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A simulation experiment on ICT and patent intensity in South Africa: An application of the novel dynamic ARDL machine learning model

Festus Fatai Adedoyin [a,*], Nicholas Mavengere [a], Alfred Mutanga [b]

[a] Department of Computing and Informatics, Bournemouth University, United Kingdom
[b] University of Botswana, Botswana

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ABSTRACT

The aim of this study is to examine the effect of shocks to patent intensity and its empirical and practical policy implications for the South African economy. This stems from the gap in the literature on policy simulation exercises related to the boost in Information and Communications Technology (ICT) and patent intensity in African countries. Hence, this study established the dynamic relationship between patent intensity and economic growth in South Africa for the period of 1980–2020, alongside essential macroeconomic variables such as government expenditure, gross fixed capital formation, labour force, and trade. We use the Autoregressive distributed lag model (ARDL) to capture short-run and long-run relationships, novel dynamic ARDL and Kernel-based Regularized Least Squares (KRLS) to capture the counterfactual shocks in the economic growth. The ARDL result revealed that government expenditure, labour force, and trade openness significantly foster economic growth in the long-run and short-run. Also, while patent intensity and gross fixed capital formation increase the economy in the long-run and short-run, their interaction term significantly diminishes the growth. Further in the analysis is the dynamic ARDL simulation and KRLS, which predicted the counterfactual shocks of economic growth based on a + 26 % change in patent intensity. The result showed that the increasing volume of patent intensity first has a low effect on South Africa economic growth, but later rebound upwardly, thus indicating that change in patent intensity has a long-lasting impact on sustainable economic growth. The direction that is useful for policy is also highlighted and discussed.

1. Introduction

Globalisation and advancement in technology have increased competition among the world leaders making innovation critical for organisations, industries and countries. “Innovation is invariably identified as the key driver of long-term economic growth, competitiveness and a better quality of life”, posited Moses et al. (2012). This is well demonstrated by the innovation strategy of different organisations and countries e.g., SADC's protocol on Science, Technology and Innovation (SADC, 2008) and South Africa's policy on Innovation, Science and Technology (Department of Science and Technology, 2019). This is in line with key organisations e.g., United Nations and the World bank's view that innovation and technology development are some of the prerequisites for developing countries to implement to attain growth and development (Lefophane and Kalaba, 2021). Jovanović et al. (2018) urged that digitalization is one of the key stimuli of today's development. In addition, they called for studies that seek to understand the impact of technology on sustainable development considering the economy, society and environment. In addition, patents and other ICT innovations have strong potential to boost economic competitiveness (Krammer, 2017), whilst also strengthening the overall progress of many sectors within the economy (Suh and Oh, 2015).

ICT-importance on economic growth have been examined by some past studies, though with contracting evidence, for instance, Edquist and Henrekson (2017) and Mačiulytė-Šniukienėa and Gaile-Sarkane (2014) found either a negative or no significant effect of ICT investment on countries' growth. This could be because of a small share of investment in ICTs gaps in the econometric approaches used in the studies and aggregating industries in the analysis (Lefophane and Kalaba, 2021). In understanding the relationship between ICT development and human development index in Indonesia, (Machfud and Kartiwi, 2018) concluded that there are significant correlations between the ICT development, human development index, education index, expenditure index and the percentage of poor people. Therefore, the value of

* Corresponding author.
E-mail addresses: fadedoyin@bournemouth.ac.uk (F.F. Adedoyin), nmavengere@bournemouth.ac.uk (N. Mavengere), mutangaa@ub.ac.bw (A. Mutanga).

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Table 1
Summary statistics.

Variable	Obs.	Mean	Std. Dev.	Min	Max
Natural logarithm transformation					
lnRGDP	40.00	26.36	0.28	25.98	26.79
lnGEXP	40.00	24.72	0.31	24.20	25.21
lnTRAD	40.00	3.96	0.16	3.62	4.29
lnLABF	40.00	16.55	0.28	16.07	16.97
lnGFCF	40.00	24.59	0.43	23.97	25.22
lnPATE	40.00	7.02	0.86	4.93	8.54
At levels					
RGDP	40.00	292,000,000,000.00	83,800,000,000.00	192,000,000,000.00	430,000,000,000.00
GEXP	40.00	57,100,000,000.00	18,000,000,000.00	32,400,000,000.00	88,900,000,000.00
TRAD	40.00	52.96	8.25	37.49	72.87
LABF	40.00	16,000,000.00	4,227,438.00	9,530,918.00	23,300,000.00
GFCF	40.00	52,000,000,000.00	22,200,000,000.00	25,700,000,000.00	89,500,000,000.00
PATE	40.00	1616.58	1525.71	138.00	5134.00

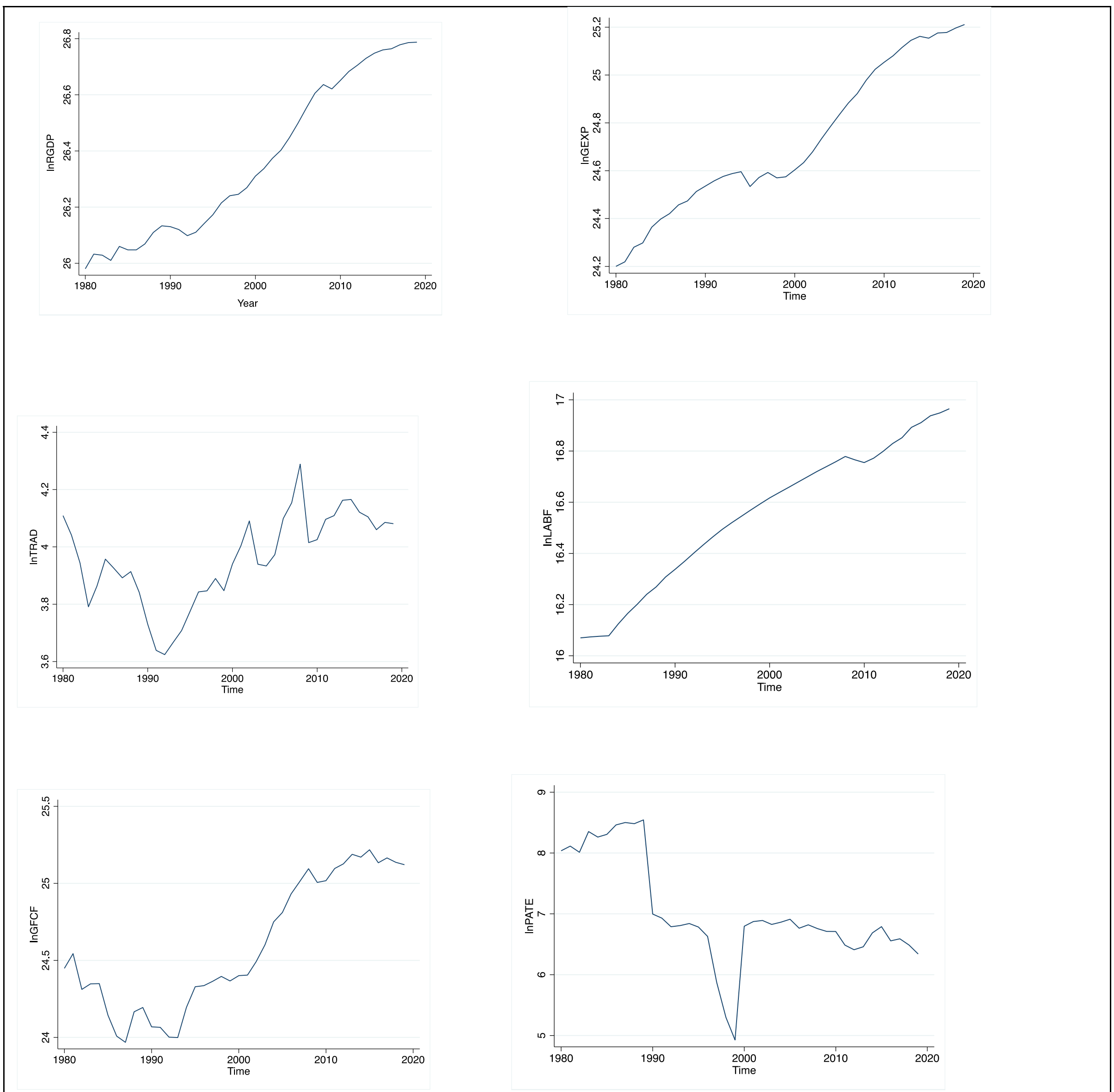


Fig. 1. Trend of variables.

