The role of a national system of innovation in facilitating development in South Africa from a comparative BRICS perspective.

A Thesis Submitted in Fulfilment of the Requirements for the

MASTER OF ECONOMICS

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ABSTRACT

The aim of the dissertation was to investigate whether the adoption of a national system of innovation has helped facilitate development in South Africa from a comparative BRICS perspective.

South Africa has an expanding focus on science and technology, as per the Science and Technology White Paper (1996). There appeared to be innovation that had left out much of the citizenry. There continued to be poverty, inequality, and joblessness. The study aimed to understand how the NSI approach could be used to foster inclusive and transformative development.

The study used a mixed-methods approach. The qualitative aspect of the research focused on an innovation and public policy study which assessed the various policies and initiatives implemented in each of the BRICS countries to drive innovation and foster development. The qualitative aspect of the study found that the innovation paradigm required governments to adopt a more holistic approach to public policy design and analysis. The quantitative aspect of the research focused on a trend, correlation, and regression analysis. The trend analysis revealed that China and Brazil increased their allocation of resources towards R&D compared to the other countries. Brazil is regarded as a social investment state, while China is a developmental state: this means the state plays an extraordinarily strong coordinative and financing role in the NSI. On the other hand, the correlation matrix for South Africa revealed a statistically significant positive linear association between various NSI indicators and human development. This suggested that the innovation benefits are trickling down to the general citizenry.

In essence the study articulated key elements of the understanding of current and potential impacts of technological change in productivity and growth, employment and inequality that can be used for policy making.

DECLARATION

Except where explicitly stated otherwise and acknowledged, "The role of a national system of innovation in facilitating development in South Africa from a comparative BRICS perspective" is wholly my own work and has not been submitted to any other University, Technikon or College for degree purposes. All sources I have used or quoted have been indicated and acknowledged by means of complete references.

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ACRONYMS AND ABBREVIATIONS

BIPP	Biotechnology Industry Partnership Programme
BRICS	Brazil, Russia, India, China, and South Africa
DACST	Department of Arts, Culture, Science and Technology (South Africa, pre-2004)
DOE	Department of Education
DST	Department of Science and Technology (South Africa, since 2004)
FUNDEF	National Fund for primary education development for enhancing the value of the teaching profession (Brazil, 20006)
GDP	Gross Domestic Product
GEAR	Growth Employment and Redistribution
HDI	Human Development Index
ICT	Information and Communication Technology
IP	Intellectual Property
IPR	Intellectual Property Rights
KEI	Knowledge Economy Index
MDIC	Ministry of Development Industry and Foreign Trade (Brazil, 2003)
MEC	Minerals-Energy Complex
MED	Ministry of Economic Development
MES	Ministry of Education and Science
NDP	National Development Plan (South Africa)
NGO	Non-governmental organisations
NICs	Newly Industrialised Countries
NKC	National Knowledge Commission
NPC	National Planning Commission (South Africa)
NRDC	National Research Development Cooperation
NRDS	National Research Development Strategy
NRF	National Research Foundation
NSI	National System of Innovation
OECD	Organisation for Economic Cooperation and Development
PDE	Plan for Development of Education
PDP	Policy for Production Development (Brazil, 2006)
PGM	Platinum Group Metal
PITCE	Industrial, Technology and Foreign Trade Policy (Brazil, 2003)
PPF	Production Possibilities Frontier

PPPs	Public-private partnerships
PRS	Public Research System
PURSE	Promotion for University Research and Scientific
R&D	Research and Development
RVC	Russian Venture Capital
S&T	Science and Technology
SI	Systems of Innovation
SME	Small and Medium enterprises
STI	Science Technology and Innovation
STI	Science, Technology, and Innovation
THM	Triple Helix Model
TIA	Technology Innovation Agency
UNDP	United Nations Development Programme
WC	Washington Consensus

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This work would not have been possible without the grace of God. It has been an exceedingly difficult journey filled with trials and tribulations; however, I have come to understand Psalm 138:8, “The Lord shall perfect all that which concerns me”.

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CHAPTER 1: THE NEED FOR A NATIONAL SYSTEM OF INNOVATION

1.1 Rationale for the Research

The national system of innovation (NSI) can be defined as "a network of public and private-sector institutions which act to initiate, modify and diffuse new technologies" (OECD, 1997:10). Niosi (2002) views the NSI as a "set of interrelated institutions; its core is made up of institutions that produce, diffuse and adapt new technical knowledge, be they industrial firms, universities and government agencies. Additionally, Lundvall (2003), as cited in Manzini (2012), states that the elements and relationships interact in the production, diffusion and use of new and economically useful knowledge. The provided definitions show that the NSI concept is relational as it emphasises the importance of connections – the cooperation of different players within the country's NSI. Furthermore, the common themes that emerge are a variety of institutions, interactions, and technological learning. These common themes emphasise the role of the state, where the state plays a facilitating role and/or an entrepreneurial role (Mazzucato, 2016). Likewise, the role of the state is to provide coordination capacity, which is achieved through the nature and idea of embedded autonomy. The idea of the embedded autonomy is pertinent as "it places emphasis on the fact that knowledge is not easily lost as it becomes embedded within the fabric of institutional networks of an innovation system" (Manzini 2012:4).

The analysis of technology and technological change in developing countries was not developed in early mainstream development theory. Before 1960, technology and technological change were treated as exogenous to growth models (Burda and Wypolz, 2013). Technological change was seen to occur because of scientific advancements and "could not be influenced by incentives" (Deraniyagala, 2006:132). However, post 1960's, and during the 1970's, at the peak of the Keynesian era, technological change became viewed as an endogenous process in growth models (Mytelka and Smith, 2001).

The neoclassical approach to technology and development can be used as a point of departure in identifying how the nature of the relationship between technology and development has reformed over time. Deraniyagala (2006) highlights two aspects of the neoclassical approach to technology. The first is the idea of technology being available in the form of a "blueprint" (Deraniyagala, 2006:130). This meant that developing countries simply imported foreign technologies rather than engaging in technological development themselves. The second aspect that Deraniyagala (2006) highlights is that the neoclassical approach assumed that learning was a ‘minimal cost’ and ‘risk-free’ activity. Although this may seem sufficient, it was a narrow perspective. On the other hand, Maharj (2007) purports that technological change refers to improvements in products, services and institutional strategies as required by the user. This suggests that the neoclassical approach was limited as it essentially treated technological progress as exogenous, and there was no exploration of its nature or determinants. There was little disagreement on the importance of technology in growth and development but a considerable difference on how to foster technological progress.

The neoclassical approach to technology addressed demand-side factors and neglected the supply-side aspects of technological change. Ultimately, this led to the introduction of alternative approaches to technology and development. These include endogenous growth theory (Arrow, 1962; Nelson, 1997), new trade and technology theory, imperfect information and technology theory and evolutionary approaches (Freeman, 1994; Nelson and Winter, 1982).

These alternative approaches do not entirely reject the neoclassical approach to technology and development, but they critique and extend it. Alternative approaches to technology place public policy at the centre of the technological change process, unlike the neoclassical perspective that believes in efficient innovation through market forces (Amsden, 1992).

The evolutionary approaches define technology as knowledge with commercial potential (Dosi, 1997; Nelson and Winter, 1982; Stiglitz, 1989). The evolutionary approaches emphasise the importance of capabilities and skills in absorbing and fostering technological progress. They also emphasise the need to understand the process of “learning by doing” (Deraniyagala, 2006; Khan and Blankenburg, 2009). In this process, nations have devised systems of innovation, where public policy is placed at the centre of technology development (Khan and Blankenburg, 2009; Mazzucato, 2011).

Innovation has been an important driver of economic growth and development. Conversely, it has been argued that there have been negative consequences of innovation in the context of developing countries. Kaplinsky et al. (2010) demonstrate that the dominant innovation paradigm based on the rent-seeking firms introduce new products and processes has been exclusive to the poor. Schillo and Robinson (2017) argue that innovation has been a contributor to inequalities, an issue of social and economic exclusion.

Following the Millennium Development Goals (MDGs), which sought to improve the economic and social positions of the poor, there has been an upsurge of interest in pro poor or inclusive innovation for development”. These terms refer to the production and delivery of innovation, solutions to the problems of the poorest and most marginalized societies and communities and income groups. Schroeder *et al*. (2016) define inclusive innovation as “how new goods and services are developed for and by billions living in lower levels of income, whilst also requiring engagement with the poor in the development, adoption and assimilation and innovative solutions for their problems.”. This definition suggests that inclusive innovation combines elements from innovation research with a strong normative element.

Ali and Son (2007) assert that inclusive innovation ensures equal access to the opportunities created for all segments of society, particularly for the poor. Inclusiveness not only depends on the diffusion to the poor, but also their generation according to the principle of participation and equity derived from contemporary theories of global justice (Schroeder *et al,* 2016*)*. These are conditions that directly impact meeting the poor’s basic needs and increasing the capabilities to function. This affirms the notion that the key driver of inclusive innovation is the social-well-being of marginalised populations. Grassroots innovation movements seek an innovation process that is socially inclusive towards local communities regarding the knowledge process and the outcomes it involves. Addressing twenty-first-century developmental challenges require an innovation process and products, which help in reducing and/or eliminating, the gap between the rich and the poor within a society (Papaionnou, 2014).

The NSI approach has been a key area of interest as it has assisted in achieving developmental objectives in various countries (Orelemans and Pretorius, 2006). There have been key debates that have emerged in relation to the national system of innovation being used as a method to achieve developmental objectives.

Khan and Blankley (2009) contend that the major flows of R&D expenditure are found to be within, rather than between, the firms. Therefore, there would need to be restructuring amongst institutions to change the circumstances facing the key players in the national system of innovation. Khan and Blankley (2009) argue that there need to be interactions between higher education and firms. On the other hand, Rooks and Oerlemans (2014) claim that the number of innovation projects are indicators of the effectiveness of flows of different institutions in the South African economy. This notion of the difference in the effectiveness of institutions is in line with the view of Nelson and Nelson (2002), where institutions or social technologies are not the rule of the game that constrain human action but as more or less effective ways to ensure achievement when human cooperation is needed. Furthermore, they claim that the effectiveness of a country's NSI also depends on its macroeconomic environment. Kaplan (2000) supports this view and contends that there are extreme social disparities that must be dealt with to enhance access to infrastructure to allow for the occurrence of inclusive innovation.

Economic policy would need to aim for rapid development of more value addition in various industries that contribute to economic growth and development. To achieve inclusive innovation for development through a national system of innovation, sectors of particular importance to the marginalized populations such as health, education and small-scale agriculture would have to be prioritised in policymaking. Abrahams and Pogue (2012) argue that there are complexities of transitioning to knowledge-based economies in "less-favoured" regions and the implications for policymaking, while at the local level, small enterprises and local innovation systems need to be invigorated and aligned to national policies.

Historically, there are roots of the South African NSI in the Mineral Energy Complex (MEC). The MEC refers to a system of accumulation that had a determining and retarding effect on South African industrialisation (Fine and Rustomjee, 1999). The MEC has fostered a non-inclusive innovation system. This has provided background to the problems of non-inclusivity and the need to use the NSI in a transformative effect. South Africa has adopted the NSI framework as a national policy (DST, 2008; DST, 2002). South Africa was the first developing country to adopt the national system of innovation. This is set out in the 1996 White Paper on Science and Technology (DASCT, 1996). According to the DASCT (1996), the White paper's core vision is to conceptualise a national system of innovation, which seeks to harness the diverse aspects of science and technology through the various institutions where they can be developed, practised, and utilised. There is a need to interrogate the role of a national system of innovation in the achievement of South Africa's developmental objectives. The current S&T framework has been framed with an inclusive agenda in mind. The National Development Plan (National Planning Commissions, 2012: ii) sets out the intention to transform South Africa to be a "capable" state with the country becoming a knowledge-based economy. The idea is to use technology development as a source of growth and higher productivity and ultimately reduce unemployment, poverty, and inequality. Ultimately, the NSI provides the recognition of the economic importance of knowledge, thus increasing the use of systems approach in the growing number of institutions in knowledge generation.

1.2 Objectives of the Research

The research adopts a post-positivist approach within a political economy framework, which is augmented and bolstered by a comparative case study approach. The post-positive paradigm is concerned with the subjectivity of reality and moves away from the purely objective stance adopted by logical positivists (Ryan, 2006). The political economy perspective allows for an approach to technology and development while considering their implications for economic growth and sustainable development at the same time. The main goal of this research is to investigate whether the adoption of the national system of innovation in policy has facilitated development in South Africa, drawing from the comparative experience of the BRIC countries. To achieve this goal, the study provides an examination of the NSI and why it is the most useful conceptual tool in analyzing technological development. The study then examines policies followed by South Africa in comparison with other BRIC countries in developing the South African NSI. Finally, the study investigates whether technology development by means of an NSI has facilitated economic development over the past twenty-three years in South Africa.

1.3 Outline of Chapters

Chapter 2 reviews the neoclassical theory of innovation and its extensions. Section 2.2 presents the distinction between the narrow definition and the broad definition of technological change. Section 2.3 introduces the concept of the neoclassical approach to technology and development. The concept of the blueprint notion is introduced in this section of the chapter. The blueprint notion is significant as it is the foundation of the neoclassical approach theory. Section 2.4 evaluates the alternative approaches to technology and development, which are extensions to the neoclassical approach of innovation. These extensions to the neoclassical approach of innovation include endogenous growth theory, new trade theory and technology, imperfect information and technology, trade theory and evolutionary approaches to technology and development.

The evolutionary approaches to technology and development are explained in detail as two distinct evolutionary models of innovation are reviewed. These models are the "Sobato Triangle" and the "Triple Helix Model of Innovation". These models are significant as they lay the foundation of interactions and institutions, which become the core fundamentals of the National System of Innovation (NSI). Section 2.5 provides a comparative synthesis of the innovation school of thoughts. This comparative synthesis highlights the broad claims of each, taking into account the implications for technology and development in public policy whilst providing a critique and stressing various limitations for each school of thought. Section 2.6 analyses other alternatives to the analysis of technology and development, which go beyond the neoclassical approach. Section 2.7 assesses the role of the state in influencing technological change.

Chapter 3 aims to shed light on the National Systems of Innovation (NSI). Section 3.2 provides a comprehensive overview of the system of innovation approach. This approach bases explanations of the evolutionary patterns on the decisions and the actions of actors in relation to institutional rules, which become the foundation of the National Systems of Innovation. Section 3.3 develops the concept of the NSI. This section provides an in-depth analysis and exploration of the elements of the NSI, whilst providing a critique of the NSI. Section 3.4 provides the idea of inclusive innovation for a development agenda. Section 3.5 addresses the concept of the fourth industrial revolution, as well as the advantages and disadvantages of the fourth industrial revolution.

Chapter 4 evaluates the evolution of the NSIs within the BRICS bloc. The analysis of the evolution of the NSI drew from literature, such as the edited series by Lastres and Scerri (2013) and various other sources. Section 4.2 provides an in-depth review of the adoption of the NSI framework within the BRICS bloc. The objective of this section is to identify the implicit and explicit state policies on science and technology, which have contributed to the formation of the NSI. The review of the adoption of the NSI framework then provides a direct linkage of the theoretical elements mentioned in Chapter's two and three. Section 4.3 reflects on policy prescriptions and other initiatives that the BRICS economies have taken to assess how technology has been a source of growth and higher productivity and ultimately reduce inequality, unemployment, and poverty within the BRICS context.

Chapter 5 provides a comprehensive review of the data collection methods employed in the analysis of whether a national system of innovation can assist in facilitating development in South Africa from a comparative BRICS perspective. Furthermore, this chapter outlines and justifies the quantitative and qualitative methods employed throughout the study. Section 5.2 outlines the different forms of data analysis, which are applied throughout the study. Section

5.3 elaborates on the data collection methods in the research. To conclude, section 5.4 emphasises the ethical considerations that were considered undertaking the research.

Chapter 6 examines traditional performance indicators which investigate whether technology development by the means of an NSI has facilitated development over the past twenty three years. Section 6.2 provides a trend analysis that assesses the trend which emerges through policy consideration and intervention. This graphical trend analysis is two-fold, as it is done from a comparative BRICS perspective using aggregated data and from a South African country-specific context, using disaggregated data. Section 6.3 focuses on a correlation analysis for South Africa, which considers the linear relationship of two-variables. The purpose of the correlation analysis is to assess the interaction dynamism in the NSI, whilst evaluating the links between innovation and development. Section 6.4 included the regression analysis which consisted of the bounds test for cointegration and the Parsimonius ARDL regression models.

Chapter 7 concludes by providing an overview of the research. Section 7.2 provides the theoretical framework that was used in the literature review, whilst considering the empirical evidence that the BRICS countries have provided to investigate whether the adoption of a national system of innovation has helped to facilitate development in South Africa, doing so from a comparative BRICS perspective. Section 7.3 provides lessons and policy recommendations for South Africa's NSI.

CHAPTER 2: TECHNOLOGICAL CHANGE, INNOVATION AND BEYOND

2.1 Introduction

The purpose of this chapter is to review the earlier theories of innovation before the NSI was postulated. Section 2.2 presents the distinction between the narrow definition and the broad definition of technological change. Section 2.3 introduces the neoclassical approach to technology and development. Section 2.4 evaluates the alternative approaches to technology and development, which are extensions to the neoclassical approach of innovation. These extensions to the neoclassical approach of innovation include endogenous growth theory, new trade theory and technology, imperfect information and technology, trade theory and evolutionary approaches to technology and development.

The evolutionary approaches to technology and development – the Sobato Triangle and the Triple Helix Model of Innovation are reviewed. These models are significant as they lay the foundation of interactions and institutions, which become the core fundamentals of the National System of Innovation (NSI). Section 2.5 provides a comparative analysis of the different schools of thought, stressing the core arguments and the implications for technology and development. Section 2.6 assesses the role of the state in influencing technological change. Eventually, this chapter aims to provide broader claims for each school of thought and highlights the implications for technology and development policy whilst providing critique.

2.2 Technological change defined.

In early mainstream literature, the analysis of innovation and technological change in developing countries was not well developed. Deraniyagala (2006:123-124) postulates that there are two definitions of technological change. The first definition provides a narrow perspective of the term 'technological change'. This definition of technological change refers to the notion that technological change was seen as the "invention and innovation at the global technology frontier" (Deraniyagala, 2006:123-124). The narrow definition of technological change implied that it was largely absent in developing economies.

The second definition, which is a much broader definition, portrays technological change as the "creation or absorption" of new products and processes (Deraniyagala, 2006:123-124). This definition asserts that the distinction between innovation and diffusion as more blurred. Diffusion refers to the "process by which innovation is communicated over time among the participants of a social system" (Rodgers, 2003:3). This means that the concept of diffusion seeks to explain the rate of new ideas and technology spread. Rodgers (2003) takes this further by explaining that there are four elements that influence the "spread of new ideas." These elements include innovation itself, communication channels, time, and the social system. Added to this, the neoclassical perspective of diffusion becomes relevant as it explains that follower economies share by imitation in the technological advances by leading-edge economies as imitation seems to be cheaper than innovation.

2.3 Neoclassical Approach to technology and development

Technological change was conceptualised as exogenous in neoclassical theory. This idea proposed that technology was made up of clearly defined techniques and products, and information on technology was easily and readily available to all users in the form of a blueprint (Deraniyagala, 2006). Nelson and Winter (1982:60) stated, "Technological knowledge often is identified with a book of blueprints or the knowledge of engineers and scientists". The latter is at least consistent with the view that specific operational knowledge exists in the context of theoretical understanding while the "blueprint" metaphor suggests that the knowledge is unitised, organised in packages labelled "all you need to know about X".

In the standard treatment, the production set is simply taken as given. The issues of its change over time are not considered. The question of whether different firms have different production sets is not treated in a uniform way in orthodox models, but neither is it much discussed. In general, it appears that the most natural assumption within the orthodox framework is that all firms' production sets are identical, and therefore, the blueprint is a matter of public information.

By assuming that technology was readily available, could be readily and costlessly copied and transplantable, neoclassical theory did not explore the characteristics of knowledge. In essence, technical progress was directed by its correspondence to the neoclassical theory of supply in terms of a shifting production function. This guided the assumption that the blueprint notion contained all the information required for the adoption and utilisation of given technology; hence the process of assimilating knowledge was assumed to be relatively easy. This implied that developing countries faced limited costs when introducing new technologies. Instead, it was assumed that the costs involved in learning to use technology efficiently were minimal or non-existent.

The blueprint neglected the supply-side factors of technological change. The supply-side factors include the availability of skills, capabilities, institutions, and infrastructure. Although the blueprint notion has been key to understanding technology, it is important to recognise that in many fields, it takes a highly trained professional to make sense of the blueprint.

Solow (1957), as cited in Burda and Wypolsz (2013), introduced the idea that technological progress was a "residual" in the production function. It was the residual growth that caused the shift in the production possibilities frontier (PPF).

Furthermore, the neoclassical growth theory explains how the "capital accumulation and technological changes affect the economy" (Popa, 2014:26). There are a number of characteristics that feature in the theory which include:

a) Perfect competition on the market of goods and production factors
b) Taking into account consideration of two factors , the labour force and capital
c) The yields are constant throughout the factors
d) The growth of economic rate correlated with the population rate

Solow(1957) argued that the production level depended on both the quantity and on the factors of productivity- the labour and the capital – he incorporated a third factor – the technical progress , whose role was considered exogenous. Masoud (2013) argues that the neoclassical growth theory is simply a general equilibrium model that emphasises the process , which leads the economy to a steady-state crucial role in ensuring convergence such as steady-state , the productivity of capital is zero, the capital labour ratio is fixed and the growth generated endogenous factors such as capital accumulation , are zero as well.

Aghion and Howitt (1998) make the claim that the neoclassical model is in the form $Y=F(K,L)$ where

Y= the production

K=the amount of capital

L=the amount of labour force

Function allows explaining extensive growth depending on:

The capital increase by investment in capacity

The workforce growth by demographic effect

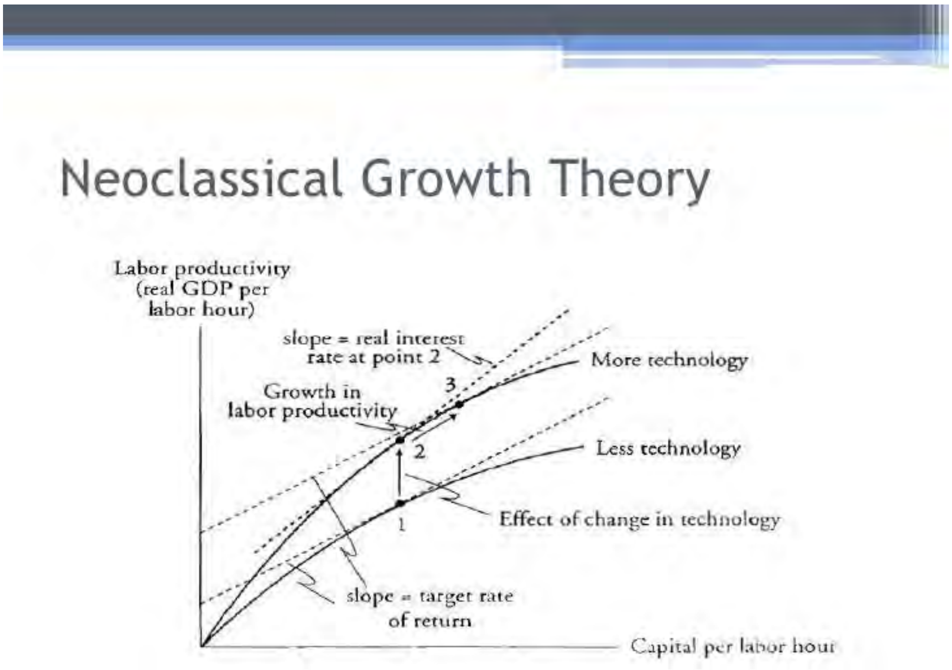
Starting from the function: $Y=F(K,L)$, it is considered :

1. On a constant offer of workforce , the production function shall be expressed as a function of capital Y=F(K) and shows the volume of output Y produced with a given stock of aggregate capital, K at the given level of knowledge
2. Characteristics for the accumulation of capital ; the revenues are decreasing – the marginal product of capital is decreasing (in the capital stock); the growth can be generated only by the capital increase
3. Equation of the neoclassical theory highlights how the rate of the capital stock changes at any time is determined by the volume of the existing capital at that time

$K=sF(K)-\delta K$ where:
s-constant saving of population
in the absence of population growth and of technological changes , the economic growth is limited due to capital decreases.
Capital stock reach the stationary level $Y^*=F(K)$- the rate of output growth ceases the economic growth if of temporary nature
Aggregate output stream depends on the capital and labour force , in the scale production function Y=F(K,L), the output per person is y= Y/L and depends on the stock of capital per person k=K/

Froyen (2009) elaborates on this further by explaining that the concept of the steady-state expresses the idea that all variables are growing at a constant rate, whilst the growth rate of income and income per head is constant with the population growing at a constant, proportionate rate, while the rate of technology is not changing. Therefore, the saving rate and the rate of investment in both physical and human capital will affect the growth for a considerable period and furthermore, would influence the steady-state capital/labour and capital/output ratios

Figure 2.1 The neoclassical growth model



Source: Mativachranon (2010)

Figure 2.1 depicts the shift of the production function from point 1 to point 2 or at any other point on the curves. This is the effect of the change in technology. The effect of the change in capital causes a growth in labour productivity which is apparent from point 2 to point 3.

The neoclassical perspective has significant limitations. This perspective deals with demand-side factors and neglects the supply-side factors of technological change (Deraniyagala, 2006). Fundamentally, the neoclassical approach assumes that firms face well-behaved production functions, where all technological options or alternatives are known. In addition, it was assumed that these options or alternatives could be accessed at no cost. The choice of any particular technology is the result of the optimizing behaviour of firms that bid to allocate resources on the basis of the capital-labour cost (Solow, 1957).

The neoclassical approach limits state intervention into 'correcting' market imperfections, which would fix the market for technology. The neoclassical approach confined the role of government to correcting the market failures and distortions. Contrary to this, alternative approaches see the prospects of dynamic technological change as necessitating explicitly and not merely fixing market failures (Deraniyagala, 2006:132). Unfortunately, the neoclassical theory does not assign provision on institutions such as patents and intellectual property rights (IPRs).

2.3 Extensions to the basic Neoclassical Approach

2.3.1 Endogenous Growth Theory

Endogenous growth theory represents an extension of the neoclassical approach to technology and development. It addresses some of the shortcomings of the neoclassical growth model. Nelson (1995) argues that the endogenous growth model aims to delve deeper into the aspects that have been repressed in standard growth theory. Endogenous growth theory does not argue that the neoclassical growth theory is incorrect; it simply suggests that the theory is incomplete. The neoclassical theory applies deductive logic to a set of assumptions about consumer behaviour and technology production. The theory of endogenous growth overtly introduced investments in technological development as a determinant of long-run economic growth (Romer, 1990). The endogenous growth theory conceptualizes technology as knowledge. Cortright (2001) explains that the endogenous theory of growth internalized technology into a model of how markets function. Deraniyagala (2006) emphasises the fact that the endogenous growth model highlights the contribution to the growth of a range of technology investments, such as investments in research and development (R&D) and human capital.

