Volume 22
Number 3
Fall 2024

ISSN 1854-6935

Managing Global Transitions International Research Journal

EDITOR IN CHIEF
Jana Hojnik

Managing Global Transitions
International Research Journal
ISSN 1854-6935 · www.mgt.fm-kp.si

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Managing Global Transitions
International Research Journal
VOLUME 22 · NUMBER 3 · FALL 2024 · ISSN 1854-6935

https://doi.org/10.26493/1854-6935.22_3

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INDEXING AND ABSTRACTING

Managing Global Transitions is indexed/ listed in the International Bibliography of the Social Sciences, EconLit, IBZ Online, DOAJ, Erih Plus, EconPapers, Cabell's, EBSCO, and ProQuest.

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Managing Global Transitions (MGT) is a quarterly, scholarly journal that covers diverse aspects of transitions and welcomes research on change and innovation in increasingly digitalized and networked economic environments, from a societal, organizational, and technological perspective. MGT fosters the exchange of ideas, experience, and knowledge among developed and developing countries with different cultural, organizational, and technological traditions. MGT invites original scientific, research, and review papers advancing the field of transitions in societies, organizations, and technologies.

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- Science and technology policy that fosters transformative advancement
- Modeling technological change in VUCA (volatile, uncertain, complex, ambiguous) environments

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PUBLISHED BY

University of Primorska Press
Titov trg 4, 6000 Koper, Slovenia
zalozba@upr.si · www.hippocampus.si

Revija Managing Global Transitions je namenjena mednarodni znanstveni javnosti; izhaja v angleščini s povzetki v slovenščini. Izid revije je finančno podprla Javna agencija za znanstvenoraziskovalno in inovacijsko dejavnost Republike Slovenije iz sredstev državnega proračuna iz naslova razpisa za sofinanciranje izdajanja domačih znanstvenih periodičnih publikacij.

Does Digitalisation Increase Economic Growth? Evidence from SADC Countries

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The fourth industrial revolution has contributed significantly towards the growing global technological transfers that enhance productivity, employment and standard of living. The outbreak of the COVID-19 pandemic has undeniably disrupted lives globally; however, it enhanced technological transformation by causing an abrupt shift towards digital technology usage. The development and diffusion of digitalisation is expected to drive economic growth as we move towards the 2030 Sustainable Development Agenda. This study examines the impact of digitalisation on economic growth for 14 Southern African Development Community (SADC) countries from 2000 to 2020 employing the Fixed Effects model. Results reveal that all digitalisation indicators employed tend to have a positive impact on economic growth. A percentage change in individual usage of information communication technologies (ICTs), fixed broadband subscriptions, and mobile cellular subscriptions leads to a 0.17%, 0.11% and 0.12% increase in GDP per capita, respectively. Therefore, usage of and access to digital technologies stimulate economic growth in the SADC region. Public policies should seek to stimulate private sector investments in technological infrastructure and liberalise the telecommunications and innovation market. This accelerates digitalisation and consequently leads to higher economic growth and development in the SADC region.

Key Words: digitalisation, economic growth, fixed effects model, SADC
JEL Classification: 033, 01, 047, R11, C5

Received 2022/09/09 · Revised 2023/01/06 · Accepted 2023/01/11
Published online 2024/09/30 https://doi.org/10.26493/1854-6935.22.201-229

Introduction

The world economy has experienced a transition in respect to the social, economic and business landscape due to increased usage of digital technology. To adapt to these dynamic lifestyles and business operations, individuals and businesses are now facing a lot of pressure to utilise digital technology. The use of and access to digital technology has smoothed the way in which businesses interact with their customers, thereby strengthening customer relationships. According to Hagberg, Sundstrom, and Egels-Zandén (2016), digitalisation is defined as the transformation from 'analogue' to 'digital' and to the facilitation of new forms of value creation, while Srai and Lorentz (2019) defined it as the way many domains of social life are restructured around digital communication and media infrastructures.

Evangelista, Guerrieri, and Meliciani (2014), Batuo (2015), Traore (2014), Mirgorodskaya, Rustamova, and Grachev (2020), and Fernández-Portillo, Almodóvar-González, and Hernández-Mogollón (2020) have shown that the development of and access to technological infrastructure drives economic growth. A lot of people are increasingly making use of digital technology for social, business, educational and other activities in these modern days. It is this technological usage by people that is pushing businesses and governments to adopt new technologies to meet the changing needs of their consumers. However, despite the increased usage and development of digital technology, not all people are able to fully utilise technologies due to some costs involved. The investment in technological equipment and usage, especially in developing countries, is costly and has aggravated online inequalities within countries. Developing countries, particularly in Africa, are still lagging with regard to digitalising their economies. According to the United Nations (2021b), extreme poverty is mainly a rural phenomenon, reflecting that most of the poverty-stricken population in developing countries are living in rural areas. In Africa, using the example of Zimbabwe, many of its rural areas have poor internet connectivity, limited devices and limited internet coverage resulting in low internet usage (World Bank 2021). In urban areas where there is better coverage, the cost associated with accessing the Internet may also be an obstacle towards technological usage. To reduce online inequalities and increase growth, governments should improve access to and use of digital technology. Arsić (2020) shows that technical innovations increase productivity, which enables enormous

growth in the world and an increase in the standard of living due to the increase of the quantity of product per worker and therefore fewer working hours.

According to International Telecommunication Union (n.d.), over the last four years, the African region has seen continued, albeit slow, growth in most areas of ICT infrastructure, access and use. This slower diffusion of digital technology could be inducing low growth and high poverty levels. Meanwhile, in most developed countries, digitalisation has become one of the main drivers of economic growth. According to Duarte (2021), for Africa to generate economic growth that leads to sustainable development, it must shift its focus to retaining and creating wealth to reboot the continent's economic structures and catch up technologically with the rest of the world. Innovation, and the digital information technology that accompanies it, has become a necessary component of any effort to address growth and poverty challenges. Adequate technological diffusion leads to economic development by enhancing the efficiency with which all the factors of production are utilised in the economy, and this reduces poverty incidence (United Nations 2010). The production frontier is enhanced by the efficient use of technology (Ekekwe 2011). The slow spread of internet technology makes it difficult for the continent to leapfrog obstacles to sustainable development. To generate transformative growth, digitalisation cannot be left mainly to civil society and the private sector. There exists scant empirical research aimed at investigating the effect of digitalisation on the economic growth of Southern African Development Community (SADC) countries. This paper fills the gap by using available data from SADC countries to examine the impact of access to and use of digital technology on economic growth.

The rest of this article is organised as follows: dynamics of economic growth and digital technology development in Africa, literature review, estimation method and model specification, results and discussion, and lastly the conclusions and implications.

The Dynamics of Economic Growth and Digital Technology Development in Africa

To promote peace and prosperity for people and the planet, the United Nations (UN), in 2015, set up a group of 17 global goals. One salient feature of these goals highlights the importance of access to digital technology, development, and diffusion of digitalisation. The United Nations (2018) explain that Sustainable Development Goal (SDG) 9 seeks to promote

industrial innovation and infrastructure development to support domestic technology development and innovation in developing countries as well as significantly increase access to information and communication technology and to provide universal and affordable access to the Internet in the least developed cfountries. Furthermore, related to this goal is SDG 17, which seeks to improve access to science, technology and innovation and enhance knowledge sharing on mutually agreed terms, promote the development, transfer, dissemination, and diffusion of ecologically sound technologies to developing countries and fully operationalise the technology and innovation capacity-building mechanism for least developed countries, and enhance the use of enabling technology in ICTs (United Nations 2018).

Although progress towards Agenda 2030[1] for Sustainable Development was moving in the right direction, the outbreak of the COVID-19 pandemic has reversed this trend (United Nations 2021a). As of 2019, just over half of the world's population was online, with a large digital divide observed among regions. The United Nations (2021a) further show that during this time, while 85 per cent of the population in Europe and Northern America had internet access, only 20 per cent were connected in the least developed countries. Additionally, while fixed-broadband subscriptions continued to increase, growth in subscriptions slowed to 2.7 per cent in 2020. In developed countries, there were more than 33 subscriptions per 100 inhabitants, representing a high penetration rate, while the number in developing countries stood at 11.5 per 100 inhabitants. In the least developed countries, fixed networks are almost completely absent, with only 1.3 subscriptions per 100 inhabitants. The United Nations (2021a) also reported that in 2018, the share of medium- and high-technology manufacturing in total manufacturing was 49 per cent in developed regions and 41.4 per cent in developing regions, compared to only 8.9 per cent in the least developed countries. The roll-out of mobile broadband networks slowed in 2020. Almost 85 per cent of the global population was covered by a 4G network at the end of 2020, following a twofold increase in coverage since 2015. However, annual growth has been slowing gradually since 2017, with the result that coverage in 2020 was only 1.3 percentage points higher than in 2019.

The COVID–19 pandemic negatively affected several development indicators in developing economies, with no exception in technological development. According to the Organisation for Economic Co-operation and Development statistics (OECD n.d.), Africa's real GDP growth

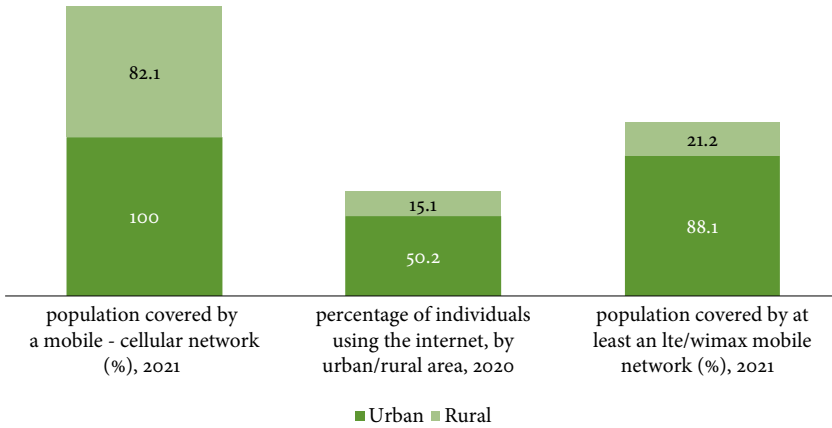

FIGURE 1 ICT Penetration Rates in Africa (based on data from International Telecommunication Union n.d.)

was –1.6% in 2020, while in 2019 the African economy grew by 3.3%. The most affected region in Africa in 2020 was the Southern region, with real GDP growth of –5.7%. Countries that recorded a very high negative growth are Botswana (Southern Africa), Mauritius and Seychelles from East Africa, Libya and Tunisia in North Africa, and Cabo Verde in West Africa. The OECD (n.d.) report shows that gross domestic product in Africa decreased in 41 countries in 2020, compared to 11 countries in 2009 when the global financial crisis occurred. In terms of digitalisation progress in Africa, the International Telecommunication Union statistics shows that Africa had the lowest subscriptions both fixed telephone and broadband subscriptions than other ITU regions by 2021 (International Telecommunication Union n.d.). Although Africa has a better number of mobile-cellular telephone subscriptions and active mobile broadband subscriptions than Arab States, the Commonwealth of Independent States (CIS), and Europe, the subscriptions were still relatively low in 2021. Additionally, the population covered by at least an LTE/WiMAX mobile network or by a mobile cellular network at a 3G mobile network, although greater than Asia Pacific and CIS regions, was still relatively low in 2021. The international bandwidth in 2021 remained very small compared to the majority of other ITU regions. The penetration rates in Africa are still very low in rural areas as compared to urban areas, as illustrated in figure 1. Figure 1 also depicts that by 2020, only 15% of individuals in rural areas were using the Internet, while 50% of the urban population were using internet. Additionally, by 2021 only 21% of the rural population

was covered by at least an LTE/WiMAX mobile network, while 88% of the urban population is covered (International Telecommunication Union n.d.). Consequently, ICT penetration rates in rural areas of Africa remained very low in spite of a greater number of the population being covered by a mobile cellular network.

To achieve UN SDG 9.c, SDG 17.6 and SDG 17.8, as well as kick-start a new growth cycle in the aftermath of the COVID-19 crisis, Africa has an opportunity to boom its digital sector. Digitalisation is one of the most powerful tools for implementing the 2030 Agenda for Sustainable Development and Africa's Agenda 2063. Figure 2 depicts a bivariate analysis of average growth in GDP per capita and average individual usage of the Internet, average fixed broadband subscriptions and average mobile cellular subscriptions for the period 2000-2020. The plots show a positive correlation between growth and all the digitalisation variables, in line with findings from Solomon and van Klyton (2020). The correlation is strongest between average GDP per capita and mobile broadband subscriptions.

Literature Review

THEORETICAL LITERATURE

The mixed performance of neoclassical theories such as Solow's (1956) neoclassical growth model in explaining long-term economic growth led to discontentment with traditional growth theory. The models predict that economies of both developed and developing countries will eventually converge to zero economic growth if there are no external technological shocks or changes. Therefore, Solow (1956) perceived increasing per capita gross national income (GNI) as a short-run occurrence emanating from technological changes or a situation where the economy is self-adjusting in order to reach its long-run equilibrium point. It is this failure by the neoclassical theories to account for sustained economic growth and ascribing it to exogenous technological shocks that led to the emergence of the endogenous growth models (Todaro and Smith 2015).

Romer (1986; 1989), and Lucas (1990) postulated alternative growth models known as Endogenous or New Growth models, where long-run growth depended on intentional investment decisions as opposed to Solow's exogenous technological innovation. These models differ from the neoclassical Solow Growth Model in that they account for sustained economic growth by disregarding the assumption of diminishing returns to capital and treating the accumulation of knowledge as deliberate

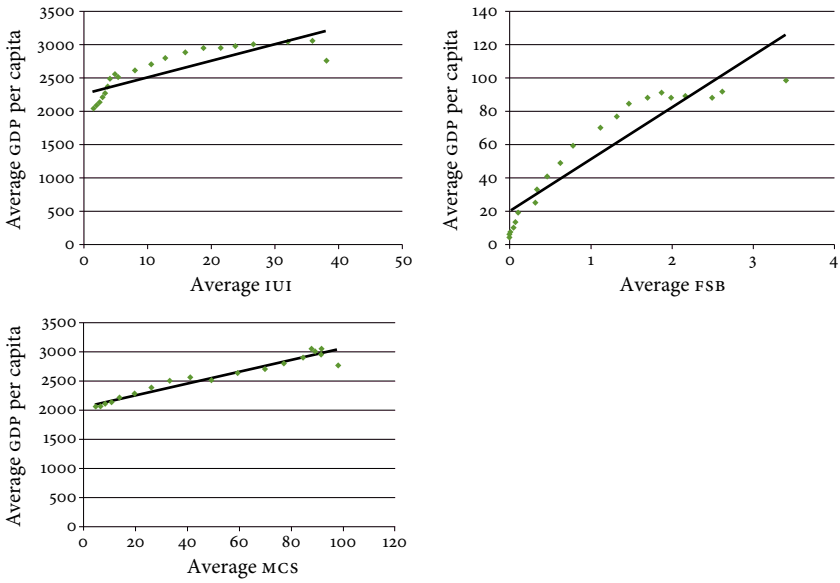

FIGURE 2 Average Growth in GDP Per Capita and Average Individual Usage of Internet (IUI), Fixed Broadband Subscriptions (FBS) and Mobile Cellular Subscriptions (MCS) for the Period 2000-2020 in Africa

decisions by profit-maximizing firms (Todaro and Smith 2015; Snowdon and Vane 2005). In the endogenous growth models, technological innovations by individual firms are partially excludable, which allows other firms to imitate the technologies and benefit the larger economy, because of these positive externalities from technological innovations. While an individual firm's production function is subject to diminishing returns, the production function of the economy is subject to increasing returns to scale owing to the positive technological spill overs (Myovella, Karacuka, and Haucap 2020). In this way, the endogenous growth models can explain the divergent long-term growth patterns among countries.

