecasts, and ignoring breaks can lead to large welfare losses (Pesaran, Pettenuzzo & Timmermann, 2006).

3.4.4 Lag order selection criteria

According to Hall (2007), lag length selection is good since it has given a lag whereby the error terms do not suffer from non-normality, autocorrelation and heteroskedasticity. Lag lengths are affected by variables that are omitted, which affects the behaviour of the model in the short run. To select the appropriate model of the long run underlying equation, it is necessary to determine the optimum lag length (k) by using proper model order selection criteria such as the Akaike Information Criterion(AIC), Schwarz Bayesian Criterion (SBC), or Hannan-Quinn Criterion (HQC) (Nkoro & Uko, 2016).

3.4.5 ARDL modelling approach Cointegration

The proposed study used the ARDL testing cointegration procedure to estimate the long-run and short-run relationships and dynamic interaction among the variables of interest as proposed by Perasan and Shin (1999) and Perasan *et al*. (2001). When one cointegrating vector exists, Johansen and Juselius's (1990) cointegration procedure cannot be applied. Hence, it becomes imperative to explore Pesaran and Shin (1995) and Pesaran *et al*. (1996b), who proposed ARDL approach to cointegration or bound procedure for a long-run relationship, irrespective of whether the underlying variables are I (0), I (1) or a combination of both. In such a situation, the application of the ARDL approach to cointegration gave realistic and efficient estimates.

Three advantages associated with this approach are as follows:

- It circumvents the problem of the order of integration associated with Johansen's likelihood approach (Johansen & Juselius, 1990).
- Unlike most of the conventional multivariate cointegration procedures, which are valid for large sample sizes, the bounds test approach is suitable for small sample size studies (Perasan *et al*., 2001); and
- Provides unbiased estimates of the long-run model and valid t-statistics even when some of the regressors are endogenous (Harris & Sollis, 2003).

The ARDL approach to cointegration helps in identifying the cointegrating vector(s). That is, each of the underlying variables stands as a single long-run relationship equation. If one cointegrating vector is identified, the ARDL model of the cointegrating vector is reparametrised into ECM. The reparametrised result gives short-run dynamics and long-run relationships of the variables of a single model (Gujarati, 2004).

According to Udoh, Afangideh and Udeaja (2015), the following ARDL model was estimated in order to test the cointegration relationship between the variables: economic growth, number of patents, research and development, labour productivity in the non-agricultural sector and manufacturing: labour productivity.

$$\Delta \ln Gdp_t = c_0 + \delta_1 \ln Nop_{t-1} + \delta_2 \ln R\&D_{t-1} + \delta_3 \ln LPnas_{t-1} + \delta_4 \ln LPman_{t-1} + \sum_{i=1}^{p} \Phi \Delta \ln Nop_{t-i} + \sum_{j-0}^{q1} \Phi \boldsymbol{j} \Delta \ln R\&D_{t-j} + \sum_{t-0}^{q2} y\boldsymbol{l} \Delta \ln LPnas + \sum_{t-0}^{q3} \Delta \ln LPman + \varepsilon_t \quad (3.20)$$

Where δ_i are the long-run multipliers, C_0 is the intercept and ε_t are white noise errors.

Furthermore, Udoh *et al*. (2015) explain that the first step in the ARDL bounds testing approach is to estimate equation (3.20) by Ordinary Least squares (OLS) to test for the existence of the long-run relationship among the variables by conducting an F-test for the joint significance of the coefficients of the lagged levels of the variables, that is:

H_N ;$\delta_1 = \delta_2 = \delta_3 =0$ against the alternative

H_A ; $\delta_1 \neq \delta_2 \neq \delta_3 \neq 0$

Two asymptotic critical values bounds provide a cointegration test when the independent variables are I(d) [where 0 < d < 1]: a lower value assuming the regressors are I(0) and an upper critical value. The null hypothesis of no long-run relationship can be rejected irrespective of the orders of integration for the time series. Conversely, if the test statistic falls below the lower critical value, the null hypothesis cannot be rejected. Finally, if the statistic falls between the lower and upper critical values, the results are inconclusive. The approximate critical values for the F-statistic test were obtained from Pesaran *et al* (2001).

Once cointegration is established, the conditional ARDL (p,q1,q2) long-run model for GDP_t can be estimated as:

$$lnGDP_t = C_0 + \sum_{i-1}^{p} \delta 1 \, \boldsymbol{lnNop} + \sum_{j-0}^{q1} \delta 2 \, \boldsymbol{lnR\&D}_{t-j} + \sum_{t-0}^{q2} \delta 3 \, \boldsymbol{lnLpnas}_{t-1} + \sum_{t-1}^{q3} \boldsymbol{lnLpman} + \varepsilon_t \qquad (3.21)$$

This involves selecting the orders of the ARDL (P, q1, q2, q3) model in the variables using the Akaike Information Criteria (AIC).

The next step is to obtain the short-run dynamic parameters by estimating an error correction model associated with the long-run estimates. This is specified as:

$$\Delta ln \; GDP_t = u + \sum_{i-1}^{p} \Phi \, \Delta lnNopt - i + \sum_{j-0}^{q1} \Phi j \, \Delta \, lnR\&Dt - j + \sum_{i-0}^{q2} y \, 1 \Delta lnLpnas + \sum_{i-0}^{q3} \Phi \, \Delta lnLpman + \vartheta ecm_{t-1} + \varepsilon_t \qquad (3.22)$$

Here δ, ɸ and y are the short-run dynamic coefficients of the model's convergence to equilibrium and ϑ is the speed of adjustment.

3.4.6 Granger causality analysis

The proposed study employed the Engle-Grange causality to investigate the causal effect of the variables as recommended by Granger (1969). Causality can be described as the relationship between cause and effect. This suggests a cause and effect relationship between two sets of variables say, *Y* and *X*. Recent advances in graphical models and the logic of causation have given rise to new ways in which scientists analyse cause-effect relationships.

In line with most of the works of literature in econometrics, one variable is said to Granger cause the other if it helps to make a more accurate prediction of the other variable. Granger causality between two variables cannot be interpreted as a real causal relationship, but merely shows that one variable can help to predict the other one better (Granger, 1969).

3.4.7 Diagnostic testing

The proposed study ran diagnostic tests to verify if the model is reliable and efficient. The time series test has to satisfy the assumption of the normal linear regression model (Gujarati, 2004).

Among the many "diagnostic tests" that econometricians routinely use, some variant or other of the RESET test is widely employed to test for a non-zero mean of the error term. That is, it tests implicitly whether a regression model is correctly specified in terms of regressors that have been included. Among the reasons for the popularity of this test is the fact that it is easily implemented, and the fact that it is an exact test whose statistic follows an F-distribution under the null (Debenedictis & Giles, 1998). The following diagnostic tests were conducted to verify if the model is reliable and efficient.

3.4.7.1 Normality test

When testing normality, an investigation on the power of several tests, well-known tests by Jarque and Bera (1980), Kuiper (1960) and Shapiro and Wilk (1965) are made. An investigation is done on the critical values of the Jarque-Bera test in the latter case for the original and standardised observations where unknown parameters u and σ have to be estimated (Thandewald & Buning, 2007). Normality tests differ in the characteristic of the normal distribution that they focus on, such as its skewness and kurtosis values, which can be measured in its distribution or characteristic function and the linear relationship existing between a normally distributed variable and the standard normal z (Seier, 2002).

3.4.7.2 Heteroskedasticity

According to Mah (2012), heteroskedasticity is when the variance of the regression error term conditional on the regressors is not constant. In addition, Even (2017) states that the disturbances whose variances are not constant across the observations are called the heteroskedastic disturbance. This is termed heteroskedasticity. In this case, Var (ε_i) = σ^2_i, I = 1, 2, …, n and disturbances are pairwise uncorrelated. Furthermore, there are various reasons in terms of which heteroskedasticity is introduced in the data. Some are:

i. The nature of the phenomenon under study may have an increasing or decreasing trend.
ii. Sometimes the observations are in the form of averages. This introduces heteroskedasticity in the model. Suppose in a simple linear regression model

   $y_{ij} = \beta_0 + \beta 1x_{ij} + \varepsilon_{ij}$, I = 1,2 …. N, j = 1,2 …, m_i (3.23)
iii. Sometimes the theoretical considerations introduce the heteroskedasticity in the data. For example, suppose in the simple linear model

   $y_i = \beta_0 + \beta_1 x_i + \varepsilon_i$, I = 1,2 …,n. (3.24)
iv. The skewness in the distribution of one or more explanatory variables in the model also causes heteroskedasticity in the model.
v. The incorrect data transformations and wrong functional form of the model can also give rise to the heteroskedasticity problem (Even, 2017).

3.4.7.3 Serial correlation

When the error terms from different periods are correlated, we say that the error term is serially correlated. Serial correlation occurs in time-series studies (*t* subscript) when the errors associated with a given period carry over into future periods (Schechtman, 2015). Furthermore, there are different types of serial correlation, such as first-order serial correlation whereby errors in the one-time period are correlated directly with errors in the ensuing period. The error in time *t* is (*t – 1*) periods' error:

$$\varepsilon_t = p\varepsilon_{t-1} + u_t, \ -1 < p < 1 \qquad (3.25)$$

The new parameter p is called the first-order autocorrelation coefficient. The process for the error term is referred to as a first-order autoregressive process or AR(1).

i. There is also a positive serial correlation in which errors in a one-time period are positively correlated with errors in the next period. Furthermore, the magnitude of p explains the strength of the serial correlation and the sign indicates the nature of the serial correlation. P = 0 indicates no serial correlation.
ii. P> 0 indicates positive serial correlation – the error term will tend to have the same sign from one period to the next.
iii. P<0 indicates negative serial correlation – the error term will tend to have a different sign from one period to the next (Schechtman, 2015).

3.4.8 Stability testing

The proposed study employed the cumulative sum (CUSUM) of recursive residuals and the cumulative sum of squares (CUSUMsq) of recursive residuals to test the stability of the long run and the short-run parameters of the model (Gujarati, 2004). Ramsey RESET test is also used to perform a stability test.

3.4.8.1 Cumulative sum (CUSUM)

The CUSUM involves a plot of the cumulative sum of recursive residuals against the order variable and checking for deviations from the expected value of zero. Symmetric confidence lines above and below the zero value allow the definition of a confidence band beyond which the CUSUM plot should not pass for a selected significance level if the regression parameters are stable (Miller, 1982).

3.4.8.2 The cumulative sum of squares (CUSUMsq)

According to Miller (1982), this test involves plotting the cumulative sum of squares (CUSUMSQ) recursive residuals against the ordering variable. The CUSUMSQs have expected values ranging linearly from zero at the first-order observation to one at the end of the sampling interval if the null hypothesis is correct. Again, symmetric confidence lines above and below the expected value line define a confidence band beyond which the CUSUMSQ plot should not pass for a selected significance level if the null hypothesis of the parameter constancy is true.

3.4.8.3 Ramsey RESET test

Ramsey RESET test tests whether non-linear combinations of the fitted values help explain the response variable. More specifically, if the null hypothesis that all regression coefficients of the non-linear terms are zero is rejected, this means that the model suffers from misspecification (Pankina, 2013). In addition, Wooldridge (2015) states that if multiple regression is found to suffer from a misspecification error, it means the model does not adequately account for the relationship between the dependent and independent variables. Furthermore, Pankina (2013) emphasises that the significance level is equal to 0.05 in all research. To implement RESET, a decision must be taken on how many functions of the fitted values to include in an expanded regression (Pankina, 2013).

3.5 Summary

This chapter outlines the data used in the study, the model specification employed as well as the estimation techniques. In the estimation techniques, the researcher discussed the visual inspection to test for stationarity with the use of line graphs as well as the formal unit root test for ADF, DF-GLS, and KPSS to test for stationarity. The appropriate lag length was also selected. Moreover, it was indicated that the ARDL approach was used to determine the long-run relationship of the variables. Furthermore, the Granger causality was used to investigate the causal effect of the variables; the diagnostic testing was used to check the reliability of the model; and lastly, the stability testing was explained to test the stability of the long run and short-run parameters of the model.

CHAPTER 4

DISCUSSION / PRESENTATION / INTERPRETATION OF FINDINGS

4.1 Introduction

This Chapter provides a presentation and interpretation of various econometric tests conducted in order to answer the questions raised in Chapter 1, which are in line with the methodology of the study. Specifically, results for graphical analysis of visual inspection, Stationarity test, Lag selection criteria, ARDL approach, Granger causality analysis, Diagnostic test and Stability tests are presented and discussed. The analysis uses techniques discussed to empirically analyse and estimate growth through innovation and productivity on the South African economic growth. The study made use of tables and graphs in the presentation of results.

4.2 Empirical tests results

The study used Eviews 11 to run the econometric tests and the empirical results. The results are presented beginning with the unit root test results that show the graphical inspection of the time series to ensure the stationarity of the variables in question. Furthermore, the study employed the ARDL technique to determine the long-run relationship between the series.

4.2.1 Unit root tests results

The presentation of the empirical results begins with the unit root test results, both the informal (which has to do with inspecting the time series plot) and the formal (which is to perform the Dickey-Fuller test to test for a stochastic trend) to ensure that the variables in question are stationary. The output is provided in Table 4.1 below.

4.2.1.1 The visual inspection test results

Graphical inspection of the time series is beneficial in identifying the nature of the variables. This makes it easy to verify whether the time series of the variables were stationary at level I(0) or after first differencing I(1).

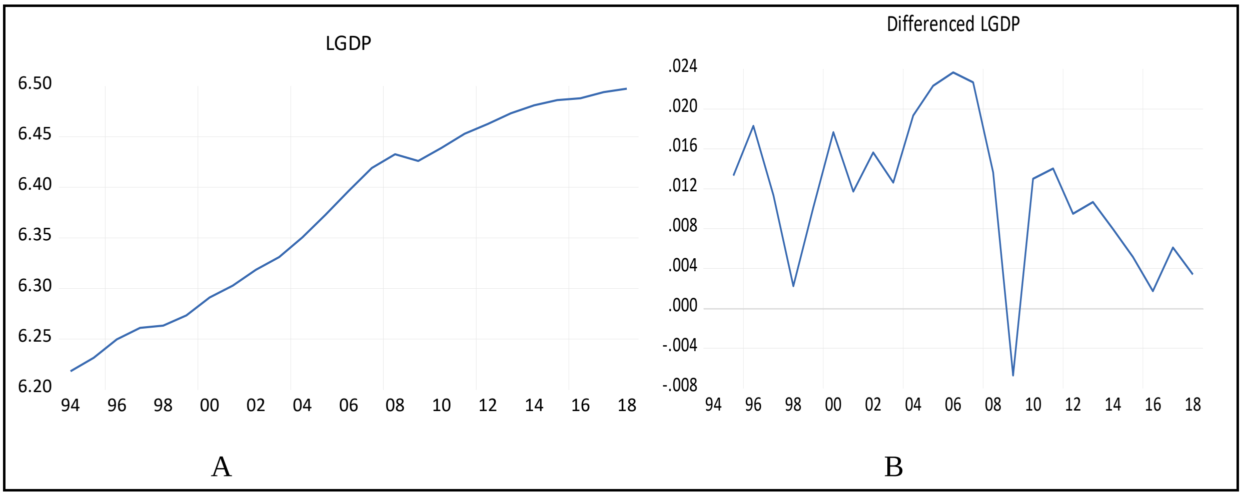


Figure 4. 1 A and B: Gross domestic product

Source: Author's compilation

The first impression of the line graph in Figure 4.1 (A) is that the LGDP time series is trending upwards away from the mean. This gives an impression that over time, LGDP has been increasing, suggesting that the mean has been changing. The general impression is that the time series is nonstationary. In Figure 4.1 (B), which shows the results of LGDP at first difference, the line graph is showing a movement around the mean.