The endogenous growth theory views technological progress as a product of economic activity. The endogenous growth theory directed attention to the role of ideas and human capital as key aspects of growth. The emphasis on human capital fits well with the capabilities approach (Evans 2010; Sen, 1999). This is because the human brain is the host of an existing stock of productive ideas, as it is the main interface between ideas and the implementation and source of these new ideas. Cortright (2001:2) suggests that the essential point of the endogenous growth theory is that knowledge drives growth as ideas can be infinitely shared and reused. This is favourable as knowledge is not subject to diminishing returns. In other words, within the endogenous growth theory, technology exhibits increasing returns, which drive the process of growth (Cortright, 2001:4; Kurz and Salvadori, 2010).

To that extent, the endogenous growth theory elaborates on the point that economic processes create and diffuse knowledge, which are significant in shaping the growth of nations, communities, and individual firms. However, one must be critical of the endogenous growth model. Although it emphasises the contribution of endogenous technology investments to long-run economic growth, this model does not extend the understanding of the process of technology generation and the determinants of technological change. This focuses on primarily the process of diffusion and interactions. The endogenous growth model does not explain conditional convergence reported in empirical literature. Another concern is that it has a cornerstone assumption of increasing returns to knowledge. Krugman (1994) claim that the endogenous growth model involves making assumptions about how unmeasurable things affected other measurable things.

The Endogenous growth theory maintains that economic growth is predominantly the result of internal forces to nations rather than external ones. If investment in new technologies exhibit increasing returns to scale or there are significant externalities that are not captured by the firms that make the investments, this provides the rationale for government support for such investments.

2.3.2 New Trade Theory and Technology

The new trade theory focuses on knowledge and technology spillovers as key mechanisms that link international trade and growth in the new theories of trade. Grossman and Helpman (1991) emphasize how international trade can boost a country's R&D sector by transmitting technological information, increasing competition, and expanding the size of the market. Coe et al. (1994) explain that these trade models emphasize the positive effects of openness by focusing on the role of capital goods' imports in promoting economic growth. In these specific trade models, technology spill overs tend to be generally proportional to capital goods' imports. The significant aspect is that these models are dependent on specific assumptions about the nature of technology in relation to technology transfer. These can be reversed when the definition of technology is refined (Deraniyagala, 2006).

Wangwe (1993) argues that the main contributions of new trade theories are basically in the recognition that economies of scale and the associated market structures and differences in technological capabilities matter and are important. New trade theories emphasise the stage towards technological development and innovations in the analysis of trade issues. New trade theory is also criticized in terms of political economy issues: the potential for foreign retaliation, inefficient government intervention, special interests, capture of policy, the problem of moral hazard, and possibly inimical redistributive effects. The implications of the new trade theory for technology and development policy are that countries should subsidise imports of capital goods. This suggests that countries should evaluate trade at the level of the firm implies that overcoming firm-level fixed costs of trade and reducing uncertainty lead to increased trade along margins that generate the highest productivity, innovation and welfare gains.

2.3.3 Imperfect Information and technology

The main argument of imperfect information and technology is that the existence of market imperfections have significant implications for the analysis of development. Greenwald and Stiglitz (1986) state that, within this approach, information is always imperfect, and markets are always incomplete. If left to the market, the existence of imperfect information is likely to result in "underinvestment in technology development" (Deraniyagala, 2006:134). Informational asymmetries can give rise to finance constraints in the credit market which could in turn result in under investment in technology development .

The micro-foundations relating to information and markets can also be used to understand the process of industrialization. Technological change is central to the industrialization process. The process of industrialization involves the continuous acquiring and managing of new knowledge whilst overcoming market failures in relation to asymmetric information, technological spill overs and the public good properties of knowledge. Although informational economics has provided the theoretical micro-foundations for placing technology development at the centre of industrialization, several problems remain in terms of the way technology is conceptualised (Deraniyagala, 2001; 2006). The market approach still assumes that correction of imperfections would bring desired outcomes in the market for technology.

2.3.4 Evolutionary Approaches to Technology

Evolutionary approaches to technology refer to "complex interactions linking potential users with new developments in science and technology" (Freeman, 1994:480). Evolutionary approaches have defined technology as knowledge. These evolutionary approaches posit that 'learning' (the acquisition of capabilities) is highly specific to individual agents (such as manufacturing firms).

Fundamentally, evolutionary approaches query that technological knowledge is well-defined and available in the form of a blueprint. Evolutionary approaches view knowledge as fuzzy and tacit as knowledge cannot be easily transmitted or communicated. The evolutionary perspective suggests that even if technology can be seen in the form of a blueprint, certain expertise is required to interpret and apply the engineering principles to a real-life situation. Only a portion of the technology is codified in the form of basic principles, and the other portion is tacit or unwritten as the other skills take time to 'learn'. This ultimately means that the innovative actions of economic agents are "seen as being highly dependent on the capabilities and skills necessary to absorb technological knowledge" (Deraniyagala, 2006:132).

In the evolutionary approaches to technology, technological change is determined by the interaction of demand and supply factors whilst emphasizing 'learning-by-doing' and capabilities development. Evolutionary approaches reinforce the variety of learning processes. This is done through making use of knowledge and the problem-solving capabilities that various firms embody in different degrees. The evolutionary perspective concentrates on how a new firm needs to master the operational know-how of simpler technologies. This is done through the process of learning. More complex skills need to be learned at a later stage where the adaption and improvement of technology can occur.

As discussed, technological diffusion is defined widely as the process by which the market for a new technology changes over time from which production and usage patterns of new products and processes result. Similarly, this process of learning is interlinked with the evolutionary perspective of diffusion. The evolutionary perspective of diffusion focuses on how innovations must be modified. The suppliers and users of innovation need to work together as new knowledge is expensive to generate, yet cheap to imitate. Evolutionary models aim to understand the processes in and by which knowledge is produced, diffused, and economically exploited (Nelson and Winter, 1982). Learning costs differ between activities and interventions in order to ensure efficient resource allocation are selective rather than uniform.

Evolutionary approaches refer to the capabilities of not only individuals, but of firms as well. In evolutionary approaches, technological change is determined by the interaction of a variety of factors, including scientific opportunities, inducements, and supply-capabilities. These approaches consider supply-side issues; however, they distinctly consider the routine within organisations and how the routine is shared.

Social Darwinism (Gough *et al,* 2006) has become the epistemological apparatus for all evolutionary theories. These evolutionary approaches use Darwin's concept of natural selection and consider that there are:

1. I=Interactors (firms and organisations).
2. Replicators (i.e., the carriers of social DNA [routines, customs, practices]).

3. Units of selection are the replicators, interactors, and institutions, which are the mechanism of natural selection which is the mechanism by which these various units (replicators, interactors, and institutions) are selected; and
4. The process of interaction (diffusion) determines the survival or extinction of these routines (Gough *et al.,* 2006:3).

Firms have learning routines that are cumulative in the sense that learning in one period impacts learning in the other period. Eventually, these learning routines determine the pace and pattern of technological change at the firm level.

Nelson and Winter (1974:891) claim that "the major commitment of evolutionary theory is the behavioural approach to individual firms". The behavioural premise, which is the core of evolutionary theories, focused on how the firm at any point operates largely according to a set of decision rules that link the domain of environmental stimuli to a range of responses on the part of the firm. On the other hand, neoclassical economics would attempt to deduce these decision rules from maximization. Ruttan (1997), as cited in Dosi (1997), argues that the evolutionary perspective, broadly defined, can easily accommodate both inducement effects and path-dependent patterns of change. Nelson (1997) describes neoclassical economics as being disinterested in the firm, suggesting that it is a puppet that dances to the tune that is being played by the market.

Evolutionary approaches also stress the role of institutions. Koress (2013) postulates that the narrow definition of institutions refers to private, semi-private, and public organisations. These institutions include government, firms, markets, social norms, and attitudes which are essential in determining how systems for producing and the combinations of artefacts emerge and function. Alternatively, a broader definition of the term 'institution' can be applied in the context of evolutionary theories. This broad definition of the term 'institution' refers to a "relatively stable set[s] of mutually agreed rules and norms which are being created and reproduced by people, while they also once in place, govern social life" (Gronning, 2008:3). These institutions include laws, social conventions, contracts, and traditions.

a. Evolutionary Models of Innovation

Sobato's triangle

Sobato (1968) introduced the triangle of three interlocking hypotheses that formed a triangular relationship which was used as a science and technology strategy to overcome Latin America's underdevelopment issues (Leydesdorff and Etzkowitz, 1998). This model was concerned with the linkages between science, industry, and government. The hypotheses focused on the idea of inserting science and technology (S&T) into the development process. The purpose of the insertion of S&T was to identify 'how' and 'where" 'to innovate (Leydesdorff and Etzkowitz, 1998; Salazar, 2010). In the evolutionary perspective, innovation is understood as an "incorporation of knowledge" which is directed towards generating or changing the production process. Sobato (1968) suggested that for development to occur, it is necessary to construct an S&T infrastructure linked to the productive structure of society (Etzkowitz *et al.,* 2004). This process involved the multiple and coordinated actions of three vertices of society (Etzkowitz *et al*., 2004), these being: government (g), the production structure (e) (which included private and government-owned companies) and the science and technology infrastructure (z) (which, included universities and private research and development centres). This concept of science-based development was premised upon the government initiating a process of strong interrelations among the three players.

The triangle occurred through commands circulating down from the top vertex (g) to the vertices at the base of the triangle "e" and "z" and horizontally between the two vertices. Nevertheless, horizontal interactions were difficult to establish. This idea of multiple and coordinated interactions were developed further into what was termed the *Triple Helix Model.* The *Sobato triangle* can be criticised for limiting all interactions to government coordination as it assumes no market (horizontal) interactions. The *Sobato triangle* implications for technology and development policy are that the government would facilitate and coordinate the interaction between the three vertices of society by providing funding or financing to these different vertices to drive innovation.

Triple Helix Model

Freeman and Perez (1988) introduced the *Triple Helix Model* (THM) of innovation which was a further development of the technology economic paradigm. The THM was based on the expectation of the university playing an active role in society. It took a proactive stance in putting knowledge to use and creating new knowledge (Leydesdorff and Etzkowitz, 1998).

This model was developed as a conceptual framework that reflected the reality of the developed countries where the concept of innovation had been associated with science-based industries and R&D activities. This meant that the THM focused more on the interactive aspects of innovation as opposed to the linear model of innovation suggested by the neoclassical approach to innovation. The THM involved the interaction links between government agencies, business, and industry (Freeman and Perez, 1988; Leydesdorff, 2009; Smith and Leydesdorff, 2000).

The THM is currently being used as a policy framework in both developed and developing countries in an attempt to strengthen their national and regional economies through learning and innovation (Leyerdesdorf, 2009). The THM suggests that university-industry-government interaction is fundamental to improving the conditions for innovation in a knowledge-based society. It argues that individual players are ineffective by themselves (Hohmann, 2016). Industry is viewed as a member of the triple helix model as it is the locus of production. Additionally, government is viewed as the source of contractual relations that guarantee stable interactions. In exchange, the university would, therefore, be the source of new knowledge and technology and the generative basis of the knowledge-based economy (Leydesdorf 2009; Leydesdorf and Etzokowitz, 1998).

The THM is a model that is underpinned by strong interactions between key actors in the form of government institutes, business organisations and teaching and research institutions. This evolutionary model of innovation is influenced by the formation of networks, collaborations, and alliances, leading to greater integration within and between the institutions.

Leydesdorf and Etzkowitz (1998) support this by emphasising the idea of rapid learning that occurs in the THM through proximity and collaborations between the main actors. This model explains the formation and the consolidation of learning societies deeply rooted in the knowledge production and dissemination of knowledge with a well-articulated relationship between university, industry, and government. The triple helix model can be used as an *ex-ante* concept which is a strategic tool for the catch-up process, which ultimately played the role of creating a learning society.

Jacobs and Mazzucato (2016:102) deduce that evolutionary theories have the following key features:

1. They are collective interactions, which are characterised by a system of heterogeneous public and private sectors interacting in different ways;
2. Uncertainty, with potentially unpredictable outcomes which are unknown;
3. They are based on routines which are difficult to emulate even when patents expire, as routines are tacit and embedded in organisational practices and memories; and
4. They are path-dependent and with fat-tailed distribution, which suggests that mean innovation occurs in clusters and waves.

In essence, evolutionary theories are dynamic. They seek to explain why something exists, which intimately rests on how it becomes what it is. Dosi (1997) reinforces this by asserting that evolutionary theories need to be consistent with the behaviour of agents, consequently explaining what agents do and why they do it. Lastres and Scerri (2013:2) add to this by explaining that evolutionary economics looks at the role of the state as a shaper and mobiliser of systems. Evolutionary economic theory and institutional economics are complementary theories capable of dealing with socio-economic issues that are not handled by conventional neoclassical economics. These theories lay the foundation of the National Systems of Innovation (NSI). Like the *Sobato Triangle*, the implications of the THM for technology and development policy is that government would facilitate and coordinate the interaction between the three vertices of society, by means of providing funding or financing to these different vertices to drive innovation. However, this would not occur in isolation- it would require the role of the university, which would play a significant role in the consolidation of learning societies deeply rooted in the knowledge production and dissemination of knowledge.

2.4 Comparative Synthesis of theories of technology development

The point of departure for technology and development policy was the neoclassical approach. The neoclassical approach was based on the premise that technology was made up of clearly defined techniques, products and information on technology was easily available in the form of a blueprint (Deraniyagala, 2006). The neoclassical approach did not have implications for public policy as it was apparent that it did not assign provision on institutions such as patents and intellectual property rights. Alternatively, the endogenous growth theory represented an extension of the neoclassical approach as it remained limited. The endogenous growth theory aimed to address some of the shortcomings of the neoclassical approach. The endogenous growth conceptualised technology as knowledge. Ultimately, it highlighted the contribution to the growth of a range of technology investments in research and development and human capital. The implications of the endogenous growth theory for technology and development policy were that countries should invest in human capital, research, and development (R&D) and institutions such as IPRS.

Like the endogenous growth theory, the new trade theory conceptualised technology as knowledge. However, it argued that spill-overs were key mechanisms that linked international trade and growth in the new trade theories. This school of thought emphasised the stage towards technological development and innovations in the analysis of trade issues. The implications of the new trade theory for technology and development policy were that countries should subsidise imports for capital goods. On the other hand, the main argument of the imperfection information and technology is the existence of market imperfections need to be centred as they have significant implications for the analysis of development. Consistent with the new trade theory, the implications of the imperfect information and technology theory to technology and development policy are that countries should consider the industrialisation of different sectors in the promotion of development. Evolutionary approaches argue for "complex interactions linking potential users with new development in science and technology" (Freeman 1994; 480). Analogous to the endogenous growth theory, the evolutionary approaches have defined technology as knowledge. These evolutionary approaches posit that 'learning' (the acquisition of capabilities) is highly specific to individual agents (such as manufacturing firms). Ultimately, evolutionary approaches aim to accentuate the role of institutions. Jointly the implications for public policy of the Sobato triangle and the Triple Helix Model (THM) advocate for the role of the state to facilitate and coordinate the interaction between the different actors and vertices of society, by means of providing funding or financing to drive innovation and improve development which lay the basis of the National System of Innovation (NSI).

2.5 Technology and Development: Beyond the Neoclassical Approach

The National System of Innovation (NSI) Concept

The concept of the national system of innovation (NSI) has been developed by writers within the evolutionary approaches to innovation. The THM model, unfortunately, does not account for the notion of the embedded autonomy. The embedded autonomy places emphasis on the fact that knowledge is not easily lost as it becomes embedded within the fabric of institutional networks of an innovation system. The embedded autonomy concept provides the underlying structural basis for successful state involvement in industrial transformation (Evans 1995, 12). Although the THM may resemble aspects of the NSI, it is significant to understand that the

NSI puts into practice context the notion of embedded autonomy. The NSI concept refers to "a network of public and private sector institutions which act to initiate, modify and diffuse new technologies" (Lundvall, 1997). Nelson (1993) describes the NSI as a set of institutions whose interactions determine the innovative performance of national firms. The functions of the NSI include the creation of knowledge, to guide existing knowledge, the supply of capital and skills, the facilitation and creation of positive externalities and finally the facilitation and formation of markets. There are various actors within the NSI. These actors are namely, government, scientific research institutions, universities, training centres and private firms (Deraniyagala, 2006). There is a recognition of the existence and role of informal networks within and outside the defined national, sub-national, sectoral, regional, and local innovations system (Mazzucato, 2011). The NSI framework contrasts with the orthodox neoclassical approaches, as the NSI framework assigns a central role for the state. The concept of the NSI shall be discussed in greater detail in Chapter 3.

2.6 The role of the state in influencing technological change.

2.6.1 Orthodox Approaches to Technology Policy

Deraniyagala (2006:137) explains that the Washington Consensus (WC) has been the dominant policy approach from the early 1980s, specifically within the area of technology policy. The WC was based on the neoliberal premise that well-functioning markets can achieve efficient and optimal resource allocation in all sectors. With regards to the WC approach, state interventions were distortionary except in the provision of a limited number of public goods. The main task of the WC approach was viewed as the creation of freely functioning factor and product markets. Although the WC is viewed as a dominant approach, it is known to have paid little attention to the analysis of technology policy. The approach assumed that both technology development and industrial policy were best undertaken by creating a correct set of incentives and through promoting cost efficiency and price regulation. Essentially, this approach left little room for active industrial policy. However, there are shortcomings to this approach. It assumes that the market will facilitate the distribution of knowledge as technology is coded in the equipment that is imported. It does not consider the skills and dispositions that are embedded in individuals that allow for the transfer of knowledge. It argued that industrial policy reform should focus on removing 'policy-induced' distortions arising from state intervention, the removal of entry and exit restrictions on private enterprise, and the removal of price controls, discretionary taxes, and subsidies (Frischtak, 1989). The issue concerning industrial policy was the view that it distorted market-based resource allocation.

The WC approach to industrial policy assumed that technology generation in developing countries would take place solely in response to the creation of a correct set of incentives. This approach did not really consider the complex nature of technological change and the supply-side factors that generate it. The WC did not recognize the specific characteristics of technology which are highlighted by the evolutionary approach. It explicitly ignores the tacit and imperfect nature of technological knowledge, which focuses on the condition of the response of economic agents to price incentives. This is innovation in the sense of knowledge. Innovations are patentable and can be classified as excludable goods for a limited period. The evolutionary approaches pay attention to these supply-side factors, which are ignored by the WC approach.

2.6.2 Alternative Approaches to Technology Policy

The alternative approaches critique the WC approach to technology policy on both theoretical and empirical grounds. Information theories, evolutionary theories and development literature provide a variety of theoretical arguments as to how the resource allocation in technological investment may not be optimal if left to the market alone (Deraniyagala, 2006:138). These theories question the simplistic notion of technology as a blueprint. The tacit and imperfect nature of technological knowledge, informational asymmetries, weak or non-existent markets for technology and the limitations of a technology strategy relies on the market mechanism alone (Deraniyagala, 2006:139). As opposed to the WC approach, the alternative approaches argue for a much greater role of the state in technology development. Three key policy interventions are proposed and seen as complementary as they interact with each other to promote technological dynamism. These key policy interventions are industrial policy, trade policy and the national system of innovation.

2.6.3 Industrial Policy

The alternative approaches to innovation suggest that rapid technology development in developing countries is unlikely to occur in the absence of interventionist industrial policy (Kim, 2009). Industrial Policy consists of sector- and industry-specific policies that aim to direct industrialisation in line with some definition of national interest. This industrialisation achieves rapid productivity growth by absorbing and learning to use the best technologies. The existence of informational imperfections is seen as necessitating interventions to create relevant institutions and infrastructure, especially in relation to the provision of information and knowledge (Stiglitz, 1998). Lall (2003) suggests that positive technological externalities and spillover effects justify 'selective' industrial policies to identify and promote specific sectors where such externalities are frequent. Wade (2003) and Chang (2002) support this by suggesting that contrary to orthodox interpretations, the manufacturing success of the East Asian economies was partly a result of highly interventionist, strategic industrial policy. Furthermore, the industrial policies in these countries were shown to have promoted technology generation by identifying dynamic sectors and providing incentives and resources for investment within these sectors. This selective industrial policy is seen as instrumental in creating 'technological winners' in sectors that demonstrate high levels of competitiveness in international markets.

2.6.4 Trade Policy

Alternative approaches to innovation interrogate the neoliberal stance that open trade policies are adequate to induce technological dynamism. Deraniyagala and Fine (2001) argued that openness leads to increased competition which induces cost-cutting technological change across all sectors, which a theoretically fragile and not empirically robust. Furthermore, it has been argued that trade liberalisation rarely leads to the costless flow of technological information for developing economies. The tacit and specific nature of technological knowledge may somewhat prevent this.

Essentially, alternative approaches provide arguments supporting infant industry protection for technology development. It argues that technology is central to ensuring infant industries mature. There is an effective selection of strategic sectors for trade protection in terms of technological criteria.

2.7. Conclusion

The chapter reviewed the neoclassical theory of innovation and its extensions. It explored the distinction between the narrow and broad definitions of technological change. Furthermore, the concept of the blueprint notion was outlined, which became the foundation of the neoclassical approach to technology and development. Although limited, the blueprint notion became useful as a point of departure in the analysis of technology and development. The chapter found that the neoclassical approach did not have implications for public policy as it was apparent that it did not assign provision on institutions such as patents and intellectual property rights. The chapter then evaluated the alternative approaches to technology and development, which go beyond the neoclassical approach. These approaches included: endogenous growth theory, new trade theory and technology, imperfect information and technology, and evolutionary approaches to technology which laid the foundation of a national system of innovation. A common theme emerged amongst these approaches: the concept of "knowledge" and how it can be diffused.

Furthermore, the approaches critiqued the WC approach to technology on both theoretical and empirical grounds. These theories questioned the simplistic notion of technology as a blueprint. They argued for a much greater role of the state in technology development. These policy interventions were industrial policy and trade policy. Ultimately, the chapter then reviewed the evolutionary approaches with a specific focus on; the Sobato Triangle and the Triple Helix Model of Innovation, which laid the foundation for the concept of a national system of innovation. These theories focused on the linkages between science, industry, and government. These evolutionary approaches aimed to accentuate the role of institutions. Jointly the implications for public policy of the Sobato Triangle and the Triple Helix Model (THM) advocate for the role of the state to facilitate and coordinate the interaction between the different actors and vertices of society by means of providing funding or financing to drive innovation and improve development which lay the basis of the National System of Innovation (NSI). To conclude, two key policy interventions were proposed and seen as complementary as they interact with each other to promote technological dynamism.

CHAPTER 3: NATIONAL SYSTEM OF INNOVATION THEORY

3.1 Introduction

The purpose of the chapter is to address the first goal of the research, which is to provide an examination of the National System of Innovation (NSI) and why it is the best conceptual tool in analysing technology development. Section 3.2 provides an overview of the system of innovation approach. This approach bases explanations of the evolutionary patterns of technology and development on the decisions and the actions of actors in relation to institutional rules, which become the foundation of the National Systems of Innovation (NSI). Section 3.3 develops the concept of the NSI. This section provides an in-depth analysis of the elements of an NSI, placing emphasis on the role of the state to ensure successful innovation. Finally, this section provides a critique of an NSI. Section 3.4 provides the idea of inclusive innovation for a development-for-development agenda. Section 3.5 addresses the concept of the fourth industrial revolution, as well as the advantages and disadvantages of the fourth industrial revolution.

3.2 Systems of Innovation

Tödtling and Trippl (2012) define the system of innovation as a complex system, which stresses its non-linear, systemic, interactive, and evolutionary character. The system of innovation (SI) approach offers researchers and policymakers a more discerning account of issues pertaining to innovation and the role of the state (as opposed to approaches aligned with conventional economic theory). Lastres and Scerri (2013:2) explain that the location of the state in the SI approach discourse is “complex and analytically rich”.

The SI approach incorporates the principles of change whilst viewing innovation as a collective learning and selection process inherited from evolutionary economics (Nelson, 1987). The systems of innovation approach examine general characteristics of innovation as a collective process, which is manifested in various social contexts. Institutional economics within the SI approach, base explanations of evolutionary patterns of change on the decisions and actions of organisational actors in relation to institutional rules. Lundvall (1992) and Nelson (1993) confirm that a system of innovation approach can be used to compare different institutional frameworks and combinations of agents in directions favourable to economic growth and development. The system of innovation approach focuses on the determinants of product and process innovation. The approach can further be characterised and compared by investigating the following six dimensions (Coenen and Diaz, 2010).

1. Systems boundaries;
2. Actors and networks;
3. Institutions;
4. Knowledge;
5. Dynamics; and
6. Policy implications.

The SI approach aims to reinforce the causal connection between technological change and economic growth (Carlsson, 1995). Edquist (1997:2) suggests there are several key characteristics in the SI approach:

1. "The SI approach aims to place innovation and learning processes at the centre of development. Innovation is then viewed as a matter of producing new knowledge or combining existing elements of knowledge in new ways. This is how learning processes are achieved".
2. "The SI approach aims to adopt a holistic and interdisciplinary perspective. The approach may be holistic in the sense that it tries to encompass a wide array of the important determinants of innovation. It is also interdisciplinary as it allows the inclusion of economic factors as well as scientific, organisational, social, and political factors".
3. "The SI approach employs a historical perspective to the processes of innovation, which develops over time and involves the influence of many factors and feedback processes. These are studied in terms of the 'co-evolution' of knowledge and innovation in organisations and institutions".
4. "The SI approach stresses the difference between systems rather than the optimality of systems. The approach aims to conduct comparisons between existing real systems rather than an 'optimal' or an 'ideal' system, as per the neoclassical approach to innovation".
5. "The emphasis of an SI approach is on interdependence, which creates non-linearity. This is because firms do not innovate in isolation. However, they interact more or less closely with other organisations through complex relations that are characterised by reciprocity and feedback mechanisms in several loops. This interaction occurs in the context of institutions, which include laws, rules and regulations, and norms and cultural habits. It is essential to understand that the elements of a system do not determine innovation, but rather the particular relations within this system";

6. “The SI approach encompasses both product and process innovations, as well as the subcategories of these types of innovation. This is significant because, due to the developing and differentiated concept of innovation, it is not solely restricted to the conventional emphasis on process innovation, which is typically of a technical nature. This is central to comprehend, as there are complex relations between growth and innovation; and”
7. “The SI approach emphasises the central role of institutions. Institutions are conceptualized as main actors or players in the process of innovation. Institutions are understood as defining the ‘rules of the game’ (North, 1990). Institutions are reciprocally related to one another. This is because institutions, such as firms, are institutionally defined and regulated. This makes them agents of institutional change as they seek to improve their economic performance”.

There are different levels at which innovation takes place (Jacobs and Mazzucato, 2016). These include namely: regional systems of innovation, national systems of innovation and the local systems of innovation. The regional systems of innovation identifies cultural, geographical and institutional proximity that create and facilitate transactions amongst socio-economic actors. The local systems of innovation (LSI) has identified spatial concentration of firms such as suppliers of equipment, services and customers. To add to this, the LSI also includes associated non-market institutions such as universities, research institutions and training institution. The focus of the research is on the national systems of innovation.