Dissimilar to the Solow model, new growth theory accounts for technological change as an endogenous outcome of public and private investments in human capital and knowledge-intensive industries. According to Todaro and Smith (2015), the endogenous growth models emphasise the need for public policy to be geared towards investments in human capital formation and the stimulation of 'foreign private investment in knowledge-intensive industries such as computer software and telecommunications'. The effects of digitalisation on economic growth can, therefore, be explained within the framework of the endogenous growth

theory (Aghaei and Rezagholizadeh 2017; Myovella, Karacuka, and Haucap 2020).

Defined as the 'incorporation of data and the Internet into production processes and products, new forms of household and government consumption, fixed-capital formation, cross-border flows, and finance' (International Monetary Fund 2018), digitalisation is enabled by the advent of Information and Communication Technologies (ICT). Myovella, Karacuka, and Haucap (2020) explained that specific ICTs, namely internet and mobile phone technologies, necessitate the creation of 'new products and processes, new market channels and organizational complexities, along with technological advancement'. Thus, ICT improves allocative efficiency both in resource and goods markets, reduces production costs, and promotes demand and investment in all sectors of the economy. Digitalisation has, among other things, revolutionised how businesses operate (e.g. e-commerce and electronic payments systems), how people communicate (e.g. social media and videoconferencing) and how governments provide services to the public (e.g. e-government portals). In this way, technological changes have brought efficiencies that have become the engines of growth for both developing and developed countries.

EMPIRICAL REVIEW

There is a bountiful amount of research detailing the impact of digitalisation on economic growth. The empirical efforts examining the digitalisation effects on growth appear to be more extensive in developing and emerging countries in comparison to other world regions. There is basically a consensus that digitalisation drives economic growth for both developing and developed countries. For the sake of brevity and relevance, we restrict our review to studies which focus on the digital technology usage and digital technology infrastructure contribution to growth. These studies can be conveniently divided into 3 strands of empirical works namely: i) Studies inclusive of developing countries, ii) Studies inclusive of developed countries, and iii) Methodology used in these studies.

The first cluster of studies includes all reviewed studies covering developing countries with their results. In this group, we include the works of Solomon and van Klyton (2020) on 39 African countries, distinguishing between the impact of individual, business and government ICT usage on growth and showing that only individual usage, social media usage and

government ICT have a positive impact. Batuo (2015) presents empirical evidence on how telecommunication infrastructure is related to growth in a panel data set covering 44 African countries and suggests that telecommunication infrastructure contributes in a major way to economic development of the continent. Bahrini and Qaffas (2019) evaluate the impact of ICT on growth for selected countries in the Middle East and North Africa region and Sub-Saharan region and shows that except for fixed telephone subscriptions, other information and communication technologies such as mobile cellular subscriptions, Internet usage, and broadband adoption are the main drivers of growth. Traore (2014) studies the effects of telecommunications infrastructure on economic development and growth in 33 Sub-Saharan African countries and shows that the implementation of mobile phone technology contributes in a major way to the economic development of the continent. Onyeji and Karner (2008) prove that the contribution of mobile subscribers to economic growth is positive and significant in the case of Africa and Central East European countries. Donou-Adonsou (2019) shows some different results, where the Internet contributes to economic growth, but only in countries with better access to education, with no strong evidence on how mobile phones promote growth in 45 Sub Saharan African countries. Salahuddin and Gow (2016) investigate the relationship among internet use, economic growth and financial development and results indicate that internet use stimulates economic growth. Sridhar and Sridhar (2007) use 63 developing countries to examine the relationship between telecommunications infrastructure on economic growth and find a positive impact of mobile and landline phones on national output. Shodiev, Turayey, and Shodiyev (2021) reveal that ICT affects GDP per capita positively and significantly in emerging countries of Central Asia. Usman et al. (2021) investigate the effect of ICT on economic growth in South Asian economies and reveal that in the long run, ICT significantly and positively contributed towards the economic growth of India only.

The impact of digitalisation on growth and development has also been widely researched in relation to developed countries. This cluster of studies includes the works of Jiao and Sun (2021) on digital economy development in China, focusing on internet development, digital literacy and industrial efficiency improvement. The study finds that digital economic development in China has a positive effect on urban economic growth, and a heterogeneity effect exists between different cities. Mirgorodskaya, Rustamova, and Grachev (2020) investigated the impact of digitalisation

on Russia's economic growth and found a strong correlation between GDP and the digital economy development indicators. Raeskyesa and Lukas (2019) analysed the effect of digitalisation on the economic growth of eight ASEAN middle income countries and found that ICT indicators have a significant positive impact on growth; however, usage and intensity of ICT have a higher impact than access to ICT. Toader et al. (2018) evaluate the effect of using ICT infrastructure on economic growth in the EU countries. Their results indicate a positive and strong effect of using ICT infrastructure on the EU member states' economic growth. According to Pradhan et al. (2019), there are strong interlinkages between ICT infrastructure, economic growth and venture capital in their analysis done using 25 European countries. Shahiduzzaman and Alam (2014) investigate the role of investment in IT on economic output and productivity in Australia. The empirical evidence points to a cointegration relationship between ICT capital and output and implies that ICT capital Granger causes economic output and multifactor productivity, as does non-ICT capital. Different results were found in the case of Japan, where Ishida (2015) estimated the relationship between ICT and economic growth and found that ICT investment does not contribute to an increase in GDP. Fernández-Portillo, Almodóvar-González, and Hernández-Mogollón (2020) investigate the impact of ICT development on economic growth on OECD European union countries. Results suggest that progress in the deployment and use of ICT drives the economic growth of countries that are within the framework of developed European countries.

In terms of economic integrations, Latif et al. (2018) investigated the dynamic relationship between ICT, FDI, and economic growth in BRICS and found that ICT positively contributes to economic growth of BRICS countries. Aghaei and Rezagholizadeh (2017) examine the impact of ICT on economic growth among the Organization of Islamic Conference members and reveals that there is a significant impact of investments in ICT on economic growth in the countries considered. By distinguishing several stages or domains of the digitalisation process, Evangelista, Guerrieri, and Meliciani (2014) evaluated the economic impact of digital technologies in Europe. The findings demonstrated that the usage of ICT, particularly digital empowerment, has a major economic impact, notably on employment and the labour-market involvement of 'disadvantaged' groups. They found that digitisation has the potential to boost productivity and employment development, and that inclusive policies

may help close the gap between the most advantaged and disadvantaged portions of the population.

Another interesting group of studies compares the most and the least developed countries to measure which group benefits the most from digitalisation. The results in this group of studies show mixed direction. Myovella, Karacuka, and Haucap (2020) compare the most and the least developed countries to measure the effects of digitalisation on economic growth using 41 SSA and 33 OECD countries. Their results show that digitalisation makes a positive contribution to economic growth in both groups of countries. Majeed and Ayub (2018) use 149 countries to analyse the impact of ICT indicators on economic growth at both global and regional levels. This analysis involves developed, emerging, and developing countries and reveals that emerging and developing countries are gaining more from ICT than developed countries, validating the argument that these economies are 'leapfrogging' through ICT. Niebel (2018) analyses the impact of ICT on economic growth in developing, emerging, and developed countries; however, the study found no statistical evidence that developing and emerging countries are gaining more from ICT than developed economies. Appiah-Otoo and Song (2021) employ a panel of 123 countries, including high-income countries or middle-income and low-income countries. Their results show that ICT increases economic growth in both countries. Additionally, poor countries tend to benefit more than rich countries from the ICT revolution. Albiman and Sulong (2017) examine both linear and nonlinear impacts of ICT on economic growth for lower middle income, lower income, and upper income categories within the SSA region. Results show that lower-middle-income countries have more first-mover advantages when it comes to absorbing benefits from ICT compared to lower-income and upper-income categories. Additionally, the impact of fixed telephone lines are higher compared to mobile phone lines even though the positive impact of the mobile phone is more robust for each income category compared to other technologies.

In further summarising the empirical literature, we can look at estimation techniques to show the trend in development of econometrics techniques used. The econometric techniques used extensively as a method of estimation are the Generalized Method of Moments (GMM), pooled OLS, fixed effects, random effects and ARDL (Bounds test and the PMG/ARDL Models). Jiao and Sun (2021), Bahrini and Qaffas (2019), Traore (2014), Donou-Adonsou (2019), Solomon and van Klyton (2020), Myo-

vella, Karacuka, and Haucap (2020), and Nasab and Aghaei (2009) employed the GMM estimator, while Elding and Morris (2018), Raeskyesa and Lukas (2019), Batuo (2015), Onyeji and Karner (2008), Toader et al. (2018), Niebel (2018), and Aghaei and Rezagholizadeh (2017) employed panel data regression analysis using either one or a combination of the Pooled OLS, Fixed and Random effects. Another widely used technique is the ARDL Model and the PMG/ARDL Model. These models are used in the works of Salahuddin, Alam, and Ozturk (2016), Salahuddin and Gow (2016), Shahiduzzaman and Alam (2014), Ishida (2015), Albiman and Sulong (2017), and Usman et al. (2021). The OLS and VECM have been used, but not more often. Latif et al. (2018) and Shodiev, Turayey, and Shodiyev (2021) employ the OLS, while Fernández-Portillo, Almodóvar-González, and Hernández-Mogollón (2020) employ the Partial Least Squares (PLS) analysis. The VECM was employed in the works of Pradhan et al. (2019) and Saidi and Mongi (2018).

Notably, there is a consensus that ICT usage and infrastructure development have a significant impact on the growth of both developing and developed countries. However, studies focusing on African economies present some challenges in terms of data collection and availability. Additionally, despite investment efforts, African countries have faltered in reaping the expected economic prosperity associated with digitalisation because of a persistent digital divide, including digital skills shortages and deficits in ICT infrastructure. This has resulted in Internet inequality (Online inequalities) in Africa, creating major challenges and, hence, the motive to investigate the impact of digitalisation on African countries.

This research contributes to the literature by being the first study to explore the dynamics between economic growth and digitalisation in the SADC region. Existing studies on this subject look at Sub-Saharan Africa as whole or at developing countries without a specific focus on the SADC region. The SADC region is an important bloc because it represents regional integration in the Southern part of Africa. The main objective of the SADC grouping is to 'Achieve development and economic growth, alleviate poverty, enhance the standard and quality of life of the people of Southern Africa and support the socially disadvantaged through regional integration' (Southern African Development Community 1992). This objective seeks to address the chronic socio-economic problems which are common in other regions of the African continent. In its Vision 2050, SADC aims 'to have efficient and effective, technologically-driven cross-border infrastructure services and networks to support and

facilitate deeper regional integration' (Southern African Development Community 2020, 6). Therefore, it is important to measure the extent to which the region has managed to exploit advancements in technology to achieve its key objectives, and this is what this study seeks to ascertain.

Estimation Method and Model Specification

To model the impact of digitalisation on economic growth in the SADC region, we begin with a Cobb-Douglas production function for country *i* and time.

$$Y_{it} = A_i L_{it}^{\beta_1} K_{it}^{\beta_2} D_{it}^{\beta_3} e^{\rho it} \tag{1}$$

where Y is output, L is labour (i.e. total employment), K is physical capital stock, D level of digitalisation and A is a country-specific multiplicative constant that could denote country-specific technological capability. The β coefficients denote the factor share of the corresponding factor inputs, and ρ is a country-specific efficiency parameter. Taking natural logs and first differencing gives:

$$\Delta In Y_{it} = \beta_1 \Delta \ln L_{it} + \beta_2 \Delta \ln K_{it} + \beta_3 \Delta \ln D_{it} + \Delta \rho_{it} \tag{2}$$

where ΔlnY, ΔL, ΔK and ΔD refer to growth in output, labour, physical capital, and level of digitalisation, respectively. The parameters β_1, β_2 and β_3 denote output elasticities with respect to the corresponding factor inputs. In line with the endogenous growth model, we do not impose constant returns to scale. Following the approach of Lokshin, Belderbos, and Carree (2008), we assume that the country-specific efficiency parameter ($\Delta\rho_{it}$) is a function of past productivity (Y_{it-1}), to allow for conditional convergence among countries (Barro 1991; Bond, Hoeffler, and Temple 2001); that is, the hypothesis that poorer countries grow faster than richer ones, conditional on other variables in the model. For example, Murthy and Ukpolo (1999) and Asongu and Odhiambo (2020) find strong evidence of conditional convergence in African countries.

$$\Delta \rho_{it} = \alpha_1 In Y_{it} + e_{it} \tag{3}$$

The error term in equation (3) (e_{it}) consists of a country-specific fixed effect, σ_i, that measures unobserved permanent differences in output across countries, a time-specific effect (τt) that captures disembodied technical change (Lokshin, Belderbos, and Carree 2008), and an idiosyncratic error term (u_{it}).

$$e_{it} = \sigma_i + \tau t + u_{it} \tag{4}$$

The level of digitalisation (D) can be approximated by usage and access (Cardona, Kretschmer, and Strobel 2013). Therefore, the usage aspect of the level of digitalisation will be proxied by *IUI* (individual using the Internet as percentage of the population) while the access aspect will be proxied by *FBS* (fixed broadband subscriptions per 100) and (Mobile-cellular subscriptions per 100 inhabitants) for each SADC country. Based on the existing theoretical and empirical bases of modelling the impact of digitalisation on economic growth reviewed, we specify a simple Cobb-Douglas production in the following specification:

$$\begin{aligned}\Delta Y_{it} = {} & \beta_0 + \beta_1 \Delta \ln L_{it} + \beta_2 \Delta \ln K_{it} + \beta_3 \Delta \ln IUI_{it} \\ & + \beta_4 \Delta \ln FBS_{it} + \beta_5 \Delta \ln MCS_{it} + \beta_6 \Delta \ln POG_{it} \\ & + \beta_7 \Delta \ln TO_{it} + \beta_8 Z_i + u_{it}\end{aligned} \tag{5}$$

where Z_i are unobserved time invariant heterogeneities across the countries $i = 1, 2, \ldots 14$.

The aim is to estimate output elasticities in equation (5) with respect to the corresponding explanatory variables holding constant Z_i. The baseline specification given in this study is a fixed effect (FE) panel regression model controlling for unmeasured cross country differences. In addition, we use the Pooled OLS (POLS) and Random Effect model.[2]

Among other variables, labour, gross capital formation and other variables are anticipated to be endogenous for two salient reasons: omitted variable bias and reverse causality. As a method to reinforce our estimations from equation (5), an approach that has been widely employed to avoid the problems associated with simultaneity is to replace a suspected variable with its lagged values. Examples of studies employing this approach include the works of Buch, Koch, and Koetter (2013), Cornett et al. (2007), Vergara (2010), Hayo, Kutan, and Neuenkirch (2010) and Clemens et al. (2012). As a result, we lagged all explanatory variables by one year. Since after diagnostic the FE model proved to be the most appropriate model, equation (6) is a representation of the Fixed Effects model, letting $\alpha_i = \beta_0 + \beta_9 Z_i$ to obtain:

$$\begin{aligned}\Delta In Y_{it} = {} & \beta_1 \Delta \ln L_{it-1} + \beta_2 \Delta \ln K_{it-1} + \beta_3 \Delta \ln IUI_{it-1} \\ & + \beta_4 \Delta \ln FBS_{it-1} + \beta_5 \Delta \ln MCS_{it-1} + \beta_6 \Delta \ln POG_{it-1} \\ & + \beta_7 \Delta \ln TO_{it-1} + \beta_8 \Delta \ln INF_{it-1} + \alpha_i + u_{it}\end{aligned} \tag{6}$$

with $i=1,\ldots 14$ and $t=2000,\ldots\ 2020$, $t-1$ is lag of one year. The α_i are country-specific intercepts that capture heterogeneities across countries.