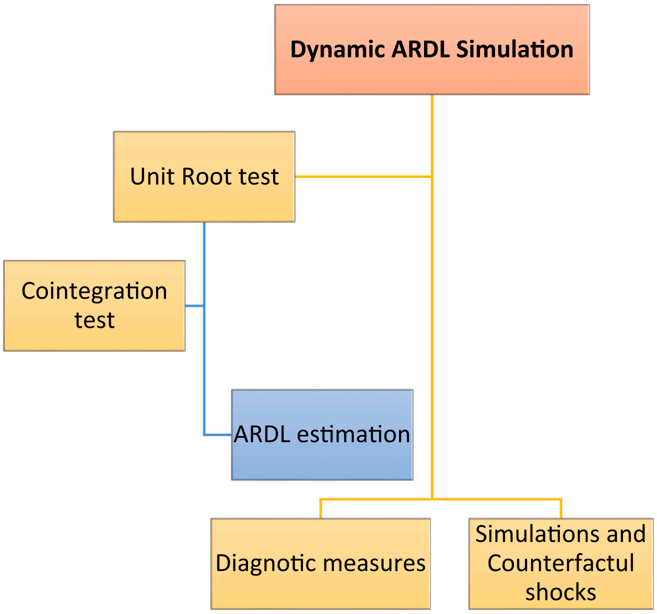


Fig. 2. Empirical scheme.

Table 2
Stationary test.

Variable	Level. PP	Δ. PP	Level.ADF	Δ. ADF
lnRGDP	0.131	−4.554***	0.280*	−4.468***
lnGEXP	−0.602	−4.650***	−0.611**	−4.480***
lnTRAD	−1.764	−5.682***	−1.700	−5.681***
lnLABF	−1.263	−3.430***	−1.584	−3.466***
lnGFCF	−0.287	−5.091***	−0.134	−5.062***
lnPATE	−1.731	−5.918***	−1.743	−5.913***
lnGFCFPATE	−1.877	−5.986***	−1.890	−5.974***

Level.PP is the level of PP unit root, Δ. PP is the first-difference value; Level.ADF level of ADF, Δ.ADF is the first difference.
*** Significance at 10 %.
** Significance at 5 %.
* Significance at 1 %.

technological innovation to national economic growth has been well established, both theoretically and empirically (Saini and Jain, 2011). This also extends to the efforts of the government to invest in research and development as well as concentrate on emerging sectors and young firms (Lee et al., 2022). Ofori et al. (2021) studied the effectiveness of financial development, financial access, and ICT diffusion in reducing the severity and intensity of poverty in Sub-Saharan Africa. They concluded that ICT usage, ICT access, ICT skills are remarkable in reducing both the severity and intensity of poverty.

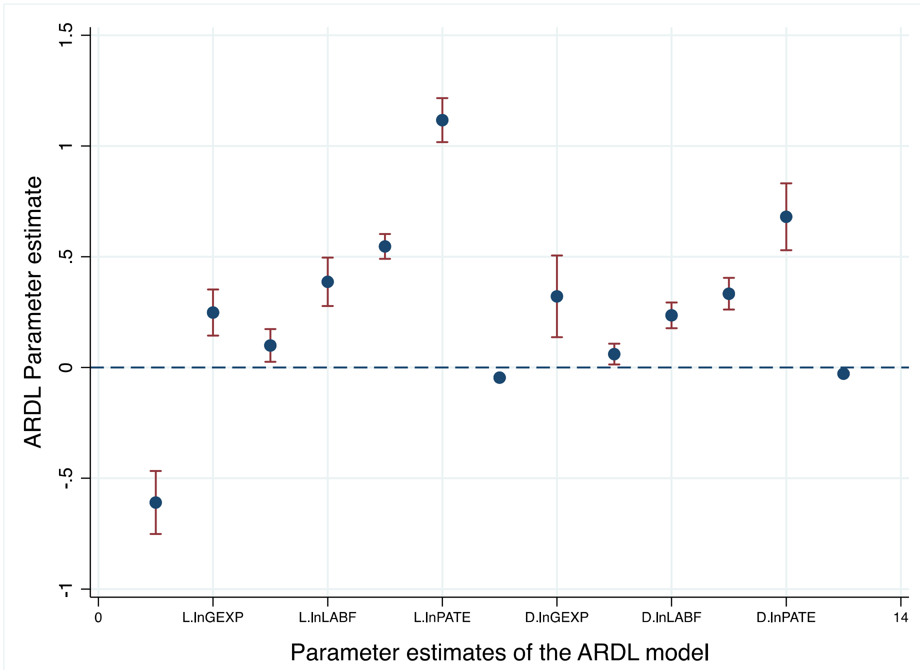
Recently, Lefophane and Kalaba, (2021) conducted a study in South Africa and concluded that ICT intensity yields higher positive and significant effects on the growth of the more ICT-intensive industries. Focusing on non-ICT sectors offers the opportunity to understand technology productive effects from the use of ICTs (Stiroh, 2002). Lefophane and Kalaba (2021) noted the limited research in South Africa to uncover the potential gains that could be accrued through investment in ICT at both the aggregate and industrial levels. Therefore, we are motivated to conduct this related study through defining ICT intensity on sustainable development in South Africa. In addition, patent analysis has been utilized to understand development trends (Albino et al., 2014). Saini and Jain (2011) noted that patenting is "identified as the most important means of protecting IP and is increasingly used as a strategic asset by companies to create sustainable competitive advantage – although, in others, secrecy is used to safeguard proprietary knowledge". Thus, it is plausible to relate patent filing to economic growth leading to sustainable development. In a 2015 report, the Global Connectivity Index predicted that a 20 % increase in ICT investment would lead to a 1 % increase in the GDP of South Africa. Saini and Jain (2011) noted the value of patents in promoting innovation, entrepreneurship and market-oriented economic growth. Therefore, we added patent intensity to ICT development and investigate their impact on the sustainable economic growth of South Africa. Moreover, since there are some other macroeconomic variables whose influence on economic growth cannot be underestimated, this study considered controlling for variables such as government expenditure, gross capital fixed formation, labour force, and trade in the context of economic growth in South Africa. In actual sense, this study contribute to the existing literature by investigating the policy simulation exercise on ICT and patent intensity in South Africa through the examination of the relationship between patent intensity and economic growth in South Africa for the period of 1980–2020. With more macroeconomic variables such as government expenditure, gross fixed capital formation, labour force, trade openness, and gross fixed capital formation and patent intensity as the interaction term, this study incorporated ARDL to capture short-run and long-run relationships, and novel estimated techniques such as novel dynamic ARDL and Kernel-based Regularized Least Squares (KRLS) to capture counterfactual shocks in improving the patent intensity while projecting towards 2039. It established stationarity of the series on which the existence cointegration test was estimated. Thereafter, the study determine the ARDL lag regression, the result – both long run and short run estimates – were presented and discussed.