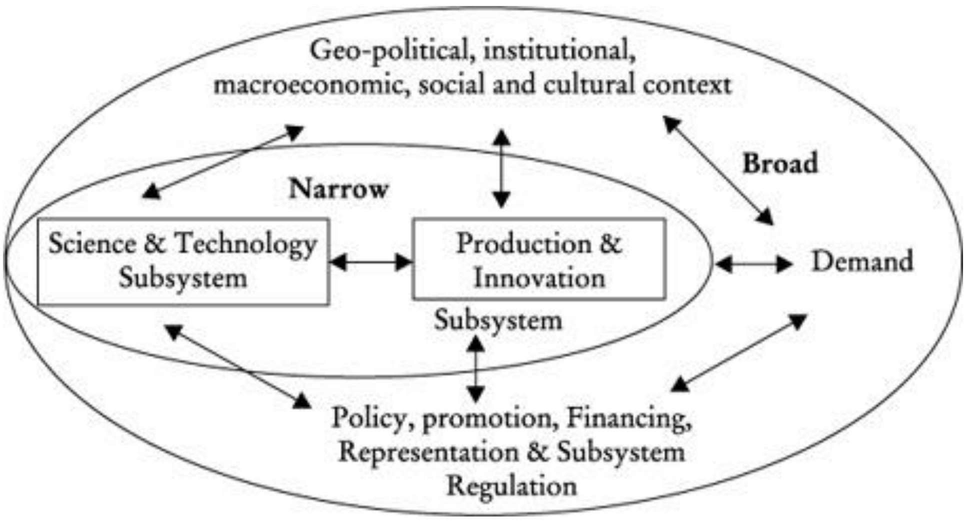
3.3 National System of Innovation

3.3.1 The concept of the National System of Innovation

Writers within the evolutionary tradition have developed the idea of a National System of Innovation (NSI). Nelson (1993) defines an NSI as a “network of public and private sector institutions which act to initiate, modify and diffuse new technologies or alternatively as a set of institutions whose interactions determine the innovative performance of national firms”. The NSI approach is used as an analytical framework for studying the differences between countries concerning their production and innovation systems (Schrempf *et al.,* 2013). Maharajh (2014:98) also states that “the NSI framework provides tools for redefining development and reconstructing appropriate institutional arrangements”. As expressed by Jacobs and Mazzucato (2016:65), “it is not the quantity of R&D that matters but how it is distributed through an economy.” This suggests that the state has a primary role in achieving equitable distribution of R&D in an economy. In view of this, the emphasis is not simply on the stock of R&D but rather on both the circulation of knowledge and its diffusion throughout the economy. In the linear model of innovation, the R&D system is seen as the root of innovation, reinforcing the ideals of neoclassical economics, where economists study the use of R&D to understand growth. The NSI approach also places emphasis on the role of historical processes, which account for the differences in the "socio-economic capabilities and for different development trajectories and institutional evolution" (Lastres and Scerri, 2013: xxvii).

The NSI advocates for promoting "basic" and "applied" research. This suggests that educational institutions and universities feed the innovation process through the applied and basic research. Research and Development (R&D) utilises basic research as an input. Jacobs and Mazzucato (2016) argue that the role of education, training and design and quality control are significant in achieving economic growth.

Figure 3.1 The broad perspective of a national system of innovation (NST)



Source: Lastres and Scerri (2013: xxviii)

The broad perspective of an NSI (Figure 3.2) includes connecting different sub-systems that are influenced by various contexts. These contexts are geo-political, institutional, macroeconomic, social and cultural. The production and innovation sub-system contemplates the structure of economic activities, their sectoral distribution, the degree of informality and their spatial and size distribution and the level and quality of innovative effort (Mazzucato,2011). The subsystem of science and technology includes education (basic, technical, undergraduate, and postgraduate). Furthermore, it includes research, training, and other scientific and technological infrastructure elements such as information, metrology, consulting, and intellectual property. The third subsystem focuses on policy promotion. This is primarily the financing, representation and regulation sub-system that encompasses the different forms of public and private policies, which are explicitly geared towards innovation or implicitly (but not necessarily) geared towards effective strategies on innovation. The final subsystem deals with the role of demand which is usually absent in the analyses of SI. This places attention on the patterns of income distribution, the structure of consumption, social organisation, and social demand (basic infrastructure, health, education).

The OECD (1997) adds to this broad perspective of the NSI by suggesting that this approach stresses the flows of technology and information among people, enterprises, and institutions, which are essential to the innovative process. The focus on interactive learning and the localized nature of the generation, assimilation and diffusion of innovation implies that the acquisition of foreign technology abroad is not a substitute for local efforts. This perspective is neither a micro- nor macro-perspective. Rather, it is a meso-perspective where the "individual firm is seen as part of a broader network of firms with whom they cooperate and compete" (Mazzucato, 2011:65). The NSI approach not only takes into account the role and policies of firms, educational and research organisations, and science and technology institutions (STIs), as well as including government policies, financing organisations and other actors and elements that influence the acquisition, use, and diffusion of technology.

The functions of an NSI include the creation of knowledge, guiding the search for existing knowledge, supplying resources such as capital and skills and facilitating the creation of positive externalities. The density of a learning network determines the size of positive learning externalities. Where there are positive externalities, markets inefficiently allocate (or under-invest in) resources towards learning and innovation. This leads to market failure, and the state, therefore, must intervene to correct this. The NSI approach highlights issues completely overlooked by the orthodox approach to technology policy and corresponds more to the empirical and historical realities of technological change (Deraniyagala, 2006:139). The national system of innovation approach gives particular attention to the economic role of knowledge. The NSI reflects the rise of systemic approaches to the study of technology development as opposed to a 'linear model of innovation' (OECD, 1997).

The NSI rejects the view of the Washington Consensus that effective technology development primarily involves getting the prices right. The NSI comprises of a complex set of relationships among the actors in the system, which entail state and non-state organizations, institutions, individuals, networks and rules and regulations. It is essential to understand that the core ideals of the NSI promote the competencies of a network of actors, which facilitate innovation. The NSI directs attention to the linkages and the web of interactions of these actors. The smooth operation of any national innovation approach is highly dependent on the fluidity of knowledge flows among enterprises, universities, and research institutions (OECD, 1997:3).

3.3.2 The building blocks of a National System of Innovation

Lundvall (1992) outlines three main building blocks with regards to the NSI. The first building block focuses on the sources of innovation and the actions of agents such as learning and exploration, which lead to innovation. The second building block distinguishes between radical innovation and incremental innovation. The final building block of an NSI constitutes non-market institutions. Here, Lundvall (1992) distinguishes between user-producer interaction as a significant form of knowledge exchange and institutions and their uncertainty reducing function. These institutions play a particularly central role in the NSI concept. Nelson (1993) claims that the NSI specifically focuses on actors aiming to understand the arrangement that exists within them in order to collaborate. In addition, Nelson (1993) is mainly concerned with institutions working in the science and technology sector or supporting it (especially in universities conducting R&D). The state plays a central role in the facilitation of innovation.

The role of the state lies at the center of the solutions to problems of order. Weber (as cited in Evans, 1995:5) defined states as the "compulsory association claiming control over territories and the people within them". However, the provided definition does not reduce the complexities of analyzing what states do. Essentially, without the state, markets, and the other master institution of modern society cannot exist or function. Evans (1995:4) states how the responsibility of economic transformation has become increasingly central to the state's role. The state must be involved in the process of economic transformation. This process of economic transformation has two facets. Firstly, states are deeply involved in the process of capital accumulation. Wealth creation is no longer considered just the nature of markets; effective statecraft is involved (Evans, 1995:6). Secondly, eliciting entrepreneurship and facilitating new productive capacities requires involvement in citizenry affairs than simply eliciting loyalty and enforcing good behaviour. The state has pervasive influence as an institution and a social actor. The state cannot facilitate innovation if the is no element of embedded autonomy.

The notion of the embedded autonomy is to understand state structure roles and relations between state and society, and how the state contributes to development. The embedded autonomy concept provides the underlying structural basis for successful state involvement in industrial transformation (Evans, 1995, 12). The ideas about the variations in state involvement have to be built on the historical examination of particular states. The variations in state involvement depend on variations in the states themselves. It becomes evident that states are not generic. They vary dramatically in their internal structures and relations to society. This means that different state structures can create different capacities for action. Institutional endowments and the exercise of agency can reshape the kinds of products a country produces. The state can facilitate local emergence of new sectors, which become important in understanding states on the national level.

It is significant to establish the "developmental impact and the structural characteristics of states- the internal organization and their relation to society" (Evans, 1995:12). Evans (1995: 13) claims that "structures confer potential for development, but potential has to be translated into action for states to have an effect". The parameters of state involvement are known and detail "how much" state involvement should occur. The first are custodian and demiurge, which represent the variations on the conventional roles of the regulator and producer. Here, the state formulates and enforces rules, but the thrust of the rulemaking varies. In the custodian perspective, some states make rules that are primarily promotional, aimed at providing stimulus and incentives, whilst other regulatory schemes take the opposite tack, aiming to prevent or restrict the initiatives of private actors. Furthermore, it identifies regulatory efforts that privilege policing over promotion. The demiurge is a specific way of playing the generic role of a producer. States play the role of a producer, taking direct responsibility of delivering on certain types of goods, good that are capability expanding in both entrepreneurial and general citizenry senses. This role is based on the assumptions about the limitations of private capital. The second pair, termed midwifery, and husbandry, focus more on the relationship between state agencies and private entrepreneurial groups (Evans, 1995:13). Taking on the role of a midwife is a response to doubts about the vitality of private capital but a response of some sort. Essentially, embedded autonomy implies dense links not with society in general, but industrial capital.

3.3.3 The key elements of a National System of Innovation

There are five core elements that emerge from the overview of the NSI literature. These are namely: sources of innovation, the role of institutions, interactive learning, interaction and social capital. Sources of innovation is of great importance in the NSI. Lundvall (1992) argues that producer-consumer relations provide a source of innovation. An example of this would be a purchase availability of equipment, and the training/upskilling of employees. Consequently, innovation can occur in the production, distribution, and consumption processes.

Secondly, the role of institutions shape the interactions between actors within the system. There are non-market and market institutions form part of the national system of innovation as these provide an incentive structure and policy framework for governments to implement policies that influence the process of innovation.

Thirdly, the aspect of interactive learning. Interactive learning placed emphasis on the importance of continuous learning to adapt to change. This identifies the connection of the NSI to concepts such as human resource management, labour market institutions and the learning capacities of firms (Arundel *et al.,* 2007). In turn, this integrates the absorptive capacities of the economy (Nooteboom, 2000).

The element of interactive learning is interlinked to the fourth element, which is interaction. Innovation is considered to take place almost exclusively through interaction. The national system of innovation can produce an environment for continuous knowledge production, knowledge use and innovation to occur. This interaction is coordinated by institutions. Inefficient coordination of interactions may lead to failure of the whole innovation system.

Social capital is the last element of the NSI . The greater the degree that institutions in a system are advanced, the more social capital there is in terms of the trust the actors are willing to show. Trust is essential, as it positively influences the rate of innovation since higher trust reduces the risk that accompanies innovation (specifically the risk of financing innovation).

3.3.4 Critique of a National System of Innovation

Oerelemans and Pretorius (2006:70) agree that a systems of innovation approach may be a fruitful framework for analysing innovation and the design of science and technology policies. On the contrary, these approaches may be problematic to a certain extent. In fact, from a 'pure' system approach, the identification of key technology and innovation areas is somewhat 'alien' and assumes that technological innovation in certain sectors can be planned, programmed and managed. Admittedly, since the approach is theoretically grounded in learning and evolutionary approaches, it assumes that innovation is a process with uncertain outcomes. Such learning is riddled with the risk of failure; hence markets fail to allocate innovative learning efficiently (Khan and Blankenberg, 2006). As such, the government would have to correct market failure

3.4 Inclusive innovation for development

Schillo and Robinson (2017) claim that innovation is an important driver of economic growth and development. In addition to this, innovation has also been established as the key contributor to increasing economic and social inequalities. Inclusive innovation refers to the "means by which new goods and services are developed for and by billions of people living in lower levels of income" (Schroeder et al., 2016:184). Alternatively, Planes-Satorra and Paunov (2017) make the claim that inclusive innovation should drive economic growth that creates opportunities for all segments of the population and distributes the dividends of increased prosperity, both in monetary and non-monetary terms, fairly across society. This suggests that inclusive innovation has the potential to be a socially responsible endeavour, which is a means to address social and economic exclusion. Papaionnou (2014) adds to this explanation by stating that innovations can be inclusive of people and places if they satisfy basic needs in an equitable and participatory way. Chataway *et al*. (2014:33) argue that "inclusive innovation needs to be understood and developed in the context of a holistic conception of the innovation cycle, the distinction between process and product innovation and the roles played by the poor as both producers and consumers

The driver behind inclusive innovation is the social well-being of marginalized populations. The distributional effects of innovation need to be considered, but more likely, the implication of inclusive innovation is that the broader outcomes such as the quality of life and the social outcomes need to be considered. The transition towards inclusive innovation will be neither effortless nor automatic, as it provides a plausible scenario for increased social and environmental sustainability on a global level. Inclusive innovation combines elements from innovation research with a strong explicit normative element. In order to achieve the goal of inclusion, the focus needs to extend past the high-technology sectors, which are traditionally considered highly innovative and labour extensive sectors. Foster and Heeks *et al.* (2014) assert that the notion of inclusive innovation includes sectors of particular importance to the marginalized populations, such as health, education, and small-scale agriculture.

Schillo and Robinson (2017) contend that inclusion can be conceptualized as the consideration of potential customers, participation in the innovation process and contribute to the evolution of innovation and societal systems. Inclusive innovation can be achieved through the basic needs approach. The Basic Needs Approach (BNA) is an approach to social justice that "gives priority to meeting people's basic needs to ensure that they are sufficient" (Papaioannou, 2014:192). It draws on an intuitive moral force of claims of need compared to the claims of preference or subjective or objective benefit. Natural and social basic needs are interrelated. For instance, health is often determined by education and housing. These interrelated natural and social needs can be considered as alternative evaluative criteria for inclusive innovation.

Emerging models of inclusive innovation cannot be branded as inclusive unless there is evidence of equal satisfaction of basic human needs in specific developmental contexts. The new models of innovation have been conceptualized as innovation for low and middle groups. Frugal innovations are often lower quality versions of more sophisticated technological products and processes. They allow the poor to buy them at affordable prices, meeting their basic needs and increasing welfare benefits. Papaioannou (2014) argues that the demand for frugal innovation reflects basic needs is only partly correct. The basic needs for quality food and good education can not be met by cheap, low-tech, and modified innovations. Inclusiveness is a multi-dimensional concept that cannot be realized if people are offered low-quality products.

It is possible to conceive several different levels at which "inclusivity" could potentially operate. There are four dimensions of inclusiveness, which display that the concept of including groups within the innovation process can take many forms. These four dimensions include a broad range of outcomes and benefits to be captured whilst discovering the governance mechanisms of innovation.

The first-dimension, anticipation, requires exact consideration of the potential of new technology and the risks that new technology may pose. This dimension requires early involvement of the public to ensure pathways of technological development are aligned with societal expectations and needs. The second dimension, reflexivity, highlights that responsibility demands engaging critically with institutional practices within science and with value systems that underlie scientific and technological creation. Furthermore, with regards to the innovation process, it is a key emerging theme within the inclusive innovation literature. The third dimension, inclusiveness, reflects the waning in the authority of expert, top-down science and policy development and suggests that legitimacy needs to be established through the involvement of broad stakeholder groups and the public. The last dimension, responsiveness, emphasizes that responsible innovation requires a capacity to change the shape or the direction in response to stakeholder and public values and changing circumstances.

Governments have become increasingly aware of both the need for, and the opportunities opened by, inclusive innovation. Schroeder *et al*, (2016) make the claim that policymakers are trying to emulate successful innovation systems to support economic growth. This suggests that innovation systems must ensure better integration of stakeholder views in the research and development process. This can be achieved through the Responsible Research and Innovation (RRI), which is a newly emerging governance framework that ensures that this integration occurs.

Inclusive innovation and RRI are similar in that they refer to the production and delivery of innovation to the poorest and most marginalized communities and income groups. RRI and inclusive innovation inject moral values into innovation governance systems (Schroeder *et al,* 2016). These concepts require that the poor be involved in the innovation process itself. If one tried to bring inclusive innovation closer to RRI, one could argue that the term inclusion would require all segments of society to benefit from the influence of innovation. This suggests that the definition of RRI focuses on entire populations, and not just simply the underprivileged. If policies such as RRI or inclusive innovation are successfully realized, innovation system analysts will find larger and more diverse networks include new actors within their systems.

Chataway *et al.* (2014) argue that a stronger evidence base is required for private and public actors to promote inclusive innovation effectively. The gap for public sector actors is even larger. There is clearly an important role in the research community to demonstrate the extent, nature, and inducements to the obstacles to the development and deployment of inclusive innovation. Public policy should be concerned with satisfying such needs through frugal and grassroots innovations with increasing capabilities, as increasing capabilities presupposes satisfying basic needs. Public policy should rather avoid developing more formal institutions of innovation. Emerging models of innovation such as frugal and grassroots innovations can be evaluated as inclusive to the extent that they satisfy both principles, meeting people's needs through non-cosmopolitan politics. Innovation is dynamic; therefore, it would be difficult to have a functional NSI without considering the Fourth Industrial Revolution. In recent times, there has been an increasing emphasis on a technology-driven society because of the advent of the fourth industrial revolution. As a result, a brief discussion of the fourth industrial revolution and what it entails for the NSI is provided.

3.5 Fourth Industrial Revolution

The Fourth Industrial Revolution "is a way of describing a set of ongoing and impending transformation in the systems that surround us" (Schwab, 2016:7). This technological revolution is blurring the lines between the physical, digital and biological. It is driven by the increasing availability and interaction of a set of extraordinary technologies. These emerging technologies driving the fourth industrial revolution build on knowledge and systems of prior industrial revolutions, in particular the digital capabilities of the third industrial revolution. The cluster of technologies includes artificial intelligence, robotics, additive manufacturing, neuroethologies, biotechnologies, virtual and augmented reality, energy technologies as well as capabilities we do not yet know exist. These technologies are "altering how individuals, companies and governments operate ultimately leading to a societal transformation" (Schulz, 2019:3).

The shifts in technology lead us to reconsider the roles of individuals, organisations and societies at work. Debates around the fourth industrial revolution have been complex, as they present advantages and disadvantages. The impact of the fourth industrial revolution differs substantially from advanced economies and emerging economies. Therefore, it would be impossible to assume a one-size-fits-all approach when it comes to considering the impact on individuals, organisations, and societies when realising the implications of the fourth industrial revolution.

It has become necessary to unpack how this shift in technology will continue to transform the global space, particularly for emerging economies. Innovations can bring access to products and services to entirely new markets.. They provide people with the opportunity to learn and earn in new ways. Schwab (2016) purports that the artificial intelligence (AI) revolution is going to transform the many jobs and spawn new kinds of jobs that drive economic growth. Agrawal (2018:2) defines AI as "the theory and development of computer systems able to perform tasks normally requiring human intelligence". There are pessimistic and optimistic views when it comes to AI. It has been argued that AI diffuses widely; the transition could mean temporary displacement of workers. Additionally, it has been suggested that this type of information technology is likely to be skill-biased, and the individuals who will benefit the most are those who are educated, and who are already doing well. In certain emerging markets where the majority of the population lacks this expertise, it could have a regressive impact on economic distribution and thus exacerbating massive inequalities that plague the globe. From an NSI perspective, this viewpoint is not the defect of the fourth industrial revolution, but a failure of societies to transform themselves into knowledge societies. Evidently, it boils down to structural defects of their educational systems. In contrast, AI could create more jobs, if organisational leaders are able to evolve their jobs by designing them to make the most of their employees' inherent nature to be social creatures and creative problem solvers. This provides the opportunity to reimagine talent models, organisational practices and business models. The role of the state becomes central in facilitating innovation.

3.6 Conclusion

In essence, this chapter has taken an evolutionary stance with regards to the National System of Innovation. It provided a comprehensive overview of the system of innovation approach. This approach-based explanation of the evolutionary patterns on the decision and the actions of actors in relation to institutional rules, became the foundation of the National System of Innovation. The evolutionary approaches explained the view of innovation as a collective process, which was manifested in social contexts. The concept of the NSI was further developed in this chapter. The chapter provided an in-depth analysis exploration of the elements of an NSI. The idea behind the NSI was to move from a linear perspective of innovation which focused on the use of research and development (R&D) to understand growth, but rather focus on socio-economic capabilities, which would enable different developmental trajectories and institutional innovation. The chapter offered a critique of a National System of Innovation.

CHAPTER 4: EVOLUTION OF THE NATIONAL SYSTEM OF INNOVATION FROM A BRICS CONTEXT

4.1 Introduction

The purpose of this chapter was to address the second goal of the research, which is to evaluate the evolution of the NSIs within the BRICS bloc with a particular focus on South Africa. The analysis of the evolution of the NSIs constituted an evaluation innovation and public policy drawing literature in Lastress and Scerri (2013) and various other sources. Section 4.2 assesses the role of public policy in stimulating innovation. The aim of this section is to gauge the different public policies that were aimed at driving innovation, whilst taking into consideration key macroeconomic, fiscal, and monetary policies that economic growth, broader economic development, and international competitiveness. Section 4.3 provides an in-depth review of the adoption of the NSI framework within the BRICS bloc. The purpose of this section is to identify the implicit and explicit state policies on science and technology, which have contributed to the formation of the NSI. The section concludes by the application of theoretical elements mentioned in Chapter's two and three. These theoretical elements are significant as some of these public policies implemented by the BRICS bloc display the transition of the different theories of technology and development reflecting on the decisions of different actors in relation to the institutional rules, which have become the foundation of a national system of innovation. Section 4.4 presents a comparative synthesis that reflects policy prescriptions and other initiatives that have taken by the BRICS economies to assess how technology has been a source of growth and higher productivity and ultimately reduce inequality, unemployment, and poverty within the BRICS context.

4.2 The role of public policy in stimulating innovation.

Sennes (2008) argues that the complexity of the entire innovation paradigm requires governments to adopt a more holistic approach to public policy. These public policies are necessary to create a favourable environment for long-term investment, R&D, the quest for innovation, and the development of new products. Lundvall and Borras (2005) state that several countries are broadening their range of innovation policies to solve issues like inequality, urbanism, and poverty, as well as environmental issues like reducing pollution and improving energy use and generation. Walwyn and Cloete (2018) argue that policies themselves interact and are independent, requiring a more holistic approach to policy design and analysis. The policy mix approach is particularly significant in addressing the objectives of socio-technical transformation and sustainability transitions.

The most significant public policies are separated into five categories. Firstly, industrial and sectoral policies. These policies aim at promoting productive activity, directed at development stages that are longer than the pre-existing ones (Ferraz et al., 2000). Secondly, foreign trade policies with import policies that assist in increasing the competitiveness of the national industry against international competitors. Thirdly, promotional financing policies that enable long-term investments and the development of new technologies with research and development (R&D) expenses. Fourthly, policies for competition and regulation also play a significant role aim at creating and maintaining a competitive environment in critical areas of innovation, including intellectual property policies. Policies to support micro-, small-, and mid-sized enterprises (SMEs) that can play a significant role in creating an innovative economy. Lastly, education policies to train skilled labour and in the fields of science and technology and innovation that promote and stimulate the generation of knowledge and society by supporting academic and scientific research.

4.3 The adoption of the NSI framework within the BRICS bloc

The BRICS economies have had different historical trajectories where the very nature of the state have been challenged or altered. These diverse histories are not only interesting, but also they affect the respective analysis within the broad definition of an NSI. The histories of these economies played a major role in determining the shape of the national innovation systems that have emerged.

The explicit state policies on Science and Technology (S&T) have been designed with the intention to affect innovative activity directly. These explicit policies are related to technological innovations and their deployment of innovation in the production process. Alternatively, implicit state policies are those that affect sectors that are peripheral to innovation, but nonetheless form and institutional context within which innovation occurs Jointly, the implicit and explicit S&T policies imply that long-term investment and characteristics of human capital development have influenced the role of the state in shaping the evolutionary path of the national system of innovation. In essence, the objective of this chapter is to conduct a brief study of the main stimulus policies for innovation amongst the BRICS economies. The assessment of the different implicit and explicit policies was accompanied by an examination of different initiatives, which have aimed to strengthen the framework of a national system of innovation, which has been adopted by the BRICS economies. The discussion now turns to a country-specific policy document analysis for each of the BRICS countries.

4.3.1 Brazil

Sennes (2008; 5) purports that a "good combination of government policies and business strategies is central to the creation of an environment propitious to generate innovation". There were four instruments in the Brazilian governments that had been effective in spurring innovation. The first was the establishment and promotion of the National Fund, which sponsored the establishment of innovation that was a system of support to public enterprises in the pre-project phase. The second was the use of this system of pre-project support to help nascent firms perform self-assessments, and to identify key weaknesses and opportunities. Thirdly, it was used to stimulate investment in new products and enterprises through the creation of the venture capital fund. Lastly, it was the design of a plan to apply the governments 'purchasing power to generate innovation.

Alternatively, Lastress and Scerri (2013) contend that the implicit policy that laid the foundation for the adoption of the NSI framework was the *Law of National Education Guideline*. The explicit policies were namely: *Industrial, Technological and Foreign Trade Policy, Policy for Production Development, and the Plan for Development of Education.*

Implicit and Explicit Policies

a. Law of National Education Guideline (1996)

The role of the federal government of Brazil was to provide basic and higher education. The government advocated for the dispersal of material and financial resources to municipalities to encourage them to invest in their basic and secondary education. This led to the introduction of the *National Fund for Primary Education Development (FUNDEF)*. The aim purpose of this fund was to enhance the value of the teaching profession. This fund defined the appropriate criteria for the distribution of funds for the education system between states and municipalities, dependent on the number of students enrolled in the education system (WDE, 2006).

The *Law of National Education Guideline* ensured the elaboration of curricular pre- and in-service training for professionals. It included increasing the length and number of teaching days and formulating the evaluation of courses and institutions, which go beyond the evaluation of pupil performance. This created mechanisms for improving the quality of teaching within the education system. It provided instruments that gave value to the learning processes, such as continuous and partial progression, concepts of classification and reclassification, which allowed learners the opportunity to progress in their level of studies depending on their level of achievement and evidence of learning.

Sennes (2008) argues, since the implementation of industrial policy, innovation has assumed a role in the Brazilian government's program and policy agenda. The first policy that was implemented was the Industrial, Technologies and Foreign Trade Policies (PITCE), which was later on accompanied by the Bigger Brazil Plan, which defined the industrial, technological and foreign trade policies for the period 2011 to 2014.

b. Industrial, Technologies and Foreign Trade Policies (PITCE) (2003)

The Industrial, Technologies and Foreign Trade Policies (PITCE) took a favourable standpoint towards industrial policy, which aimed to provide support to the domestic production sector. The ministry of development, industry, and foreign trade (MDIC) coordinated it. The objective of this policy was to reduce the country's external restrictions, in the short to long run, and to equate the development of key activities in the attempt to generate capabilities that allow a country to raise its global competitiveness.

The actions of the PITCE were structured according to the following three axes:

i. Horizontal action lines

- Innovation and technology development
- International insertion
- Industrial modernization
- Production capacity and scale

ii. Strategic options

- Semiconductors
- Software
- Capital goods
- Pharmaceutical and medicines

iii. Activities with future perspectives

- Biotechnology
- Nanotechnology
- Biomass/renewable

The establishment of action lines, choice of strategic sectors and activities that bear future perspectives, contribute to the restructuring of the production sector.