Estimating the FE model with regressors, taking averages on both sides of equation 4 we obtain:

$$\begin{aligned}\frac{1}{n}\sum_{i=1}^{n}\ln Y_{it} = {} & \beta_1\frac{1}{n}\sum_{i=1}^{n}\ln L_{it-1} + \beta_2\frac{1}{n}\sum_{i=1}^{n}\ln K_{it-1} \\ & + \beta_3\frac{1}{n}\sum_{i=1}^{n}\ln IUI_{it-1} + \beta_4\frac{1}{n}\sum_{i=1}^{n}\ln FBS_{it-1} \\ & + \beta_5\frac{1}{n}\sum_{i=1}^{n}\ln MCS_{it-1} + \beta_6\frac{1}{n}\sum_{i=1}^{n}\ln X_{it-1} \\ & + \frac{1}{n}\sum_{i=1}^{n}\alpha_i + \frac{1}{n}\sum_{i=1}^{n}\mu_{it} \end{aligned} \tag{7}$$

DATA AND DESCRIPTIVE STATISTICS

We estimate equation (7) for a sample of 14 SADC countries from 2000 to 2020. The study used this period because of data availability on all the variables in the study, and although employing an unbalanced panel data, the number of observations is more than 225 in all variables, which is enough to perform regression analysis. Due to data unavailability, Seychelles and Malawi are removed from the sample. Table 1 summarises the list of variables and the respective descriptions.

Table 2 shows the within and between summary statistics. The descriptive statistics of the panel data for SADC countries shows that the overall mean GDP per capita was about US$ 2595.26, which fluctuated between $294.65 and $10643.77 over the period.

Trade liberalisation is improving in the SADC region as shown by a high degree of trade openness with an overall mean of 78.60%. The degree of trade openness has not been stable over the period, as indicated by a high standard deviation of 32.41%. The minimum trade openness was 23.98%, recorded in Tanzania in 2000, showing lower trade density in that country, while Eswatini recorded the highest trade density of 175.80% in 2002. In terms of technological diffusion, mobile cellular subscriptions reached an average of 53%, with Comoros having recorded zero subscriptions between the periods 2000-2003 and South Africa having recorded the highest subscriptions of 165% in 2019. The overall mean for the fixed broadband subscriptions was very low over the period, showing lower diffusion of these subscriptions in the region. SADC countries are still struggling when it comes to fixed broadband subscriptions with

TABLE 1 Description of Variables

Variable	Short Description	Source
ΔInY_{it}	Growth in GDP per capita (constant 2015 US$)	World Bank (2022a)
ΔInL_{it}	Growth in Employment to population ratio, 15+, total (%)	World Bank (2022a)
ΔInK_{it}	Growth in Gross capital formation (% of GDP)	World Bank (2022a)
$\Delta InIUI_{it}$	Growth in Individuals using the Internet (% of population)	World Bank (2022a)
$\Delta InFBS_{it}$	Growth in Fixed broadband subscriptions (per 100 people)	World Bank (2022a)
$\Delta InPOG_{it}$	Growth in Population growth (annual %)	World Bank (2022a)
$\Delta InTO_{it}$	Growth in Trade (% of GDP)	World Bank (2022a)
$\Delta InMCS_{it}$	Growth in Mobile-cellular subscriptions per 100 inhabitants	OECD (n.d.)

countries like DRC, Comoros, Lesotho and Zambia having recorded no subscriptions in some parts of the years and the highest subscriptions recorded in Mauritius in 2020. South Africa is the technological giant of the SADC region since it recorded the maximum percentage of individuals using the Internet, reaching 70% in 2020, while the DRC recorded the lowest of 0.01% in 2000 and 2001.

PRE-ESTIMATION DIAGNOSTIC TESTS

Before estimating the model specified in Equation (7), some pre-estimation diagnostics must be carried out, namely, unit root and correlation tests. The results of these tests are presented in tables 3, 4 and 5. Two types of unit root tests were conducted, that is, Im-Pesaran-Shin unit-root test and Fisher-type unit-root test, to confirm stationarity, since these tests accept unbalanced panel data.

Results for unit root tests show that all the variables are stationary in levels (I (0)) except *laglnL, laglnK* and *laglnTO,* which are stationary after first differencing, becoming I(1) variables and represented as *dlaglnL, dlaglnK* and *dlaglnTO.*

A check for multicollinearity among the variables was conducted by computing the correlation matrix and variance inflation factors as shown in table 4 and table 5, respectively. The values on the correlation matrix are very low, indicating that variables are not highly correlated.

This is further supported by the VIFs check for multicollinearity, which looks fine since it is less than 5 using the strict/conservative rule

TABLE 2 Within and Between Descriptive Statistics

Variable		Mean	Std. Dev.	Min	Max	Observations
Y	*overall*	2595.26	2403.96	294.65	10643.77	$N = 294$
	between		2422.74	419.62	7840.12	$n = 14$
	within		556.81	289.11	5398.91	$T = 21$
L	*overall*	60.41	16.86	35.78	86.03	$N = 294$
	between		17.38	38.48	83.94	$n = 14$
	within		1.71	55.66	65.01	$T = 21$
K	*overall*	22.89	9.46	1.53	53.99	$N = 274$
	between		8.06	8.97	35.96	$n = 14$
	within		5.67	6.83	42.49 T	*bar* = 19.5714
IUI	*overall*	12.54	15.94	0.01	70.00	$N = 286$
	between		9.55	2.79	32.15	$n = 14$
	within		12.97	−12.33	55.57	$T = 20.4286$
FBS	*overall*	1.38	3.77	0.00	25.41	$N = 225$
	between		2.66	0.01	10.26	$n = 14$
	within		2.57	−8.85	16.54 T	bar = 16.0714
POG	*overall*	1.98	1.07	−0.62	3.71	$N = 294$
	between		1.08	0.28	3.47	$n = 14$
	within		0.26	1.09	2.67	$T = 21$
TO	*overall*	78.60	32.41	23.98	175.80	$N = 286$
	between		30.58	37.63	145.88	$n = 14$
	within		16.22	35.77	143.04 T	*bar* = 20.4286
MCS	*overall*	53.34	45.56	0.00	165.60	$N = 293$
	between		27.81	23.11	102.89	$n = 14$
	within		36.78	−32.78	117.57 T	*bar* = 20.9286

TABLE 3 Panel Unit Root Test

	Unit root test results in levels		Unit root test results after first difference	
Variable	Im-Pesaran-Shin	Fisher-type	Im-Pesaran-Shin	Fisher-type
lagln$Y$	−2.16***	4.34***	--	--
lagln$L$	−0.98	−2.01	−1.11**	5.84***
lagln$K$	−0.81	0.21	−7.40***	25.69***
laglnIUI	−1.67**	5.31***	--	--
laglnFBS	−3.13	20.35***	--	--
laglnPOG	−2.47*	20.87***	--	--
laglnTO	−0.68	0.34	−6.94***	23.18***
laglnMCS	−6.81***	64.77***	--	--

NOTE *, ** and *** means statistically significant at 10%, 5% and 1% level, respectively.

of thumb that an individual VIF greater than 5 indicates the presence of severe collinearity.

A value between 1 and 5 indicates moderate correlation between a given explanatory variable and other explanatory variables in the model, but this

TABLE 4 Correlation Matrix

	dlaglnL	*dlaglnK*	*laglnIUI*	*laglnFBS*	*laglnPOG*	*dlaglnTO*	*laglnMCS*
dlaglnL	1.0000						
dlaglnK	0.0675	1.0000					
laglnIUI	−0.1183	−0.0756	1.0000				
laglnFBS	−0.0733	−0.0764	0.7909	1.0000			
laglnPOG	−0.0084	0.0638	−0.3040	−0.3763	1.0000		
dlaglnTO	0.0456	0.1242	−0.1315	−0.1292	0.0775	1.0000	
laglnMCS	−0.0700	−0.0044	0.8039	0.7248	−0.1257	−0.1222	1.0000

TABLE 5 Variance Inflation Factors

Variable	VIF	1/VIF
laglnIUI	3.99	0.250673
LaglnMCS	3.31	0.301995
laglnFBS	3.13	0.319613
laglnPOG	1.27	0.786321
dlaglnTO	1.04	0.965137
dlaglnK	1.03	0.966328
dlaglnL	1.02	0.976961
Mean VIF	2.11	

is often not severe enough to require attention. Therefore, it can be concluded that the variables included in this study's model are not correlated.

Results and Discussion

Three panel regression models, the Pooled OLS (POLS), random effects (RE) and fixed effects (FE) were estimated to explore the relationship between digitalisation and economic growth in the SADC region.

The Breusch and Pagan Lagrangian Multiplier test (the chibar2) is extremely significant, showing that the RE model is better than POLS. Comparison of the consistent fixed-effects model with the random-effects model using the Hausman specification test, rejects the random effect estimator in favour of the fixed effect estimator at the 1% significance level. Therefore, the most appropriate model for this study is the FE panel regression model. With respect to model diagnostics, the variables in this model are normally distributed, as shown by the lack of significance in the Skewness/Kurtosis tests for Normality. The Pesaran's test confirms no cross-sectional dependence, while the Wooldridge test shows no autocorrelation. These diagnostic tests supports that our results are efficient, consistent and unbiased. The results of this model are the focus of this

TABLE 6 Panel Data Modelling Results

Variable	POLS		RE		FE	
	Coeff.	T statistic	Coeff.	z- statistic	Coeff.	t-statistic
dlaglnL	−1.91***(0.16)	−12.32	−1.60***(0.14)	−11.25	−1.22***(0.14)	−8.55
dlaglnK	0.11(0.09)	1.24	0.06 (0.05)	1.13	0.04(0.05)	0.73
laglnIUI	−0.01(0.69)	−0.21)	0.03 (0.03)	0.97	0.17***(0.05)	3.52
laglnFBS	0.29***(0.03)	9.12	0.10***(0.02)	4.89	0.11***(0.02)	5.68
laglnPOG	−0.003 (0.05)	−0.07	−0.08***(0.24)	−3.23	−0.10***(0.02)	−4.35
dlaglnTO	0.37***(0.11)	3.24	0.27***(0.08)	3.33	0.28***(0.08)	3.64
laglnMCS	−0.23***(0.09)	−2.55	−0.06*(0.04)	−1.48	0.12**(0.05)	2.36
Const	12.84***(0.84)	17.62	13.03***(0.76)	17.08	10.23***(0.82)	12.42
F-stat	69.44***		286.85***		13.89***	
R-squared	0.71		0.65		0.78	
Breusch and Pagan Lagrangian multiplier test (chibar2)	617.76 (0.00)***					
Hausman Test (chi2)	37.81 (0.00)***					
Skewness/Kurtosis tests for Normality	3.35 (0.18)					
Pesaran's test of cross sectional independence	3.61 (0.48)					
Average absolute value of the off-diagonal elements	0.51(0.68)					
Wooldridge test for autocorrelation in panel data	82.78 (0.34)					
Modified Wald test for groupwise heteroskedasticity	40.19 (0.12)					

NOTE (***) indicates significance at 1%, (**) indicates significance at 5%, (*) indicates significance at 10%. Number inside brackets represents Std. Error. Breusch and Pagan Lagrangian multiplier test for random effects - choosing between POLS and RE model. Hausman test for fixed/random effect model. Cross-sectional time-series FGLS regression to check for heteroskedacity and correlation.

study's analysis of the relationship between digitalisation and economic growth in SADC.

The model estimation results show that all the digitalisation variables in the model *laglnIUI, laglnFBS* and *laglnMCS* have the expected positive signs and are highly statistically significant at either the 1% or 5% significance level. Therefore, it can be said that the three digitalisation variables Individual Internet Usage (*laglnIUI*), Fixed Broadband Subscriptions (*laglnFBS)* and Mobile Cellular Subscriptions (*laglnMCS*) have a strong positive impact on economic growth in SADC countries. All the control variables included in the model besides *DlaglnTO*, namely *DlaglnL* and *laglnPOG*, have a statistically significant impact on economic growth in SADC countries at the 1% significance level. Of these three significant variables, only *DlaglnTO* bears the expected positive sign.

In line with international trade theory, increasing trade liberalisation in the SADC region, which was the mean calculated to be 78.6%, seems to be paying off as reflected by the positive significant impact of the trade openness (*DlaglnTO*) variable on growth in the region. Counterintuitively, the labour variable (*DlaglnL*) has a highly significant negative effect on growth in the SADC region, which can be attributed to a poorly skilled labour force coupled with low labour productivity within the region (World Bank 2022c). The capital variable (*DlaglnK*) also has a negative but insignificant impact on growth in the region. This could be owing to the low intensity of technology in the capital investments carried out in the region (Apulu and Ige 2011). Population growth has a negative influence on growth in the SADC area, contradicting findings from studies such as Peter and Bakari (2019), who investigated the impact of population expansion on African nations' economic growth from 1980 to 2015 using a panel data technique, and found the relationship to be positive. However, results from this study corroborate results from studies done in Uganda (Klasen and Lawson 2007) and Nigeria (Ukpolo 2002). The negative impact of population increase on economic growth is owing to the fact that children and young people aged 15 to 29 make up the majority of the population in Sub-Saharan Africa, which houses the SADC region (Bello-Schünemann 2017). A young population imposes a variety of economic burdens and risks, including large public expenditures on public health, education, and basic services; high unemployment and poverty rates; and a high risk of social instability (Bello-Schünemann 2017).

The coefficient value of the usage variable (*laglnIUI*) is 0.17, which means that a one percent increase in the number of individuals using the Internet generates an increase in GDP per capita of 0.17% in the SADC region. This result, showing a positive effect of individual internet usage on growth, corroborates results from studies by scholars such as Solomon and van Klyton (2020), Bahrini and Qaffas (2019) and Albiman and Sulong (2017), who also evaluated the impact of internet usage on growth in the African countries. Access to ICT technology as measured by the *laglnFBS* and *laglnMCS* variables have coefficients of 0.11 and 0.12, respectively. This means that a one percent increase in fixed broadband subscriptions and in mobile cellular subscriptions leads to a 0.11% and 0.12% increase in GDP per capita in the SADC region, respectively. Onyeji and Karner (2008) and Sridhar and Sridhar (2007) found similar results in their study on developing countries and Central East European countries, respectively. However, Donou-Adonsou (2019) could not find strong evidence on how mobile phone subscriptions promote growth in 45 Sub Saharan African countries.