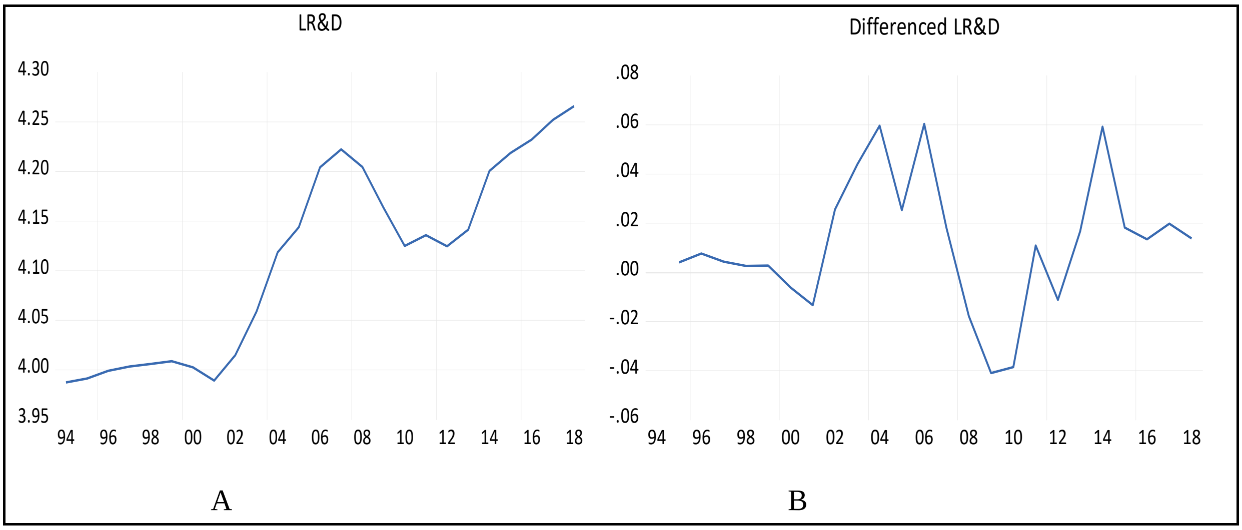


Figure 4. 2 A and B: Research and development

Source: Author's compilation

Figure 4.2 (A) shows that LR&D is trending upwards with fluctuations. This reflects a steep increase from the years 2001 to 2008 and followed by a decrease until 2010. Moreover, this is an indication that the LR&D rises overtime after the year 2012. This suggests that the variable is nonstationary and should be subjected to a process of differentiation. Similarly, the line graph in Figure 4.2 (B) shows R&D trends along with the mean, which indicates stationarity at I(1).

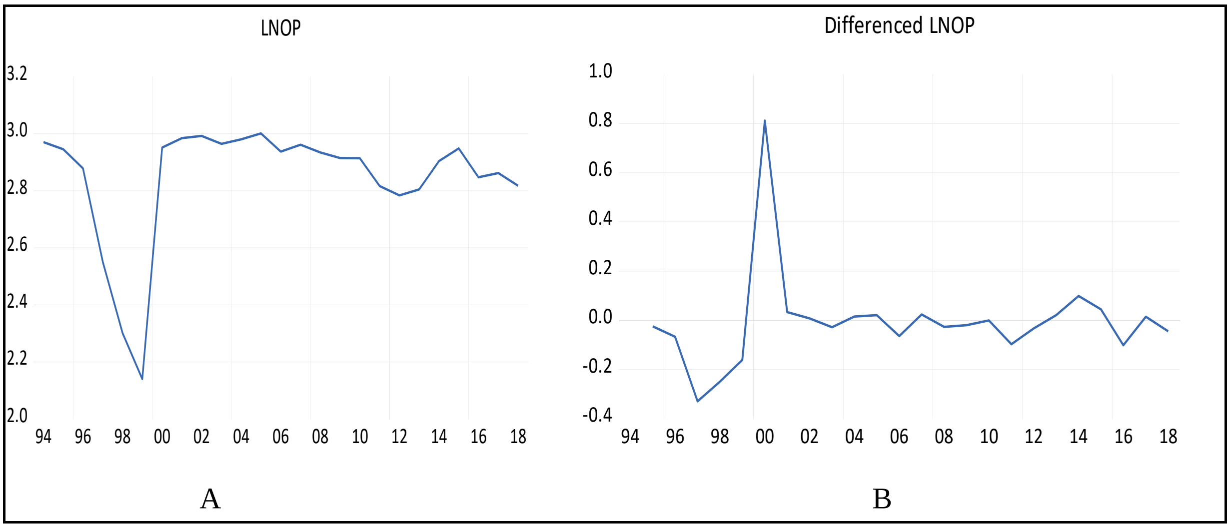


Figure 4. 3 A and B: Number of patents

Source: Author's compilation

Figure 4.3 (A) shows LNOP fluctuating away from the mean, which indicates the possibility of nonstationarity, and Figure 4.3 (B) shows the outcomes of LNOP after first differencing. Its movement along the mean suggests that it is stationarity at first difference.

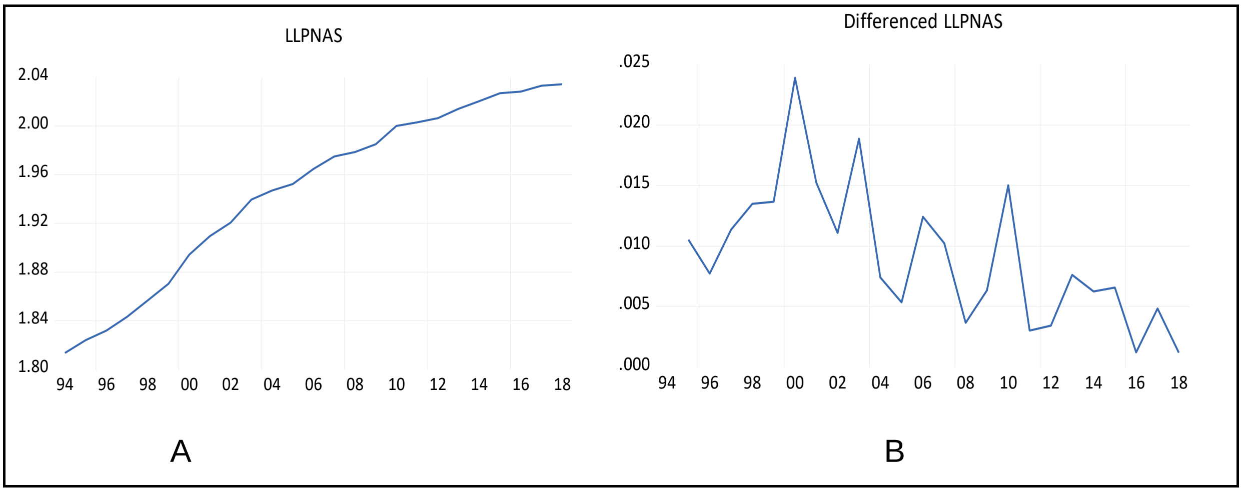


Figure 4. 4 A and B: Labour productivity in the non-agricultural sector

Source: Author's compilation

Figure 4.4 (A) indicates that LPNAS is trending upwards, suggesting that the mean is changing with time. The general impression is that the time series is nonstationary. Figure 4.4 (B) shows the results of LPNAS trending downwards after first differencing.

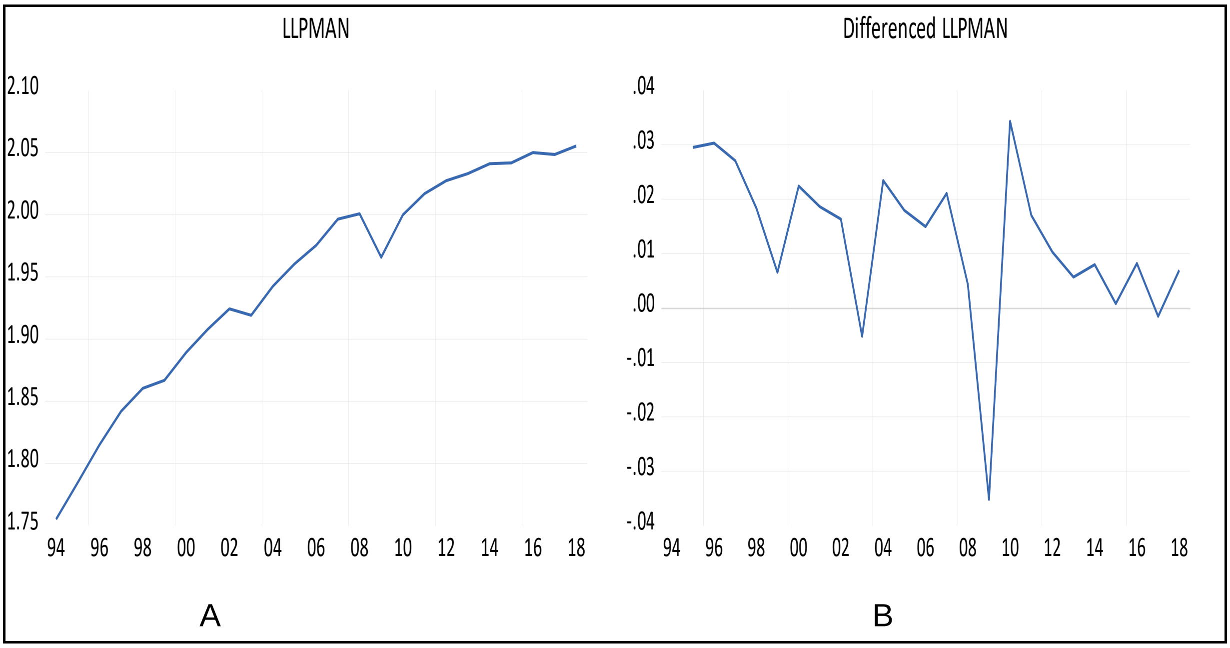


Figure 4. 5 A and B: Manufacturing: Labour productivity

Source: Author's compilation

The upward trending movement of a line graph in Figure 4.5 (A) suggests that LPMAN is nonstationary at I(0), whereas Figure 4.5 (B) shows stationarity and a fluctuation of the variable. After LPMAN has been I(1) it indicates stationarity because it crosses the mean value of zero.

Over and above the visual inspection test results suggest that all the variables might be stationary at first differencing I(1) because most of them oscillate around the mean value of zero.

4.2.1.2 Formal Unit root tests results

Although the ARDL cointegration technique does not require pre-testing for unit root, to evade the crash of the ARDL model in the presence of integrated stochastic trend of I(2), the study was of the view that the unit root test should be carried out to determine the number of unit roots in the series under consideration. The stationarity results are presented in Table 4.1 as follows:

Table 4. 1: Stationarity results

Variable	ADF		DFGLS		KPSS	
	∪	∩	∪	∩	∪	∩
LGDP	-1.95	0.11	-0.42	-1.38	0.72**	0.15
D(LGDP)	-2.72***	-3.08	-2.79*	-3.24*	-	-
LLPMAN	-3.04**	-2.34	-0.58	-1.97	0.72**	0.19**
D(LLPMAN)	-	-	-4.31*	-5.73*	-	-
LLPNAS	-3.52**	0.98	-1.65***	-1.93	0.71**	0.19**
LNOP	-2.46	-2.56	-2.46**	-2.59	0.13	0.08
D(LNOP)	-4.37*	-4.28**	-	-	0.06	0.06
R & D	-1.14	-3.04	-0.99	-3.19**	0.63**	0.07
D(R & D)	-2.56	-2.51	-2.61**	-2.62	-	-

∪ denotes intercept
∩ denotes trend and intercept
Asterisk *, **, *** denote significance at the 1%, 5% and 10% respectively.
Source: Author's compilation

When an ADF value is greater than the critical value, it shows that the underlying series is stationary. From the results given in Table 4.1, GDP is nonstationary at level I(0). Therefore, the time series data is then transformed by differencing it I(1) to remove the trend components for all the variables from the time series. The results for the number of patents are inconclusive since the ADF test suggests stationary after first differencing, and the DFGLS suggests stationarity at level. This leads to the impression that stationarity has been achieved at first difference, that is I(1) because visual variance seems to be time-invariant. However, the null hypothesis cannot be rejected about non-stationarity based on the ADF test, since its power is not strong as such. This decision has been verified by a related test Kwiatkowski-Phillips-Schmidt-Shin (KPSS) (1992). The KPSS test suggests no stationarity at both levels and first differencing for the number of patents. Overall, the informal test results of the study are similar to the formal unit root test results because they show that all the variables of the study are stationary at first differencing I(1).

It is worth noting, however, that the ARDL bounds test technique can differentiate between variables of different stationary properties, and stationarity is not a pre-requirement in the bounds testing technique. The next step was to determine the lag length criteria. The results are presented in Table 4.2 below.

4.2.2 Breakpoint test

Structural break tests help us to determine when and whether there is a significant change in our data.

Table 4. 2: Structural breaks

Variables	Year	Probability
LNOP	1999	0.001
LLNAS	1999	0.001

Source: Author's compilation

Table 4.2 shows the structural breaks. The table caters for a structural break that happened in 1999. The model has inserted a dummy variable which is shown in the appendix section. Structural change is often sparked by technological innovation, new economic developments, global shifts in the pools of capital and labour, changes in resource availability, changes in supply and demand of resources, and changes in the political landscape. In South Africa, the structural breaks took place in the year 1999 which was the transition in government. Furthermore, low investment, job losses, and limited black participation in the commanding heights of the economy from the mid-1990s stimulated the political impetus for a stronger role for the state during the 2000s. The formal introduction of industrial policy in 2007 has had some successes and helped to avert even deeper deindustrialization. However, it has been undermined by unsupportive macroeconomic policies and a weak articulation between policies to advance black ownership and structural transformation. Rising corruption and maladministration have further undermined structural transformation.