The formation of these action lines led to the introduction of the policy of production development.

The Bigger Brazil Plan was a plan, which was intended on stimulating innovation and boosting the competitiveness of the Brazilian industry in foreign and domestic markets, as well as strengthening services to support industrial production, including information and communication technology. Sennes (2008) argues that there are three main possibilities for promoting innovation policies.

Firstly, it was through the application of the fundamental advances that had occurred concerning the understanding of innovation. Secondly, there was a need to contextualise analytical and policy indicators as well as instruments in the attempt to articulate innovation policy with strategic development needs and opportunities targeted in the different territories. Finally, the state should exercise a fundamentally important role, not only for the development of active, selective and systematic policies aimed at strengthening the national techno-productive base, but also for ensuring convergence with social development objectives, granting compliance with basic priority needs of the population, overcoming backwardness, in areas critical to combating social exclusion and attenuating regional inequalities. It becomes evident that the previous policies were not aimed at building a production structure that promotes social equity or that satisfies the basic consumption needs of the low-income population.

Soares and Cassiolato (2008) extend this argument further by arguing that a dramatic increase in inequality is an important feature of these developments. The new technology systems and content have caused novel and more complex inequalities between individuals, social groups, organizations, countries, and economic blocs, both rich and poor. There have been significant disparities in conditions of generation; access, and use of knowledge. Cassiolato *et al.* (2014) argue that Brazil had been well-positioned to address the challenges of sustainability and inclusive development in the new paradigm.

The IPP (2016) argues that the government has recently introduced significant changes in STI governance. The administration merged the science and telecommunication ministries to become the Ministry of Science, Technology, Innovations and Communications (MTIC). Furthermore, within the same period, it launched a new National Strategy for Science, Technology, and Innovation. Mari (2020) argues the newly adopted strategy aims to foster the development of new technologies focused on improving the economy and delivery of public services. It sets out the country's key challenges for STI policy: i) closing the technological gap with developed economies ii) strengthening institutional capabilities to increase productivity through innovation iii) reducing social and regional inequalities in access to a country national system of innovation iv) developing innovative solutions for productive and social inclusion; and v) promoting sustainable development.

c. Policy for Production and Development (2006-current)

The Policy for Production Development aimed to expand the supply capacity to ensure the robustness of the balance of payments to enhance innovation capacity whilst still strengthening small enterprises. The government defined twenty-five priority sectors that they would focus on. These economic sectors were divided into three main categories, namely: programmes for advancing strategic areas, strengthening competitiveness and consolidation, and advancing of leadership. There were policy mechanisms that were identified for each of these areas. These mechanisms included incentive mechanisms, government purchasing power, regulatory mechanisms, and technical support.

i. Incentive mechanisms: This focused on ensuring that firms had access to credit and financing.
ii. Government purchasing power: This necessitated the direct purchases by the government and state entities.
iii. Regulatory mechanisms: This involved economic and competition regulation.
iv. Technical support: This involved technical support, which included 1trade promotion management of intellectual property, business and human resources capacity building and intra-governmental coordination with the private sector.

Although there were twenty-five sectors that were focused on, the core purpose of this policy was to ensure that four thematic macroeconomic areas were tackled. These being the expansion of investment, rise in private expenditure in R&D, expansion of exports (including the participation of global exports) and the direct stimulation of small to medium enterprises.

d. Plan for the Development of Education (PDE) (2006-current)

The Plan for Development of Education was a programme, which reflected a direct initiative in constructing a functional NSI. This programme was based on a systematic concept where various territorial and social dimensions were considered for its implementation. The territorial and educational matters were interconnected through the notion of an educational arrangement.

The programme was organised according to four main lines, namely: basic education, vocational education, higher education, and literacy. Furthermore, the programme was founded on the following assumptions:

a. Systematic vision of education;

b. Territoriality;

c. Development;

d. Collaborative regime;

e. Accountability; and

f. Social mobilization.

These assumptions supported the amplification of a programme, which aimed to alleviate the social and territorial disparities in the country.

Other initiatives

Chainiri *et al* (2020) argue that innovation practices and political behaviour adopted by businesses shape the Brazilian NSI. Although businesses play a prominent role in leading innovation nationally, they are not supportive of institution intensive solutions for strengthening NSI. There have been state-owned, and hybrid companies that capably managed innovation in a systematic and sustainable manner. The three major companies that have stood out in this field are Petrobus (Brazilian Petroleum Corporation), Embrapa (Brazilian Agricultural Research Corporation) and Fiocruz (Oswald Cruz foundation). According to Sennes (2008:14), "between 1990 and 2006, Petrobus (the second largest patent holder) filed for 733 national and international patents securing 216 of these patents to date". This company is among the leading R&D investors in the world, while much of the company's R&D's efforts are carried out in its research center (Leopolodo Americo Miguez de Mello Research and Development Centre-Cenpez). This research center maintains many partnerships with universities and outside research institutions.

The Sectoral Funds for Science and Technology was created in 1999. These were financing tools for research, development, and innovation projects. Furthermore, these tools had become complementary resources for developing strategic sectors, stimulating the generation of knowledge, and ensuring that such knowledge was transferred to companies. The research and projects funder (FINEP), which was subordinate to the ministry of science and technology

(MCT), administered the funds. These were specific sectoral funds. These being namely: Aeronautics, Agribusiness, Amazon, Waterway, Biotechnology, Energy, Space, Water Resources, Information Technology, Mineral Oil and Natural Gas, Health, Land, Transportation, and Telecommunications. To add to this, IPP (2016: 2) argues that FINEP aims to raise the level of R&D in companies through the company innovative plan, which encourages greater technology risks through combining credit finance with non-refundable grants and equity financing, amongst other measures". Additionally, there are three cross-sectional funds: Green-Yellow Funds, geared towards university-business interaction; infrastructure for supporting improvements in science and technology institution infrastructure; and audiovisual, for developing cinematographic and audiovisual activities in consonance with federal government programmes. Nassif (2007:2) argues that the greater performance of a national system of innovation is explained by its capacity for coordinating conventional macroeconomic policies (mainly monetary and exchange rate policies). The absence of such capacity in Brazil from the mid-1990s to the end of 2006 has damaged its NSI and innovative performance.

Theoretical application of public and innovation policy in Brazil

The national system of innovation framework in Brazil exposes the active role of the state. The alternative approaches to technology development which go beyond the neoclassical approach are evident throughout the different policies implemented in this economy. The endogenous growth theory becomes noticeable as education, and the idea of human capital and idea becomes the centre of public policy collectively through the *Law of National Guideline (1996)* and the *Plan for the Development of Education (2006).* The state plays a direct role by the dispersal of material and financial resources to encourage investment in basic and secondary education. The formation of the National Fund for primary education reveals the creation, nurturing and generation of new ideas.

The *PITCE (2003)* and the *Policy for Production Policy Development (2006)* reveal aspects of the new trade theory and the technology where knowledge spill-overs are key mechanisms that link international trade. The theory of imperfect information and technology also becomes evident as the centrality of technology becomes core in the industrial process. The *PITCE* (2003) takes a clear standpoint towards industrial policy. The *Policy for Production Policy Development (2006) and* the *Bigger Brazil Plan* paid particular attention to the mechanisms the government provides to ensure the competitiveness of sectors. However, these policies were shown to fail at promoting social equity or satisfying the basic consumption needs of the lower-income population. Ultimately, technology became a source of growth and higher productivity but were unsuccessful in the attempt to alleviate inequality, unemployment, and poverty. The evolutionary approaches which ensure that the nature and depth of interactions is robust is not quite apparent.

4.3.2 China

The implicit and explicit nature of public and innovation policy occurred in different phases of reform in China. Schmid and Wang (2016) argue that the socio-economic reform in the People's Republic of China (PRC) has transformed China's innovation policy over the years. In addition to this, targeted policies and government-led reform since 1978 has become less hierarchical, and the tiers between the three primary actor types have strengthened. Alternatively, Motohashi (2006) argues that the Chinese economic development process has become larger in China's innovation system as it was gradually solved by several policy actions to facilitate science- industry linkages. The institutional reforms towards market- based innovation system has played and continue playing a decisive role in the building of a capable developmental state. The reform transpired in three distinct phases, to which the discussion now turns.

a. *First phase of reform (1985-1992)*

Lastress and Scerri (2013) claim that this phase of reform existed to restructure the financing system and governance of scientific research institutions. The purpose of this phase was to alter the dependency relationship between scientific research institutions and administrative departments. The objective of this was to promote economic development whilst aiming to acquire multiple sources of financing to attain technological development goals. This phase of reform aimed to not only improve efficiency and effectiveness of science and technology progress on various levels; however, it offered flexibility to scientific research institutions, and scientific and technology personnel.

The reform of the financing system necessitated a clear division of science and technology-related activities. It divided the national research expenses into different categories. For scientific research institutions to receive funding, they had to be engaged in technological development. These institutions had to be committed to ensuring development in basic research which was achieved through the implementation of a funding system. The system proposed that the funding system subsidised a portion of their operating expenses.

Secondly, this phase of reform formed the opening of the technology market, which allowed for the implementation of intellectual property regulations. Furthermore, this phase of reform aimed to expand the autonomy of scientific research institutions, educational agencies, design units and production units. The purpose of this was to strengthen the capability of enterprises in technology absorption and development. Essentially, the objective was to develop and support private- and scientific- technological enterprises.

b. Second phase of reform (1992-1998)

Following the first phase of reform, the second phase of reform focused on strengthening the nature and the depth of the scientific research institutions. This aimed at strengthening support towards basic research. The government granted managerial authority to some scientific research institutions. These institutions operated state-owned assets and encouraged them to invest in setting up scientific and technological enterprises or groups.

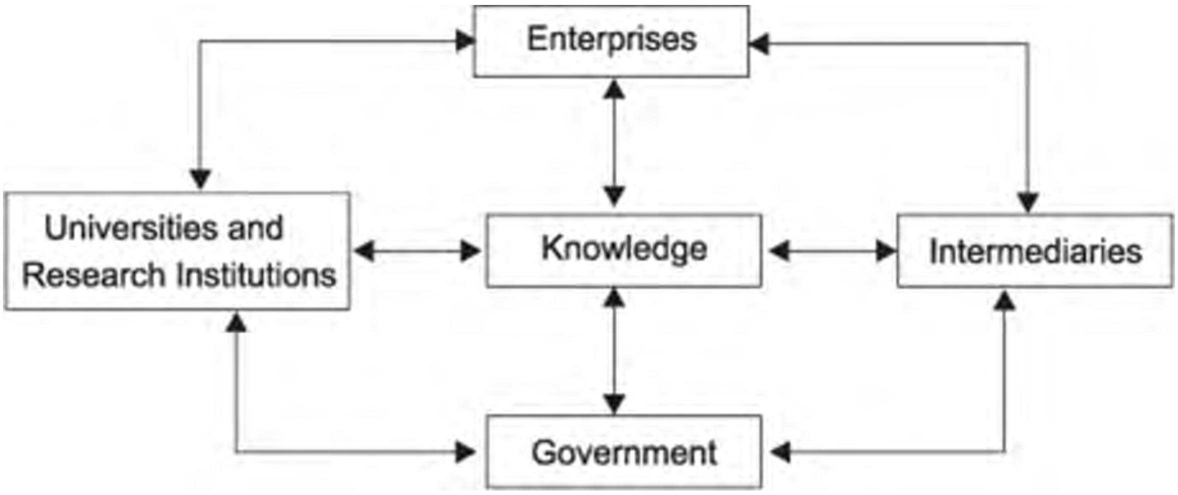
c. Third phase of reform (1998-current)

Motohashi (2006:50) asserts that after China's accession to World Trade Organisation (WTO) in 2001, there have been several actions to improve the IPR system and the enforcement mechanism had been taken. This had been an important effort for China to develop in the knowledge-based economy. The Chinese Academy of Sciences initiated the "Knowledge Innovation Programme" as a pilot base in establishing the NSI. The Ministry of Finance (MOF), in conjunction with other relevant departments, developed the following policies, which promoted the implementation of technology. These policies were namely:

a. Management Rules of Expenditure Pertaining to Science and Technology (Ministry of Finance, 1996).
b. Notification of Finance and Taxation to Promote Technology Progress (Ministry of Finance, 1996).
c. Grants Funds Management Approach and National Key New Products (Ministry of Finance, 1996).
d. Loan and Discount Management Approach on Special Technology Renovation Project (Ministry of Finance 1997).

Shortly after the implementation of these policies, the state council outlined the *National Medium and Long-term Strategic Plan* for the development of science and technology. The intention for this plan was to build an innovation-based economy by fostering indigenous knowledge innovation capabilities. It intended to foster an enterprise technology innovation and enhance the innovation capabilities of the different Chinese firms. Further reforms had to occur, which focused on the protection of intellectual property rights and improving the intellectual rights property section.

Figure 4.1 National System of Innovation (NSI) China



Source: Lastress and Scerri

Figure 4.1 illustrates the national system of innovation in China. The figure shows the different actors and components of a national system of innovation which need to interact and coordinate with one another to guarantee a successful innovation system.

Other initiatives

BMI Lab (2017) makes the claim that other than the government, there have been other key actors that have played a key role in leading the Chinese innovation system in the last decade. These actors are namely: frugal innovators, and the last wave of innovators, which comprised of serial entrepreneurs, angle investors, venture capitalists and big internet companies.

The venture capital sector had been growing rapidly. Most of the venture capital investment in digital technologies such as big data and artificial intelligence (AI). China is at the top three in the world of venture capital in three areas of digital technology. These areas are namely: virtual reality, autonomous vehicles, 3D printing, robotics, drones, and artificial intelligence. The strategy was to build a dominant position in the digital world which intended to remove inefficient, fragmented, and low-quality offline markets while driving technical performance to set new world standards.

Edler (2017) asserts that a comprehensive there needed to be a comprehensive and holistic view for policies in enterprises centred around innovation systems. This would require enabling small and medium enterprises (SMEs) and broadened innovation activity. This suggests that SMEs should be considered as a major source of employment and the basis of the economy.

Edler (2017) highlights the specified challenges faced by SMEs in terms of innovation which include: risk, early financing, intellectual property, partnership, human resources, market entry/credibility, ability to adopt least management techniques and technology. Edler (2017) makes the claim that there needs to be improved local infrastructure and additional venture capital. Edler (2017) suggests mixed financing with a strong institutional framework and compliance through all three policy levels and private sources.

Edler (2017) states that there needs to be a financial incentive that will stimulate cooperation, especially in the longer term.

Theoretical application of public and innovation policy in China

The national system of innovation framework in China exposes the active role of the state. The alternative approaches to technology development go beyond the neoclassical approach throughout the different policies implemented in this economy. The endogenous growth theory becomes noticeable as education becomes the centre of public policy through the *Decision and Accelerating Science and Technology Progress* policy.

The first and third phases of reform jointly reveal aspects of the new trade theory and the technology where knowledge spill-overs are key mechanisms that link international trade. The first phase of reform starts off with the opening of technology markets, which allowed for the implementation of intellectual property regulation. The theory of imperfect information and technology also becomes evident as the centrality of technology becomes core in the industrialisation process. Then again, these policies failed at promoting social equity and satisfying the basic consumption needs of the lower-income population. Ultimately, technology became a source of growth and higher productivity but were unsuccessful in an attempt to alleviate inequality, unemployment, and poverty. As Edler (2017) stated, there needed to be a comprehensive and holistic view for policies in enterprises centred around innovation systems. In turn, these SMEs should be considered as a major source in employment and the basis of the economy. The evolutionary approaches which ensure the nature and depth of interactions are robust is quite apparent.

4.3.3 India

India had articulated its intention to create an NSI through the Science and Technology (S&T) policy statement (2003). The Ministry of Science and Technology was the department that spear-headed the implementation of this policy statement. This department had two important bodies. These important bodies were namely: the department of science and technology and the department of scientific and industrial research. These two bodies administered and implemented the innovation programme and schemes on behalf of the government. In addition to this, the ministry-level bodies coordinated various business enterprises, industries, and associations in a range of innovation policy-related matters. Herstatt *et al.* (2010) adds to this by suggesting that India has emerged as a major destination for corporate research and development strategy, especially for multinational corporations. The purpose of the policy statement was to make sure that India placed great emphasis on the structure and the network of relationships and institutional arrangements which existed between different actors within the national system of innovation.

The structure of the proposed national system of innovation consists of:

a. Public Research System (PRS):
   The Public Research System Comprises of national laboratories from the areas of space and technology agencies, space atomic energy, agricultural research agencies and industrial research agencies.
b. Private Business Enterprises and Transactional Corporations (TNCs):
   The private business enterprises and transactional corporations had a global competitive edge in pharmaceuticals, automotive, software, telecommunications and biotechnology.
c. Higher Education Institutions (HEIs)

Implicit and explicit policies

The Science and Technology (S&T) policy statement (2003) had government initiatives that had been taken in the attempt to strengthen policy between 1990 to 2009. These initiatives directed the inclusive innovation strategy, which was geared towards developing the competitive nature of small and medium scale enterprises in the endeavour to build linkages between the formal, modern, and rural S&T systems. These initiatives were namely: National Science and Engineering Research Board, Innovation in Science Pursuit for Inspired Research, National Knowledge Commission (NKC), Widening the Education and Research Base, Promotion of University Research and Scientific Excellence (PURSE), Public-private partnership in science education for innovation and excellence in research, Biotechnology Industry Partnership Programme, The Protection and Utilization of public-funded intellectual property Bill, the New Millennium Indian Technology Leadership Initiatives.

a. *National Science and Engineering Research Board*

The purpose of this board was to establish the modalities of funding research as well as creating facilities and structure that would assist in improving the quality and quantity of scientific research to researchers in public research institutions and industrial enterprises. The primary objective was to make sure that the scientific knowledge base is up to date globally to maintain a healthy innovation ecosystem within the country.

b. *Innovation in Science Pursuit for Inspired Research*

The programme provided scholarships to attract talent to the discipline of science. It founded the link between the various levels of education for those who wanted to pursue a career in science and technology.

c. *National Knowledge Commission (NKC)*

According to the NKC (2007), the biggest barrier to innovation for all firms was the skills shortage due to a lack of emphasis on industrial innovation, problem-solving, design and experimentation. The National Knowledge Commission (NKC) created the framework for a national system of innovation. The NKC assessed, planned, and recommended solutions to the knowledge challenges of the 21^{st} century.

d. *Widening the Education and Research Base*

This placed emphasis on the knowledge-based economy and the demand for highly skilled resources.

e. *Promotion of University Research and Scientific Excellence (PURSE)*

There had been continued effort to strengthen the scientific research in universities, and the government provided conditional grants to the PURSE scheme. These special grants were based on the competitive nature of the university's publication in SCI-based journals.

f. *Public-private partnership in science education for innovation and excellence in research*

This was the launch of a fellowship programme in doctoral research in computer science and medical electronics. This programme was in association with various software companies.

g. *Biotechnology Industry Partnership Programme*

The Department of Biotechnology had launched a public-private partnership (PPP) programme for high-risk discovery, innovation, and accelerated technology development. The programmes were aimed at enhancing global competitiveness in new technologies in agriculture, energy, and the environment.

h. *The Protection and Utilization of public-funded intellectual property Bill*

The Bill gave the right of ownership to public research institutions and universities for R&D output leading to intellectual property. It authorized institutions to institute technology transfer and innovation units of R&D commercialization.

i. *The New Millennium Indian Technology Leadership Initiatives*

This aimed to foster partnerships between research public research systems and the industry to attain global leadership in a few niche areas.

Nevertheless, Parthasarathy and Ranganathan (2010) argue that the darkest shadow that exists within the national system of innovation is the shortage of skills resulting from an institutional structure that limited both access to education and the quality of what is delivered. Despite initiatives directed at the inclusive innovation strategy, which was geared towards developing the competitive nature of small and medium scale enterprises in the endevour to build linkages between the formal, modern and rural S&T systems, the country failed to enable "inclusive innovation" to acknowledge and integrate the innovation that takes place in the ignored informal sector.

Theoretical application of public and innovation policy in India

The national system of innovation framework in India exposes the active role of the state. The alternative approaches to technology development which go beyond the neoclassical approach are evident throughout the different initiatives implemented in this economy. The endogenous growth theory becomes noticeable as education becomes the centre of public policy through namely the *National Science and Engineering Board* and the *National Knowledge Commission*.

The *National Science and Engineering Board* focused on the modalities of the funding of research as well as creating facilities and structures that would assist in the quantity and quality of scientific research to researchers in public research institutions and industrial enterprises. The *NKC* demonstrated how the government provided conditional grants to the PURSE programme, which were based on the competitive nature of the university's publications in SCI-based journals. It promoted public-private partnership in science education for innovation through a fellowship program in doctoral research in computer science and medical electronics.

The *Biotechnology Industry Partnership Programme (BIPP)* and the *Protection and Utilisation of public-funded intellectual bill* uncovered the promotion of the new trade theory, where knowledge and spill-overs were key mechanisms that linked international trade and the growth of new theories of trade. On the surface, these policies succeeded at promoting social equity and satisfying the basic consumption needs of the lower-income population. Ultimately, technology became a source of growth and higher productivity, but was unsuccessful in the attempt to alleviate inequality, unemployment, and poverty. The evolutionary approaches which ensure the nature and depth of interactions are robust is quite apparent.

4.3.4 Russian Federation

Williams (2011) states that the current situation concerning science and innovation in the Russian Federation cannot be understood without an explanation or examination of the legacy of the Soviet period. Lastress and Scerri (2013) purport that under the USSR, the national S&T policy was shaped under strict ideological control and in the situation of an applicably closed S&T sphere. The effectiveness of the Russian S&T and innovation government policy was dependent on Russia's ability to tackle a plethora of problems. These problems were connected to the generation and transformation of ideas into high technologies. The lack of an assessment of these problems hindered the acceleration of processes, which took place amongst customers and suppliers of R&D products. After the collapse of the USSR, the ideological restrictions and the closed nature of the S&T sector were overcome quite easily.

The aim of the Russian Federation innovation system was to create and develop a qualified workforce, build effective knowledge creation and dissemination, and to create a favourable company atmosphere while encouraging companies to innovate.

Implicit and Explicit Policies

The implicit and explicit policies that were used by the Russian Federation targeted a few development goals and criteria, which are highlighted in the Innovation and Development Strategy and the Strategy 2019/20 policy documents.

The Innovation and Development Strategy highlighted the prospects for the transition of the government-owned R&D organizations into a different form. The policy included the support of the best innovative higher education institutions (HEIs) and research universities. The significant component of this scheme was that it provided support measures for HEIs, which were implementing innovative education programmes. The support led to the competitive distribution of competitive grants for developing unique R&D and innovation projects and the improvement of innovation infrastructure. These are discussed below:

a. *Public-private partnership mechanisms*

In 2006, the Russian Federation government established the Russian Venture Company (RVC). The purpose of this company was to promote venture investment and financial support for S&T throughout the country. The creation of this company was since the high-tech sector was unable to absorb enough investment whilst still finding the demand for innovation.

b. *Human Resources for S&T innovation*

The Russian Federation government formulated the "*Science and Education Manpower for Innovation Russia*". The purpose of the programme was to improve and develop the human potential for R&D and the innovation activity in HEIs and R&D institutions designed between 2009 to 2013. The programme focused the institutional support, and the development of efficient human resources in S&T, education within the innovation sphere. Alternatively, the programme aimed to improve and attract young talent alongside highly skilled professionals in S&T and innovation projects to consolidate excellent and competitive scholars in the best universities and R&D institutes.

The Strategy 2019/20 reflected the government's innovative development goals, targets, and criteria. The policy targets many of the Russian Federation's missing elements that established R&D, educational, finance and operational responsibilities. Some of the broad mandates of the strategy included:

a. Incentives to students studying engineering and applied sciences;
b. Stronger integration of international cooperation on innovation;

c. Improvement of the education system, including entrepreneurship and technology management; and
d. The development of technology platforms aimed at bringing together stakeholders in the most promising technological areas to bridge the gap between science and industry.

These broad mandates of the strategy were to be achieved through various objectives. The first objective addressed the development of the talent pool in science, education, technologies, and innovations. The second was to raise the innovative attractiveness of business and speeding up the emergence of new innovative companies. The third was the implementation of state-of-the-art innovative technologies in the activity of public administration authorities on the widest possible scale. In addition to this was the shaping of a balanced and sustainable sector of research and development. Following this, efforts were made to ensure the openness of the national innovation system and the economy as well as an integration of Russia in the global processes of innovations creation and use. Lastly was the intensification of the innovation policy implementation activity performed by the government authorities of the constituent of the Russian Federation.

Other initiatives

Lastress and Scerri (2013) purport that although there had been special programmes, which focused on the modernisation of the structure, functions, and funding mechanisms in the academic R&D sector. The purpose of these programmes was to streamline the network of academic organizations and to introduce some new organizational forms for R&D.

The number (and proportion) of government-owned R&D institutions made Russia quite different from other industrially developed countries. In addition to these programmes, a new government institution was created and introduced to operate in the social sphere. This institution was known as the “autonomous institution”. The purpose of this institution was to increase the government’s responsibility for the expected innovation results. The institution focused on primarily on the autonomy and independence in attracting (and spending) funds from non-government sources, including credits and investments.

Theoretical application of public and innovation policy in the Russian Federation

The national system of innovation framework in the Russian Federation exposes the active role of the state. The alternative approaches to technology development which go beyond the neoclassical approach are evident throughout the different initiatives implemented in this economy. The endogenous growth theory becomes noticeable as education becomes the centre of public policy through namely, the *Science and Education Manpower for Innovation Russia* and the *Strategy 2019/20*

The *Science and Education Manpower for Innovation Russia* and the *Strategy 2019/20* improved and developed human potential for R&D and the innovation activity in HEIs and R&D institutions designed between 2009 to 2013. The programme focused the institutional support, and the development of efficient human resources in S&T, education within the innovation sphere. Otherwise, the programme aimed to improve and attract young talent alongside highly skilled professionals in S&T and innovation projects to consolidate excellent and competitive scholars in the best universities and R&D institutes.

Unfortunately, there were no policies that uncovered the promotion of the new trade theory, where knowledge and spillovers were key mechanisms that linked international trade and the growth of new theories of trade. Although, most of the policies of the Russian Federation aimed to improve the human capital and education aspect to ensure a national system of innovation. These policies failed at promoting social equity and satisfying the basic consumption needs of the lower-income population. Ultimately, technology became a source of growth and higher productivity but was unsuccessful in an attempt to alleviate inequality, unemployment, and poverty. The evolutionary approaches which ensure the nature and depth of interactions are robust was also not quite apparent.

4.3.5 South Africa

Implicit and Explicit Policies

a. White paper on Science and Technology (1996)

The White paper on Science and Technology made several institutional changes designed to ensure that parts of the S&T system were aligned to the new national priorities (DASCT, 1996). Despite the development and progress in the governance system, at the institutional level, there was no "integrated capacity to address innovation systematically" (DST 2002:38). It appeared as if there was a disjuncture of the STI framework which effectively implied an interventionist approach and increased overall economic policy intervention.