The above results demonstrate that access to and usage of ICTs have generated a wide array of opportunities 'for economic growth, improved health, better service delivery, learning through distance education, and social and cultural advances' (World Bank 2022b) in the SADC region. Using technological devices such as smartphones and tablets, individuals can access the Internet and process a lot of information for use in learning, communication, business, and health. Access to and usage of digital technology may promote economic development by impacting both the supply and demand sides of an economy. For example, digital connection may have a direct impact on the productivity of enterprises, workers, and other inputs in the manufacturing process (Hjort and Poulsen 2019). On the demand side, an internet connection may affect the ability of sellers and buyers to access marketplaces, as well as the availability and quality of information on the items and services being sold (Donou-Adonsou 2019).

Although the access variables were significant in this study, developing countries like those in the SADC region are confronted with challenges which inhibit them from full utilisation of the Fourth Industrial Revolution (4IR) technologies, as shown by statistics released by International Telecommunication Union (n.d.). African countries are still battling low access rates to digital technologies like the Internet due to the high costs, which makes technology unaffordable for greater sections of the population, especially the poverty-stricken living in the rural areas

(International Telecommunication Union n.d.). Furthermore, data from the World Bank also showed that least developed countries like the ones in the SADC region only had 20% of their populations accessing the Internet, while in Europe and other developed regions the rate was about 85%.

Although the COVID-19 pandemic was largely disruptive, the UN's Sustainable Development Goals Report of 2022 spotlighted the importance of industrialisation, technological innovation, and resilient infrastructure in helping nations to achieve the 2030 Agenda (United Nations 2022). The report demonstrated that countries with a diversified industrial sector and strong infrastructure such as transport, internet connectivity and utility services experienced less economic misfortune during the pandemic and are recovering faster than those countries which are less diversified and less digitalised. Considering that usage of the Internet has a positive effect on growth in SADC, there is a need to leverage on technological advancements of the 21st century and further increase the impact of usage on economic growth and development. The access aspect can be improved through intensive investments in infrastructure, with respect to power and telecommunication technologies, especially in the rural areas of SADC countries. Due to their mobility, ease of use, adaptable deployment, and comparatively low and decreasing rollout costs, wireless technologies can be exploited to reach the rural populace (World Bank 2022b), and the resulting increase in access and usage of digital technologies (thus a reduction in online inequalities) will further accelerate economic development in SADC.

Conclusions and Implications

The SADC region, like the rest of Africa, has witnessed a revolution in ICT technology as seen by growing numbers of people who are able to access and use the Internet and the growth in the number of both fixed broadband and mobile subscriptions. The outbreak of the COVID-19 pandemic has intensified the use of internet and other technologies. However, there is a glaring lack of empirical research investigating the effect of digitalisation on the economic growth of SADC countries. This research paper fills that gap by using available data from 14 SADC countries from 2000 to 2020 to examine the impact of digitalisation on economic growth. Results from the Fixed Effects Model showed that the usage and access aspects of technology both have a significant positive impact on growth. Specifically, the variables individuals using the In-

ternet (*lagInIUI*), fixed broadband subscriptions (*lagInFBS*), and mobile cellular subscriptions (*lagInMCS*) have a positive effect on the economic growth of the SADC region.

Given the significant positive impact of digitalisation in the SADC region revealed in this study, the growth effects of digitalisation can be maximised by ensuring that the labour force is adequately skilled through education and a regulatory environment that facilitates digital innovations. The relevant skills are necessary to meet the changing technical needs. Governments in SADC need to embark on programmes that are aimed at increasing access to and usage of the Internet by their people. There is a greater need for advancement in the use of digital technologies and improvement in the technical abilities of SADC countries through implementation of prudent science, technology, and innovation policies to promote the realisation of SDG 9 and SDG 17 in the SADC region. Favourable innovation policies are paramount to attract private sector investments, considering that government expenditure alone is insufficient to provide the necessary 4IR-friendly infrastructure which stimulates growth. Policies that liberalise the telecommunications and innovation market, attract private sector investments and encourage competition will reduce costs for investors while improving the quality, access, and usage of digital technologies in the SADC economies.

This way, the SADC region stands to reap the benefits of digitalisation because rapid developments of the Internet, ICTs and mobile technologies have become the new engines of economic growth and development. The technological advancements are accelerating globalisation and promoting efficiency, transparency, and effectiveness in both the private and public sector, and the SADC region should not lag.

Future studies on the digitalisation-economic growth nexus in SADC should explore the transmission mechanism of digitalisation on economic growth, exploring the role of variables such as ICT policies, infrastructural development, and investments in research and development (R&D). Such research will further provide useful information that can be incorporated in policy making regarding digitalisation and will increase the ability of SADC to exploit the benefits of digitalisation.

Notes

1 The 2030 Agenda for Sustainable Development, adopted by all United Nations Member States in 2015, provides a shared blueprint for peace and prosperity for people and the planet, now and into the future. At its heart are the 17 Sustainable Development Goals (SDGs), which

are an urgent call for action by all countries–developed and developing–in a global partnership. They recognise that ending poverty and other deprivations must go hand-in-hand with strategies that improve health and education, reduce inequality, and spur economic growth – all while tackling climate change and working to preserve our oceans and forests.

2 The time period selected and members of SADC included in this investigation depends on data availability. Having mentioned this, the final sample used resulted in the number of countries (N) being less than time period (T). Therefore, in such models, the pooled ordinary least squares (POLS), Random Effect (RE) and Fixed Effects (FE) estimators would be more appropriate than any other estimators.

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Research Synthesis in Pro-environmental Behaviour in Education: A Text Mining Approach

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There have been many academic investigations on promoting human behaviour in favour of environmental sustainability though education. Yet only a limited number of review papers are found which have summarized the key findings of this vital area. This study uses both bibliometric and text mining approaches to examine pro-environmental behaviour in education literature for the first time. Through bibliometric analysis, different networks in contemporary literature are highlighted. These networks reveal the influence of social welfare on pro-environmental behaviour, highlighting the value of human innate connection to raise environmental consciousness. Additionally, using posterior probability and Latent Dirichlet allocation (LDA), text mining identifies 12 different topic models by log-likelihood estimation, addressing a variety of topics related to environmental education and behaviour, such as how visitors and sustainability in environmental education affect pro-environmental behaviour, how education towards sustainability is provided in schools and universities, how the theory of planned behaviour is applied, how education and pro-environmental behaviour are related, and how sustainable education

and travel are explored through different channels.

Keywords: pro-environmental behaviour, education, text mining, bibliometric analysis
JEL Classification: I20, I24, I25

Received 2023/08/15 · Revised 2023/11/12 · Accepted 2023/11/29
Published online 2024/09/30 https://doi.org/10.26493/1854-6935.22.231-251

Introduction

Environmental behaviour is defined as efforts taken to protect the environment, often known as green, sustainable, or eco-friendly conduct. This can involve things like interacting with nature sustainably or reusing domestic waste. Choosing sustainable products like organic food and eco-friendly cleaning supplies, conserving energy and water, switching to sustainable modes of transportation like walking and cycling, embracing electric vehicles, and even building off-grid homes are all part of embracing sustainability (Vicente-Molina, Fernández-Sáinz, and Izagirre-Olaizola 2013). Various issues, like global warming, urban air pollution, water scarcity, loud noises, and habitat destruction are all threats to environmental preservation. Most of these problems are caused by humans (Schüßler, Richter, and Mantilla-Contreras 2019). This has become a significant concern in today's world, and everyone should be aware of it (Valkengoed, Abrahamse, and Steg 2022). Education is the most efficient means of informing people about the value of pro-environmental action, making it one of the most effective strategies. Education for lifelong learning is not only a means of informing people but also a tool for raising their awareness. Education can also demonstrate its potential to promote environmentally conscious decision-making.

Education is crucial in influencing human behaviour toward the environment to make the future world more attractive, healthier, and worth living in. Environmental education that promotes sustainable development will help to protect natural systems while also fulfilling human aims (Chankrajang and Muttarak 2017). Several studies have already examined the pro-environmental behaviour. However, a detailed theoretical assessment of the articles on this issue is yet to be completed as far as we know. As a result, a thorough literature review is a valuable tool to make individuals more concerned about their behaviour towards the environment. This review contributes to a more knowledgeable and successful approach to behaviour modification.

The Scopus database has generated many papers on pro-environmental behaviour through education during the last 25 years. In the first step of the investigation, a citation mapping approach known as bibliometric analysis is used to assess the entire list of documents connected to the literature. The findings of this bibliometric analysis demonstrate the importance of this research issue in determining the value of environmental education. This study's bibliometric analysis included the co-occurrence network and bibliometric coupling on 608 papers, yielding new research directions for the future. However, the text mining technique is utilized on a selected 34 publications to cover as many documents on pro-environmental behaviour as possible with a careful review.

The study's reasoning is based on the identification of a discrepancy between the growing call for sustainable practices and the pervasive negative environmental effects of unrestrained consumerism. This disagreement highlights how critical it is to address environmental issues by reducing consumption and changing public perceptions of the environment. The study's primary objective is to provide a comprehensive assessment of the literature on environmental education and pro-environmental behaviour using state-of-the-art analysis tools. It aims to identify key themes, connections, and gaps in the research landscape in the context of global environmental concerns and consumerism in order to advance our knowledge of how education may promote pro-environmental behaviour.

The remaining part of the paper is divided into five parts. The second section contains the methodological elements and a summary of the text mining, bibliometric analysis, and trend analysis processes employed in this work. The third section explains references network analysis, and trend analysis of the environmental education literature. The advanced review is demonstrated in the fourth section, which includes the text mining approach, results, discoveries, and a description followed by implications, conclusion and research limitations in the fourth and the fifth section.

Methodology

For bibliometric review, this paper presents reference network analysis, which shows the visual evaluation of repetition of author keywords per document, co-authorship of countries, and citation relevancy per document. After that, topic tracking of the documents was done with the help of Latent Dirichlet Allocation (LDA) (Kaushik and Naithani 2016). Apart from these, a trend analysis is also introduced to represent the journal trend of the documents.

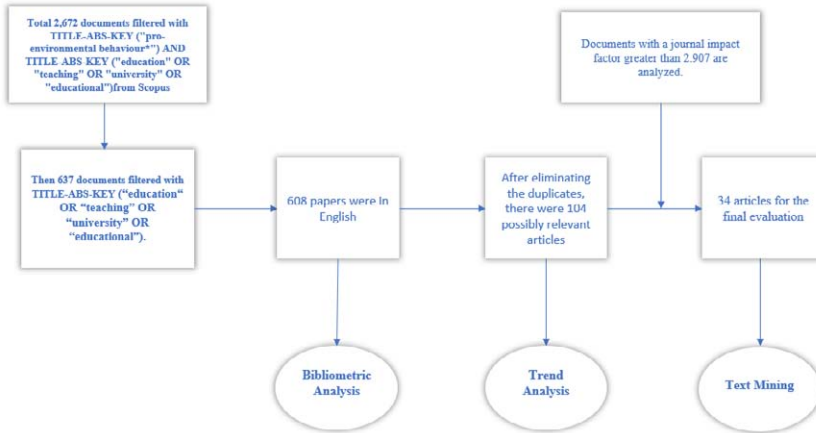

FIGURE 1 Selection of Papers

By using the following options applied to the title, abstract, and keywords: TITLE-ABS-KEY ('pro-environmental behaviour*') AND TITLE-ABS-KEY ('education' OR 'teaching' OR 'university' OR 'educational') a selection of published papers on pro-environmental behaviour in education was gathered from the online database of Scopus. Since Scopus database provided the maximum number of documents, which is much more than the WOS database, and the software used in this paper does not support WOS data, this study decided to continue with the Scopus database. Afterward, only English-language articles were chosen, totalling 623 papers, and only 608 papers were found as possessing materials within the topic range for the bibliometric review after manual examination by the researchers. After deleting the duplicates, 104 eligible papers for trend analysis were found. Only 34 papers were selected manually for text mining premised on journal impact factor higher than 2,907. Figure 1 depicts the selection procedure of the articles.

This review study follows four parts for examining the selected studies: the source of the documents, the techniques used to analyse the documents, the indicators utilized in the procedures, and the analysis outcome. The source of the documents is Scopus database. VOSviewer is used to create Bibliometric Networks, including bibliographic coupling analysis and co-occurrence networks. The outcome indicates author keyword relevance and a full citation summary of each article. The R-tool for Text Mining, which is the primary emphasis of this article, is utilized to perform Trend Analysis and Latent Dirichlet Analysis. The outcome demonstrates good attitudes toward pro-environmental behaviour in ed-

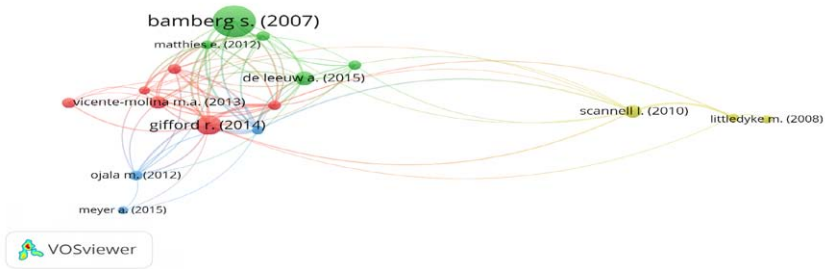

FIGURE 2 Bibliographic Coupling Analysis of Documents

ucation, as well as the construction of subject models with appropriate topic phrases per article.

Analysis

REFERENCES NETWORK ANALYSIS

Bibliographic Coupling Analysis of Documents

Bibliographic coupling is a similarity measure that uses citation analysis to build a similarity link between documents. A document-based bibliometric coupling study is shown in figure 2. Only 15 papers out of 608 meet the criterion when the minimal number of local citations is 115. After the bibliographic coupling, 20 nodes were separated into 4 clusters. The node's size indicates the number of times the papers have been mentioned. Red, green, blue and yellow are, respectively, the 4 clusters available here.

The Red cluster (cluster 1) mainly focuses on environmental knowledge and behaviour. There are seven nodes in this cluster. Gifford and Nilsson (2014) set out to count the influences on pro-environmental concerns, which are grouped into 18 personal and social factors.

The Green cluster (cluster 2) which consists of 4 nodes, focuses on environmental awareness. Bamberg and Möser (2007) assert that problem awareness is a significant but unreliable indicator of pro-environmental intention. Its effects appear to be moderated by guilt, attributional processes, and moral and social norms.

The Blue cluster (cluster 3) emphasizes influences and factors like social welfare and ecology-aiding PEV (Pro-Environmental Behaviour). This cluster consists of 3 nodes. According to Meyer (2015), education makes people more concerned with social welfare and thus more ecologically conscious.

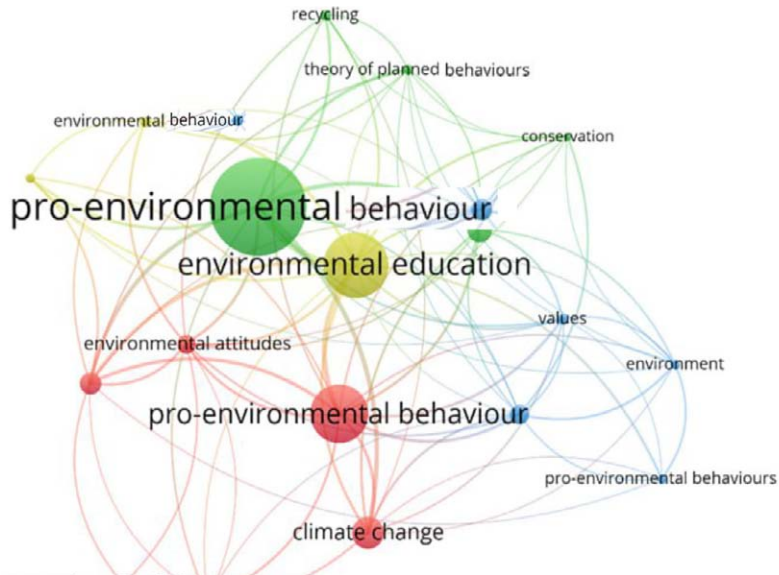

FIGURE 3 Co-occurrence Network of Author Keywords

The Yellow cluster (cluster 4) mainly talks about pro-environmental behaviour and social identity. Scannell and Gifford (2010) discovered that when the neighbourhood, length of residency, gender, educational level, and age were considered, only a person's natural connection to a place was found to predict pro-environmental behaviour.