4.2.3 Lag order selection criteria

Table 4.3 presents the lag length selection for the study. This is shown by the Hannan-Quinn information criterion, Final prediction error, sequential modified LR test statistic, Schwarz information criterion and Akaike information criteria, with an asterisk on the lag of the various criteria.

Table 4. 3: Lag Length Selection

Lag	LogL	LR	FPE	AIC	SC	HQ
0	220.8689	NA	4.85e-15	-18.77121	-18.52436	-18.70913
1	339.2051	174.9318*	1.54e-18	-26.88740	-25.40632*	-26.51492
2	368.6575	30.73294	1.50e-18*	-27.27457*	-24.55926	-26.59168*

* indicates lag order selected by the criterion
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

Source: Author's compilation

The Schwarz information criterion recommended one lag, while both the Akaike information and Hannan-Quinn information criteria recommended two lags. In this regard, given that the observations are few, one lag was chosen as recommended by the Schwarz information criterion to avoid the loss of economies of freedom. Following this, the ARDL Bounds test was run to determine cointegration between the variables in question. The results are illustrated in Table 4.4 below.

4.2.4 ARDL Bounds test results

ARDL cointegration technique is preferred when dealing with variables that are integrated of different orders (I(0), I(1)), or a combination of both. This has been discussed under the unit root results in Table 4.1. The long-run relationship of the variables is detected through the F-statistic when the F-statistic value exceeds both the lower and upper critical value bounds. The summary of the results is presented in Table 4.4 as follows:

Table 4. 4: ARDL Bounds Test results

Test Statistic	Value	K
F-statistic	7.004809	4
Critical Value Bounds		
Significance	I(0) Bound	I(1) Bound
10%	2.08	3
5%	2.39	3.38
2.5%	2.7	3.73
1%	3.06	4.15

Notes: ***indicates significance at the 10% level

Source: Author's compilation

From Table 4.4, it is evident that the computed F-statistic value is greater than both the lower and upper critical values at all levels of significance. In essence, this implies that the variables have a long-run relationship. The general principle states that the F-statistic must be greater than all levels of significance to have a long-run relationship between variables employed in the study. The next step was to estimate the long-run and short-run coefficients of the variables in the model. The results are provided in Tables 4.5 and 4.6 below.

4.2.2.1. ARDL short-run and long-run coefficient

In this section of the ARDL modelling, the researcher estimates the long and short-run coefficients of the model presented in Table 4.5 (long-run coefficient results) and Table 4.5 (short-run coefficient results).

Table 4. 5: Long-run coefficient results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LR_D	0.2208	0.0694	3.1800	0.0062
LNOP	0.0706	0.0881	-3.3812	0.0070
LLPNAS	-0.3234	0.4284	0.7548	0.4620
LLPMAN	0.5257	0.0079	3.9238	0.0028
C	4.0447	0.2621	15.428	0.0000

Notes: Asterisk *, **, *** indicate statistical significance at the 1%, 5% and 10% level

Source: Author's compilation

Table 4.5 shows the long-run elasticities. The findings reveal that in the long run, research and development, number of patents and manufacturing: Labour productivity has a positive and a statistically significant impact on the South African economy. However, labour productivity in the non-agricultural sector has a negative impact on the South African economy.

The final step of the ARDL model was estimating the error correction for estimating the speed of adjustment. These results are presented in Table 4.6.

Table 4. 6: Short-run coefficients results

Cointegrating Form				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(LR_D)	0.0504	0.0212	2.3742	0.0337
D(LLPNAS)	0.0337	0.0701	0.4815	0.6448
D(LNOP)	0.0254	0.0036	6.8942	0.0002
D(LLPMAN)	0.0961	0.0271	3.5387	0.0095
CointEq(-1)	-0.8953	0.2948	3.0360	0.0006

Notes: Asterisks *, **, *** indicate statistical significance at the 1%, 5% and 10% level
Source: Author's compilation

The results in Table 4.6 indicate that in the short run, the research and development coefficient is 0.0504. The findings show a positive and statistically significant relationship between research and development, and economic growth in South Africa. The results of the study are in line with the findings by Sokolov-Mladenović *et al.* (2016), who investigated the influence of research and development expenditure on economic growth in 28 European Union member countries.

The number of patents has a coefficient of 0.0254. The results indicate that there is a positive and statistically significant impact on economic growth in South Africa. Manufacturing labour productivity is positive and statistically significant with a 0.0961 coefficient. The results are in line with the findings by Mongale (2019) on the implications of labour productivity and labour costs on the South African economy.

However, labour productivity in the non-agricultural sector has a positive yet statistically insignificant impact on the GDP. The coefficient of the error correction term, which indicates the speed of adjustment to equilibrium is negative (-0.8953), as expected, and statistically significant at a 1% level. This indicates that the 1% increase will lead to equilibrium at the rate of 89.53%. This means that the model has a speed of adjustment that is acceptable both in the short-run and in the long-run.

4.2.5 Granger Causality test results

The Engle-Grange causality was employed to investigate the causal effect of the variables under study. The results are presented as follows:

Table 4. 7: Granger Causality test

Null Hypothesis:	Obs	F-Statistic	Prob.
LLPMAN does not Granger Cause LGDP	24	1.15	0.29
LGDP does not Granger Cause LLPMAN		1.66	0.21
LLPNAS does not Granger Cause LGDP	24	10.11	0.01**
LGDP does not Granger Cause LLPNAS		2.26	0.15
LNOP does not Granger Cause LGDP	24	1.13	0.29
LGDP does not Granger Cause LNOP		0.53	0.47
LR_D does not Granger Cause LGDP	24	0.21	0.66
LGDP does not Granger Cause LR_D		1.24	0.28
LLPNAS does not Granger Cause LLPMAN	24	9.32	0.00*
LLPMAN does not Granger Cause LLPNAS		1.21	0.28

None: Asterisks *, **, *** indicate significance at the 1%, 5% and 10% significance levels

Source: Author's compilation

The Granger causality test found no causal relationship between the GDP, manufacturing labour productivity, number of patents, and research and development. A uni-directional causal relationship was found from the labour productivity non-agricultural sector to the gross domestic product at 5% significance level.

4.2.6 Diagnostic tests results

The diagnostic tests verify if the model is reliable and efficient. The results of the diagnostic test are summarised in Table 4.8.

Table 4. 8: Diagnostic test results

Diagnostic analysis	Test	P-value	Conclusion
Serial correlation	Breusch-Godfrey	0.4280	There is no serial correlation
Heteroskedasticity test	White test	0.2931	There is no heteroskedasticity
Heteroskedasticity test	Breusch-Pagan Godfrey	0.3054	There is no Heteroskedasticity
Heteroskedasticity test	ARCH	0.2320	There is no Heteroskedasticity
Normality test	Jarque- Bera	0.9924	Residuals are normally distributed

Source: Author's compilation

According to the Breusch-Godfrey test Serial Correlation test results in Table 4.8, the model has no serial correlation because it indicates a p-value of 0.4280. Therefore, the null hypothesis of no serial correlation is accepted. Heteroskedasticity was tested using the Breusch-Pagan-Godfrey test, White test and the ARCH test. The results indicate that the model does not suffer from heteroskedasticity with p-values of 0.3054, 0.2931 and 0.2320, respectively.

Since residual testing has become a formal procedure in econometric analysis, several residual tests were performed. The normality test presented is illustrated in Appendix G and shows that the data is normally distributed given the kurtosis value of 2.98, which is close to the recommended value of 3.7.

4.2.7 Stability tests results

To make the ARDL results stronger, the model was taken through the stability test, which includes the CUSUM, the CUSUMSQ and the Ramsey RESET test. The outcomes of CUSUM and CUSUMSQ are presented in Figures 4.6 and 4.7, while the Ramsey RESET outcomes are summarised in Table 4.9 and the complete output is in Appendix H.

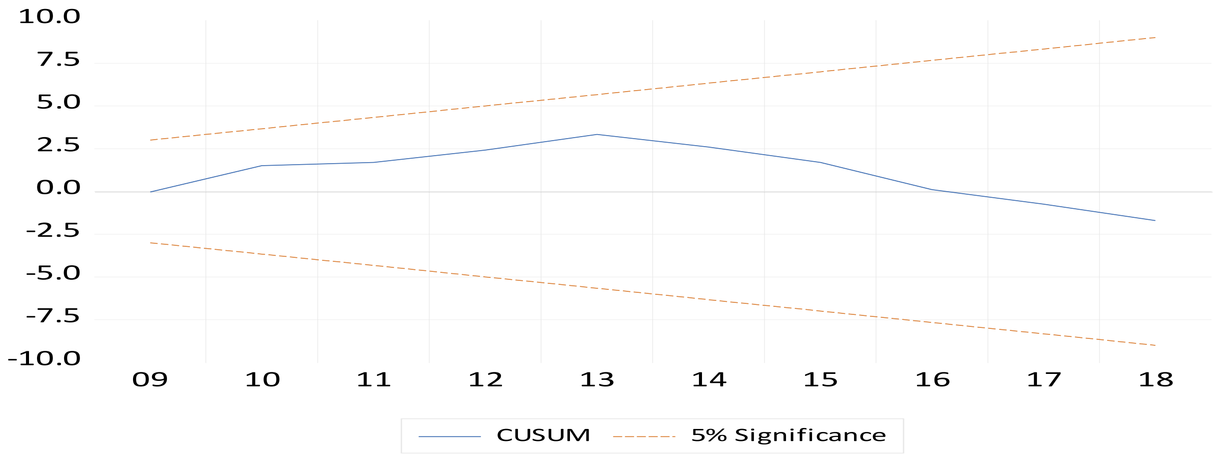


Figure 4. 6: CUSUM test results

Source: Author's compilation

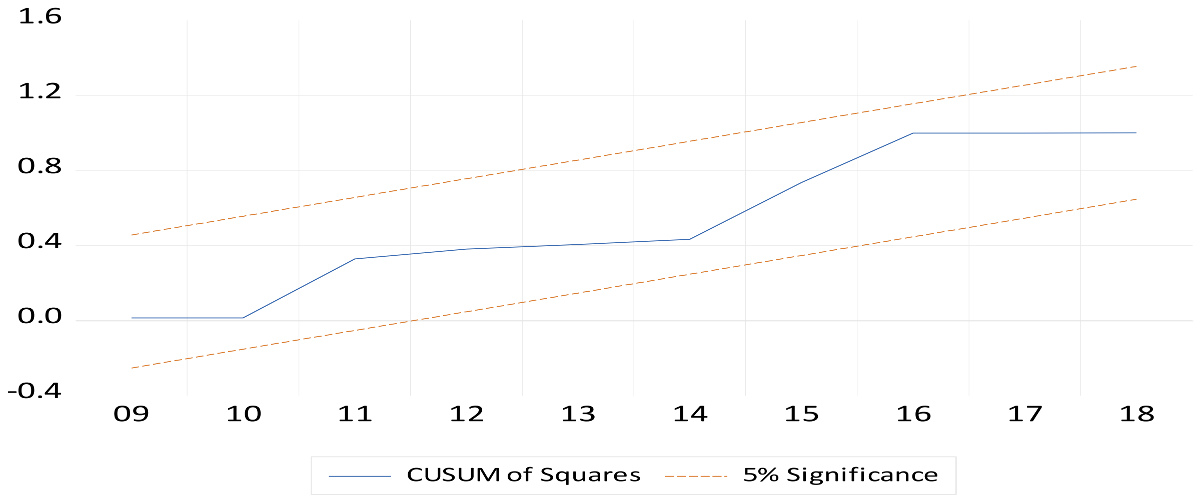


Figure 4. 7: CUSUM of squares test results

Source: Author's compilation

Figures 4.6 and 4.7 illustrate the CUSUM and CUSUM of squares stability tests. These diagrams illustrate the pattern or performance of the residuals concerning their stability (Onoja, Achike & Ajibade, 2017). The purpose of the tests was to determine whether or not the specified model is stable over time. If the curved line that represents the residuals was to fall outside the two extreme lines that represent the critical regions, the residuals would be regarded as unstable. The stability of the model is evidenced by the results of the stability test using the CUSUM as indicated in Figure 4.6. Since the residual plot is within the critical lines of a 5% level of significance, this serves as evidence that our model is stable.

The CUSUM of squares in figure 4.7, on the other hand, is estimated using the ECM model of ARDL. The line representing the CUSUM of squares indicates the residual plot within the 5% significant boundaries. This proves that the model is stable for the period sampled.

Table 4.9 presents the results of the Ramsey RESET test to ensure that the model does not suffer from any misspecification error.

Table 4. 9: Ramsey RESET test

Test	Null hypothesis	t- statistic	P-Value	Conclusion
Ramsey RESET test	The model is correctly specified	0.046522	0.9639	There is no specification error.

Source: Author's compilation

The F-statistic, t-statistics and likelihood ratio are significant and show that there is no specification error. The probability value is less than 0, 05. Since the probability value is greater than a 5% level of significance at p-value 0.9639, the study could not reject the null hypothesis. Therefore the model is correctly specified.
The full details of the test are provided in Appendix H.

4.3 Summary

This chapter presents the interpretation of the results and findings of the study, which addresses the research questions and objectives of the study. The study revealed that there is a long-run relationship of the variables, as detected through the F-statistic. This is evident because the F-statistic is greater than the lower and upper critical bounds at all levels of significance. The next section of the study outlines the summary, recommendations and conclusions of the study.

CHAPTER 5

SUMMARY, RECOMMENDATIONS AND CONCLUSIONS

5.1 Introduction

This chapter presents the summary, recommendations and interpretation of the findings of the study. Section 5.2 provides a summary and interpretation of findings, 5.3 presents the contributions of the study, sections 5.4 presents the conclusions, the future policy directions and recommendations and lastly, section 5.5 presents future research.

5.2 Summary and nterpretation of Findings

The study aimed to investigate growth through innovation and productivity in South Africa. For this purpose, the researcher determined the impact of innovation on economic growth, investigated the relationship between productivity and economic growth, examined the long run and short-run relationships between innovation, productivity, and economic growth and determined the direction of causality between innovation, productivity and economic growth. The Autoregressive distributive lag (ARDL) and the Granger causality approaches were employed to achieve these objectives. The analysis used the annual time series data obtained from the South African Reserve Bank and the International Monetary Fund from 1994 to 2018.