The development and application of science and technology within a National System of Innovation was central to the Growth and Development Strategy (GDS). The White Paper on Science and Technology became an enabling framework for science and technology development. The primary objective of the NSI was to enhance the rate and quality of technology transfer and diffusion from science, engineering, and technology (SET) sector by the provision of quality human resources, effective hard technology transfer mechanism and the creation of more effective and efficient users of technology in the business and government sectors. The White Paper followed two broad themes. Firstly, it served the need to "promote cohesion between South African S&T institutions and the programmes they form part of in the interest of the National System of Innovation" (DASCT, 1996). Secondly, it supported the "creation of a system of output measurements for these institutions" (DASCT, 1996).

The White Paper proposed a coordinating mechanism for all government departments, science, engineering, and technology institutions which would be grouped as science councils and department-based institutions. The purpose of this comprehensive system for the management of government and other institutions was to guarantee that their roles within the NSI were clearly defined. It aimed to facilitate and manage the process of evaluation and review created within this system. It aimed to stimulate and coordinate interdepartmental initiatives relating to the support of innovation and technology diffusion. There was a government-wide science budget which permitted ministers to assess their relative spending priorities across the spectrum of governments' activities in support of innovation. Furthermore, it contained a proposal to develop an indigenous technology initiative in collaboration with the Department of Trade and Industry. This collaborative measure aimed to address the technology requirements of small-, medium-, and micro-size enterprises.

The core vision of the White Paper was the conceptualization of a national system of innovation that "seeks to harness the diverse aspects of S&T through the various institutions where they are developed, utilized or practiced" (DASCT, 1996:4). Its intent was to address one of the pillars of the National Strategic Vision in recognizing the need to invest in people at a skills level (DASCT, 1996). The policy thrusts of the White paper were in line with the White Paper on Education and Training in its identification of investment in mathematics, science, and technology as a fundamental goal.

The White Paper outlines the coordinated effort to achieve excellence in serving national goals. It focused simultaneously on maintaining cutting edge global competitiveness addressing the needs of citizens who are unable to assert themselves in the market. There were five broad interrelated themes that addressed this, which were regarded as fundamental in the expression of a sound S&T policy. These broad themes were:

1. Promoting Competitiveness and Employment Creation;
2. Enhancing Quality of Life;
3. Developing Human Resources;
4. Working Towards Environmental Sustainability; and
5. Promoting an Information Society.

The White Paper outlined what was required for the investment in skills development, however there was a need for the National Research and Development Strategy which played an integration role across the science and technology system and had the ability to catalyze focused societally beneficial research and development in support of knowledge generation, human capacity development and innovation.

b. The National Research and Development Strategy (2002 -2007/8)

The National Research and Development Strategy (NRDS) was a strategy "intended to provide focus and deliver particular outcomes" (DST 2002:9). The NRDS aimed to identify the key weaknesses and deficiencies in the system and then proposed several concrete measures designed to overcome these. Lastress and Scerri (2013) suggest that the NRDS was drafted since there were systematic fault lines within South Africa's NSI that needed to be addressed. These systematic fault lines did not which play an integral role across the science and technology system which focused societally beneficial research and development in support of knowledge generation, human capacity development and innovation.

Furthermore, it was introduced as an innovation chasm which ensured that the gap between innovation and diffusion was addressed. The innovation chasm refers to the inability of academic research to reach the market as products and services.

The NRDS identified six key deficiencies that needed to be addressed. They were namely: South Africa spends far too little on R&D, increasing exposure to security risks, Human Resources: A declining scientific population, Declining R&D in the private sector, No policy framework for intellectual property and the Fragmentation of Government S&T.

There had been great concern that South Africa spent far too little on research and development. Kaplan (2004) makes the claim that direct comparison cannot be made with more developed countries. This is since, in comparison with other countries, South Africa has a higher share of activities, particularly in extractive industries, which have low levels of R&D intensity. However, equal emphasis should be placed on enhancing returns from R&D as increasing the quantum of R&D.

The Department of Trade and Industry (DTI) claimed that more should be done to promote the business sector. This is central to the manufacturing strategy, which is central to the DTI mandate, which places emphasis on the centrality of knowledge-based activities, including innovation as being critical to securing global competitiveness.

NRDS is concerned that there had been no policy framework for IP that arises from publicly funded research, which in turn generates considerable uncertainty and hampers productivity. Intellectual property made a significant contribution to wealth creation and had important beneficial implications for foreign trade and especially encouraging direct foreign trade and encouraging foreign direct investment. The NRDS also brought attention to the way in which S&T was managed by the government, most conspicuously the lack of coordination as different programmes as different parts of government drives their technology-intensive institutions and programmes. There was a system fragmentation, and a lack of oversight of the entire system is evident. Latress and Scerri (2013) add to this by stating that NRDS identified extensive fragmentation of R&D activity which was spread across state-owned corporations, science councils (performance and funding agencies), universities and domain-specific research organisations' capacities within the public sector with separate budgets and reporting systems.

According to the CSIR (2003), there should be increased funding, controls and mechanisms that are internal to the organisation are required to ensure that activities undertaken do indeed link with and reinforce the institution's S&T capacities. In essence, the NRDS stated categorically that the size, shape, and content of the system of government-owned and funded science and technology institutions and programmes should be aligned with the economic and social development strategies of government.

The NRDS (DST 2002) further encouraged private sector intervention where several new incentives and restructuring schemes were introduced to stimulate and facilitate private sector R&D. These included:

1. Tax incentives for R&D.
2. Provincial innovation initiatives (such as incubators to be run by the proposed foundation for technological innovation); and
3. Dedicated funding for global technology sourcing (aimed at small and medium firms complemented by information drives to expose local firms to new sources of technology).

c. *South Africa's Ten- Year Innovation Plan (2008)*

South Africa's Ten-Year Innovation Plan articulated a firm commitment to move S&T planning towards innovation and to shift the base of the economy from natural resources to a knowledge economy. It marked a decisive shift in the policy stance towards the development of the South African system of innovation. It identified the main constraints on the path to a knowledge-based system of innovation which were identified as the following:

1. Human capital development;
2. Low R&D level and intensities;
3. A poor knowledge infrastructure; and
4. Suboptimal levels of ancillary functions such as finances that impede the flow from R&D to innovation.

The plan provided priority areas for R&D support based on the contribution of these areas to the transformation and the development of a national system of innovation. The plan had an explicit vision for the South African National System of Innovation by 2018 which included the country being among the global top ten in terms of the pharmaceutical, nutraceutical, and bio-pesticide industries. It aimed to deploy satellites that provide a range of scientific, security and specialised services of the government and the public and private sector.

The ten-year innovation plan identified five great challenges which demanded a multi-disciplinary approach designed in the attempt to stimulate multidisciplinary interacion and to challenge our country's researchers. These challenges were supposed to tackle existing questions, create new disciplines, and develop new technologies, including:

1. The Farmer to Pharma value chain to strengthen the bio-economy;
2. Space science technology;
3. Energy security;
4. Global change science with a focus on climate change; and
5. Human and social dynamics.

The plan aimed to address the fragmentation of funding mechanism for STI by forming a separate entity, the technology innovation agency (TIA) as a special agency which incorporated among others the innovation fund and the biotechnology regional innovation centres. The TIA was established in 2008, and its brief is to enhance market opportunities in partnerships with industry and state research institutions. The TIA's broad objectives were listed as follows (DST, 2007:32):

1. Act as a complementary strategy that will provide funding and complementary services to bridge the gap between the formal knowledge base and the real economy;
2. Stimulate development of technology-based services and products;
3. Support development of technology base enterprises (both public and private);
4. Provide an intellectual property support platform; and
5. Stimulate investment (venture capital, foreign direct investment, etc.) and facilitate the development of human capital for innovation.

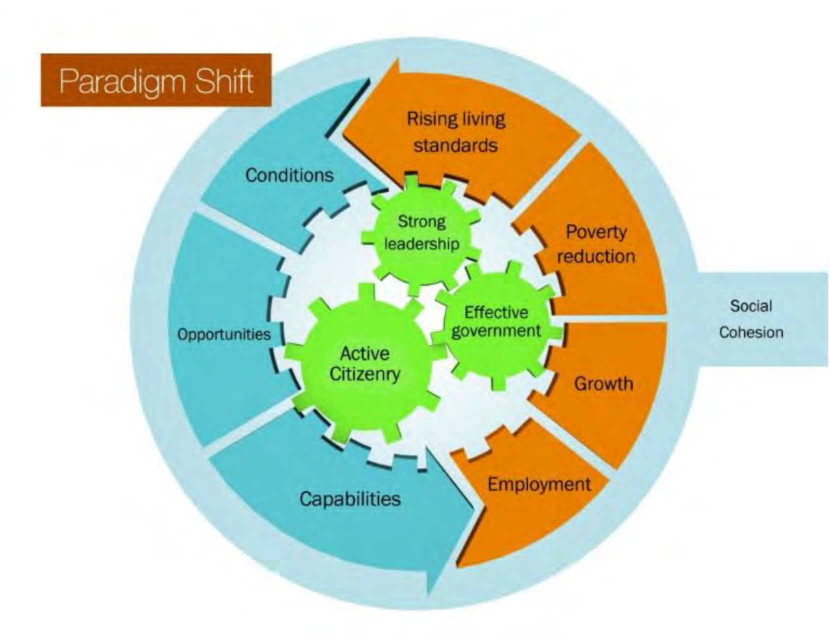
d. National Development Plan (2012-current)

The National Development Plan aims to eliminate poverty and reduce inequality by 2030 (NPC, 2012:14). Cele (2018:8) elaborates on this further by stating that innovation that addresses the triple challenge of inequality, poverty and unemployment enables all sectors of society to equitably access the knowledge infrastructure participate in creating and actualising innovation opportunities as well as enabling all individuals to share in the benefits of innovation to advance development goals. South Africa has realised these goals by drawing on the energies of its people, growing in an inclusive economy, building capabilities, enhancing the capability of the state, whilst promoting leadership and partnership throughout society. The plan focuses on the critical capabilities needed to transform the economy and society. Through the building of critical capabilities, South Africa can find ways to reduce alarming levels of youth unemployment, whilst providing young people with broader opportunities.

The plan draws extensively on the notion of capabilities. Key capabilities that emerge from development literature include (NCP, 2012:17)

i. Political freedoms and human rights;
ii. Social opportunities arising from education, health care, public transport and other public services;
iii. Social security and safety nets;
iv. An open society, transparency, disclosures, and culture of accountability; and
v. Economic facilities, work, consumption, exchange, investment, and production.

Figure 4.2 An approach to change



Source: National Planning Commission (2012:16)

Figure 4.2 demonstrates the close link between capabilities, opportunities, and employment on social and living conditions. The above figure illustrates how leadership, an active citizenry and active government can drive development in a socially cohesive environment. A developmental state builds the capabilities of people to improve their own lives while intervening to correct historical inequalities. Neither government nor the market can develop the necessary capabilities on their own.

Industrial Policy Action Plan (2018/19-2020/1)

The industrial policy action plan (IPAP), which has iterations since the National Industrial Policy Framework (NIPF) 2007aims to increase the economy's ability to produce more and more complex and high value-added products with greater efficiency. The objective of the IPAP is to ensure the building of the economy's industrial capabilities is a continuous and long-term endeavour as technology continuously evolves. Traditionally, industrial policy had placed emphasis on the manufacturing sector because of such spill-over effects and in terms of production disciplines, mastery of technology and ultimately design capabilities. Technology plays a huge role in industrial development within the IPAP as once developed, the industrial sectors bolster causing an increase in potential exports.

Theoretical application of public and innovation policy in South Africa

The national system of innovation framework in South Africa exposes the active role of the state. The alternative approaches to technology development which go beyond the neoclassical approach are evident throughout the different initiatives implemented in this economy. The endogenous growth theory becomes noticeable as education becomes the centre of public policy through namely the *National Research and Development Plan (2002-2007/8), South Africa's Ten-Year Innovation Plan and the National Development Plan (2012-current).*

The *NRDS* focused on repairing the faltering education system, which had been unable to provide the required flow of knowledge which qualified for higher education. This was done through the programmes which were aimed to increase the matric pass rate and the number of pupils taking science and mathematics. Following this, the South African *Ten-year Innovation Plan* articulated its firm commitment to move S&T planning towards innovation and to shift the base of the economy from natural resources to a knowledge economy. Furthermore, it marked a decisive shift in the policy stance towards the development of the South African innovation system. In addition, it identified the main constraints on the path to a knowledge-based system of innovation.

The *Industrial Policy Action Plan (2018/19-2020/1)* reveals aspects of the new trade theory and technology, where knowledge and technological spill-overs are key mechanisms that link international trade and the growth of new theories of trade. The theory of imperfect information and technology also becomes clear as the centrality of technology becomes core in the industrialisation process. Furthermore, this policy focuses on the idea of building economic and industrial capabilities whilst ensuring the competitiveness of sectors.

Alternative theories to technology and development are reflected through policy prescription which have argued for a much greater role of the state in technology and development. They have advocated for policy interventions which were industrial and trade policy. The White Paper on Science and Technology (1996) reflects an element of evolutionary approaches which ensure the nature and depth of institutions is robust in an NSI. It proposed a coordinating mechanism for all government departments, engineering, and technology institutions to facilitate and manage the process of evaluation and review created within this system. However, how this would happen in collaborative terms was not quite explicit throughout the implementation of policy.

The NDP and the STI policy package (consisting of the 1996 White paper, 2002 National Research and Development Strategy and the Ten- Year Innovation Plan) set out the framework for the establishment of the national system of innovation (NSI) based on the strong science and technology system. It aimed to promote STI as critical to long-term sustainable and inclusive socio-economic development, reducing poverty, unemployment, and inequality (Cele, 2018).

4.4 Comparative Synthesis

The policy documents of the BRICS economies outlined the individual policy prescriptions and initiatives that were taken by the BRICS countries in the attempt of implementing a functional NSI. All the countries reflect and expose the role of the state, however, at different degrees. There are elements of the embedded autonomy concept which are visible amongst the BRICS countries. However, when assessing the extent of "embedded autonomy" amongst the individual BRICS countries, it becomes clear that some of the countries "degree of state involvement" can be multifaceted. China and Brazil were "custodians" as their STI policies aimed at providing stimulus and incentives. In Brazil, China, India and South Africa, the state played the role of the producer. This implied the direct responsibility of delivering certain goods and services. China, Brazil, India and South Africa were also "midwifery and husbandry" as their policies focused on fostering relationships between state agencies and private entrepreneurial group.

All the BRICS countries revealed the idea of "shared responsibility" were their institutions not only had a clear and distinct role, but there were strong interactions between their scientific and educational institutions. Brazil, China, India, and South Africa have industrial and trade policies which ensure value added on goods, thus ensuring the competitiveness of the different sectors. The implementation of these policies was also articulated clearly through the different initiatives suggested in each policy. In contrast, the Russian Federation was not as explicit with its trade and industrial policies.

The finance policies of the different countries are interlinked to the education policies of the different countries. For instance, in Brazil, the financing policy was centred around the distribution of resources to municipalities to encourage them to invest in basic and secondary education. The same can be seen for India and the Russian Federation. Brazil also provided incentive mechanisms for firms to acquire access to credit. China restructured its financing system, which entailed a clear division of science and technology-related activities. Like this, South Africa aimed to rectify the fragmentation of the funding mechanism through the formation of the TIA and biotechnology regional centres.

When it comes to the effectiveness of implementation, China has the most successful NSI. The different phases of reform in China deal with different elements of constructing a NSI, whilst achieving developmental capabilities at the firm level and at a societal level. Similarly, this can be seen in the case of India and Brazil. South Africa has attempted to have a successful NSI from a policy prescription perspective, but its implementation is not as clear as the Chinese context. The extent and level of coordination amongst the different departments is not as clear as India, Brazil and China, and the Russian Federation does not seem to be effective in implementation, as there appears to be a lack of interdepartmental coordination.

4.5 Conclusion

This chapter evaluated the evolution of the NSIs within the BRICS bloc. The analysis of the evolution of the NSIs was done drawing from literature in Lastres and Scerri (2013). It then provided an in-depth review of the adoption of the NSI framework within the BRICS bloc. The objective of this section was to identify the implicit and explicit state policies on science and technology which have contributed to the formation of the NSI. The review of the adoption of the NSI framework provided a direct linkage of the theoretical elements mentioned in chapter two and three. Finally, the chapter presented a comparative synthesis which reflected policy prescriptions and other initiatives that have been taken by the BRICS economies in the attempt to implement their NSI policy framework.

CHAPTER 5: METHODOLOGY

5.1. Introduction

The purpose of this chapter is to focus on the methods of analysis and data collection that were employed to investigate whether the adoption of the national system of innovation in South Africa has facilitated development. The analysis is done from a comparative BRICS perspective. The first objective of the research is to provide an examination of the NSI and why it is the most useful conceptual tool in analysing technological development. Secondly, the study examines policies followed by South Africa in developing the South African NSI by comparison with other BRIC countries. Lastly, the study investigates whether technology development by means of an NSI has facilitated economic development over the past twenty-three years.

Section 4.2 defines and explains the research design that was used, underlining the different approaches of undertaking research. This section pays particular attention to the quantitative and qualitative methods that were employed throughout the research. Section 4.3 discusses content analysis that was used for the research. Section 4.4 examines the different forms of data analysis that were used in the research. These include a trend analysis, correlation analysis, unit root tests and regression analysis. Section 4.5 delineates the ethical aspects that were considered in undertaking the research.

5.2 Methods of Research

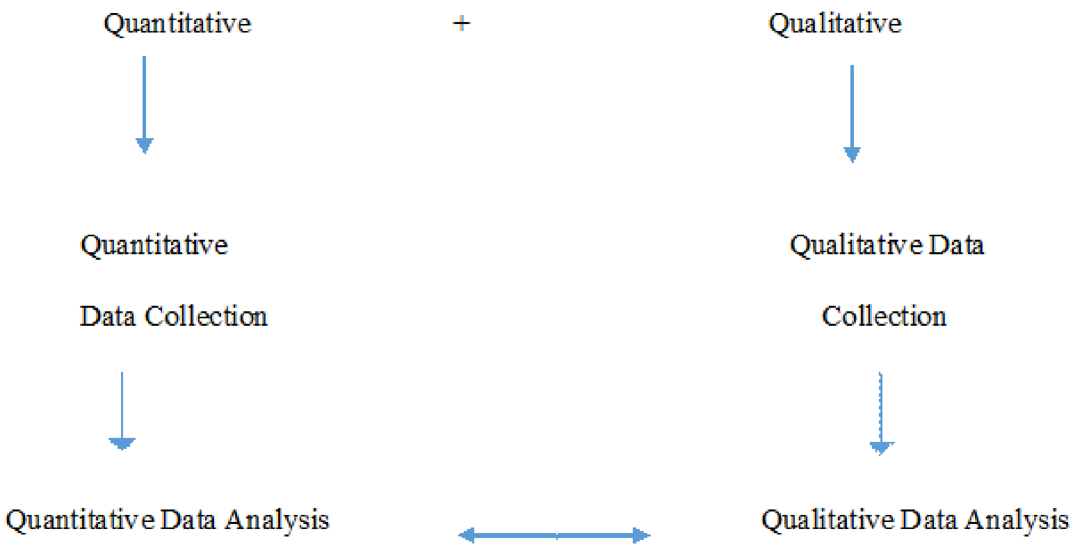
Research Methods

Creswell (2009:3) defined research design as "plans and procedures for research that span the decisions from broad assumptions to detailed methods of data collection". Bless *et al.* (2006:71) explain that research relates directly to the testing of a hypothesis. Furthermore, the research design is focused on the steps that are taken to demonstrate or test the validity of a particular hypothesis. In the context of this research, the hypothesis was to investigate whether a national system of innovation does contribute to development in South Africa from a comparative BRICS perspective.

This research used a post-positivist approach within a political economy framework. Ryan (2006) explained that the post-positivist approach has a meta-theoretical stance that critiques and amends positivism. Bryman (2006) defined positivism as an epistemological position that advocates the application of natural sciences to the study of social reality and beyond. This can also be understood as the researcher and the researched person or aspect being independent of one another. Fischer (1998) added to this by stating that post-positivists accept that the background knowledge and values of the researcher can influence what is being observed. The post-positivist approach took into consideration the possible effects of the biases that occurred in the research.

The method of concurrent triangulation was used throughout this study. Triangulation refers to the use of multiple methods or data sources in research to develop a comprehensive understanding of phenomena (Patton, 1999). To add to this definition, Creswell (1999) also stated that the mixed-method approaches refer to "an emergent methodology of research that advances the systematic integration or mixing of quantitative and qualitative data within a single investigation or sustained program of enquiry" (Creswell, 2009). The intentional use of the triangulation method was to overcome problems that might have emerged in the research, which pertained to bias and validity. The mixed-method approach allowed a better understanding of the proposed research problem, compared to using these methods separately.

Figure 5.1 The Concurrent Triangulation Strategy



Source: Cameron and Sankran (2015:1)

Figure 5.1 illustrates the concurrent triangulation strategy. The concurrent triangulation strategy has two concurrent data collection phases. Within this strategy, equal priority is given to both the qualitative and quantitative methods. Integration occurs at many levels, from data collection through to interpretation. Food Risc (2016) explained that triangulation allows one to identify aspects of the phenomena more accurately from different vantage points using different methods and techniques.

5.2.1 Qualitative method used in the research.

The qualitative aspect of this research was focused on a document study. The document content study was done through peer-reviewed publications which include the use of books, websites, policy documents, reports and newspaper articles that deal specifically with the economic policy evolution within the BRICS bloc. This method focused on the second objective of the research which constituted an examination of policies followed by South Africa by comparison with other BRIC countries in developing the South African NSI. The different public policies aimed at driving and stimulating innovation that were reviewed whilst taking into consideration key macroeconomic, fiscal, and monetary policies that economic growth, broader economic development, and international competitiveness were namely:

Table 5. 1 Policy documents for BRICS Bloc

Country	Name of policy	Year implemented
Brazil	Law of National Education Guideline	1996
	Industrial, Technologies and Foreign Trade Policies (PITCE)	2003
	Policy for Production and Development	2006 to current
	Plan for development of Education	2006 to current
China	National Medium and Long-Term Strategic Plan	1998 to cujrrent
India	India Science and Technology policy statement	2003 to current
Russian Federation	Innovation and Development Strategy	
South Africa	White Paper on Science and Technology	1996 to current
	The National Research and Development	2002 to 2007 /8
	Soutgh Africa's Ten-Year Innovation Plan	2008
	National Develolpment Plan	2012
	Industial Policy Action Plan 2018/19	2019

Source: own composition

5.2.2 Quantitative method used in the research.

a. Graphical Trend Analysis

Hayes (2019) refers to trend analysis as a technique that is used to predict the future movements of performance indicators based on recently observed trend data. Pertaining to this research, the trend analysis was used to indicate the trajectory of performance indicators.

The trend analysis is two-fold. The first part of the graphical trend analysis was done from a comparative BRICS perspective, whilst the second part looked at specifically South African related indicators. The data for the comparative perspective was sourced from different data sources such as the World Bank, United Nations Development Programme (UNDP), social progress imperative and the world intellectual property organisation. These data sources provided aggregated data for the different BRICS countries. The period that was used for the data was 2000 to 2018 for the world bank data, 2015 and 2019 for the social progress imperative data, 2000 to 2019 for the UNDP data and finally 2011 to 2019 for the WIPO data. These different periods were due to data availability.

The analysis that was specific to the South African context was sourced from the Human Sciences Research Council (HSRC). The decision to use HSRC data was that it provided disaggregated data for South Africa. The period that was used for the data was 2004 to 2018 as this is when the data was available. However, the data starts from 2001/2 but there was no data available for 2002/3 and then it resumed with the 2003/4 data. The following indicators were used to do the trend analysis.

Table 5. 2 Variables for comparative trend analysis

Indicators/Variable	Period	Source
Research and Development Expenditure	2000 to 2018	World Bank (WB)
Scientific and Technical Journals	2000 to 2018	World Bank (WB)
Researchers (per million people)	2000 to 2018	World Bank (WB)
Social Progress Index	2015 and 2019	Social Progress Imperative (SPI)
Human Development Index	2000 to 2019	United Nations Development Programme (UNDP)
Global Innovation Index	2011 to 2020	World Intellectual Property Organisation

Source: Own Composition

Table 5. 3 Variables for disaggregated South Africa trend analysis

Indicators/ Variable	Period	Source
Total Research (applied, experimental and basic) and HDI	2004 to 2018	HSRC
Total Researchers (Business, Government, NPOs, Scientific Councils and HEIs) and publications	2004 to 2018	HSRC
Receipts, Payments and high- tech exports % of manufactured exports	2004 to 2018	HSRC
Receipts, Payments and registered patents	2004 to 2018	HSRC
GDP per capita in constant LCU and HDI	2004 to 2018	HSRC

Source: own composition

b. Correlation Analysis

Gujarati and Porter (2010) state that correlation analysis measures the strength or degree of linear association between two variables. The correlation coefficient measures the strength of linear association but does not establish causation. In addition to this, in correlation analysis, the two variables are treated symmetrically as there is no distinction between the dependant and explanatory variables. The correlation analysis was run through STATA, where the p-values indicated the reliability of the estimates. The correlation was done for the sample 2013-2018. The correlation analysis was done for South Africa. In the context of this research, the correlation analysis was used for two reasons. The first was to assess the interaction dynamism in the NSI. Secondly, it was used to evaluate the linkages between innovation and development.

The p-value was used to evaluate the significance of correlation coefficients. The p-value was used as it measured the precision of the estimates. The period that was used for the data was 2004 to 2018 as this is when the data was available. However, the data starts from 2001/2 but there was no data available for 2002/3 and then it resumed with the 2003/4 data.

Table 5. 4 Variables for Correlation Analysis

Variable	Source
Human Development Index	HSRC
Gross Domestic Product per Capita	World Bank
Patents	HSRC
Basic Research	HSRC
Applied Research	HSRC
Experimental Research	HSRC
Researchers	HSRC
Technicians	HSRC
Research and Development	HSRC

Source: own composition

d. Unit root tests

Unit root tests were conducted using the Phillips-Perron test. According to, Gujarati (2011), the Phillips-Perron test is a unit root test. It is used in time-series to test the null hypothesis that a time-series is integrated of order. This test builds on the Dickey-Fuller test of the null hypothesis in where the first difference operator is. Like the augmented Dickey-Fuller test, the Phillips-Perron test addressed the issue that the process generating data may have a higher order of autocorrelation than is admitted in the test equation making it endogenous and thus invalidating the Dickey-Fuller test.

The Dickey-Fuller test addresses this issue by introducing lags as regressors in the test equation, whilst the Phillips-Perron test makes a non-parametric correction to the t-test statistic. The test is robust with respect to unspecified autocorrelation and heteroscedasticity in the disturbance process of the test equation.

e. Regression Analysis

Regression analysis "is concerned with the study of the dependence of one variable, the dependent variable, on one or more other variables the explanatory variables, with the view to estimating and/or predicting the mean or average value of the former in terms of the known or fixed values of the latter" (Gujarati and Porter, 2009:15).