The next session reviews the literature on ICT and Patent Intensities and how they influence the economy. This is followed by Section 3 which presents details of data, model and methodology used for this study. The empirical results are discussed in Section 4 with implications of the findings presented in Section 5. The study concludes in Section 6 with some vital recommendations for patent and ICT policies in African countries.

2. Literature review

2.1. Theoretical review of ICT structure in South Africa

ICT firms are frequently confronted with complicated challenges relating to corporate regulations and intellectual property rights (IPR), notably ICT patents. Because ICT patents will undoubtedly play a critical role in influencing the nation's future economy, the patent expertise required to resolve ICT patent issues includes a thorough understanding of communication technology, and digitalization of different economics sectors. Given the complex nature of ICT, continuous innovation is essential for making the ICT operations more profitable. The expansion of the ICT sector in recent years has resulted in the establishment of what is known as the "innovation economy." Furthermore, nations' futures have acknowledged that sustained development is greatly contingent on how inventive the economy is. In a report led by the European Commission (2013), increased in knowledge and innovation was noted as the key to smart economic growth. However, giving enough and suitable incentives to innovators becomes critical ICT sector, which is wholly driven by innovation. This is where patent rights come into play. Patents right or protection is one among the methods to create incentives is to ensure a solid framework that protects inventors' rights and allows them to capture the financial rewards of their invention. First, securing patent protection guarantees that an innovator retains control over the economic application of their idea. Second, patent protection helps to promote the development of technology since the profits earned by innovators are utilized to fund significant research and development (Comino et al., 2017). The emergence of technology with the networking communication significantly has positive impact on the economic growth and well-being of any country (Alison et al., 2018). The authors, in their article, posited that the foundation of the



Notes: blue (●) is the estimate in a log-log model, long-dash 3-dots is the reference line, red-spike denotes lower 95% and upper 95% confidence limit. Legend: RGDP represents Real Gross Domestic Product; GEXP represents Government Expenditure; LABF represents labour force; PATE represents Patents; TRAD represents trade openness.

Fig. 3. Parameter estimates of the ARDL model.
Notes: blue (●) is the estimate in a log-log model, long-dash 3-dots is the reference line, red-spike denotes lower 95 % and upper 95 % confidence limit. Legend: RGDP represents Real Gross Domestic Product; GEXP represents Government Expenditure; LABF represents labour force; PATE represents Patents; TRAD represents trade openness. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

contemporary economy and society, in South Africa, is based on the recognition of communication by the governing bodies. Also, a framework provided by South Africa to realize her vision of 2030 is based on a widespread broadband communication system will underpin a dynamic and connected vibrant information society and a knowledge economy that is more inclusive, equitable, and prosperous, but national commitments to ICTs that followed framework have failed to meet their set targets or make significant progress to meet specified objectives, because there is limited debate related to the aforementioned framework (Breitenbach and Malan, 2020). As stated in the introduction, the purpose of this study was to address such gaps.

2.2. *Empirical reviews*

The advances in technology are such that its value is increasing at different dimensions e.g. organisational, national and regional. Technology is becoming increasingly valuable for an equitable, inclusive and sustainable economy. Latif et al. (2017) empirically concluded that there is a positive relationship between ICT and environmentally sustainable development and in addition that ICT and environmentally sustainable development are proportional to each other unless other considerations, such as the environment, culture, human behaviour and education, drastically change. The innovations of a country could be reflected by a country's patents. The availability of innovations and technology is important for a country's sustainable economic development and growth. Technology has drastically changed economic, environmental and social trajectory (Mardikyan et al., 2015).

Jayaprakash and Radhakrishna Pillai (2021) conducted a country-level examination of the impact of information and communication technologies (ICTs) on sustainable development. They noted that the sustainable development agenda of nations could be aided by technology because of its ubiquitous nature. In addition, they concluded that technology has a significant positive influence on the dimensions of sustainable development of a nation, namely, economic, social and environmental. Saini and Jain (2011) argued that countries that generate innovations, create new technologies, and encourage adoptions to grow faster. The process of a country's constructive economic development includes implementing economic, social and political transformations in the global competition context (Dalevska et al., 2019). This economic, social and political transformation is based on the efforts of different stakeholders including the country's citizens, government, business and non-governmental organisations. These players define and contribute to variables, such as government expenditure, labour force, and trade openness which have an impact on economic growth.

Ecological components in defining the prerequisites for sustainable development include clean development mechanisms (Karakosta et al., 2009) and low carbon growth pathways (Yang et al., 2018). These are complemented by socio-economic which are based on economic development and fight against income inequality. Income inequality matures into socio-economic inequality including wellbeing inequality which negatively impacts the basis of society's structure (Dalevska et al., 2019). An example of socio-economic based efforts to sustainable development is human rights-based approaches to global challenges (Arts, 2017).

Table 3
ARDL (1,0,0,1,0,1) regression.

Variables	Model without an Interaction term	Full Model
ECT	0.0380	−0.609***
	(0.0370)	(0.0697)
Long-Run		
$lnGEXP_{t-1}$	2.319	0.248***
	(1.891)	(0.0510)
$lnTRAD_{t-1}$	0.282	0.0995***
	(0.942)	(0.0362)
$lnLABF_{t-1}$	−1.183	0.387***
	(1.825)	(0.0537)
$lnGFCF_{t-1}$	−0.491	0.547***
	(0.846)	(0.0276)
$lnPATE_{t-1}$	−0.112	1.117***
	(0.211)	(0.0488)
$lnGFCFPATE_{t-1}$		−0.0455*** (donations)
		(0.00208)
Short-Run		
Δ lnGEXP	0.155	0.321***
	(0.108)	(0.0903)
Δ lnTRAD	0.0849**	0.0606**
	(0.0319)	(0.0230)
Δ lnLABF	0.0450	0.236***
	(0.0414)	(0.0284)
Δ lnGFCF	0.140***	0.333***
	(0.0255)	(0.0351)
Δ lnPATE	0.00426*	0.681***
	(0.00510)	(0.0739)
Δ lnGFCFPATE		−0.0277***
		(0.00308)
Observations	39	39
R-squared	0.866	0.911

Note: Standard errors in parentheses. Parameters estimates of the ARDL model. Legend: RGDP represents Real Gross Domestic Product; GEXP represents Government Expenditure; LABF represents labour force; PATE represents Patents; TRAD represents trade openness.
*** $p < 0.01$ represents 1 % statistical significance level.
** $p < 0.05$, 5 % statistical significance level.
* $p < 0.1$ represents 10 % statistical significance level.

The social aspects of sustainable development include people's access to social rights and freedoms including the right to access to education, health care and employment. Lack of access to social rights and freedoms creates social tensions which are reflections of human values. "From the existential standpoint, sense-of-life values are formed based on recognition of the objectively rational meaninglessness of existence, which forces an individual to construct his value system by choosing and taking responsibility for this choice to oneself" (Dalevska et al., 2019, pg. 1841). Access to education is essential for a society's knowledge creation and transfer which is a scarce resource. The ability to utilise knowledge forms human capital, a fundamental of economic development. This also relates to information and information processing as a resource for sustainable development. Salahuddin and Gow (2016) detected a positive and significant long-run relationship between internet usage and economic growth over the period 1991–2013. A recent study by Canh and Nadia (2022) investigates the role of innovation (proxied by patents number) on the economic growth (real GDP per capita) of sample of forty-three countries (twenty-six developed and seventeen developing countries) for the time span of 1998–2006. The results of the study revealed that the impact of patents on the economic growth is not significant whereas ICT has positive and significant effects. On the account of developed and developing countries, their study revealed that patent effects on the economic growth have stronger effect in the developed countries than the developing countries. Also, ICT patents in the developed and developing countries exercise positive and negative impact, respectively. This means that the advance countries were far better than the emerging or developing countries in term of patents and ICT industry, hence more studies are needed to investigate the patent and ICT industry on the economic structure of the emerging economics, of which South African is among.