The background of this study was done by studying the literature on growth through innovation and productivity in South Africa and internationally. The literature of the study was done in chapter two on the research already conducted on the impact of growth through innovation on economic growth in South Africa and other countries. The theories of the study were discussed in line with the literature. The research approach used in this study was the quantitative approach. The findings were presented and discussed in chapter four by making use of tables and line graphs.

This section provides a brief overview of the research findings. The objectives of the study were achieved. The results are summarised as follows.

5.2.1 The impact of innovation on economic growth

From the discussion, the study noted that the Schumpeterian growth theory is about growth generated by innovation. Furthermore, innovation resulting from entrepreneurial investment involves the replacement of old technologies, which implies that growth involves being innovative as well as the sequence of quality-improving innovations. From the findings of the study, it is evident that research and development are positive and has a statistically significant impact on economic growth in South Africa. These findings hold and are supported by the Schumpeterian growth theory, which emphasises that investment in innovation leads to a positive impact and growth on the economy. Moreover, the findings of the study are supported by the Solow growth theory and Romer's endogenous growth theory because they are all about the improvement of human capital as well as government expenditure in the form of investing in research and development to increase productivity and further result in economic growth in the country. The findings of the study are consistent with the findings by Sokolov-Mladenović *et al.* (2016). This indicates that research objective one has been achieved. This has been proven by the analysis that innovation has an impact on economic growth.

5.2.2 The relationship between productivity and economic growth

The study noted that the Cobb-Douglas production function was the most ubiquitous theory in theoretical and empirical analyses of growth and productivity. The estimation of the parameters of aggregate production function is central to much of today's work on growth, technological change, productivity and labour. The findings of the study indicate that manufacturing: labour productivity has a positive and significant impact on economic growth. The study is therefore supported by the Lucas growth theory as it is about the improvement of human capital to improve productivity resulting in increases in economic growth in the country. These findings are in line with the results by Mongale (2019) on the implications of labour productivity and labour costs on economic growth in South Africa.

5.2.3 The relationships between innovation, productivity and economic growth

From the results of the study, the ARDL bounds test results indicated evidence of a long-run relationship between the variables in the model, meaning that there is cointegration. This was based on the fact that the F-statistic value is greater than both the lower and upper critical value bounds at all levels of significance.

Additionally, the results revealed that in the short run, research and development, the number of patents and manufacturing labour productivity were positive and statistically significant on economic growth. However, labour productivity in the non-agricultural sector has a positive yet statistical insignificant impact on economic growth in South Africa. Moreover, the coefficient of the error correction term revealed that a 1% increase will lead to a 0.8953% change, which indicates the speed of adjustment to equilibrium. The results of the study are similar to the findings by Adak (2015) on new investments in technology that bring with them high production levels and positive economic growth. These results imply that research objective three has been achieved because the findings reveal that there exists a long-run and short-run relationship between innovation, productivity and economic growth. The findings of this study are also similar to those of Kortkmaz and Korkmaz (2017).

5.2.4 Determination of the direction of causality between the variables

In analysing this objective, extensive literature was reviewed on the causal relationship between innovation, productivity and economic growth. The Granger causality test found no causal relationship between economic growth, manufacturing labour productivity, number of patents and R&D. Conversely, there exists a uni-directional causal relationship running from labour productivity non-agricultural sector to the economic growth at a 5% significance level. Finally, the diagnostic and stability tests reveal that the model is of good fit. These findings are similar to those by Kortkmaz and Korkmaz (2017).

Research objective four has been achieved since there exists a uni-directional causal relationship.

5.3 Limitations of the study

The study could not cover all aspects and variables that have an impact on economic growth. It was limited to investigating innovation and productivity's impact on economic growth from the South African context. Moreover, the findings of the study are limited within the range of the time series data collected from the periods 1994 to 2018.

5.4 Conclusions

The study set out to investigate the impact of innovation and productivity on the South African economy. The study outlined the following questions to be answered: what is the impact of innovation on economic growth? What is the nature of the relationship between productivity and economic growth? Is there a long-run and short-run relationship between innovation, productivity and economic growth? What is the direction of causality between innovation, productivity and economic growth? Furthermore, the study adopted the quantitative approach, whereby data was collected over 24 years. The interpretation and analysis were done after the extensive theories and literature reviewed in this study.

The findings of the study indicate that there is a long-run relationship of the variables, which is indicated through the F-statistic value that is greater than critical value bounds, both lower and upper. The F-statistical value is greater than the critical value bounds at all levels of significance. Furthermore, in the short-run research and development, manufacturing labour productivity and number of patents have a positive and statistically significant impact on GDP. However, labour productivity in the non-agricultural sector has a positive yet statistical insignificant impact on GDP. The results also show that in the long run, research and development, number of patents and manufacturing: labour productivity has a positive and statistically significant impact on economic growth. On the contrary, labour productivity in the non-agricultural sector has a negative impact on economic growth in South Africa.

In addition to the findings, the granger causality revealed no causal relationship between GDP, manufacturing labour productivity, the number of patents and R&D. However, it showed a uni-directional causal relationship from labour productivity in the non-agricultural sector to the GDP at a 5% level of significance. The study recommends that the government needs to increase investment in innovation given the presence of the 4IR. South Africa has been the lowest in this sector as compared to the BRICS countries. Therefore, an increase in investment will lead to positive repercussions on economic growth.

5.5 Area of future research

Future research can focus on other macroeconomic objectives such as unemployment, inflation and the balance of payments on how they impact the country's economic growth.

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APPENDICES

Appendix A: Data of the study

YEARS	LGDP	LR&D	LNOP	LLPNAS	LLPMAN
1994	6,218058	3,987353	2,970812	1,813581	1,755112
1995	6,231383	3,991403	2,945961	1,824126	1,784617
1996	6,249695	3,999087	2,879096	1,83187	1,814913
1997	6,261041	4,003417	2,550228	1,843233	1,841985
1998	6,263282	4,005995	2,30103	1,856729	1,860338
1999	6,273404	4,00877	2,139879	1,870404	1,866878
2000	6,291082	4,002598	2,951823	1,894316	1,889302
2001	6,302803	3,989227	2,984977	1,909556	1,907949
2002	6,318447	4,014856	2,992554	1,920645	1,924279
2003	6,331069	4,058843	2,964731	1,939519	1,919078
2004	6,350412	4,118529	2,980458	1,946943	1,942504
2005	6,372746	4,143858	3,001301	1,952308	1,960471
2006	6,396425	4,204283	2,937518	1,964731	1,975432
2007	6,419103	4,222326	2,961421	1,974972	1,996512
2008	6,432745	4,204554	2,934498	1,978637	2,000868
2009	6,426013	4,163549	2,914872	1,984977	1,965672
2010	6,439018	4,124993	2,914343	2	2
2011	6,453052	4,135864	2,816904	2,003029	2,017033
2012	6,462559	4,124667	2,783904	2,006466	2,02735
2013	6,473221	4,141387	2,804821	2,0141	2,033021
2014	6,481169	4,200604	2,904174	2,020361	2,040998
2015	6,486322	4,218798	2,948902	2,026942	2,041787
2016	6,488052	4,232259	2,847573	2,028164	2,049993
2017	6,494152	4,252076	2,862131	2,033021	2,048442
2018	6,497557	4,265902	2,817565	2,034227	2,055378

Appendix B: Unit root results

Null Hypothesis: D(LR_D) has a unit root
Exogenous: Constant, Linear Trend
Lag Length: 0 (Automatic - based on SIC, maxlag=5)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-2.504013	0.3232
Test critical values:	1% level	-4.416345	
	5% level	-3.622033	
	10% level	-3.248592	

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation
Dependent Variable: D(LR_D,2)
Method: Least Squares
Date: 04/17/21 Time: 16:08
Sample (adjusted): 1996 2018
Included observations: 23 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(LR_D(-1))	-0.476820	0.190422	-2.504013	0.0211
C	0.004752	0.011263	0.421904	0.6776
@TREND("1994")	8.93E-05	0.000768	0.116265	0.9086

R-squared	0.238875	Mean dependent var	0.000425
Adjusted R-squared	0.162763	S.D. dependent var	0.026623
S.E. of regression	0.024361	Akaike info criterion	-4.470597
Sum squared resid	0.011869	Schwarz criterion	-4.322489
Log likelihood	54.41187	Hannan-Quinn criter.	-4.433348
F-statistic	3.138454	Durbin-Watson stat	1.863937
Prob(F-statistic)	0.065247		

Null Hypothesis: D(LR_D) has a unit root
Exogenous: Constant
Lag Length: 0 (Automatic - based on SIC, maxlag=5)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-2.563614	0.1147
Test critical values:	1% level	-3.752946	
	5% level	-2.998064	
	10% level	-2.638752	

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation
Dependent Variable: D(LR_D,2)
Method: Least Squares
Date: 04/17/21 Time: 16:07
Sample (adjusted): 1996 2018
Included observations: 23 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(LR_D(-1))	-0.475064	0.185310	-2.563614	0.0181
C	0.005893	0.005398	1.091676	0.2873

R-squared	0.238361	Mean dependent var	0.000425
Adjusted R-squared	0.202092	S.D. dependent var	0.026623
S.E. of regression	0.023781	Akaike info criterion	-4.556878
Sum squared resid	0.011877	Schwarz criterion	-4.458139
Log likelihood	54.40410	Hannan-Quinn criter.	-4.532045
F-statistic	6.572118	Durbin-Watson stat	1.865687
Prob(F-statistic)	0.018099		

Null Hypothesis: LR_D has a unit root
Exogenous: Constant, Linear Trend
Lag Length: 1 (Automatic - based on SIC, maxlag=5)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-3.043100	0.1427
Test critical values:	1% level	-4.416345	
	5% level	-3.622033	
	10% level	-3.248592	

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation
Dependent Variable: D(LR_D)
Method: Least Squares
Date: 04/17/21 Time: 16:06
Sample (adjusted): 1996 2018
Included observations: 23 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LR_D(-1)	-0.312505	0.102693	-3.043100	0.0067
D(LR_D(-1))	0.677699	0.168048	4.032776	0.0007
C	1.239898	0.405995	3.053975	0.0065
@TREND("1994")	0.003774	0.001373	2.749787	0.0127

R-squared	0.513888	Mean dependent var	0.011935
Adjusted R-squared	0.437134	S.D. dependent var	0.027316
S.E. of regression	0.020493	Akaike info criterion	-4.780665
Sum squared resid	0.007980	Schwarz criterion	-4.583188
Log likelihood	58.97765	Hannan-Quinn criter.	-4.731000
F-statistic	6.695215	Durbin-Watson stat	2.395504
Prob(F-statistic)	0.002856		

Null Hypothesis: LR_D has a unit root
Exogenous: Constant
Lag Length: 1 (Automatic - based on SIC, maxlag=5)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-1.137445	0.6826
Test critical values:	1% level	-3.752946	
	5% level	-2.998064	
	10% level	-2.638752	

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation
Dependent Variable: D(LR_D)
Method: Least Squares
Date: 04/17/21 Time: 16:06
Sample (adjusted): 1996 2018
Included observations: 23 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LR_D(-1)	-0.063377	0.055719	-1.137445	0.2688
D(LR_D(-1))	0.570969	0.188425	3.030222	0.0066
C	0.265931	0.228679	1.162902	0.2586

R-squared	0.320433	Mean dependent var	0.011935
Adjusted R-squared	0.252476	S.D. dependent var	0.027316
S.E. of regression	0.023617	Akaike info criterion	-4.532604
Sum squared resid	0.011155	Schwarz criterion	-4.384496
Log likelihood	55.12495	Hannan-Quinn criter.	-4.495355
F-statistic	4.715245	Durbin-Watson stat	1.942246
Prob(F-statistic)	0.021005		

Null Hypothesis: D(LNOP) has a unit root
Exogenous: Constant, Linear Trend
Lag Length: 0 (Automatic - based on SIC, maxlag=5)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-4.275364	0.0134
Test critical values:	1% level	-4.416345	
	5% level	-3.622033	
	10% level	-3.248592	

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation
Dependent Variable: D(LNOP,2)
Method: Least Squares
Date: 04/17/21 Time: 16:05
Sample (adjusted): 1996 2018
Included observations: 23 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(LNOP(-1))	-0.956696	0.223770	-4.275364	0.0004
C	-0.017555	0.097515	-0.180026	0.8589
@TREND("1994")	0.000937	0.006680	0.140234	0.8899

R-squared	0.477655	Mean dependent var	-0.000857
Adjusted R-squared	0.425421	S.D. dependent var	0.279890
S.E. of regression	0.212160	Akaike info criterion	-0.141848
Sum squared resid	0.900234	Schwarz criterion	0.006260
Log likelihood	4.631252	Hannan-Quinn criter.	-0.104599
F-statistic	9.144442	Durbin-Watson stat	1.982303
Prob(F-statistic)	0.001512		

Null Hypothesis: D(LNOP) has a unit root
Exogenous: Constant
Lag Length: 0 (Automatic - based on SIC, maxlag=5)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-4.377652	0.0024
Test critical values:	1% level	-3.752946	
	5% level	-2.998064	
	10% level	-2.638752	

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation
Dependent Variable: D(LNOP,2)
Method: Least Squares
Date: 04/17/21 Time: 16:04
Sample (adjusted): 1996 2018
Included observations: 23 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(LNOP(-1))	-0.954929	0.218137	-4.377652	0.0003
C	-0.005369	0.043206	-0.124276	0.9023

R-squared	0.477142	Mean dependent var	-0.000857
Adjusted R-squared	0.452244	S.D. dependent var	0.279890
S.E. of regression	0.207148	Akaike info criterion	-0.227822
Sum squared resid	0.901119	Schwarz criterion	-0.129083
Log likelihood	4.619950	Hannan-Quinn criter.	-0.202989
F-statistic	19.16384	Durbin-Watson stat	1.983376
Prob(F-statistic)	0.000263		

Null Hypothesis: LNOP has a unit root
Exogenous: Constant, Linear Trend
Lag Length: 0 (Automatic - based on SIC, maxlag=5)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-2.556586	0.3010
Test critical values:	1% level	-4.394309	
	5% level	-3.612199	
	10% level	-3.243079	

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation
Dependent Variable: D(LNOP)
Method: Least Squares
Date: 04/17/21 Time: 16:04
Sample (adjusted): 1995 2018
Included observations: 24 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LNOP(-1)	-0.457354	0.178892	-2.556586	0.0184
C	1.242337	0.499574	2.486794	0.0214
@TREND("1994")	0.004217	0.005476	0.770100	0.4498