Economic theory suggests that innovation impacts development with a lag. It takes some time lag from basic research to be transformed into applied and experimental research. This means that R&D expenditures also impact innovation outputs like patents with a lag, which in turn impact development with a lag. Using R&D expenditure as a proxy for innovation or using registered patents, still requires one to control for lags. As such, an Autoregressive Distributed Lag (ARDL) model is a suitable modelling framework, which is also flexible because variables only need to be integrated of order zero and one. A mixture of these orders of integration allows for the testing of the existence of a long run relationship. The following ARDL models were estimated as part of testing the link between innovation and development and the link between innovation and R&D expenditure.

$$\Delta lnpatents_t = \beta_{10} + \sum_{p=1}^{j} \beta_{11}^{p} \Delta lnpatents_{t-p} + \sum_{p=1}^{j} \beta_{12}^{p} \Delta lnbasic_{t-p} + \sum_{p=1}^{j} \beta_{13}^{p} \Delta lnapplied_{t-p} + \sum_{p=1}^{j} \beta_{14}^{p} \Delta lnexperimental_{t-p} + \theta_1 ECT_{t-1} + \mu_{1t} \quad (1)$$

$$\Delta lngdppc_t = \beta_{20} + \sum_{p=1}^{j} \beta_{21}^{p} \Delta lngdppc_{t-p} + \sum_{p=1}^{j} \beta_{22}^{p} \Delta lnbasic_{t-p} + \sum_{p=1}^{j} \beta_{23}^{p} \Delta lnapplied_{t-p} + \sum_{p=1}^{j} \beta_{24}^{p} \Delta lnexperimental_{t-p} + \theta_2 ECT_{t-1} + \mu_{2t} \quad (2)$$

$$\Delta lnhdi_t = \beta_{30} + \sum_{p=1}^{j} \beta_{31}^{p} \Delta lnhdi_{t-p} + \sum_{p=1}^{j} \beta_{32}^{p} \Delta lnbasic_{t-p} + \sum_{p=1}^{j} \beta_{33}^{p} \Delta lnapplied_{t-p} + \sum_{p=1}^{j} \beta_{34}^{p} \Delta lnexperimental_{t-p} + \theta_3 ECT_{t-1} + \mu_{3t} \quad (3)$$

$$\Delta lngdppc_t = \beta_{40} + \sum_{p=1}^{j} \beta_{41}^{p} \Delta lngdppc_{t-p} + \sum_{p=1}^{j} \beta_{42}^{p} \Delta lnpatents_{t-p} + \theta_4 ECT_{t-1} + \mu_{4t} \quad (4)$$

$$\Delta lnhdi_t = \beta_{50} + \sum_{p=1}^{j} \beta_{51}^{p} \Delta lnhdi_{t-p} + \sum_{p=1}^{j} \beta_{52}^{p} \Delta lnpatents_{t-p} + \theta_5 ECT_{t-1} + \mu_{5t} \quad (5)$$

In equations (1) to (5), p is a lag ranging from 1 to j. The lag structure is not necessarily uniform across all variables in the model. The actual structure is determined empirically using the Schwarz Information Criterion (SIC). In the equations, β_{ik}^{p} are short run coefficients and $\theta_1, \dots, \theta_5$ are speed of adjustment to the long run and for a long run relationship to exist they must satisfy $-2 < \theta_i < 0$. ECT is the error correction term. The residual terms $\mu_{1t} \dots \mu_{5t}$ are assumed to be normally and identically distributed. Equation (1) tests the performance of the NSI in terms of the link between R&D expenditure and innovation. Equations (2) to (5) are various specifications for testing the link between innovation and development. The bounds test for cointegration was applied in each case.

5.3 Content Analysis

Content analysis is the research method which allowed qualitative data collected in the research to be analysed and systematically and reliably so that generalisations can be made from them in relation to categories of interest in relation to the researcher (Haggarty, 2009). As mentioned in section 5.2.2.1 the content analysis was carried out through peer reviewed publications which include the use of books, websites, and newspaper articles. The content analysis addressed the second objective which was to examine policies followed by South Africa in developing the South African NSI by comparison with other BRIC countries.

There was peer reviewed literature that discussed the different public and innovation policies as most of the initiatives and policies that were taken to implement innovation policy were in the respective BRICS member country languages, which the researcher could not read. This was a limitation to the research as at times it was not easy to gauge the main themes and similarities of the different policies.

5.5 Ethical Consideration

When conducting this research, important ethical standards had to be adhered to throughout the research process. Pera and Van Tonder (1996:4) define ethics as a code of conduct or behaviour considered correct in research. The documents relating to this research were publicly available and the data collected were from secondary sources. Despite the overarching ethical considerations inherent in research, there were no ethical problems that were encountered, due to the public nature of the data in this research. An in-depth discussion of the various ethical considerations is, therefore, not warranted for this project.

5.6 Conclusion

The chapter outlined the research methodology used throughout the dissertation. The research involved a comparative analysis and various data collection and analysis methods of a qualitative and quantitative nature. The research focus was on a comparative analysis of the role of an NSI in South Africa and other BRIC countries. The qualitative method was primarily focused on a document content study which laid the foundation for the quantitative method. The quantitative method focused on a graphical trend, correlation, and regression analysis. Thematic analysis was then used to trace the patterns within the findings from the data collection. Finally, the chapter noted the ethical considerations which were necessary to satisfy the requirements of research.

In essence, this chapter outlined the methods that were used to address the different objectives of the study. Firstly, the policy study/content analysis was useful in the examination policies followed by South Africa by comparison with other BRIC countries in developing the South African NSI. Secondly, the graphical trend, correlation and regression analysis assisted with the investigated whether technology development by the means of an NSI has facilitated economic development over the past twenty-three years Jointly, these methods were used to make policy assessments on how South Africa’s NSI can be developed to ensure the prospect of development in South Africa.

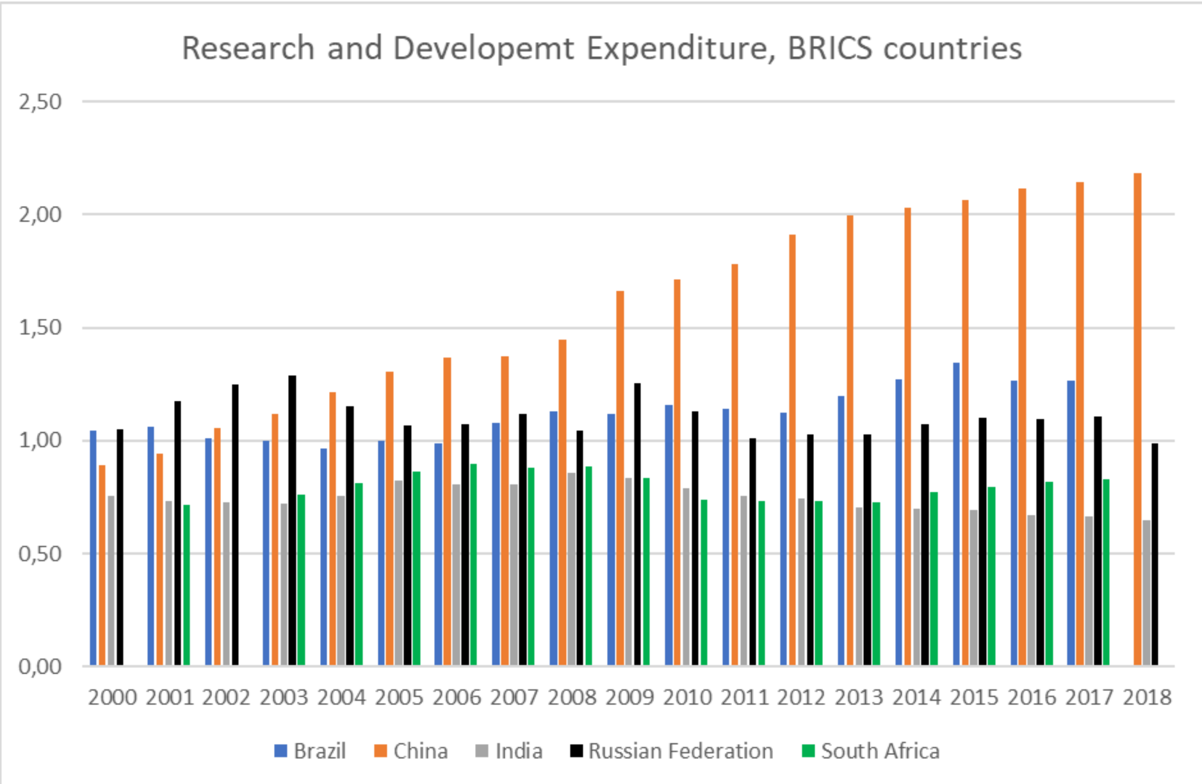
CHAPTER 6: PERFORMANCE INDICATORS

6.1 Introduction

The purpose of this chapter is to address the third and final objective of the research, which is to investigate whether technology development by the means of an NSI has facilitated development over the past twenty-three years. Section 6.2 reviews trends of various input and output indicators and link them to policy changes that took place in the respective countries. The trend analysis is two-fold as it was done through a comparative BRICS perspective using aggregated data and disaggregated data from a country specific context. Section 6.3 focuses on a correlation analysis which assesses the interaction dynamism in the NSI, whilst evaluating the links between innovation and development. Section 6.3 includes the regression analysis which consists of the Bounds test for Co-integration and the Parsimonius ARDL regression models.

6.2 Performance Indicators

Figure 6. 1 Research and Development Expenditure for BRICS countries

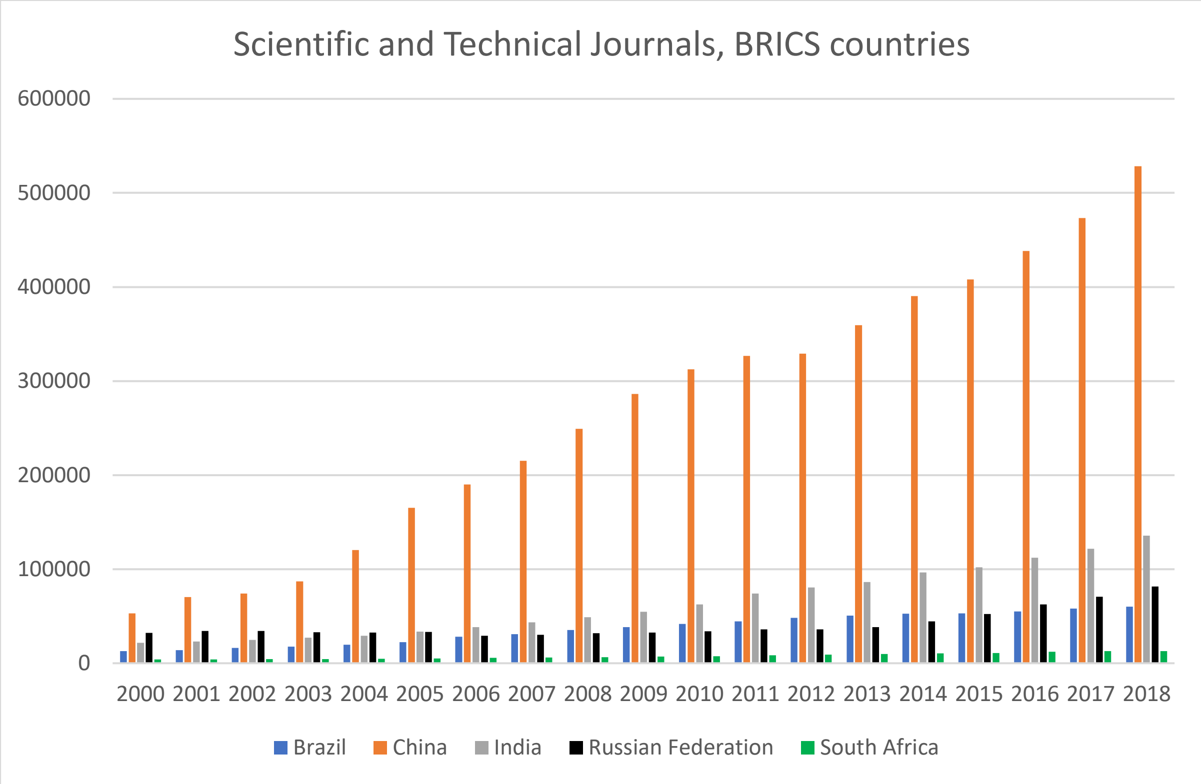


Source: World Bank

Figure 6.1 demonstrates that in the BRICS bloc, China and Brazil have considerably increased their allocation of resources towards R&D, with China pending outstandingly high amounts. Russia, India, and South Africa tend to have stable allocations of resources towards R&D

although there was a significant slump in R&D expenditure following the global financial crisis. For example, Brazil is regarded as a social investment state, while China is a developmental state: this means the state plays an extraordinarily strong coordinative and financing role in the NSI. The gradual peak in R&D expenditure in China can be attributed to the first (1985 to 1992) and second (I992 to 1998) phases of reform that occurred in China. The first phase of reform attempted to restructure the financing system and governance on scientific research institutions, whilst acquiring multiple sources of financing. This phase of reform warranted that scientific research institutions received funding if they were involved in technological development. Once, the financing around the scientific institutions had been secured the second phase of reform strengthened the depth of scientific research institutions. This explains why Brazil and China stand out, more so China.

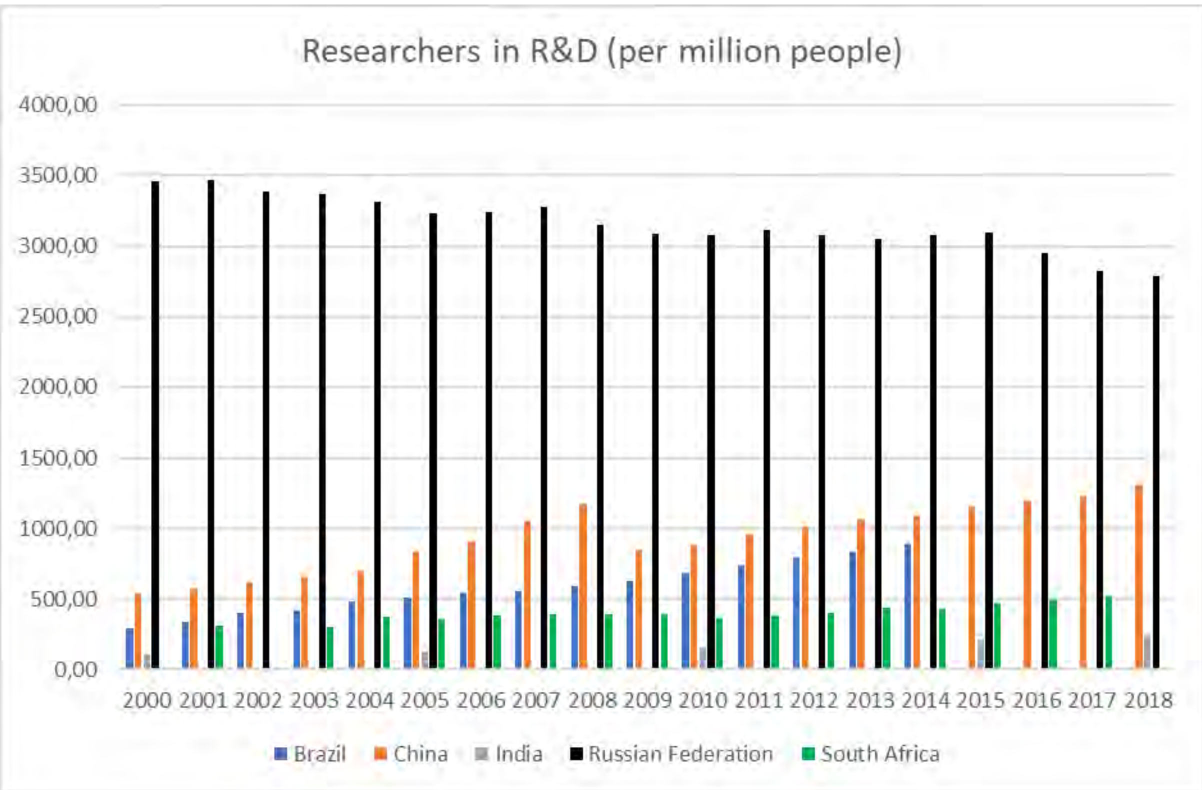
Figure 6. 2 Scientific and Technical Journals for BRICS countries



Source: World Bank

Figure 6.2 illustrates that in the year 2000, South Africa had the lowest Scientific and technical journals whilst China had the highest scientific and technical journals. During the period 2000 to 2018, there was a sharp increase in the number of scientific and technical journals for China The increase in the number of scientific and technical journals for China may be attributed to the increased expenditure in research and development (Figure 6.1). the sharp peak in the number of science and technical journals may be ascribed by the first two phases of reform that have occurred in China. As discussed in the previous chart, the peak in the number of scientific and technical journals suggests that an increase in research and expenditure can potentially increase innovation outputs such as scientific and technical journals.

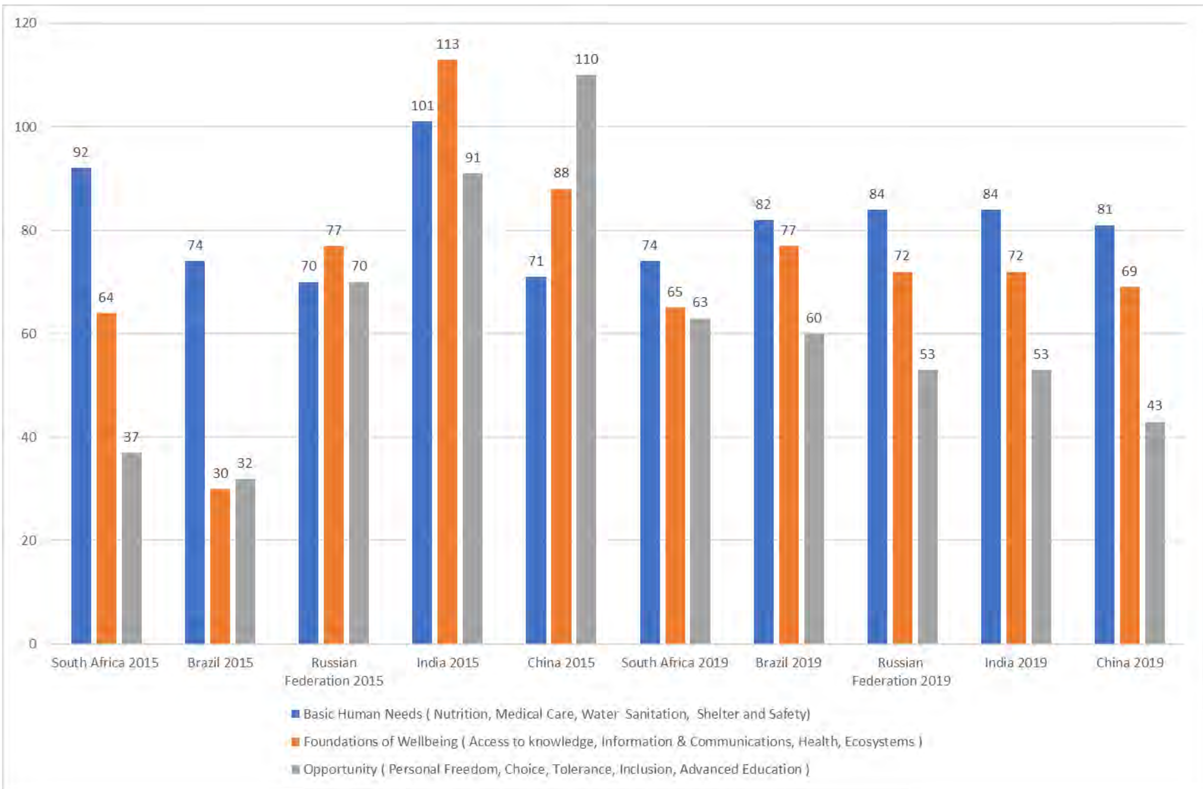
Figure 6. 3 Researcher in R&D (per million people)



Source: World Bank

Figure 6.3 illustrates that in the year 2000, India had the lowest researchers per million people while the Russian Federation had the most researchers per million people. From the year 2000 to 2008, the number of researchers per million people in China increased from 538 researchers in R&D (per million people) to 1176 researchers in R&D (per million people) respectively. This was almost double the number of researchers from the year 2000. The expenditure in R&D (Figure 6.1) does not influence the number of researchers in research and development (per million people), however innovation outputs, such as scientific and technical journals (Figure 6.2) are more consistent with the increase of the number of researchers in R&D per million people.

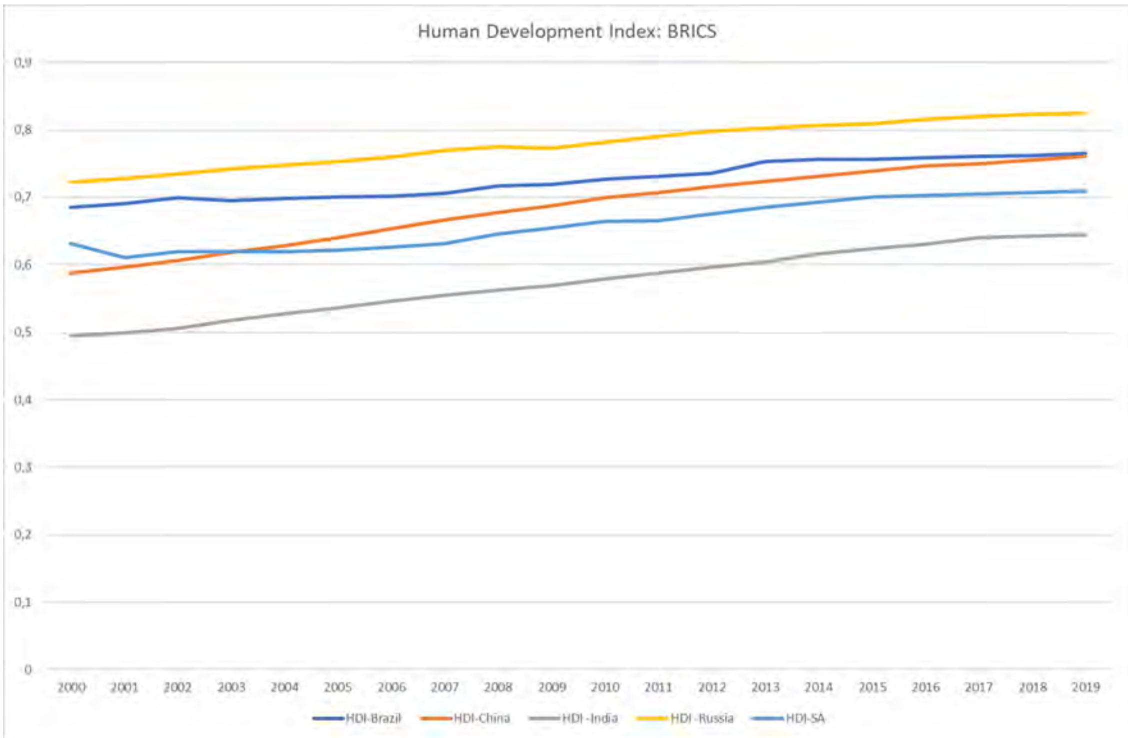
Figure 6. 4 Social Progress Index



Source: Social Progress Imperative

Figure 6.4 illustrates the social progress index for the different countries. The social progress index measures the extent to which countries provide for the social and environmental needs of its citizens. The components of the SPI are namely, basic human needs, foundations, and opportunity to progress. For Brazil, all three components of the SPI improved. The South Africa SPI reveals that the grey and amber bars increased in 2019 relative to 2015 although the other two components showed a decline.

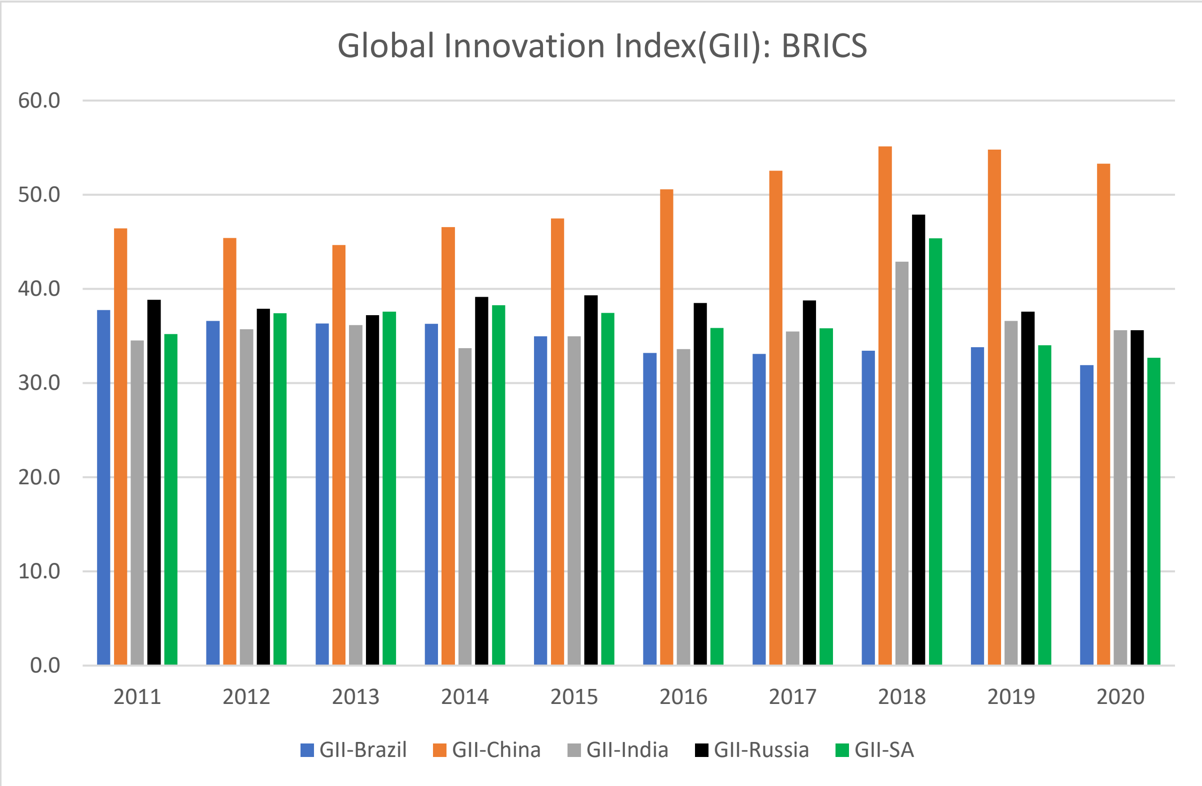
Figure 6. 5 Human Development Index



Source: United Development Programme

Figure 6.5 illustrates that India had the lowest (0,49) HDI at the start of the period. However, the HDI for India gradually increased from 2000 to 2019. Conversely, the Russian Federation had the highest (0,72) HDI at the start of the period. The HDI for the Russian Federation continued to increase throughout the period. Intriguingly, the HDI for China (0,58) was low at the start of the period however from the year 2017 to 2019 it started to intersect with the HDI for Brazil. The way the Chinese HDI is catching up that of better performing countries in human development terms in the BRICS reflects the prediction of the conditional growth convergence hypothesis. While the hypothesis is applied to the catch-up process in growth economics, the inference is logical here because improvement in innovation, improves growth in a sustained manner, the outcome of which is higher levels of human development. Put differently, it can be stated that countries that start with lower levels of human development tend to experience faster catch up with better performing courtiers once innovation begins to impact their growth and development outcomes.