Co-occurrence Network of Author Keywords

Co-occurrence network analysis is a set of graphs that show the possible connections between ideas, institutions, people and other elements in texts. Figure 3 shows the co-occurrence network of author keywords, which displays terms used by writers in similar but not identical texts and about the same subject. When the minimum number of occurrences for a keyword is 11, 18 out of 1,645 keywords pass the test. Each node represents a list of terms used by the writers. The pro-environmental behaviour through education co-occurrence network has 14 nodes in four clusters, with 46 linkages and 142 link strengths.

TREND ANALYSIS

Table 1 shows a trend analysis of the top 15 journals with the highest impact factor in encouraging pro-environmental behaviour through education.

TABLE 1 Trend Analysis of Journal

Element	h_ index	g_ index	m_ index	TC	%	Trend	NP	%	Cor. Doc	%	PY_ start
Building and Environment	1	1	0.08	11	0.14	↰	1	0.58	1	0.005	2009
Ecological Economics	4	5	0.6	214	2.81	↑	5	2.91	5	0.02	2015
Energy Policy	2	2	0.2	18	0.24	↰	2	1.16	3	0.01	2012
Environmental Education Research	21	41	0.95	1724	22.61	↰	52	30.23	32	0.16	2000
Environmental Research Letters	1	1	0.5	4	0.05	↰	1	0.58	4	0.02	2020
Environmental Science and Pollution Research	2	2	0.4	21	0.28	→	2	1.16	5	0.02	2017
International Journal of Environmental Research and Public Health	3	6	0.5	107	1.40	↰	6	3.49	10	0.05	2016
Journal of Cleaner Production	16	22	1.78	1165	15.28	↰	22	12.79	31	0.15	2013
Journal of Environmental Management	3	3	0.3	24	0.31	↰	3	1.74	6	0.03	2013
Journal of Environmental Psychology	14	19	0.93	3363	44.10	↰	19	11.05	15	0.07	2007
Nutrients	1	1	0.25	35	0.46	↑	1	0.58	1	0.005	2018
Resources, Conservation and Recycling	6	6	0.6	336	4.41	↰	6	3.49	8	0.04	2012
Sustainability (Switzerland)	14	19	1.56	488	6.40	↑	44	25.58	69	0.34	2013
Sustainable Development	2	2	0.2	11	0.14	↑	2	1.16	1	0.005	2012
Waste Management	4	6	0.3	104	1.36	↑	6	3.49	12	0.06	2011

Because a single publication might contain many citations, the total citations add up to 7,625. There are 172 publications in total, with 203 corresponding documents. The percentages of these are calculated based on the total number. The biblioshiny in R tool is used to calculate the h-index, m-index, and g-index. The evolution of the last five years (2017–2021) was examined to measure trends in citation numbers. The slope in the number of citations per year was used in this case (Dominković et al. 2021). For instance, the slope is $\{(5-1)/(2021-2017)\} = 1$ if one journal has citation number one in 2017, two in 2018, three in 2019, four in 2020, and five in 2021. Five ranges of trends were added after establishing the publishing development (slope) for all authors, providing four ranges of positive and negative trends and one range for a constant citing number

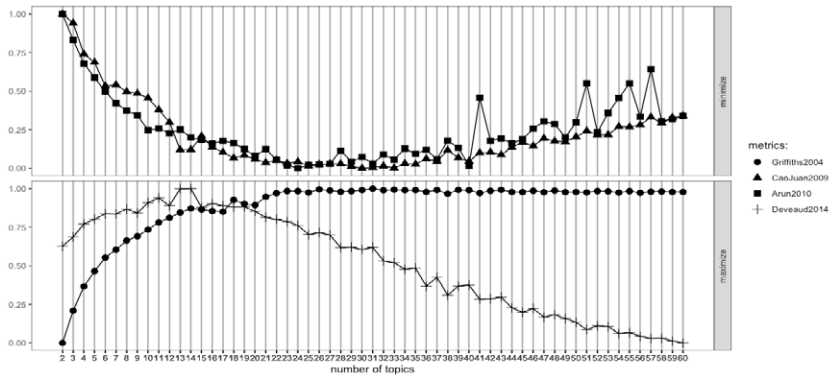

FIGURE 4 Log-Likelihood and Perplexity Metrics to Evaluate *K*

NOTES ● Griffiths and Steyvers (2004); ▲Cao et al. (2009); ▪ Arun et al. (2010); + Deveaud, SanJuan, and Bellot (2014)

(i.e. slope = 0.0). For the ranges the arrows indicating the trend are: For range (≥25) arrow (↑), range (1-24) arrow (↰), range (0) arrow (→), range ((−1)-(−24)) arrow (↲), and range (≤−25) arrow (↓).

Research Synthesis with Text Mining

LDA ANALYSIS

One of the most powerful text mining approaches for data analysis, latent data exploration, and finding links between data and text documents is topic modelling. Topic modelling can be done in a variety of ways, but the most common one utilized in this study was Latent Dirichlet Allocation (Jelodar et al. 2019). Latent Dirichlet Allocation (LDA) is the major topic of this study. The number of latent themes was calculated using the log-likelihood and perplexity of the data (Arun et al. 2010; Cao et al. 2009; Griffiths and Steyvers 2004). Perplexity is a measure that shows whether 'the model predicts the remaining words in a given subject after witnessing a portion of it, whereas log-likelihood evaluates how well the latent topics represent the observed data' (Guerreiro, Rita, and Trigueiros 2016). Figure 4 shows the range of possible themes investigated in this study, which ranged from $K = 2$ to $K = 60$.

In the figure, Griffiths and Steyvers (2004) show a sharp rise after 20 topics, which suggests that the model is picking up increasingly detailed and distinct themes in the data as the number of subjects rises. The plateau at about 20 topics indicates that adding more topics does not improve the model's capacity to detect more significant patterns after a certain point. Given that Deveaud, SanJuan, and Bellot (2014) continuously

decreases after 20 subjects, it is possible that the model or methodology employed there needs to be clearer to distinguish between coherent and significant themes after that. It can indicate that as the number of subjects rises, the data gets smoother and clearer, which makes it more difficult for the algorithm to identify different themes accurately. The results of the models show that the measure has a first inflexion on $K = 12$ in both the minimize and maximize version, hence this paper used $K = 12$ to evaluate the groups, assuming that the variance reported has a first inflexion and that the explanation is based on a small cluster. This log-likelihood was generated using the R-tool.

The corpus is then analysed with R packages (tm, topicmodels, LDAvis, stringr, and stringi) to determine the posterior probability and word frequency in each document. $K = 12$, *alpha* = 1, *eta* = 0.001, and *iterations* = 10 were utilized, with K denoting the topic model number and the rest denoting functionality parameters. There are 12 different topic models created, each with its own set of terminology. The subject terms are the most commonly used words in each text, which are grouped into topic models based on their significance (Ramage et al. 2009). With the help of LDA, the 34 documents are assigned to these 12 topic models based on their posterior probability.

TEXT MINING EXPERIMENTS, RESULT, AND ANALYSIS

The variables for LDA functionality are selected. The functions of the chosen parameters are $K = 12$, *alpha* = 1, *eta* = 0.001, and *iterations* = 10. The commands for generating topic models and distributing co-related terms to the topic models are provided with the aid of R. The computer runs the commands, selects the most frequently used phrases, and distributes them across the 12 topic models ($K = 12$) according to relevance. Each topic model has a maximum of 12 co-related words (lda fit. terms [1:12,]). The frequency of subject phrases in each document's topic model is depicted in figure 5.

During the generation of the topic models, R programming commands for determining the posterior probability of each article for each topic model using the same parameters are provided. The R software ran for roughly an hour for the papers and provided a correct posterior probability result. The names of the topic models are determined by the terms they cover. Table 2 shows the linked documents of the topic models created by manually selecting the journal, impact factor, paper type, and affiliations.

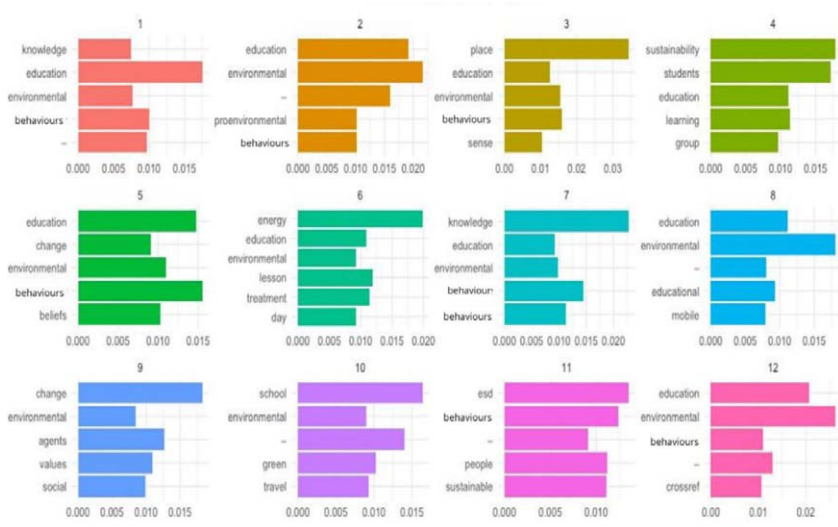

FIGURE 5 Topic Term Frequency Allocated to Topic Models

Table 2 shows the LDA result of topic modelling with 12 topics discussing each topic, with at least two documents per topic.

Topic 1, 'Visitor impact on behaviour', deals with the papers expressing the influence of visitors on behaviour and education. Dodds and Holmes (2018) (posterior probability = 0.18) examine three primary hypotheses about how visitor categories differ in knowledge, social standards, accreditation, and beach satisfaction based on past research. Residents and older beachgoers were shown to be more likely to participate in environmental education initiatives, according to their research.

Topic 2, 'Sustainability in environmental education', discusses the documents concerning having a proper sense of and maintaining sustainability in environmental behaviour. From an ecological standpoint, Kudryavtsev, Stedman, and Krasny (2012) (posterior probability = 0.25) contribute to environmental behaviour studies on the sense of community. They discuss many aspects of place sense, such as place connection and meanings. The logic and evidence supporting a relationship between connectivity, place interpretations, pro-environmental behaviour, and elements influencing sense of community are next reviewed. Schaal and Lude (2015) (posterior probability = 0.16) want to figure out what these devices could be used for, as well as what hurdles they might face.

TABLE 2 Latent Topics

Topic Name	Topic Terms	Correlated Papers	Posterior probability	Journal (Impac t Factor)	Method of Study
Visitor impact on behaviour	Age, behaviour, education, children, educational, environmental, knowledge, learning, pro-environmental, results	Dietz, Mulford, and Case (2009)	0.22	Building and Environment (6.456)	Qualitative
		Dodds and Holmes (2018)	0.18	Ocean and Coastal Management (3.284)	Qualitative
Sustainability in environmental education	Actions, behaviour, education, environmental, change, concern, knowledge, pro-environmental, schooling, willingness, years	Kudryavtsev, Stedman, and Krasny (2012)	0.25	Environmental Education Research (3.512)	Quantitative
		Schaal and Lude (2015)	0.16	Sustainability (3.251)	Mixed method
Impact on pro-environmental behaviour	Attachment, behaviour, education, environmental, gamification, place, pro-environmental, meanings, sense, social	Sánchez-Maroño et al. (2015)	0.16	Neural Processing Letters (2.908)	Qualitative
		Begum et al. (2021)	0.18	International Journal of Environmental Research and Public Health (3.39)	Quantitative
		Wang et al. (2021)	0.11	Sustainability (3.251)	Qualitative
Environmental education through organization	Activities, education, educational, group, learning, online, students, sustainability, sustainable, travel	Cole and Altenburger (2019)	0.16	Environmental Education Research (3.512)	Qualitative
		Pérez-López et al. (2020)	0.12	Frontiers in Psychology (2.99)	Mixed method
		Neaman, Otto, and Vinokur (2018)	0.15	Sustainability (3.251)	Qualitative
		Esteban Ibáñez et al. (2020)	0.16	Sustainability (3.251)	Qualitative
		Määttä and Uusiautti (2020)	0.11	Sustainability (3.251)	Quantitative
Sustainable responsibility	Behaviour, beliefs, change, climate, control, education, effects, environmental, norms, pro-environmen tal	Winter and Cotton (2012)	0.15	Environmental Education Research (3.512)	Quantitative
		Manfredi et al. (2021)	0.13	Sustainability (3.251)	Quantitative
		Nursey-Bray et al. (2019)	0.11	Sustainability (3.251)	Qualitative
Education towards sustainability of environmental behaviour	Conservation, energy, education, environmental, day, electricity, households, lesson, school, treatment, use	Sarid and Goldman (2021)	0.19	Sustainability (3.251)	Qualitative
		Gomera et al. (2021)	0.11	Sustainability (3.251)	Qualitative
		Zelenika et al. (2018)	0.14	Environmental Education Research (3.512)	Quantitative

Continued on the next page

TABLE 2 *Continued from the previous page*

Topic Name	Topic Terms	Correlated Papers	Posterior probability	Journal (Impac t Factor)	Method of Study
Sustainable implications for educational interventions	Attitude, behaviour, environmental, education, food, knowledge, pro-environmental, sustainable, social, waste	Mahmud, Husnin, and Soh (2020)	0.25	Sustainability (3.251)	Qualitative
		Grund and Brock (2019)	0.18	Sustainability (3.251)	Qualitative
Pro-Environmental behaviour with planned behaviour	Activities, devices, environmental, education, learning, mobile, nature, program, sustainability, university	Grund and Brock (2020)	0.20	Sustainability (3.251)	Quantitative
		Leeuw et al. (2015)	0.15	Journal of Environmental Psychology (5.192)	Qualitative
Educational approaches for environmental education	Agents, agency, change, different, environmental, framework, model, social, sustainability, values	Ouariachi, Li, and Elving (2020)	0.13	Sustainability (3.251)	Quantitative
		Schüßler, Richter, and Mantilla-Contreras (2019)	0.17	Sustainability (3.251)	Quantitative
Education and pro environmental behaviour	Behaviour, building, change, education, environmental, school, green, participants, school, students, sustainability, travel	Chankrajang and Muttarak (2017)	0.23	Ecological Economics (5.389)	Qualitative
		Hoffmann and Muttarak (2020)	0.12	Environmental Research Letters (6.793)	Quantitative
		Payne (2002)	0.16	Environmental Education Research (3.512)	Quantitative
		Meyer (2015)	0.18	Ecological Economics (5.389)	Quantitative
		Suárez-Perales et al. (2021)	0.13	Journal of Cleaner Production (9.297)	Quantitative
Sustainable education and travel	Behaviour, education, future, hope, people, positive, sustainability, young	Gill and Lang (2018)	0.20	Energy Policy (6.142)	Quantitative
		Hale (2019)	0.17	Sustainability (3.251)	Quantitative
Exploring environmental education through different channels	Behaviour, education, environmental, empowerment pro-environmental, psychological, religiosity, students	Cavaliere, De Marchi, and Banterle (2018)	0.15	Nutrients (5.717)	Quantitative
		Collins et al. (2020)	0.22	Environmental Education Research (3.512)	Qualitative
		Redman and Redman (2014)	0.15	Journal of Cleaner Production (9.297)	Quantitative

Topic 3, 'Impact on pro-environmental behaviour', examines the influence of organizational, moral, and science-based education on pro-environmental behaviour in diverse ways. Sánchez-Maroño et al. (2015) (posterior probability = 0.16) presented the organizational education on environmental behaviour using a decision-making model for the agents based on the organization's response data. Using conservation of resource theory concepts, Begum et al. (2021) (posterior probability = 0.18) explored the link between environmental moral education and pro-environmental conduct. In this link, the mediating effect of psychological empowerment and the moderating effect of religion were studied.