R-squared	0.238500	Mean dependent var	-0.006385
Adjusted R-squared	0.165977	S.D. dependent var	0.198177
S.E. of regression	0.180985	Akaike info criterion	-0.464335
Sum squared resid	0.687868	Schwarz criterion	-0.317079
Log likelihood	8.572023	Hannan-Quinn criter.	-0.425268
F-statistic	3.288583	Durbin-Watson stat	1.636344
Prob(F-statistic)	0.057218		

Null Hypothesis: LNOP has a unit root
Exogenous: Constant
Lag Length: 0 (Automatic - based on SIC, maxlag=5)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-2.469188	0.1350
Test critical values:	1% level	-3.737853	
	5% level	-2.991878	
	10% level	-2.635542	

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation
Dependent Variable: D(LNOP)
Method: Least Squares
Date: 04/17/21 Time: 16:03
Sample (adjusted): 1995 2018
Included observations: 24 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LNOP(-1)	-0.426494	0.172726	-2.469188	0.0218
C	1.207238	0.492868	2.449415	0.0227

R-squared	0.216995	Mean dependent var	-0.006385
Adjusted R-squared	0.181404	S.D. dependent var	0.198177
S.E. of regression	0.179303	Akaike info criterion	-0.519819
Sum squared resid	0.707294	Schwarz criterion	-0.421648
Log likelihood	8.237832	Hannan-Quinn criter.	-0.493775
F-statistic	6.096889	Durbin-Watson stat	1.630336
Prob(F-statistic)	0.021781		

Null Hypothesis: LLPNAS has a unit root
Exogenous: Constant, Linear Trend
Lag Length: 2 (Automatic - based on SIC, maxlag=5)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-0.220163	0.9879
Test critical values:	1% level	-4.440739	
	5% level	-3.632896	
	10% level	-3.254671	

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation
Dependent Variable: D(LLPNAS)
Method: Least Squares
Date: 04/17/21 Time: 16:02
Sample (adjusted): 1997 2018
Included observations: 22 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LLPNAS(-1)	-0.017746	0.080605	-0.220163	0.8284
D(LLPNAS(-1))	0.006679	0.228292	0.029257	0.9770
D(LLPNAS(-2))	-0.169453	0.230733	-0.734413	0.4727
C	0.053000	0.144750	0.366147	0.7188
@TREND("1994")	-0.000557	0.000873	-0.638312	0.5318

R-squared	0.533799	Mean dependent var	0.009198
Adjusted R-squared	0.424105	S.D. dependent var	0.005900
S.E. of regression	0.004477	Akaike info criterion	-7.782920
Sum squared resid	0.000341	Schwarz criterion	-7.534956
Log likelihood	90.61212	Hannan-Quinn criter.	-7.724507
F-statistic	4.866246	Durbin-Watson stat	2.068937
Prob(F-statistic)	0.008437		

Null Hypothesis: LLPNAS has a unit root
Exogenous: Constant
Lag Length: 2 (Automatic - based on SIC, maxlag=5)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-3.517083	0.0173
Test critical values:	1% level	-3.769597	
	5% level	-3.004861	
	10% level	-2.642242	

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation
Dependent Variable: D(LLPNAS)
Method: Least Squares
Date: 04/17/21 Time: 16:02
Sample (adjusted): 1997 2018
Included observations: 22 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LLPNAS(-1)	-0.067659	0.019237	-3.517083	0.0025
D(LLPNAS(-1))	0.064017	0.206393	0.310170	0.7600
D(LLPNAS(-2))	-0.100859	0.200791	-0.502308	0.6215
C	0.141820	0.039219	3.616136	0.0020

R-squared	0.522626	Mean dependent var	0.009198
Adjusted R-squared	0.443063	S.D. dependent var	0.005900
S.E. of regression	0.004403	Akaike info criterion	-7.850145
Sum squared resid	0.000349	Schwarz criterion	-7.651773
Log likelihood	90.35159	Hannan-Quinn criter.	-7.803414
F-statistic	6.568757	Durbin-Watson stat	2.111063
Prob(F-statistic)	0.003424		

Null Hypothesis: LLPMAN has a unit root
Exogenous: Constant, Linear Trend
Lag Length: 0 (Automatic - based on SIC, maxlag=5)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-2.339498	0.3989
Test critical values:	1% level	-4.394309	
	5% level	-3.612199	
	10% level	-3.243079	

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation
Dependent Variable: D(LLPMAN)
Method: Least Squares
Date: 04/17/21 Time: 16:00
Sample (adjusted): 1995 2018
Included observations: 24 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LLPMAN(-1)	-0.274082	0.117154	-2.339498	0.0293
C	0.515849	0.210151	2.454663	0.0229
@TREND("1994")	0.002366	0.001460	1.620614	0.1200

R-squared	0.374472	Mean dependent var	0.012511
Adjusted R-squared	0.314898	S.D. dependent var	0.014559
S.E. of regression	0.012051	Akaike info criterion	-5.882925
Sum squared resid	0.003050	Schwarz criterion	-5.735668
Log likelihood	73.59510	Hannan-Quinn criter.	-5.843858
F-statistic	6.285818	Durbin-Watson stat	2.275329
Prob(F-statistic)	0.007254		

Null Hypothesis: LLPMAN has a unit root
Exogenous: Constant
Lag Length: 0 (Automatic - based on SIC, maxlag=5)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-3.043130	0.0450
Test critical values:	1% level	-3.737853	
	5% level	-2.991878	
	10% level	-2.635542	

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation
Dependent Variable: D(LLPMAN)
Method: Least Squares
Date: 04/17/21 Time: 16:00
Sample (adjusted): 1995 2018
Included observations: 24 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LLPMAN(-1)	-0.089931	0.029552	-3.043130	0.0060
C	0.187368	0.057516	3.257662	0.0036

R-squared	0.296240	Mean dependent var	0.012511
Adjusted R-squared	0.264250	S.D. dependent var	0.014559
S.E. of regression	0.012488	Akaike info criterion	-5.848417
Sum squared resid	0.003431	Schwarz criterion	-5.750246
Log likelihood	72.18100	Hannan-Quinn criter.	-5.822372
F-statistic	9.260637	Durbin-Watson stat	2.433805
Prob(F-statistic)	0.005966		

Null Hypothesis: D(LGDP) has a unit root
Exogenous: Constant, Linear Trend
Lag Length: 0 (Automatic - based on SIC, maxlag=5)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-3.088863	0.1321
Test critical values:	1% level	-4.416345	
	5% level	-3.622033	
	10% level	-3.248592	

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation
Dependent Variable: D(LGDP,2)
Method: Least Squares
Date: 04/17/21 Time: 15:59
Sample (adjusted): 1996 2018
Included observations: 23 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(LGDP(-1))	-0.648082	0.209812	-3.088863	0.0058
C	0.011430	0.004681	2.441468	0.0240
@TREND("1994")	-0.000314	0.000225	-1.392688	0.1790

R-squared	0.326048	Mean dependent var	-0.000431
Adjusted R-squared	0.258653	S.D. dependent var	0.007835
S.E. of regression	0.006746	Akaike info criterion	-7.038556
Sum squared resid	0.000910	Schwarz criterion	-6.890448
Log likelihood	83.94339	Hannan-Quinn criter.	-7.001307
F-statistic	4.837858	Durbin-Watson stat	1.849129
Prob(F-statistic)	0.019332		

Null Hypothesis: D(LGDP) has a unit root
Exogenous: Constant
Lag Length: 0 (Automatic - based on SIC, maxlag=5)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-2.721182	0.0858
Test critical values:	1% level	-3.752946	
	5% level	-2.998064	
	10% level	-2.638752	

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation
Dependent Variable: D(LGDP,2)
Method: Least Squares
Date: 04/17/21 Time: 15:58
Sample (adjusted): 1996 2018
Included observations: 23 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(LGDP(-1))	-0.548990	0.201747	-2.721182	0.0128
C	0.006159	0.002816	2.186737	0.0402

R-squared	0.260689	Mean dependent var	-0.000431
Adjusted R-squared	0.225484	S.D. dependent var	0.007835
S.E. of regression	0.006896	Akaike info criterion	-7.032953
Sum squared resid	0.000999	Schwarz criterion	-6.934214
Log likelihood	82.87895	Hannan-Quinn criter.	-7.008120
F-statistic	7.404831	Durbin-Watson stat	1.852741
Prob(F-statistic)	0.012794		

Null Hypothesis: LGDP has a unit root
Exogenous: Constant, Linear Trend
Lag Length: 0 (Automatic - based on SIC, maxlag=5)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		0.112638	0.9954
Test critical values:	1% level	-4.394309	
	5% level	-3.612199	
	10% level	-3.243079	

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation
Dependent Variable: D(LGDP)
Method: Least Squares
Date: 04/17/21 Time: 15:58
Sample (adjusted): 1995 2018
Included observations: 24 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LGDP(-1)	0.012332	0.109485	0.112638	0.9114
C	-0.059829	0.679687	-0.088025	0.9307
@TREND("1994")	-0.000568	0.001447	-0.392439	0.6987

R-squared	0.153969	Mean dependent var	0.011646
Adjusted R-squared	0.073394	S.D. dependent var	0.007340
S.E. of regression	0.007065	Akaike info criterion	-6.950768
Sum squared resid	0.001048	Schwarz criterion	-6.803511
Log likelihood	86.40921	Hannan-Quinn criter.	-6.911700
F-statistic	1.910889	Durbin-Watson stat	1.303633
Prob(F-statistic)	0.172805		

Null Hypothesis: LGDP has a unit root
Exogenous: Constant
Lag Length: 0 (Automatic - based on SIC, maxlag=5)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-1.953062	0.3041
Test critical values:	1% level	-3.737853	
	5% level	-2.991878	
	10% level	-2.635542	

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation
Dependent Variable: D(LGDP)
Method: Least Squares
Date: 04/17/21 Time: 15:55
Sample (adjusted): 1995 2018
Included observations: 24 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LGDP(-1)	-0.030186	0.015456	-1.953062	0.0636
C	0.203978	0.098487	2.071107	0.0503

R-squared	0.147764	Mean dependent var	0.011646
Adjusted R-squared	0.109026	S.D. dependent var	0.007340
S.E. of regression	0.006928	Akaike info criterion	-7.026794
Sum squared resid	0.001056	Schwarz criterion	-6.928623
Log likelihood	86.32153	Hannan-Quinn criter.	-7.000749
F-statistic	3.814451	Durbin-Watson stat	1.243437
Prob(F-statistic)	0.063648		

Null Hypothesis: D(LR_D) has a unit root
Exogenous: Constant, Linear Trend
Lag Length: 0 (Automatic - based on SIC, maxlag=5)

		t-Statistic
Elliott-Rothenberg-Stock DF-GLS test statistic		-2.62457...
Test critical values:	1% level	-3.77000...
	5% level	-3.19000...
	10% level	-2.89000...

*Elliott-Rothenberg-Stock (1996, Table 1)
Warning: Test critical values calculated for 50 observations
and may not be accurate for a sample size of 23

DF-GLS Test Equation on GLS Detrended Residuals
Dependent Variable: D(GLSRESID)
Method: Least Squares
Date: 04/17/21 Time: 15:54
Sample (adjusted): 1996 2018
Included observations: 23 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
GLSRESID(-1)	-0.476614	0.181597	-2.624572	0.0155

R-squared	0.238440	Mean dependent var	8.28E-05
Adjusted R-squared	0.238440	S.D. dependent var	0.026623
S.E. of regression	0.023233	Akaike info criterion	-4.643939
Sum squared resid	0.011875	Schwarz criterion	-4.594569
Log likelihood	54.40529	Hannan-Quinn criter.	-4.631522
Durbin-Watson stat	1.863291		

Null Hypothesis: D(LR_D) has a unit root
Exogenous: Constant
Lag Length: 0 (Automatic - based on SIC, maxlag=5)

		t-Statistic
Elliott-Rothenberg-Stock DF-GLS test statistic		-2.61098...
Test critical values:	1% level	-2.66935...
	5% level	-1.95640...
	10% level	-1.60849...

*MacKinnon (1996)

DF-GLS Test Equation on GLS Detrended Residuals
Dependent Variable: D(GLSRESID)
Method: Least Squares
Date: 04/17/21 Time: 15:53
Sample (adjusted): 1996 2018
Included observations: 23 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
GLSRESID(-1)	-0.472535	0.180980	-2.610981	0.0160

R-squared	0.236364	Mean dependent var	0.000425
Adjusted R-squared	0.236364	S.D. dependent var	0.026623
S.E. of regression	0.023265	Akaike info criterion	-4.641216
Sum squared resid	0.011908	Schwarz criterion	-4.591847
Log likelihood	54.37398	Hannan-Quinn criter.	-4.628800
Durbin-Watson stat	1.865210		

Null Hypothesis: LR_D has a unit root
Exogenous: Constant
Lag Length: 1 (Automatic - based on SIC, maxlag=5)

		t-Statistic
Elliott-Rothenberg-Stock DF-GLS test statistic		-0.99373...
Test critical values:	1% level	-2.66935...
	5% level	-1.95640...
	10% level	-1.60849...

*MacKinnon (1996)

DF-GLS Test Equation on GLS Detrended Residuals
Dependent Variable: D(GLSRESID)
Method: Least Squares
Date: 04/17/21 Time: 15:52
Sample (adjusted): 1996 2018
Included observations: 23 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
GLSRESID(-1)	-0.055652	0.056003	-0.993737	0.3317
D(GLSRESID(-1))	0.653588	0.177909	3.673726	0.0014

R-squared	0.269751	Mean dependent var	0.011935
Adjusted R-squared	0.234977	S.D. dependent var	0.027316
S.E. of regression	0.023892	Akaike info criterion	-4.547632
Sum squared resid	0.011987	Schwarz criterion	-4.448893
Log likelihood	54.29776	Hannan-Quinn criter.	-4.522799
Durbin-Watson stat	1.977014		

Null Hypothesis: LNOP has a unit root
Exogenous: Constant, Linear Trend
Lag Length: 0 (Automatic - based on SIC, maxlag=5)

		t-Statistic
Elliott-Rothenberg-Stock DF-GLS test statistic		-2.59160...
Test critical values:	1% level	-3.77000...
	5% level	-3.19000...
	10% level	-2.89000...