3. Data, models and methods

3.1. Data and variables

In this study, the panel data covering the period of 1980–2020 was used to assess the effect of some selected macroeconomic variables on policy simulation exercise of ICT and Patent Intensity in South Africa. The observations – dependent and independent variables – used are from secondary source, which is World Development Indicator (WDI). The independent variables or predictors are the real gross domestic product (measured in 2010 constant US dollars), government expenditure (percent of GDP), labour force, trade openness, gross fixed capital formation as well as patent and ICT which represent the dependent variable. The characteristics of the variables are presented in the Table 1 and the Fig. 1 below. In the Table 1, we revealed the mean and measure of the deviation of the studied variables both at natural logarithm (upper panel) and at level (lower panel). Although, at level, the real or actual characteristics – mean, standard deviation, minimum, and maximum - of the variables are preserved, but noticeable issues are large disparity in the data which was hugely reduced by taking the natural logarithm of the variables. Taking real gross domestic product (RGDP) as an example, it has an average and standard deviation of $26.36 million and $0.28 million respectively at natural logarithm compared with higher standard dispersion of $838 million. The same issue was noticed in other variables. It is noteworthy that, because of loss of information, the natural logarithm of variables does not represent the actual nature of the variables, but it, thus, needed to be incorporated in our model, although with a certain assumption, which would be discussed in the model, to avoid the spurious outcome.

Henceforth, the model, analysis, and result would be based on the natural logarithms of the variables. Therefore, we plot the log of each variable against time to reveal the trend of the data over time. From the plot, real gross domestic product (RGDP), government expenditure (GEXP), and labour force (LABF) were closely observed to be increasing over the period of study. This is evidence that the economic growth of South Africa is improving every year. On the other hand, TRAD (trade openness), GFCF, patent (PATE) seems to behave sporadically. TRAD have the nature of rise-fall over the years, gross fixed capital formation (GFCF) observed to be increasing but after some random movement between the year 1980–1993, as for PATE, it declined from the beginning of the year till around 1998 when it rose and then seem to be contracted from around 2001 upward.

3.2. Model and methods

3.2.1. Policy simulations and an application of the novel dynamic ARDL model

The effective or smooth running of government activities is always a top priority of any developed or developing country across the world. These smooth activities could access affordable quality education, continuous increase in economic growth, improvement in health care facilities, advancement in communication technology, and sustainable energy system. However, the ability to achieve tremendous results of effectiveness is largely dependent on the organized structure of potential factors that could have been shadowed by the government or policymakers. Based on this, the government, for instance, may made effort to increase gross domestic product and yet the effort may remain futile. It is against this backdrop that policy simulation exercise is required for more urgent attention in such activities.

Simply defined, any policy activities designed to enhance, and evaluate preparedness is referred to as policy simulation exercise. It is a practice that prepares participants – individual, government, institution,

Table 4
Model diagnostics tests.

a. Pesaran, Shin, and Smith bounds testing.

–		10 %		5 %		1 %		*p*-value	
	K	I (0)	I(1)	I (0)	I (1)	I (0)	I (1)	I (0)	I (1)
F	25.858	1.97	3.236	2.39	3.821	3.402	5.214	0.000**	0.000**
T	−8.740	−1.611	−3.673	−1.975	−4.103	−2.701	−4.971	0.000**	0.000**

b. Breusch-Godfrey LM test for autocorrelation.

lags(p)	F	Df	Prob > F
1	0.011	(1,31)	0.9178
2	0.109	(2,30)	0.8973
3	0.236	(3, 29)	0.8703
4	0.433	(4, 28)	0.7834

c. Cameron & Trivedi's decomposition of IM-test.

Source	chi2	Df	*p*-value
Heteroskedasticity	26.1	26	0.4574
Skewness	4.49	6	0.6111
Kurtosis	0.29	1	0.5916
Total	30.88	33	0.5731

d. Skewness/Kurtosis tests for normality.

Variable	Obs.	Pr. (skewness)	Pr. (kurtosis)	Joint adj. $chi^2(2)$	Prob>chi2
Residuals	39	0.2901	0.431	1.85	0.3961

I(0) is the lower band critical values; I(1) is the upper band critical values.
** Indicate the significance of KS critical values at the 0.01 significance level.

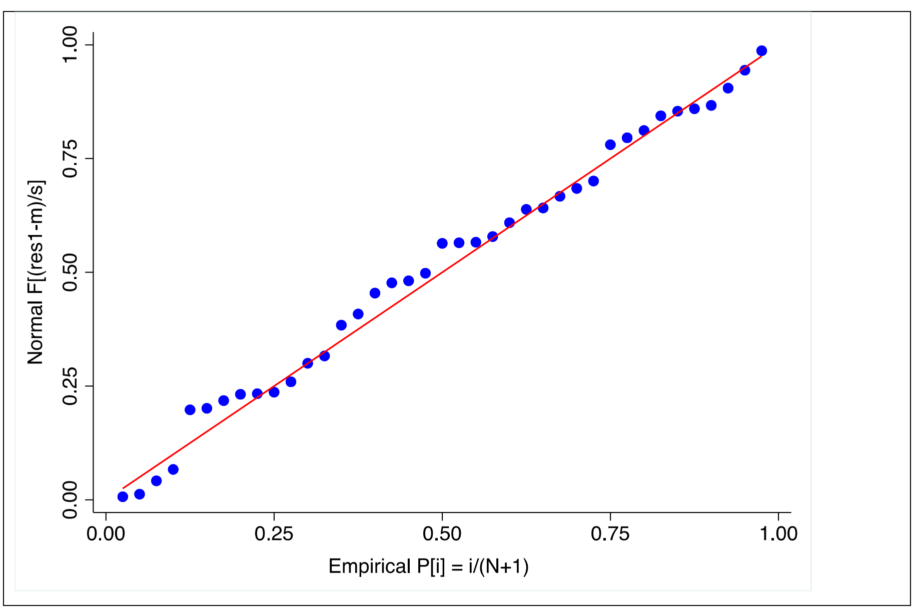


Fig. 4. Standardized normal probability plot.

personnel – in a simulated situation required of them to function as they would in the real situation. Purposedly, policy simulation evaluates the preparedness of participants' abilities to carry out one or more portions of simulated responses. In this particular study, the participants involved in the simulation exercise is South Africa government/policy-makers, and the activities to be simulated is ICT and Patent Intensity in South Africa. So, we applied the novel dynamic ARDL simulation to capture the future shocks of patent intensity on South Africa economic growth, and based on the outcome, we highlighted policy measures for which the government or policymakers should be prepared to act upon.

The application of novel dynamic ARDL simulation to our data has a set of guidelines to be followed as prepared in the empirical scheme below (Fig. 2). We referred to Fig. 2 below and pinpoint the step used in carryout the analysis.