Topic 4, 'Environmental education through organization', discusses the teaching orientation towards environmental behaviour within school, college or university education. Cole and Altenburger (2019) (posterior probability = 0.16) look at three case studies from across the United States on Teaching Green Buildings. Pérez-López et al. (2020)as outdoor contexts, might contribute to the development of students' affective relations toward nature, proenvironmental attitudes, and protective actions; neverthless, these aspects begging to be explored. This preliminary research investigates the impact that the use of organic gardens to teach natural sciences at university has on kindergarten pre-service teachers' KPST (posterior probability = 0.12) look into the impact of using organic gardens to teach natural sciences at university on kindergarten pre-service teachers' sense of connection to and ideas of nature.

Topic 5, 'Sustainable responsibility', deals with the sense of responsibility towards pro-environmental behaviour to maintain sustainability. Winter and Cotton (2012) (posterior probability = 0.15) used a phono myographic technique to explore students' views of a 'hidden sustainability curriculum' at a top sustainability university in order to increase students' environmental responsibility. Researchers used a linear pre-test and post-test experimental design in a study by Manfredi et al. (2021) (posterior probability = 0.13), to investigate whether two co-designed interventions, a garbage and recycling bin system and a materials exchange programme, could improve sustainability literacy and material conservation behaviours throughout the School of Design.

Topic 6, 'Education towards sustainability of environmental behaviour', discusses educating people about sustainability development. Intending to generate competent environmental citizens, Sarid and Goldman (2021) (posterior probability = 0.19) aspire to improve theoretical understanding of what motivates people to act as change agents, as well

as the type and degree of change they wish to see. The overall goal of Gomera et al. (2021) (posterior probability = 0.11) is to provide a realistic atmosphere for involvement, communication, motivation, and competence, which are all necessary for effective pro-environmental conduct. Those who engaged in the Field School programme were compared to the garden visitors who did not participate in the Field School programme. Zelenika et al. (2018) (posterior probability = 0.14) revealed that participants' awareness of environmental issues, sense of connection to nature, and intentions and desire to participate in sustainability all rose after the programme's activities.

Topic 7, 'Sustainable implications for educational interventions', deals with teaching staffs' ability for implying sustainability in educational interventions. The goal of Mahmud et al. (2020) (posterior probability = 0.25) was to look into the impact of teaching presence in online gamification on long-term learning and self-determination and determine the elements that drive and hinder students' engagement in online gamified activities. The modest expectation of favourable socio-ecological changes may deter half of the sample from acting more sustainably, showing significant room for optimism. The consequences for Sustainable Development Education are highlighted in Grund and Brock (2019) (posterior probability = 0.18).

Topic 8, 'Pro-Environmental behaviour with planned behaviour', discusses the application of the theory in environmental behaviour. The goal of Grund and Brock (2020) (posterior probability = 0.20) aims to forecast long-term behaviour based on reported Educational Sustainable Development implementation, as well as psychological (e.g. attitudes, emotions) and socio-demographic factors. The theory of planned behaviour was used by de Leeuw et al. (2015) (posterior probability = 0.15) to uncover the ideas that impact young people's pro-environmental conduct. High school students completed a questionnaire regarding their pro-environmental behaviour early in the academic year and reported on their behaviour at the end of the year.

Topic 9, 'Educational approaches for environmental education', discusses taking approaches through education for environmental behaviour. Ouariachi, Li, and Elving (2020) (posterior probability = 0.13) aim to look into the function of gamification in influencing pro-environmental behaviour change and to find the best activities for educational reasons. Environmental education (EE) can be a valuable tool for biodiversity conservation, but implementation in low-income nations is complex.

Topic 10, 'Education and pro environmental behaviour', discusses green returns to education. According to Chankrajang and Muttarak (2017) (posterior probability = 0.23), more years of education increase the likelihood of undertaking knowledge-based environmentally beneficial actions, but not cost-effective pro-environmental behaviours. There is little evidence that formal education has a significant influence on global warming concerns or willingness to pay a carbon price. Suárez-Perales et al. (2021) (posterior probability = 0.13) validate higher environmental management education's emancipatory approach over its instrumental counterpart.

Topic 11, 'Sustainable education and travel', talks about how recycling, water conservation, and energy conservation are among the topics covered in environmental education for school pupils. According to Gill and Lang (2018) (posterior probability = 0.20), energy education may be a useful tool for policymakers interested in energy efficiency, while further research is required to improve the scheduling and subject matter of such presentations. Furthermore, Hale (2019) (posterior probability = 0.17) pushes educational travel givers (institutions, employees, and academics) to help their host communities by emphasizing the need for a broader understanding of sustainability in educational travel programmes.

Topic 12, 'Exploring environmental education through different channels', mainly discusses how different behaviours interact with the knowledge domains to differing degrees. Collins et al. (2020) (posterior probability = 0.22) show that learning lasts a lifetime, but that education can be improved with lengthier sessions. Educators can empower the future generation to make personal changes based on their future vision and make the demand on structural and organisational reforms required for a successful transformation to sustainability (Redman and Redman 2014) (posterior probability = 0.15).

Implications and Future Research Directions

The current study's findings point in the right direction for this study's purpose. The posterior probability for 12 latent subjects is estimated here, allowing future surveys on any of these topics to be done in a way that attracts researchers' attention. The articles on topic 2 (sustainability in environmental education) and topic 7 (sustainable implications for educational interventions) have the highest posterior probability compared to the other ones, indicating that these two themes have a good chance of being picked for further research. Researchers can focus on

developing sustainability in pro-environmental behaviour and make people aware of that. They can express the idea of the implication of sustainability through their future research.

Findings from trend topics and bibliometric analysis prove the relevance with the objective of this paper, which is pro-environmental behaviour through education. From these, the role of male and female students in pro-environmental behaviour can be an exciting topic for future research. Researchers can portray how the differing groups of male and female students affects environmental behaviour. Again, researchers can emphasize the approaches in preserving natural systems while also achieving the human goal for further research. Through these proper researches, people will be aware of the significance of environmental behaviour.

Conclusions

Individual efforts to lessen the negative impact of environmental degradation by enhancing and maintaining the environment are referred to as pro-environmental conduct. Values, such as caring for nature and safeguarding the environment, have been shown to have an important role in explaining pro-environmental behaviour (Begum et al. 2021). The environment is one of humanity's most vital components. Human behaviour in relation to the environment will be influenced by ongoing interactions between humans and the environment. It urges people to adjust their habits to lessen the negative consequences of environmental devastation (Gifford and Nilsson 2014). For this reason, people should be aware of environmental behaviour. If one has proper knowledge on the topic, they can understand the significance more deeply. Furthermore, this study can gain more significance since it tackles a pressing worldwide issue, suggests educational solutions, employs cutting-edge research techniques, and offers insights into the state of the field. Its conclusions can contribute to the development of practices and regulations that encourage sustainable lifestyles and lessen the damaging effects of consumerism on the environment.

The methods section outlines selecting publications for bibliometric review, trend analysis, and text mining. It also depicts the methodology employed in this study to examine pro-environmental behaviour. The most often used terms are displayed in the tree-map and subject trend, demonstrating the importance of long-term development. Following that, bibliometric analysis helps us comprehend document bibliographic coupling analysis and the author keyword co-occurrence network. In

this example, the findings involved related authors, papers, and keyword co-occurrence. The important discoveries are the document trend analysis from the biblioshiny in R- tool and the latent Dirichlet allocation from the text mining technique. The trend analysis illustrates the number of citations a journal receives each year.

However, this study has some limitations, such as the tools we used only supported the Scopus database which lacks a detailed view on this topic. Therefore, the audience are encouraged to do research using other databases which might clear others' confusions and views. Sustainability and sustainable development have become two of the most used concepts, so by concentrating on tactics that support sustainability and making sure that people are aware of the long-term advantages and effects of their environmentally friendly actions, researchers can help to promote pro-environmental behaviour change. This strategy may be crucial for bringing about long-lasting, constructive behavioural changes that promote sustainability and environmental preservation.

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The Effect of Exchange Rate Volatility on Trade between South Africa and her Top Trading Partners: Fresh Insights from ARDL *and Quantile* ARDL *Models*

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We investigate the impact of exchange rate volatility on exports and imports between South Africa and its main trading partners, namely the United States and China, across 22 import and export industries. The study employs the quantile autoregressive distributive lag (QARDL) model using quarterly data from the period spanning from 1994Q1 to 2022Q4. Our initial ARDL estimates establish that currency volatility does not significantly harm most trade sectors with both countries. In fact, many industries exhibit an insignificant or positive correlation with currency volatility. Nevertheless, upon re-estimating the regressions using the QARDL model, we uncover 'hidden cointegration' relationships existing at quantiles beyond the mean and median estimates, which are undetectable by traditional ARDL models. By considering these location-based asymmetries, we conclude that trade activities with China benefit more from exchange rate volatility compared to those with the United States. Overall, our findings imply that monetary authorities may not need to intervene in currency markets to stimulate trade with the top trading partners, as firms appear to be willing to bear the currency risks associated with the volatile Rand exchange rate.

Keywords: exchange rate volatility, exports, imports, trade, ARDL, QARDL, South Africa, United States, China
JEL Classification: F31, F10

Received 2023/10/01 · Revised 2023/12/04 · Accepted 2023/12/26
Published online 2024/09/30 https://doi.org/10.26493/1854-6935.22.253-277

Introduction

Following the demise of the Bretton Woods exchange rate system in 1971, the South African Rand has been one of the most volatile currencies worldwide, raising concerns for domestic multinational firms and foreign trading partners who rely on the exchange rate for international trade as well as for government agencies that use tariffs and subsidies to intervene in markets to mitigate such risks (Nyahokwe and Ncwadi 2013). However, the existing theoretical and empirical literature presents conflicting evidence on the effects of exchange rate volatility on trade, and three main reasons contribute to the lack of consensus. Firstly, most studies focus on the effects of exchange rate volatility on aggregated trade activity, while in reality, exchange rates have varying effects on different trade sectors and partners (Bahmani-Oskooee and Gelan 2020). Secondly, studies often fail to differentiate between export and import items, even though importers and exporters may have different risk attitudes towards currency fluctuations and are hence affected differently by exchange rate movements (Bahmani-Oskooee and Harvey 2018). Lastly, many studies do not adequately account for the asymmetric effects of different levels of currency volatility on trade performance, thus failing to distinguish the effects between 'extreme', 'normal', and 'very low' volatility.

Against this backdrop, this study examines the asymmetric effect of exchange rate volatility on disaggregated export and import items across 22 South African trade industries with her top trading partners, China and the US, utilizing quarterly data from 1994Q1 to 2022Q4. The choice of these two trading partners is significant as they represent South Africa's main trading partners in the 'West' and the 'East' parts of the world. Initially, the US was South Africa's primary global trading partner through the Africa Growth and Opportunity Act (AGOA) trade agreement until 2009/2010 when China became South Africa's main trading partner after joining the BRICS forum (Amusa and Fadiran 2019). We focus on the post-1994 period as it coincides with the democratic era in which the country experienced structural shifts in politics, trade, and central banking, including the lifting of international sanctions and the South African Reserve Bank's transition to inflation targeting. Despite South Africa's position as the trading hub of Africa, the Rand has remained one of the most volatile currencies among emerging markets, experiencing varying levels of currency volatility, particularly during events such as the

2001 emerging markets currency crash, 2007 global financial crisis, 2016 emerging markets sell-off, and the 2020 COVID-induced financial market crash (Qabhobho, Wait, and Roux 2020; Zerihun, Breitenbach, and Iyke 2020; Iyke and Ho 2021; Mpofu 2021). Our study hypothesizes that the observed varying levels of currency volatility could have different effects on bilateral trade volumes. Additionally, we distinguish between short-run and long-run effects of exchange rate volatility on trade, recognizing that firms and traders can hedge against short-term currency risk in a less costly manner than long-term risk (Peree and Steinherr 1989). To this end, we use the quantile autoregressive distributive (QARDL) model developed by Cho, Kim, and Shin (2015) to capture the impact of varying levels of currency volatility on industrial export and import activity between South Africa and her two top trading partners.

To the best of our knowledge, our study is the first of its kind and makes three specific contributions to the empirical literature. Firstly, while previous South African studies have not focused on disaggregated markets beyond the sectoral level, we follow the research of Bahamani-Oskooee, Harvey, and Hegerty (2014), Bahamani-Oskooee and Hegerty (2015), Bahamani-Oskooee and Aftab (2017), and Bahamani-Oskooee and Huseyin (2019; 2022), who conducted similar analyses at the industry level for bilateral partners such as the US and UK in separate studies. By adopting a similar disaggregated approach for South Africa, our study enables the identification of specific export and import items from different industries that are adversely, positively, or insignificantly affected by exchange rate volatility. Secondly, we focus on bilateral trade relations between South Africa and two of its trading partners. This diverges from previous studies that tend to concentrate on one trading partner at the bilateral level when conducting industry-level analyses. Consequently, our study provides more informative insights by demonstrating that exchange rate volatility can have different effects on trade within the same industry for different bilateral partners. Identifying such discrepancies can have implications for strategic trade positions against currency risk. Lastly, no prior studies have utilized the QARDL model to capture asymmetries in the relationship between exchange rate volatility and trade. Our study demonstrates the usefulness of this method in capturing location asymmetries or hidden cointegration relationships among variables, which the conventional ARDL model failed to capture.

Contrary to the findings of previous South African-based studies (see the next section for a detailed literature review), our findings reveal that

extreme volatility does not hinder trade volumes in the country's key trade industries. While the ARDL estimates indicate that most South African industries are insignificantly affected by currency volatility in their trade with both the US and China, the QARDL estimates further reveal positive hidden cointegration effects for exports and imports in several Chinese manufacturing industries. Thus, in differing from the ARDL results, the QARDL estimates suggest that high exchange rate volatility has a more positive impact on both export and import trade with China compared to the US. This insight would have been difficult to discern by relying solely on ARDL estimators. Overall, we interpret these results as evidence of both importing and exporting firms being willing to undertake currency risk in trade with China, which may be attributed to the presence of currency swap agreements between the two countries that are absent in the case of South Africa-US relations.

The rest of the study is structured as follows. The second section provides a brief review of theory and empirical studies. The third outlines the empirical framework of the study. The fourth section presents the data and empirical results. The fifth presents the analysis of the results and finally, the sixth section concludes the study.