*Elliott-Rothenberg-Stock (1996, Table 1)
Warning: Test critical values calculated for 50 observations
and may not be accurate for a sample size of 24

DF-GLS Test Equation on GLS Detrended Residuals
Dependent Variable: D(GLSRESID)
Method: Least Squares
Date: 04/17/21 Time: 15:51
Sample (adjusted): 1995 2018
Included observations: 24 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
GLSRESID(-1)	-0.442898	0.170897	-2.591604	0.0163

R-squared	0.224287	Mean dependent var	-0.009173
Adjusted R-squared	0.224287	S.D. dependent var	0.198177
S.E. of regression	0.174544	Akaike info criterion	-0.612508
Sum squared resid	0.700707	Schwarz criterion	-0.563423
Log likelihood	8.350101	Hannan-Quinn criter.	-0.599486
Durbin-Watson stat	1.623999		

Null Hypothesis: LNOP has a unit root
Exogenous: Constant
Lag Length: 0 (Automatic - based on SIC, maxlag=5)

		t-Statistic
Elliott-Rothenberg-Stock DF-GLS test statistic		-2.46409...
Test critical values:	1% level	-2.66485...
	5% level	-1.95568...
	10% level	-1.60879...

*MacKinnon (1996)

DF-GLS Test Equation on GLS Detrended Residuals
Dependent Variable: D(GLSRESID)
Method: Least Squares
Date: 04/17/21 Time: 15:50
Sample (adjusted): 1995 2018
Included observations: 24 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
GLSRESID(-1)	-0.414890	0.168374	-2.464092	0.0216

R-squared	0.207997	Mean dependent var	-0.006385
Adjusted R-squared	0.207997	S.D. dependent var	0.198177
S.E. of regression	0.176367	Akaike info criterion	-0.591726
Sum squared resid	0.715422	Schwarz criterion	-0.542641
Log likelihood	8.100716	Hannan-Quinn criter.	-0.578704
Durbin-Watson stat	1.627432		

Null Hypothesis: LLPNAS has a unit root
Exogenous: Constant, Linear Trend
Lag Length: 3 (Automatic - based on SIC, maxlag=5)

		t-Statistic
Elliott-Rothenberg-Stock DF-GLS test statistic		-1.93295...
Test critical values:	1% level	-3.77000...
	5% level	-3.19000...
	10% level	-2.89000...

*Elliott-Rothenberg-Stock (1996, Table 1)
Warning: Test critical values calculated for 50 observations
and may not be accurate for a sample size of 21

DF-GLS Test Equation on GLS Detrended Residuals
Dependent Variable: D(GLSRESID)
Method: Least Squares
Date: 04/17/21 Time: 15:49
Sample (adjusted): 1998 2018
Included observations: 21 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
GLSRESID(-1)	-0.151272	0.078259	-1.932959	0.0701
D(GLSRESID(-1))	0.394922	0.194010	2.035578	0.0577
D(GLSRESID(-2))	0.055358	0.210486	0.263000	0.7957
D(GLSRESID(-3))	0.648832	0.210335	3.084753	0.0067

R-squared	0.509953	Mean dependent var	-0.000566
Adjusted R-squared	0.423474	S.D. dependent var	0.006025
S.E. of regression	0.004575	Akaike info criterion	-7.766848
Sum squared resid	0.000356	Schwarz criterion	-7.567891
Log likelihood	85.55190	Hannan-Quinn criter.	-7.723669
Durbin-Watson stat	1.936453		

Null Hypothesis: LLPNAS has a unit root
Exogenous: Constant
Lag Length: 3 (Automatic - based on SIC, maxlag=5)

		t-Statistic
Elliott-Rothenberg-Stock DF-GLS test statistic		-1.64961...
Test critical values:	1% level	-2.67973...
	5% level	-1.95808...
	10% level	-1.60783...

*MacKinnon (1996)

DF-GLS Test Equation on GLS Detrended Residuals
Dependent Variable: D(GLSRESID)
Method: Least Squares
Date: 04/17/21 Time: 15:48
Sample (adjusted): 1998 2018
Included observations: 21 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
GLSRESID(-1)	-0.025347	0.015365	-1.649618	0.1174
D(GLSRESID(-1))	0.335061	0.181587	1.845176	0.0825
D(GLSRESID(-2))	-0.017970	0.200019	-0.089841	0.9295
D(GLSRESID(-3))	0.645600	0.183410	3.519990	0.0026

R-squared	0.501118	Mean dependent var	0.009095
Adjusted R-squared	0.413080	S.D. dependent var	0.006025
S.E. of regression	0.004616	Akaike info criterion	-7.748980
Sum squared resid	0.000362	Schwarz criterion	-7.550023
Log likelihood	85.36429	Hannan-Quinn criter.	-7.705801
Durbin-Watson stat	2.000793		

Null Hypothesis: D(LLPMAN) has a unit root
Exogenous: Constant, Linear Trend
Lag Length: 0 (Automatic - based on SIC, maxlag=5)

		t-Statistic
Elliott-Rothenberg-Stock DF-GLS test statistic		-5.73076...
Test critical values:	1% level	-3.77000...
	5% level	-3.19000...
	10% level	-2.89000...

*Elliott-Rothenberg-Stock (1996, Table 1)
Warning: Test critical values calculated for 50 observations
and may not be accurate for a sample size of 23

DF-GLS Test Equation on GLS Detrended Residuals
Dependent Variable: D(GLSRESID)
Method: Least Squares
Date: 04/15/21 Time: 09:58
Sample (adjusted): 1996 2018
Included observations: 23 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
GLSRESID(-1)	-1.197621	0.208981	-5.730762	0.0000

R-squared	0.598845	Mean dependent var	-2.19E-06
Adjusted R-squared	0.598845	S.D. dependent var	0.020403
S.E. of regression	0.012923	Akaike info criterion	-5.817155
Sum squared resid	0.003674	Schwarz criterion	-5.767786
Log likelihood	67.89729	Hannan-Quinn criter.	-5.804739
Durbin-Watson stat	2.120512		

Null Hypothesis: D(LLPMAN) has a unit root
Exogenous: Constant
Lag Length: 0 (Automatic - based on SIC, maxlag=5)

		t-Statistic
Elliott-Rothenberg-Stock DF-GLS test statistic		-4.30912...
Test critical values:	1% level	-2.66935...
	5% level	-1.95640...
	10% level	-1.60849...

*MacKinnon (1996)

DF-GLS Test Equation on GLS Detrended Residuals
Dependent Variable: D(GLSRESID)
Method: Least Squares
Date: 04/15/21 Time: 09:57
Sample (adjusted): 1996 2018
Included observations: 23 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
GLSRESID(-1)	-0.906379	0.210340	-4.309121	0.0003

R-squared	0.456396	Mean dependent var	-0.000981
Adjusted R-squared	0.456396	S.D. dependent var	0.020403
S.E. of regression	0.015043	Akaike info criterion	-5.513283
Sum squared resid	0.004979	Schwarz criterion	-5.463914
Log likelihood	64.40276	Hannan-Quinn criter.	-5.500867
Durbin-Watson stat	2.022280		

Null Hypothesis: LLPMAN has a unit root
Exogenous: Constant, Linear Trend
Lag Length: 0 (Automatic - based on SIC, maxlag=5)

		t-Statistic
Elliott-Rothenberg-Stock DF-GLS test statistic		-1.97109...
Test critical values:	1% level	-3.77000...
	5% level	-3.19000...
	10% level	-2.89000...

*Elliott-Rothenberg-Stock (1996, Table 1)
Warning: Test critical values calculated for 50 observations
and may not be accurate for a sample size of 24

DF-GLS Test Equation on GLS Detrended Residuals
Dependent Variable: D(GLSRESID)
Method: Least Squares
Date: 04/15/21 Time: 09:56
Sample (adjusted): 1995 2018
Included observations: 24 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
GLSRESID(-1)	-0.249435	0.126546	-1.971099	0.0609

R-squared	0.143811	Mean dependent var	0.000408
Adjusted R-squared	0.143811	S.D. dependent var	0.014559
S.E. of regression	0.013472	Akaike info criterion	-5.735697
Sum squared resid	0.004174	Schwarz criterion	-5.686612
Log likelihood	69.82837	Hannan-Quinn criter.	-5.722675
Durbin-Watson stat	1.706617		

Null Hypothesis: LLPMAN has a unit root
Exogenous: Constant
Lag Length: 0 (Automatic - based on SIC, maxlag=5)

		t-Statistic
Elliott-Rothenberg-Stock DF-GLS test statistic		-0.57796...
Test critical values:	1% level	-2.66485...
	5% level	-1.95568...
	10% level	-1.60879...

*MacKinnon (1996)

DF-GLS Test Equation on GLS Detrended Residuals
Dependent Variable: D(GLSRESID)
Method: Least Squares
Date: 04/15/21 Time: 09:56
Sample (adjusted): 1995 2018
Included observations: 24 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
GLSRESID(-1)	-0.024226	0.041917	-0.577965	0.5689

R-squared	-0.745214	Mean dependent var	0.012511
Adjusted R-squared	-0.745214	S.D. dependent var	0.014559
S.E. of regression	0.019233	Akaike info criterion	-5.023556
Sum squared resid	0.008508	Schwarz criterion	-4.974470
Log likelihood	61.28267	Hannan-Quinn criter.	-5.010533
Durbin-Watson stat	1.051116		

Null Hypothesis: D(LGDP) has a unit root
Exogenous: Constant, Linear Trend
Lag Length: 0 (Automatic - based on SIC, maxlag=5)

		t-Statistic
Elliott-Rothenberg-Stock DF-GLS test statistic		-3.23768...
Test critical values:	1% level	-3.77000...
	5% level	-3.19000...
	10% level	-2.89000...

*Elliott-Rothenberg-Stock (1996, Table 1)
Warning: Test critical values calculated for 50 observations
and may not be accurate for a sample size of 23

DF-GLS Test Equation on GLS Detrended Residuals
Dependent Variable: D(GLSRESID)
Method: Least Squares
Date: 04/15/21 Time: 09:53
Sample (adjusted): 1996 2018
Included observations: 23 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
GLSRESID(-1)	-0.647671	0.200041	-3.237688	0.0038

R-squared	0.322702	Mean dependent var	-3.36E-05
Adjusted R-squared	0.322702	S.D. dependent var	0.007835
S.E. of regression	0.006448	Akaike info criterion	-7.207516
Sum squared resid	0.000915	Schwarz criterion	-7.158147
Log likelihood	83.88643	Hannan-Quinn criter.	-7.195100
Durbin-Watson stat	1.841416		

Null Hypothesis: D(LGDP) has a unit root
Exogenous: Constant
Lag Length: 0 (Automatic - based on SIC, maxlag=5)

		t-Statistic
Elliott-Rothenberg-Stock DF-GLS test statistic		-2.79972...
Test critical values:	1% level	-2.66935...
	5% level	-1.95640...
	10% level	-1.60849...

*MacKinnon (1996)

DF-GLS Test Equation on GLS Detrended Residuals
Dependent Variable: D(GLSRESID)
Method: Least Squares
Date: 04/15/21 Time: 09:52
Sample (adjusted): 1996 2018
Included observations: 23 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
GLSRESID(-1)	-0.550440	0.196605	-2.799724	0.0104

R-squared	0.260361	Mean dependent var	-0.000431
Adjusted R-squared	0.260361	S.D. dependent var	0.007835
S.E. of regression	0.006738	Akaike info criterion	-7.119465
Sum squared resid	0.000999	Schwarz criterion	-7.070096
Log likelihood	82.87385	Hannan-Quinn criter.	-7.107049
Durbin-Watson stat	1.849365		

Null Hypothesis: LGDP has a unit root
Exogenous: Constant, Linear Trend
Lag Length: 1 (Automatic - based on SIC, maxlag=5)

		t-Statistic
Elliott-Rothenberg-Stock DF-GLS test statistic		-1.37640...
Test critical values:	1% level	-3.77000...
	5% level	-3.19000...
	10% level	-2.89000...

*Elliott-Rothenberg-Stock (1996, Table 1)
Warning: Test critical values calculated for 50 observations
and may not be accurate for a sample size of 23

DF-GLS Test Equation on GLS Detrended Residuals
Dependent Variable: D(GLSRESID)
Method: Least Squares
Date: 04/15/21 Time: 09:51
Sample (adjusted): 1996 2018
Included observations: 23 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
GLSRESID(-1)	-0.142884	0.103810	-1.376402	0.1832
D(GLSRESID(-1))	0.551092	0.204971	2.688640	0.0138

R-squared	0.249678	Mean dependent var	-0.001002
Adjusted R-squared	0.213948	S.D. dependent var	0.007496
S.E. of regression	0.006646	Akaike info criterion	-7.106724
Sum squared resid	0.000927	Schwarz criterion	-7.007986
Log likelihood	83.72733	Hannan-Quinn criter.	-7.081892
Durbin-Watson stat	1.910072		

Null Hypothesis: LGDP has a unit root
Exogenous: Constant
Lag Length: 1 (Automatic - based on SIC, maxlag=5)

		t-Statistic
Elliott-Rothenberg-Stock DF-GLS test statistic		-0.41582...
Test critical values:	1% level	-2.66935...
	5% level	-1.95640...
	10% level	-1.60849...

*MacKinnon (1996)

DF-GLS Test Equation on GLS Detrended Residuals
Dependent Variable: D(GLSRESID)
Method: Least Squares
Date: 04/15/21 Time: 09:50
Sample (adjusted): 1996 2018
Included observations: 23 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
GLSRESID(-1)	-0.007165	0.017231	-0.415829	0.6818
D(GLSRESID(-1))	0.838670	0.115396	7.267778	0.0000

R-squared	0.016398	Mean dependent var	0.011573
Adjusted R-squared	-0.030441	S.D. dependent var	0.007496
S.E. of regression	0.007609	Akaike info criterion	-6.836006
Sum squared resid	0.001216	Schwarz criterion	-6.737267
Log likelihood	80.61406	Hannan-Quinn criter.	-6.811173
Durbin-Watson stat	2.233946		

Null Hypothesis: LR_D is stationary
Exogenous: Constant, Linear Trend
Bandwidth: 3 (Newey-West automatic) using Bartlett kernel

		LM-Stat.
Kwiatkowski-Phillips-Schmidt-Shin test statistic		0.06719...
Asymptotic critical values*:	1% level	0.21600...
	5% level	0.14600...
	10% level	0.11900...

*Kwiatkowski-Phillips-Schmidt-Shin (1992, Table 1)

Residual variance (no correction)	0.00177...
HAC corrected variance (Bartlett kernel)	0.00465...