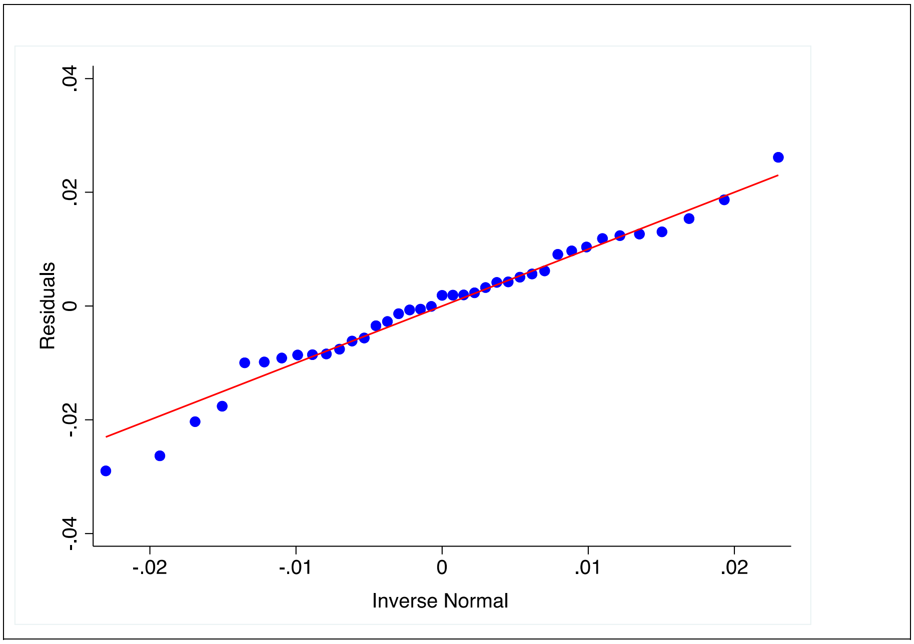
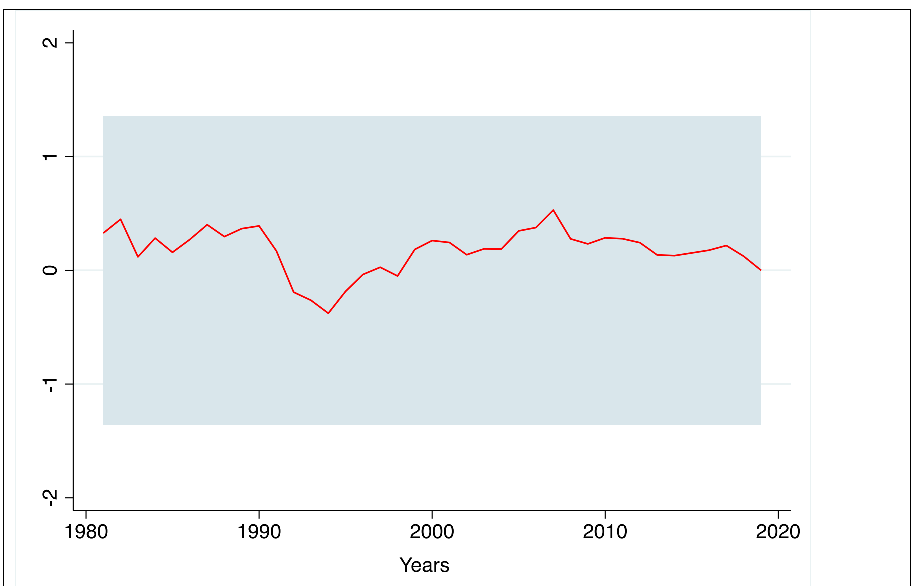


Fig. 5. Quantiles of residuals against quantiles of normal distribution.



OLS CUSUM plot of D.lnRGDP. with 95% confidence bands around the null

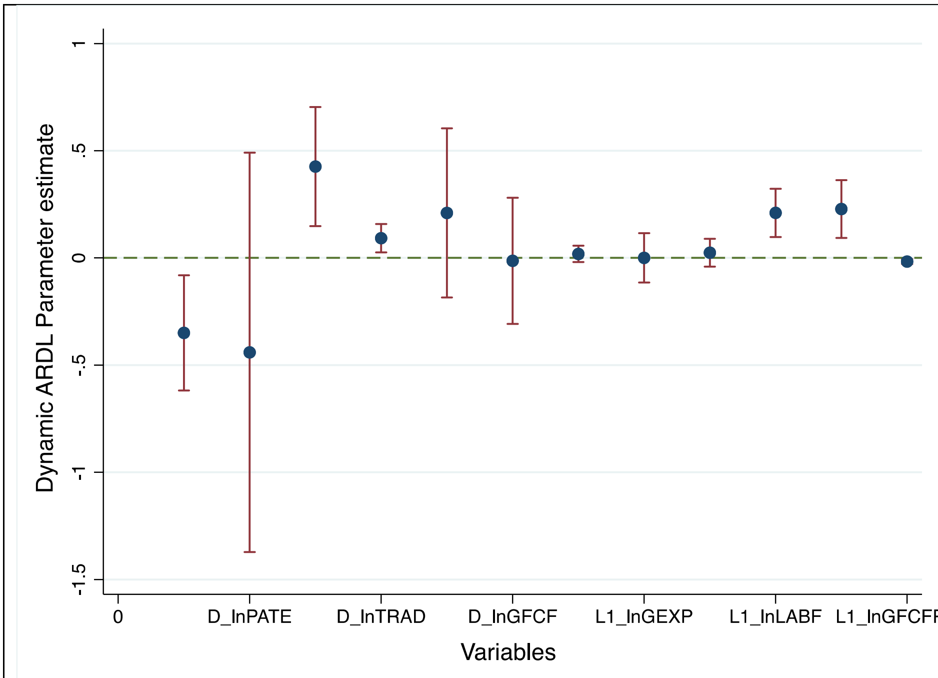
Fig. 6. Cumulative sum test using OLS CUSUM plot for parameter stability OLS CUSUM plot of D.lnRGDP. with 95 % confidence bands around the null.

3.3. Step 0: ARDL model

Before performing a novel ARDL simulation, it required a cointegration procedure which must first satisfy a strict first-difference I(1) of the dependent variable (Jordan and Philips, 2018) and independent variables must either be I(0)/I(1). This means that the integrated dependent variable of order 1 and independent variables of either order 0 or 1 is a possible entrance of cointegration measures. To test this, we proceed to step 1.

3.4. Step 1: unit root test

To test the condition of the first-difference independent variable, we used the first-generation unit root test which is augmented Dickey-Fuller (ADF) and Phillips-Perron (PP). The two methods are useful to assess the stationarity of the series is at the level and at first difference with the null hypothesis that there of a unit root in the series. If the null hypothesis is true, then it means the series is nonstationary, and thus it needs to be the difference. If the first difference of the series is stationary, then it denotes that the series has no unit root, and thus it is integrated of order one I(1).



Notes: blue (●) is the estimate in a log-log model, long-dash 3-dots is the reference line, red-spike denotes lower 95% and upper 95% confidence limit. Legend: RGDP represents Real Gross Domestic Product; GEXP represents Government Expenditure; LABF represents labour force; PATE represents Patents; TRAD represents trade openness.

Fig. 7. Parameter estimates of the Dynamic ARDL model.
Notes*:* blue (●) is the estimate in a log-log model, long-dash 3-dots is the reference line, red-spike denotes lower 95 % and upper 95 % confidence limit. Legend: RGDP represents Real Gross Domestic Product; GEXP represents Government Expenditure; LABF represents labour force; PATE represents Patents; TRAD represents trade openness. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

3.5. Step 2: cointegration test

Following the discussion of Philips (2018) on the application of Pesaran et al. (2001) ARDL bounds test, we used Pesaran, Shin, and Smith (PSS) as well as Kripfganz & Schneider (KS) critical and *p*-values to check for cointegration relationship between the lag of dependent and independent variable with the null hypothesis of no-level of cointegration.

3.6. Step 3: ARDL estimation and diagnostic measures

On satisfying the threshold of first-difference stationarity of dependent variable (lnRGDP), and after the existence of cointegration have been affirmed, the optimal lag of the model was determined using ARDL and long-run and short-run relationship of the dependent and independent variables was estimated. Although, the variables used are in natural logarithm to tackle possible heteroskedasticity problems, some ARDL diagnostic measures were carried to ascertain the degree of the estimation. Such measures are serial correlation error by Breusch-Godfrey LM test; a heteroscedastic error by Cameron & Trivedi's decomposition of IM-test; test of normality by skewness or kurtosis test; and CUSUM test/plot for estimated parameters stability.