Literature Review

In this section we present the literature. We start by discussing the theoretical foundations of the paper and then provide a review of associated empirical literature.

THEORETICAL REVIEW

During the 1970s, as the world shifted from fixed to flexible exchange rates, the theory surrounding exchange rate risk on trade balance emerged (Cushman 1983). This transition fostered the liberalization of financial markets and trade, giving rise to two schools of thought on the subject. The first school expressed concerns that greater variability and uncertainty in exchange rates would negatively impact investment and trade. In contrast, the second school argued that the removal of restrictions on capital flows and trade would result in a net increase in the volume of international trade transactions.

One of the earliest theoretical models was presented by Clark (1973), who contended that covering foreign exchange risk in forward exchange rate markets is more costly under a flexible exchange rate regime. Ethier (1973) argued that floating exchange rate regimes lead to currency uncertainty,

which makes trading firms' revenue sensitive to fluctuations and increases the trade-off between expected profit and risk reduction, ultimately reducing trade volumes. Baron (1976) found that under floating exchange rate regimes, the choice of invoice strategy is crucial. If exports are invoiced in the importers' currency, the exporter faces transaction costs and exposes revenue to currency risk. Conversely, if exports are invoiced in the exporters' currency, there is uncertainty in quantity demanded, as exporters cannot adjust the price of the product for every change in the exchange rate, leading to greater risk aversion. Without appropriate government intervention through tariffs and subsidies, these factors have an adverse effect on international trade. Peree and Steinherr (1989) expanded the analysis to medium-term uncertainty, showing that the adverse effects of medium-term currency risk on competitiveness and trade are more severe than those of short-term risk.

Conversely, other researchers argue that exchange rate volatility can have a positive impact on trade activity. For example, Frankel (1991) posited that an increase in exchange rate volatility creates differences in domestic and foreign prices, generating commodity arbitrage opportunities that can increase trade volume. Viaene and Vries (1992) further argued that if a certain proportion of exports and imports are denominated in foreign currency while the rest is denominated in the local currency (partial currency invoicing), exchange rate volatility could positively affect trade volumes when the aggregate net foreign position is positive. Sercu and Vanhuhulle (1992) found that exchange rate risk compels exporters to exploit their comparative advantages, making export-based strategies more valuable than foreign direct investment (FDI) strategies and resulting in an increase in trade activity. Broll and Eckwert (1999) discovered that large currency fluctuations make the real option to trade more profitable, increasing production volume and international trade when investors are more willing to take risks.

EMPIRICAL REVIEW

Empirical studies have extensively examined the impact of exchange rate volatility on international trade, employing various estimation techniques and synthetic measures of exchange rate volatility (see McKenzie 1999; Bahmani-Oskooee and Hegerty 2007) for a comprehensive review of previous international literature). In this section we review studies which have focused on South Africa or included it within a panel of other countries. A total of 27 related articles were identified through an

extensive search on Google Scholar using keywords such as 'Exchange rate volatility and trade/exports/imports Africa', 'Exchange rate volatility and trade/exports/imports South Africa', and 'Exchange rate volatility and exports Sub-Saharan Africa' (see table 1). Among these studies, a majority of previous South African-related studies (16 out of 27) found a negative effect of exchange rate volatility on trade volume, while fewer studies reported a positive relationship (7 out of 27) or insignificant effects (4 out of 27).

Studies that examined the trade balance at the export and import levels also displayed limited consistency in their results. For example, Bahmani-Oskooee (1996), Kargbo (2006), Omojimite and Akpokodje (2010), Musila and Al-Zyoud (2012), and Meniago and Eita (2017) found a negative relationship between exchange rate volatility and both export and import items. In contrast, Bahmani-Oskooee and Payesteh (1993) and Ekanayake, Thaver, and Plante (2012) reported insignificant and positive effects on both exports and imports, respectively. Studies conducted at the sectoral level also exhibited discrepancies in their findings. Todani and Munyama (2005) found a positive effect on total trade but insignificant effects for other trade classifications (goods, services, and gold), while Olayungbo, Yinusa, and Akinlo (2011) found a positive effect on total and manufacturing trade but insignificant effects on primary products.

Methodologically, the empirical techniques used in these studies mirrored those employed in international research, including linear estimation techniques such as OLS, GMM, FMOLS, DOLS, Engle-Granger, VECM, and ARDL models. More recently, some studies have considered the use of the nonlinear ARDL (NARDL) model, which distinguishes the effects of increasing and decreasing levels of exchange rate volatility. For instance, Bahmani-Oskooee and Arize (2020) and Dada (2021) applied the NARDL model and found negative effects on different partitions of the trade balance. Anyikwa and Domela (2022) also used the NARDL model and reported negative and positive effects on different partitions of the trade balance.

In recent years, the Quantile Autoregressive Distributed Lag (QARDL) methodology has gained popularity as a more flexible variant of the conventional ARDL, compared to the NARDL, model. Baek (2021) highlighted the superiority of the QARDL model over the NARDL model in capturing location asymmetries at different quantiles of distribution. Uche and Effiom (2021) demonstrated the usefulness of the QARDL model in

capturing locational asymmetries in exchange rate volatility as a determinant of capital flight in Nigeria.

Our study aims to address the gaps observed in the literature by applying the QARDL model to investigate the impact of exchange rate volatility on trade between South Africa and the US across 22 industries. Previous studies in South Africa have primarily focused on aggregate or sectoral levels, while this study delves into industry-level trade, reducing product aggregation bias. Additionally, while some international literature has examined the impact of currency risk on bilateral industry trade items, previous studies have only focused on one trading partner, introducing country aggregation bias. Lastly, the study utilizes the advanced QARDL model to explore short-run and long-run cointegration effects of exchange rate volatility on trade at different quantile distributions, incorporating the quantile regression model to capture location asymmetries.

Methodology

BASELINE FUNCTIONAL REGRESSIONS

To investigate the industry-level relationship between exchange rate volatility and export/import trade, we use the following Marshall-Lerner type export and import functions augmented with exchange rate volatility variable, i.e.

$$X = f(Y^d_{i,j}, Y^f_{i,j}, ERV_{i,j}) \tag{1}$$

$$M = f(Y^d_{i,j}, Y^f_{i,j}, ERV_{i,j}) \tag{2}$$

where X(M) is the value of exports (imports) of industry i to the trading partner j, Y^d is real domestic income, and Y^f is the foreign income, whereas ERV is the exchange rate volatility which is unobservable and extracted as the conditional volatility of following the GARCH (1,1) model fitted to the real exchange rate (RER):

$$RER_{it} = \mu + \theta RER_{it-1} + \varepsilon_t \tag{3}$$

$$h^2_{it} = \omega + \alpha \varepsilon^2_{it-1} + \rho h^2_{it-1}, \tag{4}$$

where α and ρ are the ARCH and GARCH parameters which are non-negative shocks and persistent parameters, and the conditional variance, h^2_{it} measures the volatility of each equity return.

TABLE 1 Summary of Related Literature

Author	Country	Period	Method	Results
Bahmani-Oskooee and Ltaifa (1992)	86 countries	1973-1980	POLS	-ve effect on exports
Bahmani-Oskooee and Payesteh (1993)	G7 and 6 emerging countries	1973:q1 – 1990:q4	E-G cointegration	Insig. for imports and exports
Bahmani-Oskooee (1996)	6 emerging economies	1973:q1 – 10090:q2	VECM	-ve for imports and exports
Sauer and Bohara (2001)	91 countries	1973 – 1979	FE and RE models	-ve effect for full and African samples
Arize, Malindretos, and Kasibhatla (2003)	10 LDC	1973:q2 – 1998:q1	VECM	+ve effect on exports
Bah and Amusa (2003)	South Africa	1990:q1 – 2000:q4	ARCH and GARCH	-ve effect
Todani and Munyama (2005)	South Africa	1980:q1 – 2004:q4	ARDL and GARCH	+ve impact for total and insignificant for goods, services, gold exports.
Kargbo (2006)	South Africa	1960-2004	VECM	-ve impact of South Africa agriculture imports and exports
Takaendesa, Tsheole, and Aziakpono (2006)	South Africa	1992:q1 – 2004:q4	VECM	-ve effect on exports
Mukherjee and Pozo (2009)	214 countries	1948-2000	Parametric and Semiparametric gravity model	-ve impact of volatility on trade balance
Ozturk and Kalyoncu (2009)	6 countries	1980-2005	E-G technique	-ve for South Africa
Omojimite and Akpokodje (2010)	8 CFA and 8 non-CFA countries	1986-2006	FE and GMM	-ve impact on imports and exports for all samples
Olayungbo, Yinusa, and Akinlo (2011)	40 African countries	1986-2005	POLS and GMM	+ve effect on total, primary and manufacturing trade for non-ECOWAS countries
Sekantsi (2011)	South Africa	Jan 1995 – Feb 2007	ARDL and GARCH	-ve
Ekanayake, Thaver, and Plante (2012)	South Africa	1980:q1 -2009:q4	DOLS and ARDL	+ve effect on both imports and exports

Musila and Al-Zyoud (2012)	42 African countries	1998 – 2007	Gravity model	-ve effect on imports and exports
Nyahokwe and Ncwadi (2013)	South Africa	2000-2010	VECM and GARCH	Insig.
Serenis and Tsounis (2014)	3 African countries	1973q1 – 1990q1	Sd moving average log of exchange rate and VECM	+ve relationship on exports
Aye et al. (2015)	South Africa	1986q4-2013q2	SVAR and GARCH-M	-ve impact on exports
Ishimwe and Ngalawa (2015)	South Africa manufacturing exports	2009q1 – 2014q4	ARDL	+ve effect on manufacturing exports
Vieira and MacDonald (2016)	106 countries	2000-2011	GMM	-ve (+ve) effect on exports (imports)
Meniago and Eita (2017)	39 SSA countries	1995-2012	FE and RE	-ve effect on both imports and exports
Senadza and Diaba (2017)	40 African countries	1993-2014	PMG	Insig. effect on exports
Bahmani-Oskooee and Gelan (2018)	12 African counties	1971q1 – 2015q4	ARDL	+ve for imports and insig. for exports
Bahmani-Oskooee and Arize (2020)	13 African countries	1973:q1 – 2015:q4	NARDL and GARCH	-ve effect for positive (negative) partition in exports (imports)
Dada (2021)	17 African countries	2005-2017	NARDL	-ve effect at both positive and negative partitions
Anyikwa and Domela (2022)	South Africa	2009:m01 – 2019:m12	NARDL	-ve (+ve) effect on positive (negative) partition
Ekanayake and Dissanayake (2022)	BRICS	1993:q1 – 2021:q2	FMOLS, DOLS, ARDL	Insig. for South Africa

BASELINE ARDL MODEL

We employ the autoregressive distributed lag (ARDL) model proposed by Pesaran, Shin, and Smith (2001) to estimate the empirical regressions (1) and (2), which capture both short- and long-run cointegration relationships between the time series. The ARDL model offers several empirical advantages, including flexibility in accommodating a mix of I(0) and I(1) variables, suitability for small sample sizes, and unbiased estimates of long-run coefficients even when some regressors are endogenous (Pesaran, Shin, and Smith 2001). Our baseline ARDL model is concisely defined as follows:

$$Y_t = \alpha_0 + \sum_{i=0}^{p} \beta_1 Y_{t-i} + \sum_{i=0}^{q} \beta_2 X_{t-i} + \gamma_1 Y_{t-1} + \gamma_2 X_{t-1} + \quad + \varepsilon_i \tag{5}$$

where Δ represents the differences operator, α denotes the intercept, β's and γ's are the short-run and long-run model coefficients, respectively, and ε represents the error term. We begin the modelling process by conducting a bounds test for cointegration, which involves testing the following null hypothesis:

$$\gamma_1 = \gamma_2 = 0 \tag{6}$$

against the alternative hypothesis:

$$\gamma_1 \neq \gamma_2 \neq 0 \tag{7}$$

To test these hypotheses, we employ F-statistics and compare them to lower-bound and upper-bound critical values provided by Pesaran, Shin, and Smith (2001). If the estimated F-statistics exceed the upper-bound critical value, we conclude the presence of cointegration effects. Conversely, if the F-statistics fall below the lower-bound critical value, we reject the existence of cointegration. In cases where the F-statistics lie between the lower and upper bounds, the test results are inconclusive.

Once cointegration effects are confirmed, we proceed to estimate the long-run regression. The long-run coefficients, computed as $\psi_1 = \gamma_2/\gamma_1$ and $\psi_2 = \gamma_3/\gamma_1$, are derived from this estimation. Finally, we derive the short-run and error correction form by extracting the error term from the long-run regression equation, resulting in the following error correction model:

$$Y_t = \alpha_0 + \sum_{i=0}^{p} \beta_1 Y_{t-i} + \sum_{i=0}^{q} \beta_2 X_{t-i} ECT_{t-1} + \varepsilon_i, \tag{8}$$

where ECT represents the error correction term, which measures the speed of reversion back to equilibrium following a system shock. It is assumed to be negative and statistically significant. Additionally, Pesaran, Shin, and Smith (2001) consider the t-statistics of the ECT as an additional test for cointegration in the ARDL model.

QARDL MODEL

While the ARDL model is recognized for its versatility in capturing long-run and short-run cointegration relationships among time series, it lacks the ability to incorporate location asymmetries. To overcome this drawback, we employ the QARDL model introduced by Cho, Kim, and Shin (2015), which expands upon the conventional ARDL model by integrating the quantile regression approach proposed by Koenker and Bassett (1978). Our baseline QARDL model can be represented as follows:

$$Y_t = \alpha_0(\tau) + \sum_{i=0}^{p} \phi_i(\tau) Y_{t-i} + \sum_{i=0}^{p} {}^{*}\phi_i(\tau) X_{t-i} + \varepsilon_{i_t}(\tau), \tag{9}$$

where Y_{it} is the dependent variable, trade, and X_{it} is the compact set of distributive lag covariates. We further re-specify equation (8) as the following compact regression:

$$Y_t = \alpha_0(\tau) + \sum_{i=0}^{q-1} W'_{t-i}\delta_j(\tau) + X'_t\gamma(\tau) + \sum_{i=0}^{q} \phi_i(\tau) Y_{t-i} + \varepsilon_{i_t}(\tau), \tag{10}$$

where

$$\gamma(\tau) = \sum_{i=0}^{q-1} W'_{t-j}\theta_j(\tau), W_t = \Delta X_t, \text{and } \delta_j(\tau) = -\sum_{i=0}^{p} {}^{*}\phi_i(\tau) X_{t-i}.$$

Following Koenker and Bassett (1978), the conditional mean function of Y on X is given as:

$$\begin{aligned} &\min_{\beta} [\theta \sum |Y_t - X_t\beta| + (1+\theta) \sum |Y_t - X_t\beta|] \\ &\{t: FS_t \geq X_t\beta\}\{t: FS_t < X_t\beta\}, \end{aligned} \tag{11}$$

where $\{Y, t = 1, 2\ldots, T\}$ represents a random sample of the regression process. $Y = {}_t + X_t\beta$, with a conditional distribution function of $F_{Y/X}(y) = F(Y_t \leq trade) = F(Y_t - X_t\beta)$, and $\{X_t, t = 1, 2\ldots, T\}$ is a sequence of known design matrices. The θ^{th} regression quantile, Q_(Y/X) (θ), where o < θ < 1, denotes any solution to the minimizing problem, and β_θ represents the solution from which the θ^{th} conditional quantile

$Q_{Y/X}(\theta) = x\beta_{\theta}$. After deriving the estimates from the baseline QARDL regression, we can compute the long-run estimator as:

$$\beta(\tau) = \gamma(\tau)(1 - \sum_{i=0}^{p} {}^{*}\phi_i(\tau) - 1. \tag{12}$$

Furthermore, the short-run and error correction models are estimated as

$$\Delta Y_t = \alpha_0(\tau) + \zeta_{*}(\tau)(Y_{t-i} - \beta(\tau)'X_{t-i}) + \sum_{i=0}^{p-1} \phi_i(\tau)\Delta Y_{t-i} + \sum_{i=0}^{p} {}^{*}\phi_i(\tau)\Delta X_{t-i} + U_t(\tau), \tag{13}$$

where $(Y_{t-i} - \beta(\tau)'X_{t-i})$ is the quantile error correction term.