KPSS Test Equation
Dependent Variable: LR_D
Method: Least Squares
Date: 04/14/21 Time: 20:03
Sample: 1994 2018
Included observations: 25

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	3.970121	0.017037	233.0310	0.0000
@TREND("1994")	0.011874	0.001217	9.757355	0.0000

R-squared	0.805424	Mean dependent var	4.112608
Adjusted R-squared	0.796965	S.D. dependent var	0.097375
S.E. of regression	0.043877	Akaike info criterion	-3.338249
Sum squared resid	0.044279	Schwarz criterion	-3.240739
Log likelihood	43.72812	Hannan-Quinn criter.	-3.311204
F-statistic	95.20598	Durbin-Watson stat	0.372105
Prob(F-statistic)	0.000000		

Null Hypothesis: LR_D is stationary
Exogenous: Constant
Bandwidth: 3 (Newey-West automatic) using Bartlett kernel

		LM-Stat.
Kwiatkowski-Phillips-Schmidt-Shin test statistic		0.63251...
Asymptotic critical values*:	1% level	0.73900...
	5% level	0.46300...
	10% level	0.34700...

*Kwiatkowski-Phillips-Schmidt-Shin (1992, Table 1)

Residual variance (no correction)	0.00910...
HAC corrected variance (Bartlett kernel)	0.02974...

KPSS Test Equation
Dependent Variable: LR_D
Method: Least Squares
Date: 04/14/21 Time: 20:02
Sample: 1994 2018
Included observations: 25

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	4.112608	0.019475	211.1735	0.0000

R-squared	0.000000	Mean dependent var	4.112608
Adjusted R-squared	0.000000	S.D. dependent var	0.097375
S.E. of regression	0.097375	Akaike info criterion	-1.781315
Sum squared resid	0.227566	Schwarz criterion	-1.732560
Log likelihood	23.26643	Hannan-Quinn criter.	-1.767792
Durbin-Watson stat	0.086601		

Null Hypothesis: D(LNOP) is stationary
Exogenous: Constant, Linear Trend
Bandwidth: 2 (Newey-West automatic) using Bartlett kernel

		LM-Stat.
Kwiatkowski-Phillips-Schmidt-Shin test statistic		0.06193...
Asymptotic critical values*:	1% level	0.21600...
	5% level	0.14600...
	10% level	0.11900...

*Kwiatkowski-Phillips-Schmidt-Shin (1992, Table 1)

Residual variance (no correction)	0.03758...
HAC corrected variance (Bartlett kernel)	0.03605...

KPSS Test Equation
Dependent Variable: D(LNOP)
Method: Least Squares
Date: 04/14/21 Time: 19:42
Sample (adjusted): 1995 2018
Included observations: 24 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.019899	0.085315	-0.233237	0.8177
@TREND("1994")	0.001081	0.005971	0.181060	0.8580

R-squared	0.001488	Mean dependent var	-0.006385
Adjusted R-squared	-0.043899	S.D. dependent var	0.198177
S.E. of regression	0.202480	Akaike info criterion	-0.276692
Sum squared resid	0.901963	Schwarz criterion	-0.178521
Log likelihood	5.320303	Hannan-Quinn criter.	-0.250647
F-statistic	0.032783	Durbin-Watson stat	1.910870
Prob(F-statistic)	0.857978		

Null Hypothesis: D(LNOP) is stationary
Exogenous: Constant
Bandwidth: 2 (Newey-West automatic) using Bartlett kernel

		LM-Stat.
Kwiatkowski-Phillips-Schmidt-Shin test statistic		0.06179...
Asymptotic critical values*:	1% level	0.73900...
	5% level	0.46300...
	10% level	0.34700...

*Kwiatkowski-Phillips-Schmidt-Shin (1992, Table 1)

Residual variance (no correction)	0.03763...
HAC corrected variance (Bartlett kernel)	0.03623...

KPSS Test Equation
Dependent Variable: D(LNOP)
Method: Least Squares
Date: 04/14/21 Time: 19:41
Sample (adjusted): 1995 2018
Included observations: 24 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.006385	0.040453	-0.157845	0.8760

R-squared	0.000000	Mean dependent var	-0.006385
Adjusted R-squared	0.000000	S.D. dependent var	0.198177
S.E. of regression	0.198177	Akaike info criterion	-0.358536
Sum squared resid	0.903307	Schwarz criterion	-0.309451
Log likelihood	5.302435	Hannan-Quinn criter.	-0.345514
Durbin-Watson stat	1.907950		

Null Hypothesis: LNOP is stationary
Exogenous: Constant, Linear Trend
Bandwidth: 2 (Newey-West automatic) using Bartlett kernel

		LM-Stat.
Kwiatkowski-Phillips-Schmidt-Shin test statistic		0.07533...
Asymptotic critical values*:	1% level	0.21600...
	5% level	0.14600...
	10% level	0.11900...

*Kwiatkowski-Phillips-Schmidt-Shin (1992, Table 1)

Residual variance (no correction)	0.04138...
HAC corrected variance (Bartlett kernel)	0.07236...

KPSS Test Equation
Dependent Variable: LNOP
Method: Least Squares
Date: 04/14/21 Time: 19:40
Sample: 1994 2018
Included observations: 25

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	2.774772	0.082350	33.69506	0.0000
@TREND("1994")	0.005807	0.005882	0.987270	0.3338

R-squared	0.040655	Mean dependent var	2.844459
Adjusted R-squared	-0.001055	S.D. dependent var	0.211971
S.E. of regression	0.212082	Akaike info criterion	-0.187065
Sum squared resid	1.034517	Schwarz criterion	-0.089555
Log likelihood	4.338307	Hannan-Quinn criter.	-0.160019
F-statistic	0.974701	Durbin-Watson stat	0.876617
Prob(F-statistic)	0.333783		

Null Hypothesis: LNOP is stationary
Exogenous: Constant
Bandwidth: 2 (Newey-West automatic) using Bartlett kernel

		LM-Stat.
Kwiatkowski-Phillips-Schmidt-Shin test statistic		0.13777...
Asymptotic critical values*:	1% level	0.73900...
	5% level	0.46300...
	10% level	0.34700...

*Kwiatkowski-Phillips-Schmidt-Shin (1992, Table 1)

Residual variance (no correction)	0.04313...
HAC corrected variance (Bartlett kernel)	0.07930...

KPSS Test Equation
Dependent Variable: LNOP
Method: Least Squares
Date: 04/14/21 Time: 19:39
Sample: 1994 2018
Included observations: 25

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	2.844459	0.042394	67.09558	0.0000

R-squared	0.000000	Mean dependent var	2.844459
Adjusted R-squared	0.000000	S.D. dependent var	0.211971
S.E. of regression	0.211971	Akaike info criterion	-0.225560
Sum squared resid	1.078358	Schwarz criterion	-0.176805
Log likelihood	3.819495	Hannan-Quinn criter.	-0.212037
Durbin-Watson stat	0.838577		

Null Hypothesis: LGDP is stationary
Exogenous: Constant
Bandwidth: 3 (Newey-West automatic) using Bartlett kernel

		LM-Stat.
Kwiatkowski-Phillips-Schmidt-Shin test statistic		0.71954...
Asymptotic critical values*:	1% level	0.73900...
	5% level	0.46300...
	10% level	0.34700...

*Kwiatkowski-Phillips-Schmidt-Shin (1992, Table 1)

Residual variance (no correction)	0.00864...
HAC corrected variance (Bartlett kernel)	0.03007...

KPSS Test Equation
Dependent Variable: LGDP
Method: Least Squares
Date: 04/14/21 Time: 19:17
Sample: 1994 2018
Included observations: 25

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	6.376512	0.018982	335.9237	0.0000

R-squared	0.000000	Mean dependent var	6.376512
Adjusted R-squared	0.000000	S.D. dependent var	0.094910
S.E. of regression	0.094910	Akaike info criterion	-1.832595
Sum squared resid	0.216190	Schwarz criterion	-1.783840
Log likelihood	23.90744	Hannan-Quinn criter.	-1.819072
Durbin-Watson stat	0.020787		

Null Hypothesis: LGDP is stationary
Exogenous: Constant, Linear Trend
Bandwidth: 3 (Newey-West automatic) using Bartlett kernel

		LM-Stat.
Kwiatkowski-Phillips-Schmidt-Shin test statistic		0.14866...
Asymptotic critical values*:	1% level	0.21600...
	5% level	0.14600...
	10% level	0.11900...

*Kwiatkowski-Phillips-Schmidt-Shin (1992, Table 1)

Residual variance (no correction)	0.00021...
HAC corrected variance (Bartlett kernel)	0.00060...

KPSS Test Equation
Dependent Variable: LGDP
Method: Least Squares
Date: 04/14/21 Time: 19:31
Sample: 1994 2018
Included observations: 25

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	6.223691	0.005924	1050.607	0.0000
@TREND("1994")	0.012735	0.000423	30.09693	0.0000

R-squared	0.975238	Mean dependent var	6.376512
Adjusted R-squared	0.974161	S.D. dependent var	0.094910
S.E. of regression	0.015256	Akaike info criterion	-5.451021
Sum squared resid	0.005353	Schwarz criterion	-5.353511
Log likelihood	70.13776	Hannan-Quinn criter.	-5.423976
F-statistic	905.8249	Durbin-Watson stat	0.236775
Prob(F-statistic)	0.000000		

Null Hypothesis: LLPMAN is stationary
Exogenous: Constant
Bandwidth: 3 (Newey-West automatic) using Bartlett kernel

		LM-Stat.
Kwiatkowski-Phillips-Schmidt-Shin test statistic		0.71685...
Asymptotic critical values*:	1% level	0.73900...
	5% level	0.46300...
	10% level	0.34700...

*Kwiatkowski-Phillips-Schmidt-Shin (1992, Table 1)

Residual variance (no correction)	0.00761...
HAC corrected variance (Bartlett kernel)	0.02500...

KPSS Test Equation
Dependent Variable: LLPMAN
Method: Least Squares
Date: 04/14/21 Time: 19:35
Sample: 1994 2018
Included observations: 25

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1.948796	0.017814	109.3953	0.0000

R-squared	0.000000	Mean dependent var	1.948796
Adjusted R-squared	0.000000	S.D. dependent var	0.089071
S.E. of regression	0.089071	Akaike info criterion	-1.959582
Sum squared resid	0.190409	Schwarz criterion	-1.910827
Log likelihood	25.49477	Hannan-Quinn criter.	-1.946059
Durbin-Watson stat	0.045333		

Null Hypothesis: LLPMAN is stationary
Exogenous: Constant, Linear Trend
Bandwidth: 3 (Newey-West automatic) using Bartlett kernel

		LM-Stat.
Kwiatkowski-Phillips-Schmidt-Shin test statistic		0.19309...
Asymptotic critical values*:	1% level	0.21600...
	5% level	0.14600...
	10% level	0.11900...

*Kwiatkowski-Phillips-Schmidt-Shin (1992, Table 1)

Residual variance (no correction)	0.00047...
HAC corrected variance (Bartlett kernel)	0.00113...

KPSS Test Equation
Dependent Variable: LLPMAN
Method: Least Squares
Date: 04/14/21 Time: 19:36
Sample: 1994 2018
Included observations: 25

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1.808196	0.008848	204.3581	0.0000
@TREND("1994")	0.011717	0.000632	18.53872	0.0000

R-squared	0.937276	Mean dependent var	1.948796
Adjusted R-squared	0.934549	S.D. dependent var	0.089071
S.E. of regression	0.022788	Akaike info criterion	-4.648588
Sum squared resid	0.011943	Schwarz criterion	-4.551078
Log likelihood	60.10735	Hannan-Quinn criter.	-4.621543
F-statistic	343.6840	Durbin-Watson stat	0.409467
Prob(F-statistic)	0.000000		

Null Hypothesis: LLPNAS is stationary
Exogenous: Constant
Bandwidth: 3 (Newey-West automatic) using Bartlett kernel

		LM-Stat.
Kwiatkowski-Phillips-Schmidt-Shin test statistic		0.70829...
Asymptotic critical values*:	1% level	0.73900...
	5% level	0.46300...
	10% level	0.34700...

*Kwiatkowski-Phillips-Schmidt-Shin (1992, Table 1)

Residual variance (no correction)	0.00507...
HAC corrected variance (Bartlett kernel)	0.01739...

KPSS Test Equation
Dependent Variable: LLPNAS
Method: Least Squares
Date: 04/14/21 Time: 19:37
Sample: 1994 2018
Included observations: 25

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1.946914	0.014537	133.9313	0.0000

R-squared	0.000000	Mean dependent var	1.946914
Adjusted R-squared	0.000000	S.D. dependent var	0.072683
S.E. of regression	0.072683	Akaike info criterion	-2.366232
Sum squared resid	0.126789	Schwarz criterion	-2.317477
Log likelihood	30.57790	Hannan-Quinn criter.	-2.352709
Durbin-Watson stat	0.021795		

Null Hypothesis: LLPNAS is stationary
Exogenous: Constant, Linear Trend
Bandwidth: 3 (Newey-West automatic) using Bartlett kernel

		LM-Stat.
Kwiatkowski-Phillips-Schmidt-Shin test statistic		0.18990...
Asymptotic critical values*:	1% level	0.21600...
	5% level	0.14600...
	10% level	0.11900...

*Kwiatkowski-Phillips-Schmidt-Shin (1992, Table 1)

Residual variance (no correction)	0.00022...
HAC corrected variance (Bartlett kernel)	0.00068...

KPSS Test Equation
Dependent Variable: LLPNAS
Method: Least Squares
Date: 04/14/21 Time: 19:38
Sample: 1994 2018
Included observations: 25

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1.831004	0.006003	304.9908	0.0000
@TREND("1994")	0.009659	0.000429	22.52513	0.0000

R-squared	0.956635	Mean dependent var	1.946914
Adjusted R-squared	0.954750	S.D. dependent var	0.072683
S.E. of regression	0.015461	Akaike info criterion	-5.424334
Sum squared resid	0.005498	Schwarz criterion	-5.326824
Log likelihood	69.80418	Hannan-Quinn criter.	-5.397289
F-statistic	507.3815	Durbin-Watson stat	0.134605
Prob(F-statistic)	0.000000		

Appendix C: Lag Selection Criteria

VAR Lag Order Selection Criteria
Endogenous variables: LGDP LLPMAN LLPNAS LNOP LR_D
Exogenous variables: C
Date: 04/17/21 Time: 19:36
Sample: 1994 2018
Included observations: 23

Lag	LogL	LR	FPE	AIC	SC	HQ
0	220.8689	NA	4.85e-15	-18.77121	-18.52436	-18.70913
1	339.2051	174.9318*	1.54e-18	-26.88740	-25.40632*	-26.51492
2	368.6575	30.73294	1.50e-18*	-27.27457*	-24.55926	-26.59168*

* indicates lag order selected by the criterion
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

Appendix D: ARDL Bounds Test

ARDL Error Correction Regression
Dependent Variable: D(LGDP)
Selected Model: ARDL(1, 2, 2, 1, 2, 2)
Case 2: Restricted Constant and No Trend
Date: 10/17/21 Time: 15:03
Sample: 1994 2018
Included observations: 23

ECM Regression
Case 2: Restricted Constant and No Trend

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(LR_D)	0.050466	0.021255	2.374248	0.0337
D(LR_D(-1))	-0.053425	0.022308	-2.394849	0.0478
D(LNOP)	0.025474	0.003695	6.894280	0.0002
D(LNOP(-1))	-0.024051	0.004292	-5.603440	0.0008
D(LLPNAS)	0.033763	0.070117	0.481514	0.6448
D(LLPMAN)	0.507632	0.035008	14.50049	0.0000
D(LLPMAN(-1))	0.096107	0.027159	3.538728	0.0095
D(DUMMY)	-0.008654	0.003095	-2.795532	0.0267
D(DUMMY(-1))	0.012162	0.002398	5.070766	0.0014
CointEq(-1)*	-0.895330	0.294899	3.036062	0.0006

R-squared	0.964469	Mean dependent var	0.011573
Adjusted R-squared	0.939870	S.D. dependent var	0.007496
S.E. of regression	0.001838	Akaike info criterion	-9.461157
Sum squared resid	4.39E-05	Schwarz criterion	-8.967464
Log likelihood	118.8033	Hannan-Quinn criter.	-9.336995
Durbin-Watson stat	2.548881		

* p-value incompatible with t-Bounds distribution.