3.7. Step 4: a novel dynamic ARDL estimation

We then apply the dynamic ARDL simulation based on +26 % changes in volume in patent intensity as counterfactual shocks from the period of 2019–2039. Following the Sarkodie et al. (2019), the specification of the model is

$$\begin{aligned} ln(RDGP)_t = {} & \beta_0(lnRGDP)_{t-1} + \beta_1 ln(GEXP)_t + \beta_2 ln(GEXP)_{t-1} \\ & + \beta_3 ln(TRAD)_t + \beta_4 ln(LABF)_{t-1} + \beta_5 ln(GFCF)_t \\ & + \beta_6 ln(GFCF)_{t-1} + \beta_7 ln(PATE)_t + \beta_8 ln(PATE)_{t-1} \\ & + \beta_9 ln(GFCFPATE)_t + \beta_{10} ln(GFCFPATE)_{t-1} + \epsilon_t \end{aligned} \quad (1)$$

4. Results and discussion

4.1. Stationary test

Relating to the staged model scheme in Section 3, the PP and ADF tests were employed to assess the stationarity characteristics of the variables. The two tests were run based on level and at first difference. The tests are insignificant at level ($p > -0.10$), but after the first difference, the variables are significant at 10 % thus rejecting the null hypothesis of no unit-roots, and hence confirming that the variables are the integration of order I(1) (Table 2).

4.2. ARDL model estimation and cointegration test

In Table 1, since the dependent variable (lnRGDP) satisfy the strict first-difference, we used ARDL parameter estimate to examine the optimal lag of the model, thereafter assessing the cointegration technique using Pesaran, Shin, and Smith (PSS) bound tests as well as the critical values and *p*-values of the novel Kripfganz & Schneider (KS). The outcome of the ARDL parameters based on ARDL(1,0,0,1,0,1) is exposed in Fig. 3 while its empirical estimates, which further clarify the ARDL lag regression, is further presented in Table 3.

Table 3 showed the long-run and short-run relationship of the concerned independent variables, both with(out) interaction terms on the lnRGDP. Without the interaction term, there is no existence of a

Table 5
Estimates of dynamic simulated ARDL model.

Variables	Dynamic model without an interaction term	Full model
	dlnRGDP	dlnRGDP
$lnRGDP_{t-2}$	0.0415	−0.350**
	(0.0383)	(0.131)
Δ lnPATE	0.00338	−0.441
	(0.00578)	(0.454)
Δ lnTRAD	0.0781**	0.0920***
	(0.0357)	(0.0321)
Δ lnLABF	0.201	0.210
	(0.221)	(0.192)
Δ lnGFCF	0.139***	−0.0135
	(0.0263)	(0.143)
Δ lnGFCFPATE		0.0184
		(0.0187)
$lnGEXP_{t-2}$	−0.131***	7.30e-05
	(0.0407)	(0.0562)
$lnTRAD_{t-2}$	−0.0166	0.0243
	(0.0327)	(0.0317)
$lnLABF_{t-2}$	0.0832*	0.210***
	(0.0431)	(0.0549)
$lnGFCF_{t-2}$	0.0315	0.228***
	(0.0216)	(0.0658)
$lnPATE_{t-2}$	0.00904	0.426***
	(0.00547)	(0.135)
$lnGFCFPATE_{t-2}$		−0.0170***
		(0.00554)
Observations	39	39
R-squared	0.864	0.904

Note: Standard errors in parentheses. Parameters estimates of the ARDL model. Legend: RGDP represents Real Gross Domestic Product; GEXP represents Government Expenditure; LABF represents labour force; PATE represents Patents; TRAD represents trade openness.
*** $p < 0.01$ represents 1 %, statistical significance level.
** $p < 0.05$ represents 5 % statistical significance level.
* $p < 0.1$ represents 10 % statistical significance level.

significant long-run relationship between the RGDP and vector of independent variables, but in the short-run, TRAD and GFCF are positively related with RGDP at 5 % and 1 % significant level, that is, one unit increase in trade openness and gross fixed capital formation increase the economic growth of South Africa by 0.085 % and 0.140 %, respectively. However, the introduction of the interaction term (GFCFPATE) into the model causes a significant decrease effect at a 1 % level on the relationship between independent variables and RGDP. It has revealed that GEXP, TRAD, GFCF, and PATE have positive as well significant long-run and short-run relationships with RGDP. Specifically, 1 % increase in government expenditure increases the economic growth by 0.248 % in the long-run and 0.321 % in the short-run respectively; trade openness increases the economic growth at 0.10 % and 0.06 % in the long-run and short-run respectively; per cent increase in labour force leads to economic growth to increase by 0.387 % and 0.236 % in the long-run and short-run respectively; gross fixed capital formation also increase the economic growth by 0.547 % and 0.333 % in the long-run and short-run respectively. Also, an intense increase in patents leads to economic growth have a tremendous increase of 1.117 % in the long run and 0.681 % in the short run. Furthermore, the r-squared of the model depicted that 91.1 % of the variation in South Africa's economic growth is explained by the studied independent variables.

4.3. ARDL diagnostic measures

Although, the ARDL (1,0,0,1,0,1) regression estimates revealed the significant long-run relationships of all the independent variables on RGDP, a diagnostic measure to firmly establish the results is required. These are presented in the next couple of tables and graphs. The first (Table 4a) showed PSS bound test, KS *p*-values of cointegration test; both F statistic value (25.858) and t statistic (−8.740) is greater than critical values of all I(1) at 10 %, 5 %, and 1 % level. This is further affirmed by KS *p*-values which is <0.01, hence, the null hypothesis of no level relationship is rejected. Thus, both tests confirmed the presence of cointegration. Also, Table 4b present the Breusch-Godfrey LM test for no serial correlation or autocorrelation, the *p*-values of all the 4 lags are >0.05, hence, upholding the hypothesis of no autocorrelation, thus affirming the residual of estimated ARDL (1,0,0,1,0,1) are not serially correlated. Next is the test of heteroscedasticity using Cameron & Trivedi's decomposition of IM-test (Table 4c), it can be inferred that the *p*-values are >0.05 indicating that the null hypothesis of homoscedasticity of residuals is retained. Next, the skewness/kurtosis (Table 4d) assess the independence of residuals through normality assumption. Fortunately, this assumption of the normal distribution is satisfied since the p-value >0.05, hence upholding the null hypothesis.

Furthermore, the plot of standard normal probability (Fig. 4) and quantile of residuals against estimates of quantile normal distributions (Fig. 5) further affirmed that the residuals based on the estimated ARDL (1,0,0,1,0,1) are normally distributed, this is ascertained from the observations which are well fitted to the regression line in both plots. Finally, the plot of the cumulative sum test for the parameter (Fig. 6) was established to examine the possible structural breaks of the estimated coefficient over time. The result from the plot showed that the statistic of the estimates does not pass the 95 % confidence boundary. This is evidence that the estimated coefficient over time is stable.