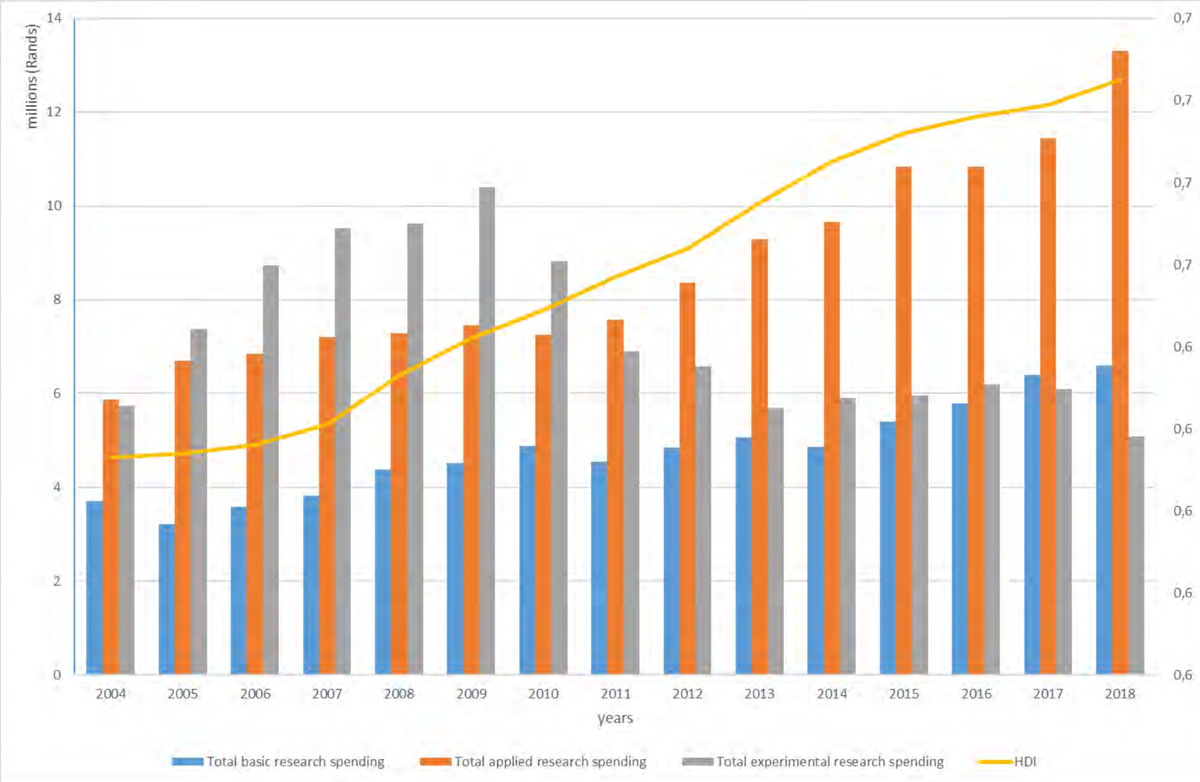
Figure 6. 6 Global Innovation Index (GII)



Source: World Intellectual Property Organisation

The GII was the highest for China in the period 2011-2018 amongst the BRICS grouping. India on the other hand, had the lowest GII compared to the other BRICS countries.

Figure 6. 7 Total Research (applied, experimental and basic) and Human Development Index for South Africa, 2004-2018



Source: Human Science Research Council

Figure 6.7 demonstrates that South Africa had the highest expenditure on the total experimental research in 2009 and experienced the lowest expenditure on total experimental research in 2018. The lowest expenditure on total applied research was clear in 2004, however gradually increased between 2004 and 2014. The increase in total applied research can be accredited to the implementation of the National Research and Development Strategy (NRDS). As discussed in the BRICS context chapter (chapter 4), the NRDS aimed to identify the key weaknesses and deficiencies in the system and then proposed several concrete measures which were designed to overcome these. This resulted in the increased expenditure in the basic, experimental, and applied research. This resulted in an increase in the human development index (HDI) as total applied research and total experimental research experienced an increase from 2004 to 2018. The increase in the HDI throughout this period was largely ascribed to the increased spending. There has been a sharp and sustained increase in applied R&D, but this seems to have come at the expense of sharp and sustained decrease in experimental R&D. Countries that do well in innovation tend to spend more on experimental research. Then you introduce issues of global financial crises, animal spirits, policy changes etc. This has resulted in a positive correlation between expenditure on applied research and HDI.

Figure 6. 8 Total researchers (business, government, NPOs, Scientific Council and HEIs) and publications

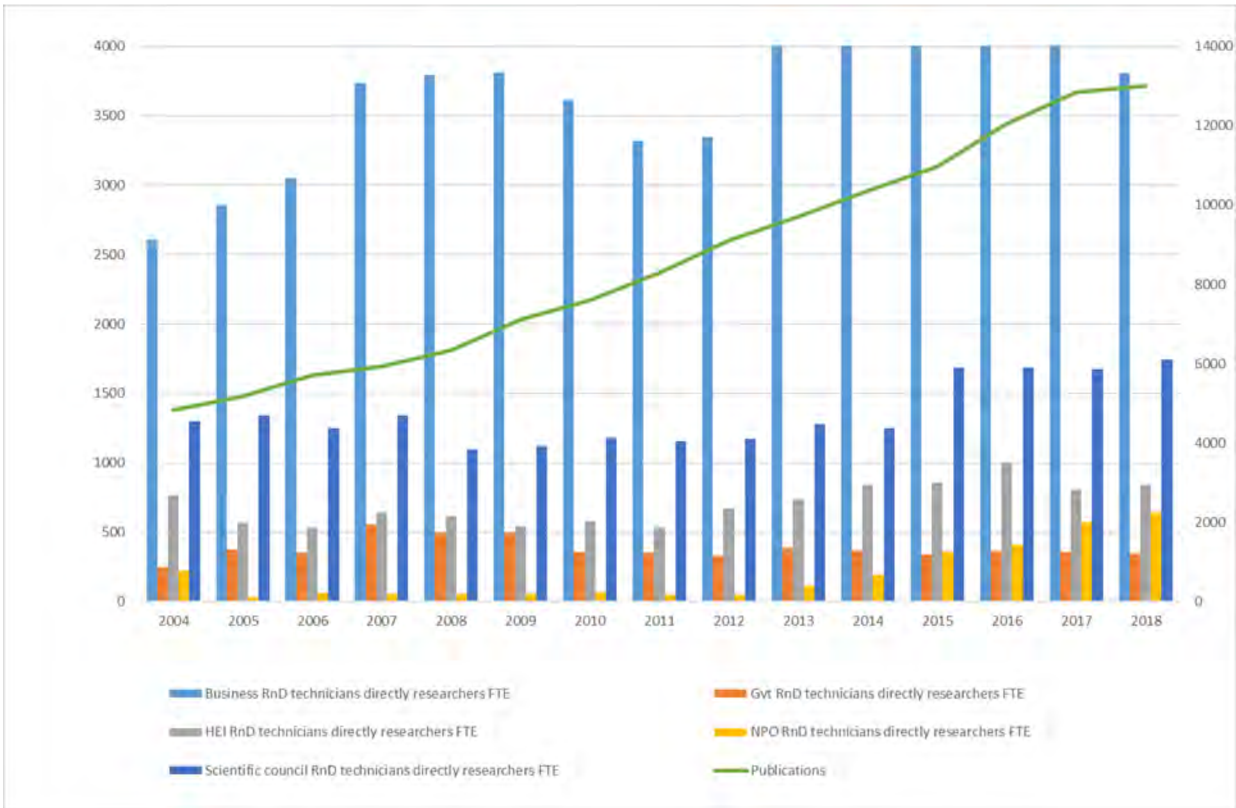


Figure 6.8 demonstrates that the number of business R&D technicians' researchers was the highest r-relative to other R&D technicians researchers throughout the period 2004 to 2018. From 2014 to 2018 the number of researchers remained unchanged. The number of NPO R&D technicians' researchers was the lowest compared to the other total researchers throughout the period. This was interesting as the NDRS (DASCT, 2002) identified the extensive fragmentation of R&D activity which was spread across state-owned corporations, science councils (performance and funding agencies), universities, non-profit organisations, and domain specific research organisations' capacities within the public sectors. This resulted to a gradual increase in the number of publications from 2004 to 2018.

Figure 6. 9 Intellectual Property (receipts and payments) and high-tech exports % of manufactured goods

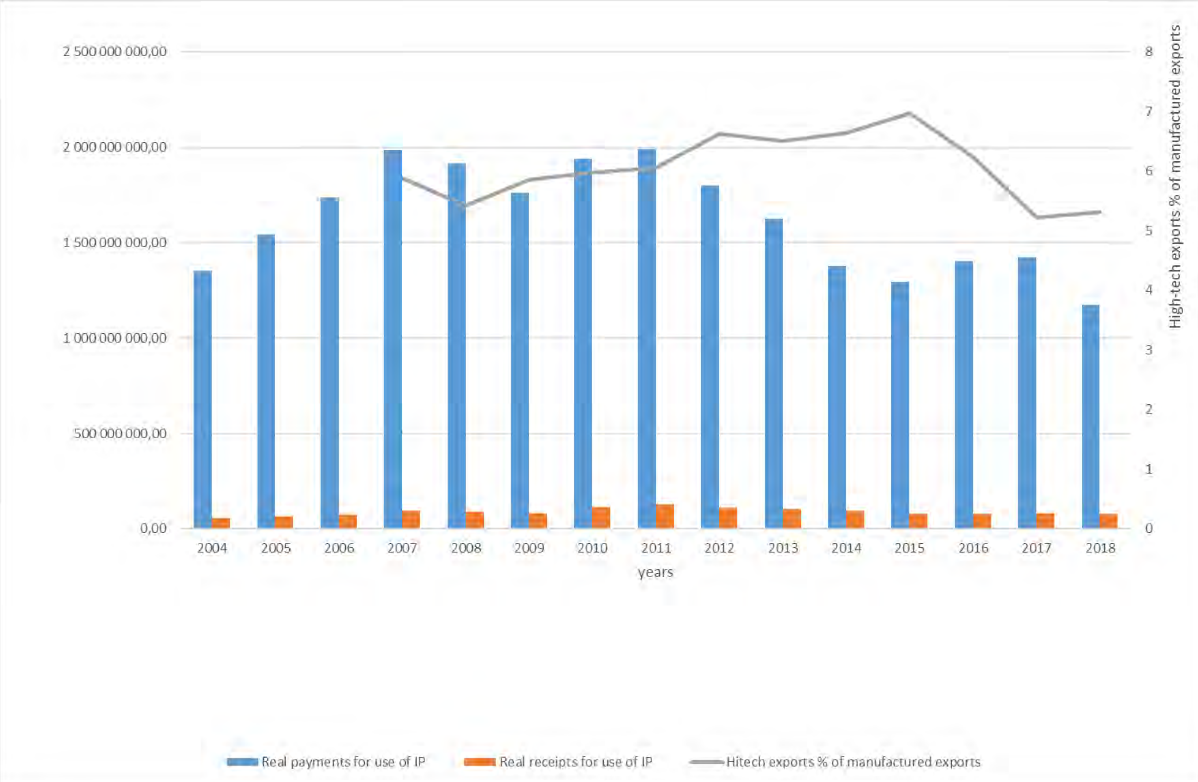


Figure 6.9 illustrates an increase in the payments for use of intellectual property (IP) from 2004 to 2007. After 2007, there was a dip in the payment for the use of IP. The decline in the use of IP caused a decline in the high-tech exports % of manufactured goods. The recovery of the increase payments of IP use caused the high-tech exports % of manufactured goods which continued to increase from 2009 up until 2015. In 2016, there was a drop in the high-tech exports % of manufactured goods which further exacerbated up until 2018.

Figure 6. 10 Intellectual Property (receipts and payments) and registered patents

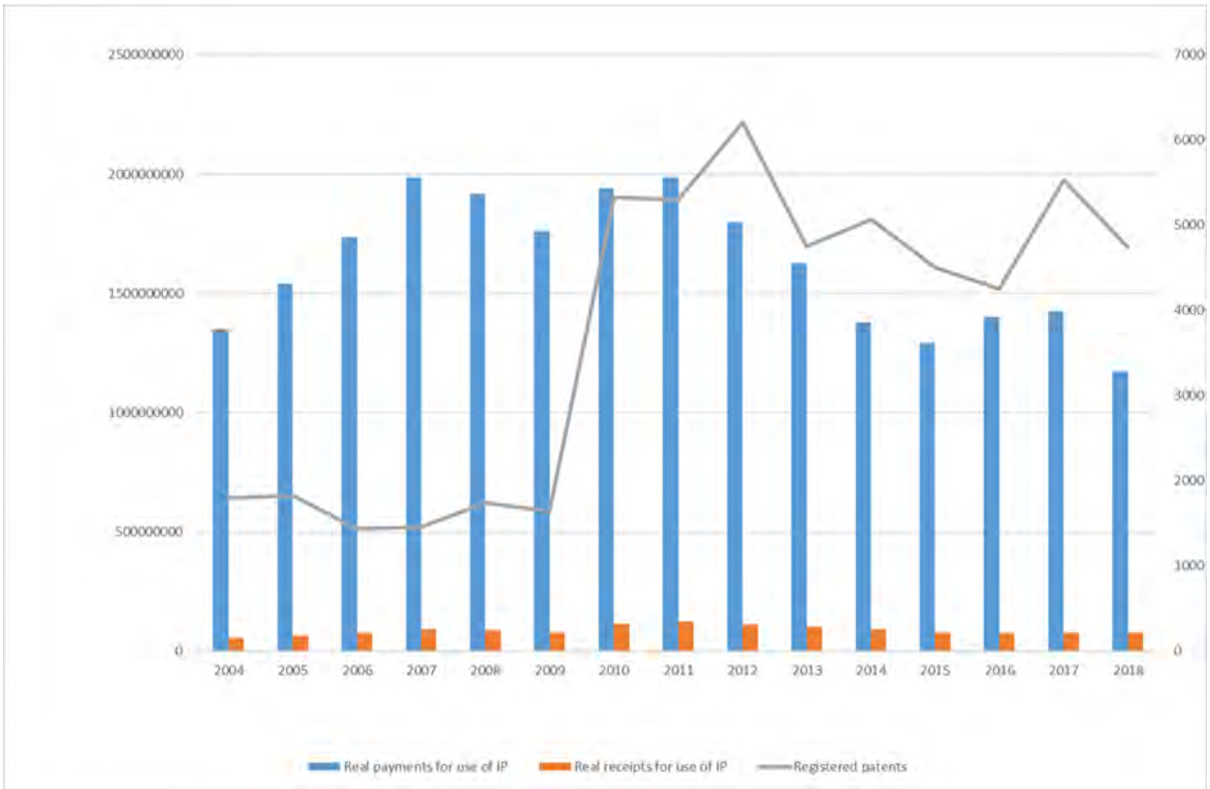


Figure 6.10 shows that the receipts for use of IP were low and stable throughout the period 2004 to 2018. As discussed in the previous graph (Figure 6.3), 2007 was the year where there were the highest payments for the use of IP. Although this year reflected the highest payments for the use of IP, this year revealed the lowest registered patents. There was a sharp peak in registered patents in 2009 to 2010 accompanied by a further peak in 2011 to 2012. Unfortunately, this peak was followed by a sharp decline in 2014 which continued up until 2016. In 2017, there was a sharp peak in the registered payments and the payments for the use of IP remained consistent from 2013 to 2018.

6.3 Correlation Analysis

(see Appendix A)

Overall, the correlation matrix shows statistically significant positive linear associations between various NSI indicators and human development. For example, the correlation between human development index (HDI) and basic research is positive (0.9825). From a theoretical standpointendogenous growth theory predicts a positive relationship between human development and basic research. This suggests that the innovation benefits are trickling down to the general citizenry thus increasing human development.

6.4 Unit Root Tests

(see Appendix B)

Table 6. 1 Phillips-Peron unit root tests

	Levels		**First difference**		**Second difference**	**Order of integration**
Variable	drift	drift & trend	drift	drift & trend	drift	
lnbasic	0.055	-2.614§		-4,922***		One
lnapplied	0,371**	-1,938	-3,903***			One
lnexperimental	-4,047***	-2.987				Zero
lnpatents	-1.201	-1.788	-3.935**			One
lnGDPPC	-12,551***	-5.392***				Zero
lnHDI	-0.101	-2.197	-2.303		-2.380	-
lncapex	-1.562	-2.529	-4.739***			One
lnlabour	-0.936	-3.272§		-8.479***		One
lnother	-1.242	-2.067	-3.934**			One

means p<0.10; ** means p<0.05 and *** means p<0.01.

Source: Own composition

According to Table 6.2, all variables meet the I (0) and I (1) mix of orders of integration required for estimating an ARDL model. However, lnHDI is not stationary even after the second difference. As a result, the study did not use it in regression analysis.

6.5 Regression Analysis

Table 6. 2 Bounds test for cointegration.

Model	F	Level of significance	Lower bound	Upper bound
lngdppct (1, 2, 2, 0)	11.414***	5% 1%	3.23 4.29	4.35 5.61
lngdppc(3, 3)	63.680***	5% 1%	4.94 6.84	5.73 7.84
lnpatents(2, 2, 2, 2)	9.096***	5% 1%	3.23 4.29	4.35 5.61
lnpatents(2, 2, 0, 1)	16.962***	5% 1%	3.23 4.29	4.35 5.61

Source: Own Composition

Table 6.3 shows that there are cointegrating relationships for the various model specifications set up to test the link between development and innovation outputs and inputs other one hand, and between innovation outputs and inputs on the other. This means that error correction models within the ARDL framework can be estimated.

Table 6. 3 Parsimonious ARDL regression models

	$\Delta lngdppc_t$ ARDL(1,2,2,0)	$\Delta lngdppc_t$ ARDL(3, 3)	$\Delta lnpatents_t$ ARDL(2, 2, 2, 2)	$\Delta lnPatents_t$ ARDL(2, 2, 0, 1)
Constant	4.844*** (0.539)	8.985*** (0.712)	-7.741* (0.762)	1.108*** (0.095)
$\Delta lngdppc_{t-1}$		0.799*** (0.078)		
$\Delta lngdppc_{t-2}$		0.313** (0.102)		
$\Delta lnpatents_t$		0.053*** (0.004)		-0.840*** (0.107)
$\Delta lnpatents_{t-1}$		-0.011** (0.003)	-0.752** (0.029)	
$\Delta lnpatents_{t-2}$		-0.026*** (0.003)		
$\Delta lnbasic_t$			-0.213 (0.205)	
$\Delta lnbasic_{t-1}$	0.146** (0.032)		-1.406** (0.108)	
$\Delta lnbasic_{t-2}$	0.084* (0.032)			
$\Delta lnapplied_t$	-0.205** (0.045)		-4.525** (0.231)	
$\Delta lnapplied_{t-1}$	-0.223** (0.049)		-3.229** (0.238)	

$\Delta lnexperimental_t$			-2.150** (0.083)	
$\Delta lnexperimental_{t-1}$			-0.589 (0.095)	
$\Delta lnrndcapex_t$				0.441** (0.154)
$\Delta lnrndcapex_{t-1}$				-1.801*** (0.238)
$\Delta lnothercosts_t$				-1.928*** (0.254)
ECT_{t-1}	-0.165*** (0.018)	-0.866*** (0.069)	-0.216* (0.018)	-0.442*** (0.041)
R^2	0.940	0.986	0.999	0.960
F	21.781 (p=0.000)	57.464 (p=0.000)	333.612 (p=0.000)	33.470 (0.000)
Jarque-Bera normality test	1.476 (p=0.478)	2.364 (p=0.307)	0.589 (p=0.745)	2.418 (p=0.299)
Serial correlation test	10.311 (p=0.006)	8.877 (p=0.012	indeterminate	3.895 (p=0.143)
CUSUM 95%	Stable	Stable	Stable	Stable
CUSUM squared 95%	stabile	stable	Stable	Unstable

Source: Own Composition

Table 6.3 shows that, taken as a block, short run changes in number of patents registered have a causal effect on development as measured by GDP per capital. Taken together, short run changes in R&D expenditure on basic research have a causal influence on development. However, there is a limitation of a small sample, which affects the reliability of some of the estimates. However, the results are indicative and must be interpreted with care.

Furthermore, Table 6.3 shows that about 16.5% of the deviation of gdppc from its long run relationship with R&D expenditures in the previous year is corrected in the current year. In addition to this, 86.6% of the deviation of gdppc from its long run relationship with registered patents in the previous year is corrected in the current year. Furthermore about 21.6% of the deviation of registered patents from its long run relationship with R&D expenditures in the previous year is corrected in the current year. Lastly, 44.2% of the deviation of registered patents from its long run relationship with capital expenditure, labour costs and other costs in the previous year is corrected in the current year.

6.4 Conclusion

In essence this chapter addressed the third and final objective of the research, which was to investigate whether technology development by the means of an NSI has facilitated development over the past twenty-three years. It showed that changes in R&D expenditure on basic research have a causal influence on development. It revealed that the catch-up process in growth economics, the inference is logical here because improvement in innovation, improves growth in a sustained manner, the outcome of which is higher levels of human development. The correlation analysis showed statistically significant positive linear associations between various NSI indicators and human development.

CHAPTER 7: CONCLUSION

7.1 Introduction

The purpose of this chapter is to provide an understanding of the research and the results thereof. Section 7.2 shed light on the objectives of the research, whilst highlighting the major findings of the research. The major findings of the research will then provide an analysis of the implications for theory, methodology and policy.

7.2 Discussion

The main goal of this research was to investigate whether the adoption of a national system of innovation has helped facilitate development in South Africa from a comparative BRICS perspective. Khan and Blankley (2009) have argued that there would need to be restructuring amongst institutions to change the circumstances facing the key players in the national system of innovation. Brooks and Oerlemans (2014) took this further by suggesting that the number of innovation projects are indicators of the effectiveness of flows of different institutions in the South African economy. Nelson and Nelson (2002) made the claim that the effectiveness of a country's NSI also depends on its macroeconomic environment. Kaplan (2000) supported this view and contended that there are extreme social disparities that must be dealt with to enhance access to infrastructure to allow for the occurrence of inclusive innovation. The idea was to use technology development as a source of growth and higher productivity and ultimately reduce unemployment, poverty, and inequality.

The main goal of the research was achieved through three other distinct goals. The first goal of the research was to provide an examination of the National System of innovation and why it was the most conceptual tool in analysing technology and development. The study found that the neoclassical approach to technology and development was based on the premise that technology was made up of clearly defined techniques and products, and that information on technology was easily available in the form of the "blueprint". The neoclassical approach did not have the implications for public policy as it did not assign provisions on institutions such as patents and intellectual property rights. The alternative approaches to technology and development provided extensions to the neoclassical approach and aimed to address some of the shortcomings thereof. Ultimately, the evolutionary approaches, namely the Sobato Triangle and the Triple Helix Model, advocated for the role of the state to facilitate and coordinate the interaction between the different actors and vertices of society by means of providing funding and/or financing to drive innovation and improve development which lay the basis of the National System of Innovation.

The second goal of the research was to evaluate the evolution of the NSIs within the BRICS bloc with a particular focus on South Africa. The purpose of broadening the innovation approach was to use innovation policies to advocate for inclusive innovation which in turn, would form a developmental agenda which aimed at alleviating problems such as inequality, urbanism, and poverty. The evolution of the NSI required an extensive analysis of implicit and explicit state policies on science and technology which have contributed to the formation of the NSI within the BRICS bloc. The role of the state was significant in the evolution of the NSI within the BRICS bloc, whilst exposing the extent of "embedded autonomy" (Evans ,1999). It was found that China, Brazil, India, and South Africa were midwifery and husbandry as their policies focused on fostering relationships between states. Brazil, China, India, and South Africa have industrial and trade policies which warranted value added on goods, thus ensuring the competitiveness of the different sectors. The implementation of these policies was also articulated clearly through the different initiatives suggested in each policy. In contrast, the Russian Federation was not as explicit with its trade and industrial policies.

The last goal of the research investigated whether technology development by means of an NSI has facilitated development over the past twenty-three years. The study found that for South Africa there was a statistically significant positive linear association between various NSI indicators and human development. Furthermore, the study found that changes in R&D expenditure on basic research have a causal influence on development. The results suggest that the adoption of the NSI has facilitated development in the NSI.

7.3 Lessons and possible changes for South Africa's NSI

The study then made policy assessments on how South Africa's NSI can facilitate development. Firstly, there would have to be policy preparation in the advances of the diffusion of AI both in the business cycle and education policy. The Menu of Policy Options endorsed by the G20 Ministers of Finance and central bank governors in March 2018 articulated key elements of their understanding of current and potential impacts of technological change in productivity and growth, employment, and inequality. It suggested ways in which members could consider policy responses; it would be essential to harness the benefits of technology for growth and productivity. These technological changes have not filtered through sufficiently to both growth and productivity in South Africa.

Additionally, the menu proposes that individuals should be supported through the transitions and augment distributional channels. South Africa would need to prepare and respond to technological changes and invest in skills development, whilst reskilling individuals to fit the demands of the dynamic technological environment. The South African education system should be centred around building capabilities which promote individuals to set their sights on longer technology driven careers, with multiple stages each involving on-going training and re-skilling.

There would have to be a stabilisation of the political administration interface, whilst professionalising public service. There would also need to be improved coordination amongst government departments, where there would be a proactive and pragmatic approach in managing a system to ensure better responsibility and capacity. Other policy implications would include providing funding for ongoing educational programmes to mitigate transaction costs whilst updating regulatory frameworks to support the new type of work that emerge through the fourth industrial revolution.

APPENDIX A CORRELATION ANALYSIS

```
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                                                        (R)
                                     Statistics/Data Analysis

                                        User: JJ Dr
                                     Project: paper

                                  (R)
                                  14.2   Copyright 1985-2015 StataCorp LLC
  Statistics/Data Analysis               StataCorp
                                         4905 Lakeway Drive
     Special Edition                     College Station, Texas 77845 USA
                                         800-STATA-PC        http://www.stata.com
                                         979-696-4600        stata@stata.com
                                         979-696-4601 (fax)

25-user Stata network perpetual license:
       Serial number:  401406287347
         Licensed to:  Juniours Marire
                       Rhodes University

Notes:
      1.  Unicode is supported; see help unicode advice.
      2.  Maximum number of variables is set to 5000; see help set_maxvar.

1 . *(13 variables, 15 observations pasted into data editor)

2 . pwcorr lnhdi lngdppc lnpatents lnbasic lnapplied lnexperimental lnresearchers lntechnicians lno
> lnrndcapex, sig star(0.05)
```

	lnhdi	lngdppc	lnpate~s	lnbasic	lnappl~d	lnexpe~l	lnrese~s
lnhdi	1.0000						
lngdppc	0.3040	1.0000					
	0.2706						
lnpatents	0.8214*	0.6411*	1.0000				
	0.0002	0.0100					
lnbasic	0.9825*	0.3425	0.7958*	1.0000			
	0.0000	0.2114	0.0004				
lnapplied	0.9857*	0.2738	0.7532*	0.9816*	1.0000		
	0.0000	0.3234	0.0012	0.0000			
lnexperime~l	0.5413*	0.4054	0.3417	0.6297*	0.5837*	1.0000	
	0.0372	0.1338	0.2126	0.0119	0.0223		
lnresearch~s	0.6071*	0.2040	0.2739	0.6894*	0.6928*	0.8108*	1.0000
	0.0164	0.4658	0.3233	0.0045	0.0042	0.0002	
lntechnici~s	0.8540*	-0.0475	0.4716	0.8491*	0.8847*	0.5799*	0.7395*
	0.0001	0.8666	0.0759	0.0001	0.0000	0.0235	0.0016
lnotherpers	0.5787*	-0.3405	0.2373	0.4916	0.6127*	0.0183	0.3531
	0.0238	0.2143	0.3944	0.0627	0.0152	0.9483	0.1967
lnrndlabor	0.9746*	0.2836	0.7332*	0.9759*	0.9887*	0.6434*	0.7479*
	0.0000	0.3056	0.0019	0.0000	0.0000	0.0097	0.0013
lnothercosts	0.8764*	0.4449	0.7065*	0.9344*	0.8968*	0.7701*	0.7642*
	0.0000	0.0966	0.0032	0.0000	0.0000	0.0008	0.0009
lnrndcapex	0.8297*	0.3004	0.5814*	0.8932*	0.8526*	0.8242*	0.7762*
	0.0001	0.2767	0.0230	0.0000	0.0001	0.0002	0.0007

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	lntech~s	lnoth~rs	lnrndl~r	lnoth~ts	lnrndc~x
lntechnici~s	1.0000				
lnotherpers	0.7242*	1.0000			
	0.0023				
lnrndlabor	0.9119*	0.5985*	1.0000		
	0.0000	0.0184			
lnothercosts	0.7589*	0.3103	0.9166*	1.0000	
	0.0010	0.2604	0.0000		
lnrndcapex	0.7474*	0.2567	0.8508*	0.8882*	1.0000
	0.0014	0.3557	0.0001	0.0000	

3 .