F-Bounds Test — Null Hypothesis: No levels relationship

Test Statistic	Value	Signif.	I(0)	I(1)
F-statistic	7.004809	10%	2.08	3
k	4	5%	2.39	3.38
		2.5%	2.7	3.73
		1%	3.06	4.15

ARDL Long Run Form and Bounds Test
Dependent Variable: D(LGDP)
Selected Model: ARDL(1, 0, 1, 0, 1, 0)
Case 2: Restricted Constant and No Trend
Date: 10/17/21 Time: 15:43
Sample: 1994 2018
Included observations: 24

Conditional Error Correction Regression

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1.114574	0.245017	4.548962	0.0004
LGDP(-1)*	-0.275563	0.059295	-4.647287	0.0003
LR_D**	0.060859	0.021126	2.880781	0.0114
LNOP(-1)	-0.019462	0.014422	-1.349480	0.1972
LLPNAS**	0.089118	0.127034	0.701531	0.4937
LLPMAN(-1)	0.144864	0.088534	1.636251	0.1226
DUMMY**	-0.017797	0.008472	-2.100658	0.0530
D(LNOP)	0.002225	0.006531	0.340731	0.7380
D(LLPMAN)	0.332126	0.079872	4.158248	0.0008

* p-value incompatible with t-Bounds distribution.
** Variable interpreted as Z = Z(-1) + D(Z).

Levels Equation
Case 2: Restricted Constant and No Trend

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LR_D	0.220854	0.069450	3.180051	0.0062
LNOP	0.070625	0.088178	-3.381208	0.0070
LLPNAS	-0.323405	0.428451	0.754822	0.4620
LLPMAN	0.525701	0.007946	3.923899	0.0028
DUMMY	-0.064585	0.026770	-2.412557	0.0291
C	4.044719	0.262165	15.42814	0.0000

EC = LGDP - (0.2209*LR_D -0.0706*LNOP + 0.3234*LLPNAS + 0.5257
*LLPMAN -0.0646*DUMMY + 4.0447)

Appendix E: Granger causality test

Pairwise Granger Causality Tests
Date: 04/22/21 Time: 20:02
Sample: 1994 2018
Lags: 1

Null Hypothesis:	Obs	F-Statistic	Prob.
LLPMAN does not Granger Cause LGDP	24	1.14565	0.2966
LGDP does not Granger Cause LLPMAN		1.65862	0.2118
LLPNAS does not Granger Cause LGDP	24	10.1062	0.0045
LGDP does not Granger Cause LLPNAS		2.25710	0.1479
LNOP does not Granger Cause LGDP	24	1.13453	0.2989
LGDP does not Granger Cause LNOP		0.53221	0.4737
LR_D does not Granger Cause LGDP	24	0.20530	0.6551
LGDP does not Granger Cause LR_D		1.23900	0.2782
LLPNAS does not Granger Cause LLPMAN	24	9.31586	0.0061
LLPMAN does not Granger Cause LLPNAS		1.21456	0.2829
LNOP does not Granger Cause LLPMAN	24	0.18843	0.6687
LLPMAN does not Granger Cause LNOP		0.77112	0.3898
LR_D does not Granger Cause LLPMAN	24	0.05134	0.8229
LLPMAN does not Granger Cause LR_D		2.67373	0.1169
LNOP does not Granger Cause LLPNAS	24	3.82089	0.0641
LLPNAS does not Granger Cause LNOP		1.14957	0.2958
LR_D does not Granger Cause LLPNAS	24	2.03035	0.1689
LLPNAS does not Granger Cause LR_D		3.17807	0.0891
LR_D does not Granger Cause LNOP	24	0.39240	0.5378
LNOP does not Granger Cause LR_D		1.11519	0.3030

Appendix F: Heteroskedasticity Test

Heteroskedasticity Test: Breusch-Pagan-Godfrey

F-statistic	1.310068	Prob. F(6,17)	0.3054
Obs*R-squared	7.588361	Prob. Chi-Square(6)	0.2698
Scaled explained SS	2.606086	Prob. Chi-Square(6)	0.8564

Test Equation:
Dependent Variable: RESID^2
Method: Least Squares
Date: 04/17/21 Time: 20:01
Sample: 1995 2018
Included observations: 24

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-6.43E-05	0.000648	-0.099176	0.9222
LGDP(-1)	6.62E-05	0.000175	0.377115	0.7108
LLPMAN	0.000334	0.000272	1.229632	0.2356
LLPMAN(-1)	-4.67E-05	0.000247	-0.188735	0.8525
LLPNAS	-0.000317	0.000430	-0.736337	0.4716
LNOP	-2.34E-05	1.74E-05	-1.343109	0.1969
LR_D	-5.46E-05	6.71E-05	-0.813224	0.4273

R-squared	0.316182	Mean dependent var	1.11E-05
Adjusted R-squared	0.074834	S.D. dependent var	1.32E-05
S.E. of regression	1.27E-05	Akaike info criterion	-19.47085
Sum squared resid	2.74E-09	Schwarz criterion	-19.12725
Log likelihood	240.6502	Hannan-Quinn criter.	-19.37969
F-statistic	1.310068	Durbin-Watson stat	3.078282
Prob(F-statistic)	0.305373		

Breusch-Godfrey Serial Correlation LM Test:

F-statistic	0.661518	Prob. F(1,16)	0.4280
Obs*R-squared	0.952880	Prob. Chi-Square(1)	0.3290

Test Equation:
Dependent Variable: RESID
Method: ARDL
Date: 04/17/21 Time: 20:00
Sample: 1995 2018
Included observations: 24
Presample missing value lagged residuals set to zero.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LGDP(-1)	-0.018746	0.059722	-0.313881	0.7577
LLPMAN	-0.022160	0.089552	-0.247451	0.8077
LLPMAN(-1)	0.000669	0.077683	0.008606	0.9932
LLPNAS	0.048085	0.147387	0.326253	0.7485
LNOP	-0.002061	0.006022	-0.342297	0.7366
LR_D	0.002690	0.021325	0.126152	0.9012
C	0.062340	0.217559	0.286544	0.7781
RESID(-1)	0.243165	0.298972	0.813338	0.4280

R-squared	0.039703	Mean dependent var	-4.86E-16
Adjusted R-squared	-0.380426	S.D. dependent var	0.003396
S.E. of regression	0.003990	Akaike info criterion	-7.948999
Sum squared resid	0.000255	Schwarz criterion	-7.556315
Log likelihood	103.3880	Hannan-Quinn criter.	-7.844820
F-statistic	0.094503	Durbin-Watson stat	1.935167
Prob(F-statistic)	0.997965		

Heteroskedasticity Test: White

F-statistic	1.341040	Prob. F(6,17)	0.2931
Obs*R-squared	7.710129	Prob. Chi-Square(6)	0.2601
Scaled explained SS	2.647905	Prob. Chi-Square(6)	0.8516

Test Equation:
Dependent Variable: RESID^2
Method: Least Squares
Date: 04/17/21 Time: 20:01
Sample: 1995 2018
Included observations: 24

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1.60E-05	0.000345	0.046524	0.9634
LGDP(-1)^2	3.64E-06	1.45E-05	0.250838	0.8049
LLPMAN^2	8.56E-05	6.95E-05	1.231480	0.2349
LLPMAN(-1)^2	-8.60E-06	6.36E-05	-0.135361	0.8939
LLPNAS^2	-7.92E-05	0.000111	-0.712095	0.4861
LNOP^2	-4.60E-06	3.30E-06	-1.393460	0.1814
LR_D^2	-6.42E-06	8.12E-06	-0.791128	0.4398

R-squared	0.321255	Mean dependent var	1.11E-05
Adjusted R-squared	0.081698	S.D. dependent var	1.32E-05
S.E. of regression	1.27E-05	Akaike info criterion	-19.47830
Sum squared resid	2.72E-09	Schwarz criterion	-19.13470
Log likelihood	240.7396	Hannan-Quinn criter.	-19.38714
F-statistic	1.341040	Durbin-Watson stat	3.088211
Prob(F-statistic)	0.293088		

Heteroskedasticity Test: ARCH

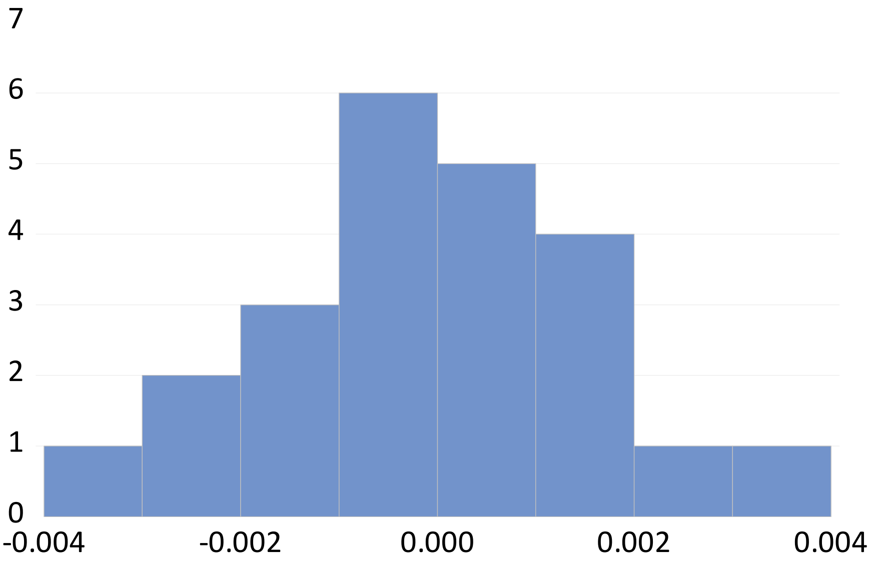
F-statistic	1.388739	Prob. F(1,20)	0.2524
Obs*R-squared	1.428427	Prob. Chi-Square(1)	0.2320

Test Equation:
Dependent Variable: RESID^2
Method: Least Squares
Date: 10/17/21 Time: 16:04
Sample (adjusted): 1997 2018
Included observations: 22 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1.99E-06	1.06E-06	1.884365	0.0741
RESID^2(-1)	0.257696	0.218674	1.178448	0.2524

R-squared	0.064929	Mean dependent var	2.73E-06
Adjusted R-squared	0.018175	S.D. dependent var	4.03E-06
S.E. of regression	3.99E-06	Akaike info criterion	-21.93844
Sum squared resid	3.19E-10	Schwarz criterion	-21.83926
Log likelihood	243.3229	Hannan-Quinn criter.	-21.91508
F-statistic	1.388739	Durbin-Watson stat	1.899559
Prob(F-statistic)	0.252450		

Appendix G: Normality test



Series: Residuals
Sample 1996 2018
Observations 23

Mean	-1.29e-15
Median	-0.000183
Maximum	0.003899
Minimum	-0.003349
Std. Dev.	0.001691
Skewness	0.062149
Kurtosis	2.981760
Jarque-Bera	0.015125
Probability	0.992466

Appendix H: Ramsey RESET test

Ramsey RESET Test
Equation: UNTITLED
Omitted Variables: Squares of fitted values
Specification: LGDP LGDP(-1) LR_D LR_D(-1) LR_D(-2) LNOP LNOP(-1)
LNOP(-2) LLPNAS LLPMAN DUMMY DUMMY(-1) DUMMY(-2) C

	Value	df	Probability
t-statistic	0.046522	9	0.9639
F-statistic	0.002164	(1, 9)	0.9639
Likelihood ratio	0.005530	1	0.9407

F-test summary:

	Sum of Sq.	df	Mean Squares
Test SSR	1.51E-08	1	1.51E-08
Restricted SSR	6.29E-05	10	6.29E-06
Unrestricted SSR	6.29E-05	9	6.99E-06

LR test summary:

	Value
Restricted LogL	114.6756
Unrestricted LogL	114.6783

Unrestricted Test Equation:
Dependent Variable: LGDP
Method: Least Squares
Date: 10/17/21 Time: 16:34
Sample: 1996 2018
Included observations: 23

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LGDP(-1)	0.609661	1.983802	0.307320	0.7656
LR_D	0.016201	0.074821	0.216529	0.8334
LR_D(-1)	-0.084652	0.285020	-0.297003	0.7732
LR_D(-2)	0.074265	0.231597	0.320664	0.7558
LNOP	0.027276	0.084332	0.323440	0.7538
LNOP(-1)	-0.016720	0.055318	-0.302256	0.7693
LNOP(-2)	0.015363	0.047815	0.321292	0.7553
LLPNAS	-0.278751	0.949649	-0.293530	0.7758
LLPMAN	0.481853	1.494864	0.322339	0.7546
DUMMY	-0.008945	0.030141	-0.296777	0.7734
DUMMY(-1)	0.012374	0.039101	0.316464	0.7589
DUMMY(-2)	-0.014393	0.044246	-0.325305	0.7524
C	1.597037	5.245749	0.304444	0.7677
FITTED^2	0.009994	0.214817	0.046523	0.9639

R-squared	0.999621	Mean dependent var	6.389712
Adjusted R-squared	0.999074	S.D. dependent var	0.086868
S.E. of regression	0.002643	Akaike info criterion	-8.754637
Sum squared resid	6.29E-05	Schwarz criterion	-8.063466
Log likelihood	114.6783	Hannan-Quinn criter.	-8.580809
F-statistic	1827.343	Durbin-Watson stat	2.615124
Prob(F-statistic)	0.000000		