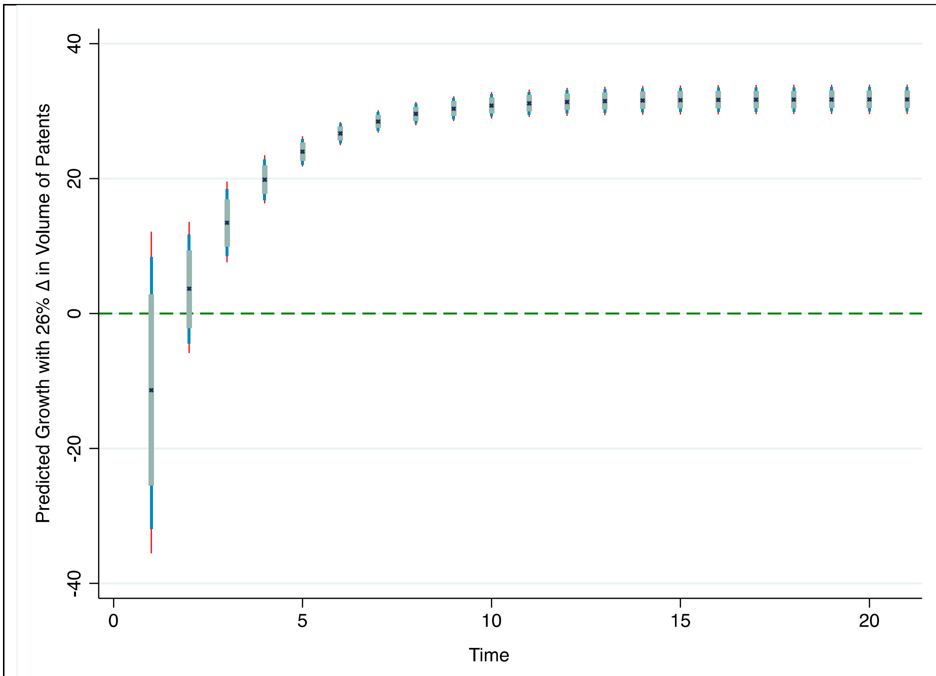
4.4. ARDL regression: post-estimation diagnostics

5. Patent policy simulations

5.1. Dynamic ARDL simulations

This section discussed the result of patent policy simulation using a novel dynamic ARDL simulation which is based on a + 26 % change in volume of patents policy in South Africa (citing required) over the period of 40 years (2019–2039). The outcome of the dynamic ARDL parameters is exposed in Fig. 7 while its empirical estimates, which further clarify the novel dynamic ARDL simulation result, is further presented in Table 5. Unlike the ARDL estimates, the lag regression result from novel dynamic ARDL is not all significant. For instance, trade openness, with(out) interaction term has only a short-run significant impact on RGDP. Gross fixed capital formation has a short-run significant relationship with RGDP without interaction term and a long-run relationship with RGDP with an interaction term.

Also, government expenditure has a negative impact on RGDP only in the short-run whereas labour force, patent, and the interaction of gross fixed capital formation has a positive, positive, and negative long-run effect on the economic growth. In summary, both ARDL (both short-run and long-run effect) and dynamic ARDL simulations (long-run effect only) revealed that patent policy simulation and the interaction effect have increasing and decreasing impacts on the economic growth of South Africa. Accounting for the impact of increasing marginal returns of +26 % volume of patent policy on improved South Africa's economic growth, dynamic ARDL simulation produced counterfactual shocks through the predicted and estimated period of 2019–2039. The result from the plot (Fig. 8) predicted that +26 % shocks in the volume of patent policy may, probably, have a bad effect on South Africa economic growth in the initial period, thereafter, the economic growth step-up sporadically, thus indicating that improvement of South Africa patent policy will have a long-lasting impact on her sustained economic growth.



Notes: black (x) is the predicted Economic Growth by a +26% shock in the volume of Patents in a log-log model; olive teal, red and green spikes denote 75, 90, and 95% confidence interval. Year 0 represent 2019 and 20 represent 2039 with a five-year interval.

Fig. 8. Counterfactual shock in predicted ICT and Patent Policy using dynamic ARDL simulations.
Notes*:* black (x) is the predicted Economic Growth by a + 26 % shock in the volume of Patents in a log-log model; olive teal, red and green spikes denote 75, 90, and 95 % confidence interval. Year 0 represent 2019 and 20 represent 2039 with a five-year interval. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 6
Pointwise derivatives using KRLS.

lnCO2	Avg.	SE	t	P > t	P-25	P-50	P-75
lnGEXP	0.19257	0.013066	14.738	0.000	0.09712	0.178788	0.278211
lnTRAD	0.099987	0.025473	3.925	0.000	−0.032389	0.100753	0.263828
lnLABF	0.227689	0.017845	12.759	0.000	0.103771	0.220405	0.346333
lnGFCF	0.077214	0.010737	7.191	0.000	0.031977	0.074367	0.137924
lnPATE	−0.004826	0.003707	−1.302	0.202	−0.020729	−0.008475	0.009084
lnGFCFPATE	0.000017	0.000181	0.092	0.927	−0.00054	−0.000047	0.000614
Diagnostics							
Lambda	0.1094	Sigma	6.000	R^2	0.997	Obs.	40
Tolerance	0.04	Eff. Df	13.84	Looloss	0.1163		

Avg. is the average marginal effect; SE is the standard error; P-25, P-50, and P-75 represent 25th, 50th, and 75th percentile. Legend: RGDP represents Real Gross Domestic Product; GEXP represents Government Expenditure; LABF represents labour force; PATE represents Patents; TRAD represents trade openness.

5.2. *Kernel-based regularized least squares (KRLS)*

For a more robust and reliable estimate, to account for the 2039 plan to improve the patent policy, we examine structural adjustment in economic growth using KRLS which is a machine learning algorithm that estimates causal-effect relationship with the implementation of pointwise marginal effect. The result, which is presented in Table 6, revealed that the average pointwise marginal effect of government expenditure, trade openness, labour force, gross fixed capital formation, and patent are 0.19 %, 0.99 %, 0.23 %, and 0.08 %, respectively. This approved the importance of these variables in the development of economic growth in South Africa. Further, in Table 6, the KRLS model is significant at 1 % with a variability power of 0.997 meaning that 99.7 % of the variation in the economic growth can be predicted by the regressors considered in this study. Also, 25th, 50th, and 75th is evidence that no heterogeneous marginal effects are observed in the model. Going further, we determine how a + 26 % increase in patent policy could project the economic growth by plotting the pointwise derivative, to capture the marginal effects, of patent policy against the economic growth. The resulting plot is in Fig. 9 and it revealed higher levels of patent policy step-up economic growth, continuous increase in the economic growth at a lower level of the patent policy until a threshold is reached where the marginal effect of patents keep on upsurging the economic growth. This infers a high possibility of improvement in South Africa economic growth due to more advanced patent policy simulation.

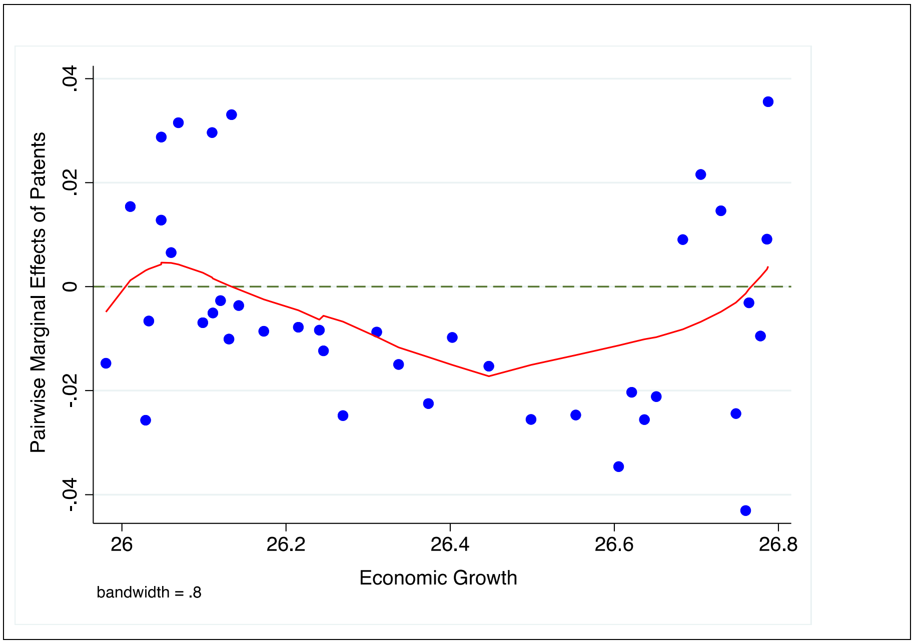


Fig. 9. Representation of Pointwise marginal effect of ICT and Patent Policies.