APPENDIX B ARDL ERROR CORRECTION REGRESSION

ARDL Error Correction Regression
Dependent Variable: D(GDPPC)
Selected Model: ARDL(1, 2, 2, 0)
Case 3: Unrestricted Constant and No Trend
Date: 03/14/21 Time: 07:27
Sample: 2004 2018
Included observations: 13

ECM Regression
Case 3: Unrestricted Constant and No Trend

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	4.843699	0.538980	8.986787	0.0008
D(LNBASIC)	0.146162	0.031944	4.575603	0.0102
D(LNBASIC(-1))	0.083832	0.031832	2.633618	0.0580
D(LNAPPLIED)	-0.204612	0.044738	-4.573552	0.0102
D(LNAPPLIED(-1))	-0.222956	0.048987	-4.551297	0.0104
CointEq(-1)*	-0.164637	0.018419	-8.938617	0.0009

R-squared	0.939607	Mean dependent var	0.007692
Adjusted R-squared	0.896469	S.D. dependent var	0.019302
S.E. of regression	0.006211	Akaike info criterion	-7.021068
Sum squared resid	0.000270	Schwarz criterion	-6.760322
Log likelihood	51.63694	Hannan-Quinn criter.	-7.074663
F-statistic	21.78140	Durbin-Watson stat	3.116778
Prob(F-statistic)	0.000391		

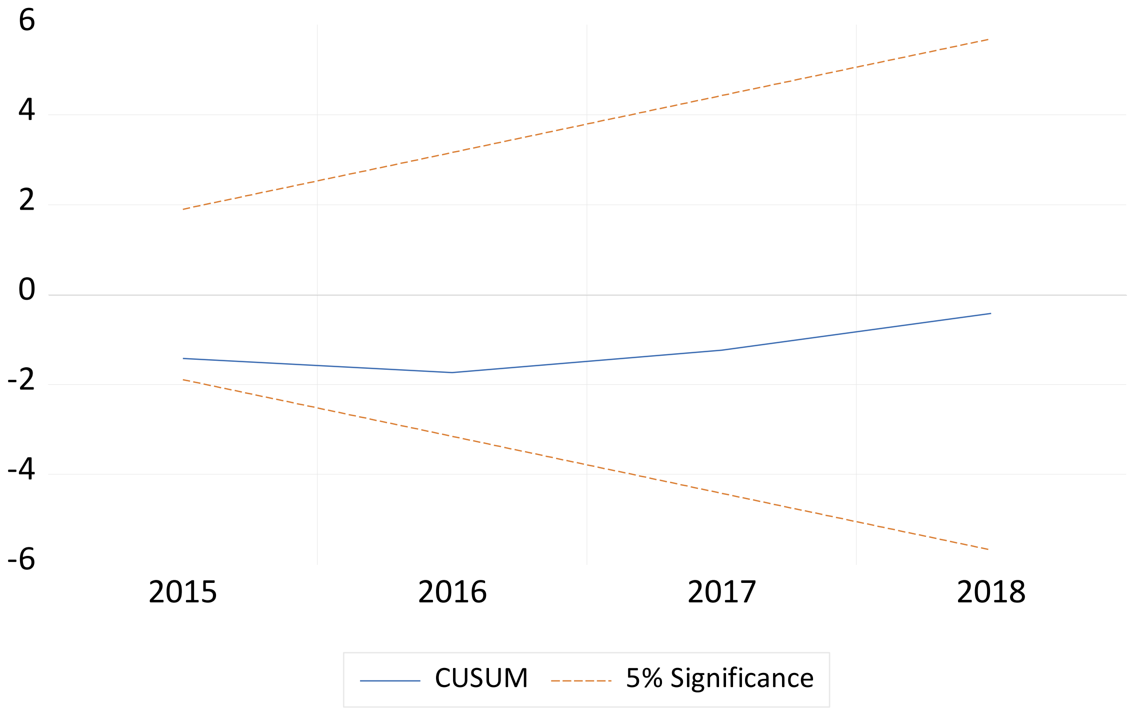
* p-value incompatible with t-Bounds distribution.

F-Bounds Test — Null Hypothesis: No levels relationship

Test Statistic	Value	Signif.	I(0)	I(1)
F-statistic	11.41412	10%	2.72	3.77
k	3	5%	3.23	4.35
		2.5%	3.69	4.89
		1%	4.29	5.61

t-Bounds Test — Null Hypothesis: No levels relationship

Test Statistic	Value	Signif.	I(0)	I(1)
t-statistic	-8.938617	10%	-2.57	-3.46
		5%	-2.86	-3.78
		2.5%	-3.13	-4.05
		1%	-3.43	-4.37


6
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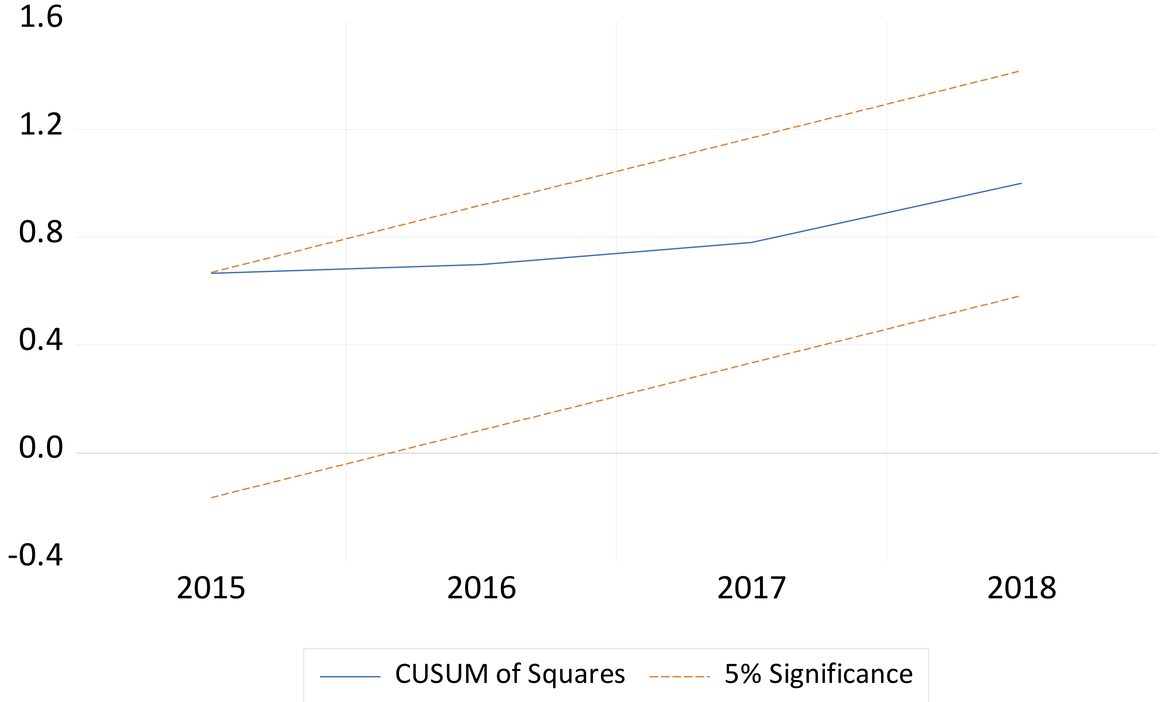
-2
-4
-6
2015
2016
2017
2018
CUSUM
5% Significance


1.6
1.2
0.8
0.4
0.0
-0.4
2015
2016
2017
2018
CUSUM of Squares
5% Significance

ARDL Error Correction Regression
Dependent Variable: D(GDPPC)
Selected Model: ARDL(3, 3)
Case 3: Unrestricted Constant and No Trend
Date: 03/14/21 Time: 07:31
Sample: 2004 2018
Included observations: 12

ECM Regression
Case 3: Unrestricted Constant and No Trend

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	8.984657	0.712024	12.61848	0.0002
D(GDPPC(-1))	0.798570	0.078145	10.21908	0.0005
D(GDPPC(-2))	0.312954	0.101930	3.070268	0.0373
D(LNPATENTS)	0.052828	0.003511	15.04489	0.0001
D(LNPATENTS(-1))	-0.011158	0.003456	-3.228307	0.0320
D(LNPATENTS(-2))	-0.025669	0.002945	-8.716477	0.0010
CointEq(-1)*	-0.866042	0.068638	-12.61746	0.0002

R-squared	0.985706	Mean dependent var	0.004833
Adjusted R-squared	0.968552	S.D. dependent var	0.017045
S.E. of regression	0.003023	Akaike info criterion	-8.474204
Sum squared resid	4.57E-05	Schwarz criterion	-8.191341
Log likelihood	57.84522	Hannan-Quinn criter.	-8.578929
F-statistic	57.46419	Durbin-Watson stat	2.578549
Prob(F-statistic)	0.000188		

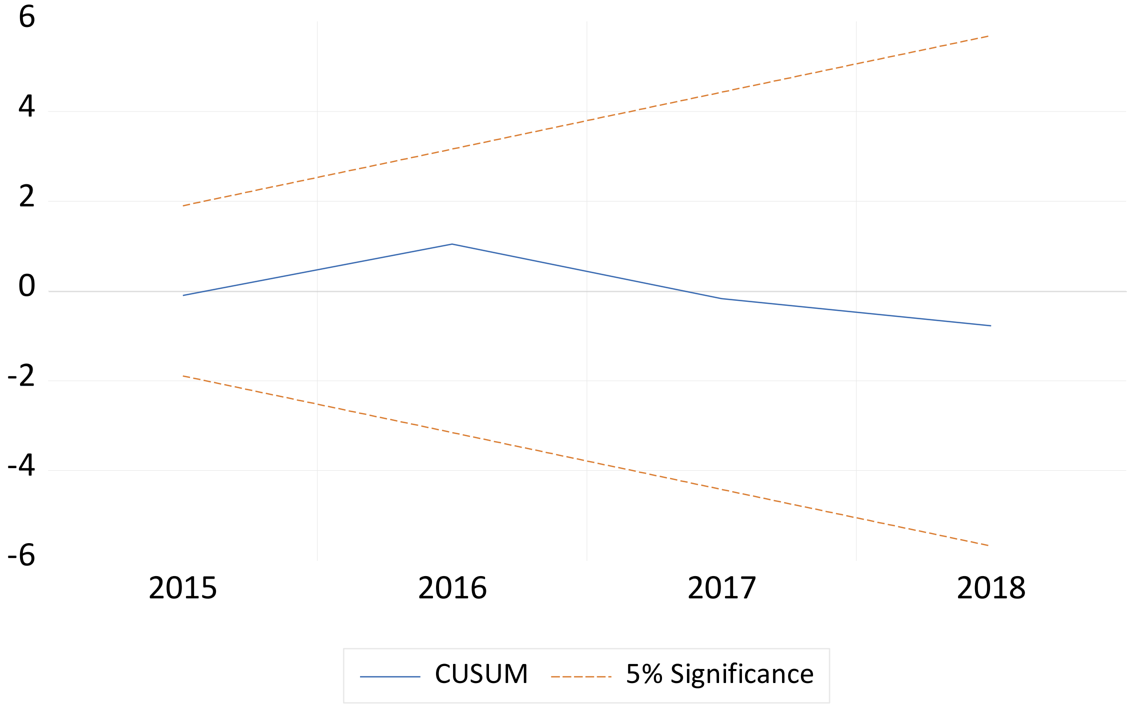
* p-value incompatible with t-Bounds distribution.

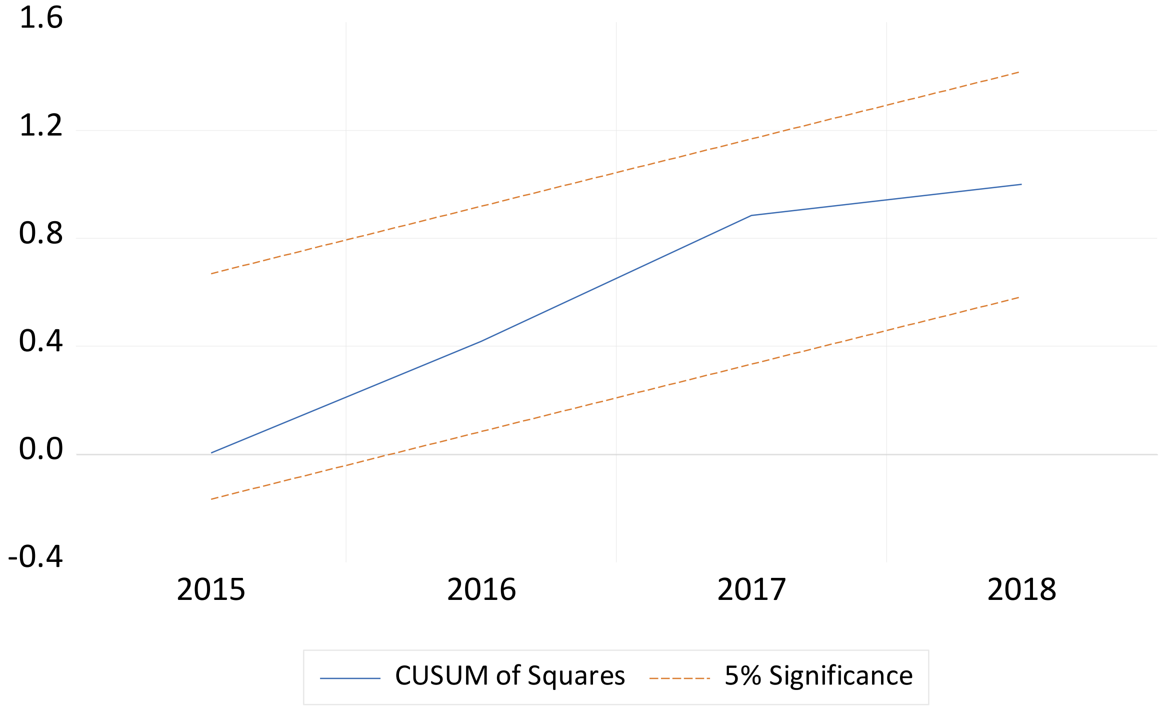
F-Bounds Test — Null Hypothesis: No levels relationship

Test Statistic	Value	Signif.	I(0)	I(1)
F-statistic	63.68014	10%	4.04	4.78
k	1	5%	4.94	5.73
		2.5%	5.77	6.68
		1%	6.84	7.84

t-Bounds Test — Null Hypothesis: No levels relationship

Test Statistic	Value	Signif.	I(0)	I(1)
t-statistic	-12.61746	10%	-2.57	-2.91
		5%	-2.86	-3.22
		2.5%	-3.13	-3.5
		1%	-3.43	-3.82


6
4
2
0
-2
-4
-6
2015
2016
2017
2018
CUSUM
5% Significance


1.6
1.2
0.8
0.4
0.0
-0.4
2015
2016
2017
2018
CUSUM of Squares
5% Significance

ARDL Error Correction Regression
Dependent Variable: D(LNHDI)
Selected Model: ARDL(2, 2, 2, 2)
Case 3: Unrestricted Constant and No Trend
Date: 03/14/21 Time: 07:34
Sample: 2004 2018
Included observations: 13

ECM Regression
Case 3: Unrestricted Constant and No Trend

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.686162	0.024499	-28.00818	0.0227
D(LNHDI(-1))	1.289276	0.039935	32.28441	0.0197
D(LNBASIC)	0.066099	0.003387	19.51762	0.0326
D(LNBASIC(-1))	0.025745	0.001618	15.90791	0.0400
D(LNAPPLIED)	-0.040759	0.003842	-10.60738	0.0598
D(LNAPPLIED(-1))	-0.057588	0.004594	-12.53539	0.0507
D(LNEXPERIMENTAL)	-0.064769	0.002405	-26.93584	0.0236
D(LNEXPERIMENTAL(-1))	-0.014772	0.001662	-8.890136	0.0713
CointEq(-1)*	-0.831404	0.029841	-27.86071	0.0228

R-squared	0.997441	Mean dependent var	0.010615
Adjusted R-squared	0.992323	S.D. dependent var	0.004700
S.E. of regression	0.000412	Akaike info criterion	-12.54608
Sum squared resid	6.78E-07	Schwarz criterion	-12.15496
Log likelihood	90.54949	Hannan-Quinn criter.	-12.62647
F-statistic	194.8868	Durbin-Watson stat	3.165861
Prob(F-statistic)	0.000065		

* 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	48.51370	10%	2.72	3.77
k	3	5%	3.23	4.35
		2.5%	3.69	4.89
		1%	4.29	5.61

t-Bounds Test Null Hypothesis: No levels relationship

Test Statistic	Value	Signif.	I(0)	I(1)
t-statistic	-27.86071	10%	-2.57	-3.46
		5%	-2.86	-3.78
		2.5%	-3.13	-4.05
		1%	-3.43	-4.37

ARDL Error Correction Regression
Dependent Variable: D(LNPATENTS)
Selected Model: ARDL(2, 2, 2, 2)
Case 3: Unrestricted Constant and No Trend
Date: 03/14/21 Time: 07:41
Sample: 2004 2018
Included observations: 13

ECM Regression
Case 3: Unrestricted Constant and No Trend

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-7.740961	0.761828	-10.16103	0.0625
D(LNPATENTS(-1))	-0.751645	0.029107	-25.82319	0.0246
D(LNBASIC)	-0.212527	0.204747	-1.037998	0.4881
D(LNBASIC(-1))	-1.406341	0.107744	-13.05256	0.0487
D(LNAPPLIED)	-4.524671	0.230722	-19.61092	0.0324
D(LNAPPLIED(-1))	-3.228980	0.237934	-13.57092	0.0468
D(LNEXPERIMENTAL)	-2.149876	0.082545	-26.04478	0.0244
D(LNEXPERIMENTAL(-1))	-0.588510	0.094845	-6.204943	0.1017
CointEq(-1)*	-0.215565	0.017868	-12.06415	0.0526

R-squared	0.998503	Mean dependent var	0.073231
Adjusted R-squared	0.995510	S.D. dependent var	0.367913
S.E. of regression	0.024652	Akaike info criterion	-4.361992
Sum squared resid	0.002431	Schwarz criterion	-3.970874
Log likelihood	37.35295	Hannan-Quinn criter.	-4.442385
F-statistic	333.6121	Durbin-Watson stat	2.420888
Prob(F-statistic)	0.000022		

* 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	9.096481	10%	2.72	3.77
k	3	5%	3.23	4.35
		2.5%	3.69	4.89
		1%	4.29	5.61

t-Bounds Test — Null Hypothesis: No levels relationship

Test Statistic	Value	Signif.	I(0)	I(1)
t-statistic	-12.06415	10%	-2.57	-3.46
		5%	-2.86	-3.78
		2.5%	-3.13	-4.05
		1%	-3.43	-4.37

ARDL Error Correction Regression
Dependent Variable: D(LNPATENTS)
Selected Model: ARDL(2, 2, 0, 1)
Case 3: Unrestricted Constant and No Trend
Date: 03/14/21 Time: 11:06
Sample: 2004 2018
Included observations: 13

ECM Regression
Case 3: Unrestricted Constant and No Trend

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1.107821	0.094937	11.66901	0.0003
D(LNPATENTS(-1))	-0.840263	0.107162	-7.841087	0.0014
D(LNCAPEX)	0.441398	0.154305	2.860554	0.0459
D(LNCAPEX(-1))	-1.801222	0.238417	-7.554935	0.0016
D(LNOTHER)	-1.928218	0.254022	-7.590751	0.0016
CointEq(-1)*	-0.442481	0.040608	-10.89652	0.0004

R-squared	0.959851	Mean dependent var	0.073231
Adjusted R-squared	0.931172	S.D. dependent var	0.367913
S.E. of regression	0.096522	Akaike info criterion	-1.534054
Sum squared resid	0.065215	Schwarz criterion	-1.273308
Log likelihood	15.97135	Hannan-Quinn criter.	-1.587649
F-statistic	33.46971	Durbin-Watson stat	1.810246
Prob(F-statistic)	0.000096		

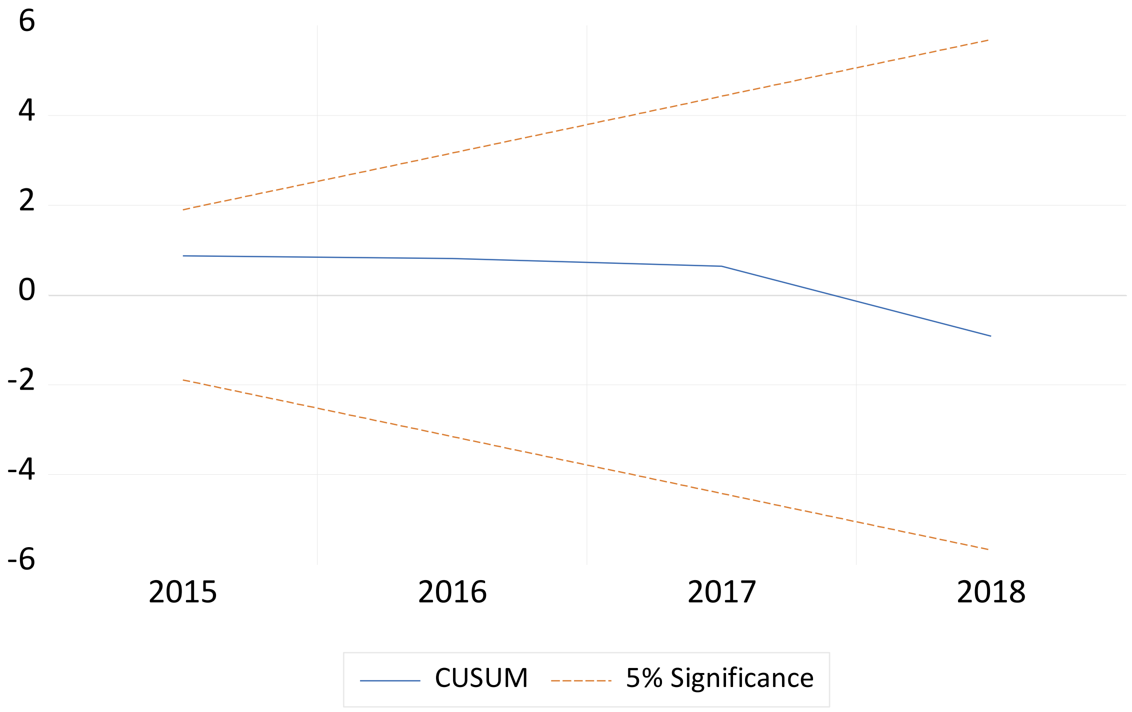
* p-value incompatible with t-Bounds distribution.

F-Bounds Test Null Hypothesis: No levels relationship

Test Statistic	Value	Signif.	I(0)	I(1)
F-statistic	16.96201	10%	2.72	3.77
k	3	5%	3.23	4.35
		2.5%	3.69	4.89
		1%	4.29	5.61

t-Bounds Test Null Hypothesis: No levels relationship

Test Statistic	Value	Signif.	I(0)	I(1)
t-statistic	-10.89652	10%	-2.57	-3.46
		5%	-2.86	-3.78
		2.5%	-3.13	-4.05
		1%	-3.43	-4.37


6
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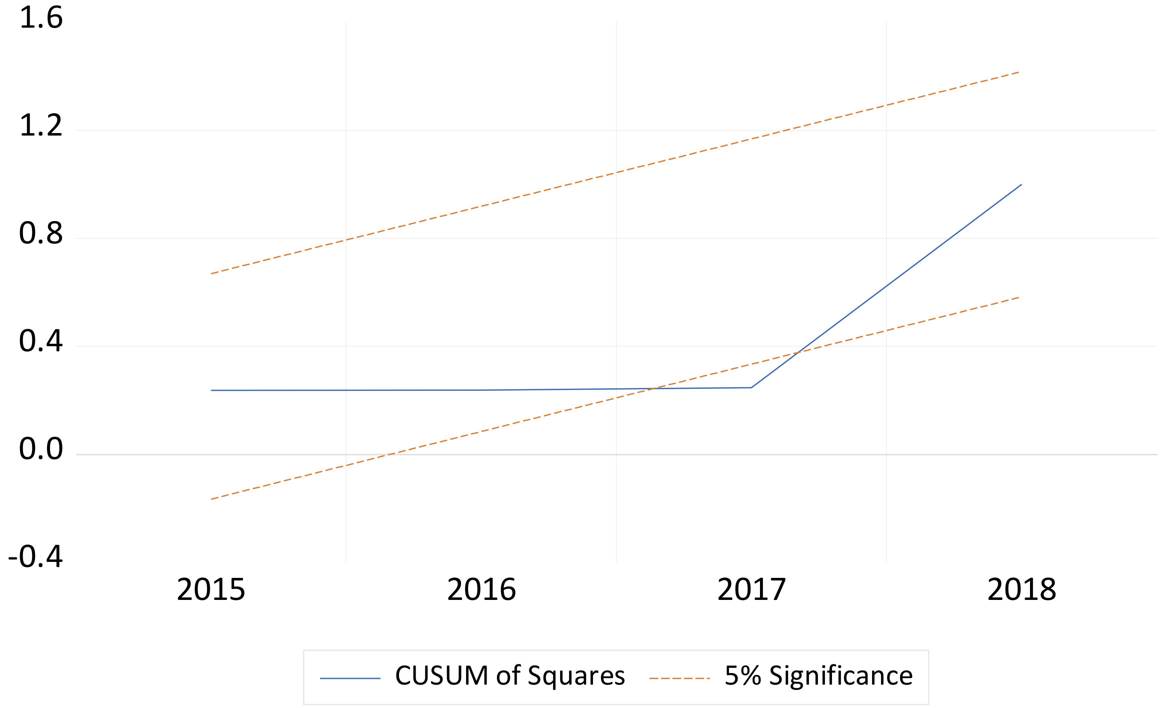
2015
2016
2017
2018
CUSUM
5% Significance


1.6
1.2
0.8
0.4
0.0
-0.4
2015
2016
2017
2018
CUSUM of Squares
5% Significance

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