5.3. Simulated shocks to ICT and patent policies in South Africa

In tandent with the empirical results on the impact of simulated shocks for ICT and patent policies in South Africa, it is vital to document current and potential policy guides with issues happening in South Africa. To start with, the global economic crisis and recessions have not spared South Africa. The vulnerability of South Africa to the global economic crisis has been catalysed by its historical and political contexts, with apartheid and its remnants being the main driver. Social upheavals by disgruntled South Africans, which include xenophobic attacks, the "Fees Must Fall Movement" dubbed the; #FeesMustFall, widespread demonstrations and looting by a disgruntled section of South Africans, have all contributed to the economic shocks that have impacted the South African ICT strategic direction.

As can be noted, the apartheid has left a legacy of protests which is a culture that is typically marred by hostilities and cynicism among various sections of the South African society. The government is often seen taking a reactive stance to these protests by developing and implementing policies that are geared to mitigate the effects of the protests, not usually based on sound economic policies. As an example, in October 2015, South African public universities faced a spate of student protests which were triggered by the proposed fee increases for the 2016 academic year. The South African government reacted by funding the proposed fee increases for the 2016 and 2017 academic years in all the South African public universities. The resultant was an increase in taxes and the establishment of new tax regimes to fund these fee increases.

The xenophobic viciousness and accounts emanating from South Africa which have been blamed on a multitude of reasons had borne severe economic ramifications which accrued over a period of over 10 years from 2008. The xenophobic attacks especially on foreigners living in South Africa have resulted in the loss of income and economic activities with South Africa. Furthermore, the accrued violation of human rights, the deaths and the displacement of several people resulted in not the only negative image of South Africa, but in significant changes in the South African immigration laws and information systems.

Against all these backdrops caused by various economic shocks, the South African government established the National Intellectual Property Management Office (NIPMO) in terms of Section 8 of the Intellectual Property Rights of the Publicly Financed Research and Development Act 51 of 2008. The South African government is furthermore assisting by funding the South African researchers and establishing technology transfer offices in all public universities. The South African government is funnelling millions of Rands into different public universities, science and research councils by funding ideas and technologies that are destined to improve South Africa and its people. In the ICT space revolutionary policy initiatives that promote universal access to ICTs, 4IR, and free Wi-Fi such as the Tshwane's free Wi-Fi program have been implemented. In a nutshell, South Africa has experienced significant negative economic shocks that impacted ICT growth, but at the same significant policy directions and initiatives that promote ICTs and patenting have been deployed.

6. Conclusion and policy directions

Investigating the policy simulation exercise on ICT and patent intensity in South Africa, this study examined the relationship between patent intensity and economic growth in South Africa for the period of 1980–2020. With more macroeconomic variables such as government expenditure, gross fixed capital formation, labour force, trade openness, and gross fixed capital formation and patent intensity as the interaction term. This study incorporated ARDL to capture short-run and long-run relationships, and novel estimated techniques such as novel dynamic ARDL and Kernel-based Regularized Least Squares (KRLS) to capture counterfactual shocks in improving the patent intensity while projecting towards 2039. After establishing the first-difference stationarity of order one I(1), existence PSS and KS cointegration test, affirmation of no serial correlation, no heteroscedasticity, and normality assumption of the residual term, we run the ARDL (1,0,0,1,0,1) lag regression and the result revealed that government expenditure, labour force, and trade openness significantly foster the economic growth in long-run and short-run.

Also, while patent intensity and gross fixed capital formation increase the economy in the long-run and short-run, their interaction term significantly diminishes the growth. The outcome here commensurate with the study of Canh and Nadia (2022), Jayaprakash and Radhakrishna Pillai (2021) in their study on the impact of ICT on sustainable economic, social, and environmental development, and Latif et al. (2017) in the study of ICT effects on the environment – culture, human, behaviour, and education. Further in the analysis is the dynamic ARDL simulation and KRLS, which predicted the counterfactual shocks of economic growth based on a + 26 % change in patent intensity. The result showed that the increasing volume of patent policy may, probably, have a bad effect on South Africa economic growth in the initial period, but the growth, thereafter, the economic growth step-up sporadically, thus indicating that improvement of South Africa patent policy will have a long-lasting impact on her sustained economic growth. Having examine the importance of the patent's effect on the economic growth, the policy directions is for the government of South Africa and appropriate authorities design a systematic framework that will rise the country system of patent to the developed countries standard. Although, there might be obstacles in designing an ideal methodological framework, but an idea can be gotten from the Turkish framework in which the patent applications were forwarded to different countries (Russia, Danish, Swedish and European Patent Offices) for examines the novelty and authenticity of her framework (Anthipi and Anastassios, 2011). The limitation and direction for future study to examine why the interactions of patent and gross fixed capita formation have negative effects need to be considered.

CRediT authorship contribution statement

Festus Fatai Adedoyin: Conceptualization, Methodology, Software, Visualization, Validation, Investigation, Data curation, Writing – original draft. **Nicholas Mavengere:** Conceptualization, Data curation, Writing – original draft. **Alfred Mutanga:** Conceptualization, Writing – review & editing.

Data availability

Data will be made available on request.

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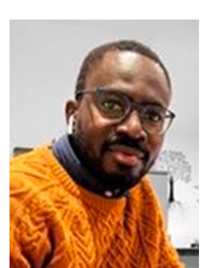

Dr. Festus Adedoyin is a Fellow of the Higher Education Academy, a Chartered Management and Business Educator, and a lecturer at the Department of Computing and Informatics, Bournemouth University, U.K. His current research interest is in the application of Machine and Deep Learning, and Econometrics tools to research stories in Energy and Tourism Economics as well as Finance and Digital Health. Festus has contributed to several thematic areas in the UN's Sustainable Development Goals, and he is open to international research collaborations.

Dr. Nicholas Mavengere is a Senior Lecturer (academic) in computer science – Business IT in the Faculty of Science & Technology, Bournemouth University. He completed his PhD in Information and Systems at Tampere University in Finland in 2013. His PhD received best PhD research award at a European conference and a university award. Before joining BU, Nicholas was a post-doctoral researcher at Tampere University. Nicholas has organized several academic workshops and co-chaired conference. He has edited conference publications and reviewed in conferences, such as, ECIS, ICIS and AMCIS. He has published papers in fully refereed international conferences, journals and edited two books. In 2020, he received a Post-Graduate Certification in HE Teaching and Learning from Bournemouth University. He is a Fellow of the Higher Education Academy (HEA), UK and a member of Association of Information Systems (AIS) and The Chartered Institute for IT (BCS).

Dr. Alfred Mutanga is a Business Intelligence Expert and an Instructional Designer. His expertise include consultancy in Higher Education, Business Intelligence, Institutional Research, Institutional Planning and Management Information Systems. Alfred has successfully proposed, designed, and implemented Business Intelligence Systems, which are used for strategic decision making, supporting strategic planning and quality assurance processes within the South African higher education landscape. He holds a Doctor of Philosophy degree from the University of Venda, and his doctoral research focused on Business Intelligence in Higher Education Institutions. Alfred's >18 years of professional experience include Computing and Information Technology research, e-Learning, lecturing in computer science, systems administration and implementing decision support systems particularly for the higher education landscape. He is a Professional Member of the South African Qualifications Authority (SAQA) accredited Institute of Information Technology Professionals of South Africa.