Empirical Data

The study utilizes a dataset spanning from 1994:q1 to 2022:q4 on a quarterly frequency. Data for the exports (X) and imports (M) for 22 industries were collected from Quantec (https://www.quantec.co.za/). The GDP growth rate for China and the US (Y^{f}) were obtained from the Federal Reserve Economic Data (FRED) database (https://fred.stlouisfed.org/). The South African GDP growth rate (Yd) and the real exchange rate (RER) were collected from the South African Reserve Bank (SARB) online dataset (https://www.resbank.co.za/en/home/what-we-do/statistics/releases/online-statistical-query). To measure exchange rate volatility, the conditional volatility of a GARCH model fitted on the RER was used as a proxy, following the conventional literature. All data were logged for empirical analysis.

Tables 2 and 3 present the summary statistics and unit root tests for the time series of Chinese and American trade, respectively. These tables report the average volume, standard deviation, and unit root test results. The statistics help identify South Africa's main export and import industries based on trade volume. For China, the top exports include mineral products, iron and steel, chemicals, wood pulp and paper, and textiles, while the top imports consist of machinery, textiles, iron and steel, chemicals, footwear, plastics and rubber, stone and glass, vehicles, aircraft, and vessels, as well as photographic and medical equipment. For the US, the main export items are precious metals, iron and steel, chemicals, vehicles, machinery, and mineral products, while the main imports include machinery, vehicles, aircraft, and vessels, photographic and medical equipment, mineral products, chemicals, plastics and rubber, iron and steel, and wood pulp and paper. These top trade products

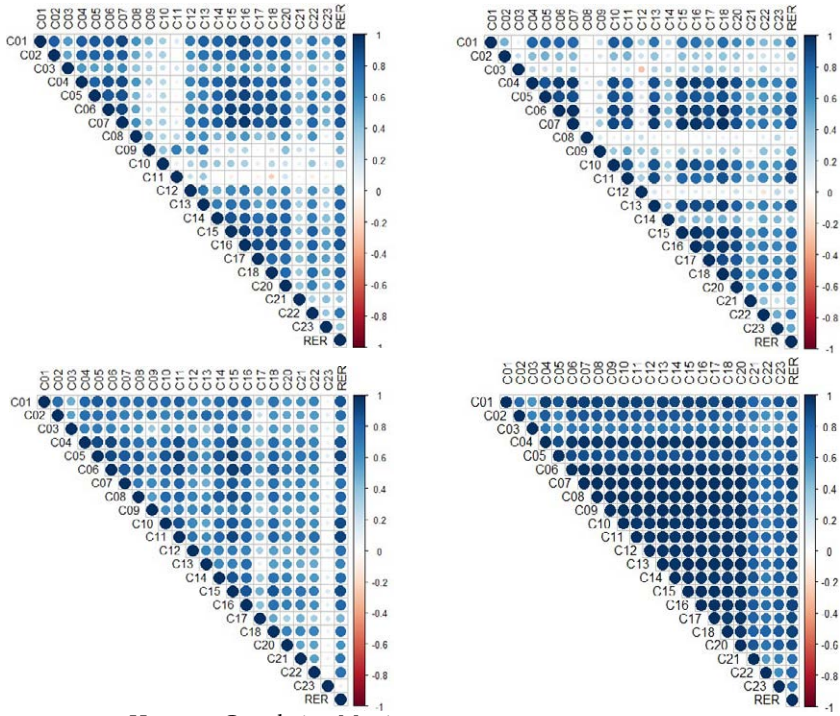

FIGURE 1 Heatmap Correlation Matrix

NOTES top right: correlation between ERV and US exports, top left: correlation between ERV and US imports, bottom left: correlation between ERV and China exports, bottom right: correlation between ERV and China imports.

align with findings from previous studies by Amusa and Fadiran (2019) and Bahmani-Oskooee and Gelan (2020), which examined the disaggregated J-curve for South Africa and the US at the industry level. Lastly, the ADF unit root tests, conducted on the first differences of the series, indicate that none of the variables exhibit an integration order higher than I(1), which is a requirement for using the ARDL and QARDL models.

Figure 1 presents a heatmap-coloured correlation matrix between exchange rate volatility and exports to China, imports from China, exports to the US, and imports from the US. The observed colour contours, predominantly blue, suggest a positive correlation between exchange rate volatility and most trade items, except for C11 (textiles) in exports to the US, C08 (raw hides & leather) in imports from the US, and C23 (equipment components) in exports to China, which exhibit a lack of correlation. However, these results are considered preliminary, and a more formal analysis is presented in the subsequent section of the paper.

TABLE 2 Descriptive Statistics (China)

		Exports				Imports			
Code	Industries	Mean	Std. Dev	JB (p-value)	ADF	Mean	Std. Dev	JB (p-value)	ADF
01	Live animals	16.680	1.8720	0.000	9.15***	17.896	1.543	0.000	−14.04***
02	Vegetables	16.285	2.825	0.000	10.18***	18.31	1.185	0.033	−11.73***
03	Animal or vegetable fats	13.513	2.392	0.000	9.27***	13.831	1.931	0.000	−11.78***
04	Prepared foodstuffs	16.891	2.4827	0.000	10 33***	17.946	2.161	0.000	−10.13***
05	Mineral products	21.543	2.192	0.001	8.52***	18.925	1.154	0.223	−12.40***
06	Chemicals	18.608	1.476	0.000	4.52***	20.224	1.671	0.024	−13.68***
07	Plastics & rubber	16.807	2.616	0.000	5.22***	19.620	1.980	0.005	−13.16***
08	Raw hides & leather	16.504	2.486	0.000	8.66***	18.786	1.363	0.005	−27.75***
09	Wood products	14.861	2.898	0.000	8.79***	17.526	1.632	0.001	−15.50***
10	Wood pulp & paper	18.208	2.296	0.000	3.26***	17.969	2.036	0.003	−12.61***
11	Textiles	18.420	1.176	0.024	3.92***	20.780	1.594	0.001	−9.82***
12	Footwear	12.183	3.181	0.000	9.16***	20.148	1.285	0.001	−11.27***
13	Stone & glass	15.968	1.783	0.000	9.36***	19.213	1.579	0.003	−13.61***
14	Precious metal	17.049	3.859	0.000	6.96***	16.837	1.981	0.000	−13.30***
15	Iron & steel	20.459	2.027	0.000	9.96***	20.319	1.833	0.005	−11.17***
16	Machinery	17.837	1.724	0.000	8.28***	21.936	1.948	0.002	−10.51***
17	Vehicles, aircraft & vessels	17.023	1.627	0.000	12.57***	19.237	2.076	0.002	−14.08***
18	Photographic & medical equipment	14.274	2.411	0.000	7.76***	19.362	1.463	0.003	−15.64***
20	Toys & sports apparel	13.010	1.990	0.000	4.13***	20.097	1.557	0.002	−33.07***
21	Works of art	12.662	2.299	0.000	9.29***	14.081	1.517	0.000	−11.41***
22	Other unclassified goods	13.842	2.987	0.001	4.94***	15.383	3.832	0.023	−6.91***
23	Equipment components	11.138	2.732	0.000	6.03***	17.961	2.638	0.000	−9.76***
	Real GDP (South Africa)	13.694	0.219	0.003	−12.4***	13.694	0.219	0.003	−12.46***
	Real GDP (United States)	29.537	0.996	0.012	−3.311*	29.537	0.996	0.012	−3.311*
	ERV	102.355	59.43	0.056	−8.75***	122.355	59.43	0.056	−8.751***

NOTES ***, **, * represent 1%, 5%, and 10%, significance levels, respectively. Critical values for ADF unit root test are −3.51 (1%), −2.89 (5%) and −1.94 (10%).

TABLE 3 Descriptive Statistics (USA)

		Exports				Imports			
Code	Industries	Mean	Std.Dev	JB(p-value)	ADF	Mean	Std.Dev	JB(p-value)	ADF
01	Live animals	17.839	0.729	0.000	−11.5***	17.783	1.214	0.000	−9.41***
02	Vegetables	18.602	1.308	0.000	−19.1***	18.946	0.65	0.000	−11.21***
03	Animal or vegetable fats	13.382	1.907	0.000	−10.0***	15.912	0.906	0.000	−11.05***
04	Prepared foodstuffs	18.951	0.987	0.000	−13.7***	18.792	0.775	0.000	−10.674***
05	Mineral products	20.27	1.092	0.001	−10.7***	19.675	0.946	0.001	−11.36***
06	Chemicals	20.703	0.783	0.000	−9.10***	21.028	0.734	0.000	−10.74***
07	Plastics & rubber	18.073	0.852	0.000	−9.5***	19.823	0.709	0.000	−9.27***
08	Raw hides & leather	17.395	0.348	0.000	−10.3***	15.681	0.625	0.000	−10.20***
09	Wood products	16.524	1.045	0.000	−9.59***	17.497	0.328	0.000	−10.12***
10	Wood pulp & paper	17.962	0.497	0.000	−10.2***	19.246	0.422	0.000	−11.50***
11	Textiles	18.49	0.687	0.000	−10.6***	18.285	0.417	0.024	−12.92***
12	Footwear	15.666	0.612	0.000	−11.2***	15.827	0.495	0.000	−12.50***
13	Stone & glass	17.383	0.713	0.000	−10.3***	18.513	0.963	0.000	−11.073***
14	Precious metal	21.411	1.555	0.000	−8.2***	17.642	1.153	0.000	−9.52***
15	Iron & steel	21.215	0.795	0.001	−8.8***	19.375	0.632	0.000	−10.93***
16	Machinery	20.314	1.002	0.000	−10.5***	21.843	0.546	0.000	−9.64***
17	Vehicles, aircraft & vessels	20.891	1.337	0.000	−8.73***	21.141	0.88	0.000	−11.12***
18	Photographic & medical equipment	17.573	0.919	0.000	−9.16***	20.439	0.712	0.000	−9.23***
20	Toys & sports apparel	17.309	0.645	0.000	−9.94***	18.57	0.672	0.000	−10.43***
21	Works of art	16.814	1.939	0.000	−1.93	15.072	1.371	0.000	−7.98***
22	Other unclassified goods	10.205	7.853	0.000	−9.91***	11.594	7.834	0.000	−7.27***
23	Equipment components	7.55	5.811	0.000	−12.7***	18.277	4.499	0.000	−7.03***
	Real GDP (South Africa)	13.695	0.22	0.000	−10.0***	13.695	0.22	0.000	−10.02***
	Real GDP (United States)	9.61	0.18	0.000	−8.18***	9.61	0.18	0.000	−8.18***
	ERV	102.355	59.43	0.056	−8.75***	122.355	59.43	0.056	−8.751***

NOTES ***, **, * represent 1%, 5%, and 10%, significance levels, respectively. Critical values for ADF unit root test are −3.51 (1%), −2.89 (5%) and −1.94 (10%).

Analysis of Results

The results obtained from the estimation of the full regressions in this study are voluminous, and the complete set of results is available upon reasonable request. In this section, we focus on the reported sign and significance of the long-run coefficient estimates of the exchange rate volatility variable in the import (table 4) and export (table 5) functions for China and the US. For comparative purposes, we present the results of the ARDL and QARDL models, with specific attention to the estimates for the 10th, 30th, 50th, 70th, and 90th quantiles.

A preliminary examination of the baseline ARDL regressions reveals that most industries are either insignificantly or positively affected by exchange rate volatility in terms of trade, with only a few industries experiencing a negative effect. Out of the 22 industries examined, the exchange rate volatility variables in the ARDL regressions indicate the following:

- Positive coefficients for: i) 8 export items to the US (prepared foodstuffs, wood products, footwear, stone & glass, machinery, photographic & medical equipment, live animals, vegetables); ii) 7 export items to China (iron & steel, plastics & rubber, wood products, other unclassified goods, machinery, vehicles, aircraft & vessels, mineral products); iii) 11 import items to the US (iron & steel, chemicals, plastics & rubber, wood products, wood pulp & paper, textiles, footwear, stone & glass, works of art, photographic & medical equipment, vegetables); iv) 8 import items to China (iron & steel, plastics & rubber, wood products, other unclassified goods, machinery, vehicles, aircraft & vessels, photographic & medical equipment).
- Insignificant coefficients for: i) 12 export items to the US (iron & steel, chemicals, plastics & rubber, wood pulp & paper, textiles, works of art, other unclassified goods, vehicles, aircraft & vessels, animal or vegetable fats, raw hides & leather, mineral products); ii) 14 export items to China (prepared foodstuffs, chemicals, wood pulp & paper, textiles, footwear, stone & glass, toys & sports apparel, works of art, equipment components, live animals, vegetables, animal or vegetable fats, raw hides & leather, precious metals); iii) 10 import items to the US (prepared foodstuffs, toys & sports apparel, other unclassified goods, equipment components, machinery, vehicles, aircraft & vessels, live animals, raw hides & leather, precious metals, mineral products); iv) 14 import items to China (prepared foodstuffs, chemicals, wood pulp & paper, textiles, footwear, stone

& glass, toys & sports apparel, works of art, equipment components, live animals, vegetables, animal or vegetable fats, raw hides & leather, precious metals).

- Negative coefficients for: i) 3 export items to the US (toys & apparel, raw hides & leather, precious metals); ii) 1 export item to China (live animals); iii) 3 import items to the US (works of art; animal or vegetable fats; vegetables); iv) 1 import item to China (live animals).

Overall, the results from the ARDL model suggest that only a few export and import items to both the US and China are not adversely affected by currency risk, with more positive and negative coefficients observed for trade items with the US and more insignificant estimates for trade items with China.

The findings from the quantile regressions align with those from the ARDL regressions and further reveal location asymmetries in a number of industries where the ARDL regressions found insignificant estimates. In such cases, significant estimates are observed at other quantiles away from the mean estimators. This occurs for 3 export items to the US (wood pulp & paper, works of art, mineral products), 9 export items to China (prepared foodstuffs, chemicals, wood pulp & paper, textiles, stone & glass, toys & sports apparel, works of art, equipment components, raw hides & leather), 3 import items from the US (equipment components, vehicles, aircraft & vessels, precious metals), and 8 import items from China (prepared foodstuffs, wood pulp & paper, textiles, footwear, toys & sports apparel, works of art, equipment components, raw hides & leather). After accounting for these location asymmetries, it is observed that most export and import trade items with China are positively affected by currency volatility, and to a lesser degree with US trade items.

All in all, our findings generally contradict most previous South African-based studies and we provide two reasons for this. Firstly, we argue that many previous studies included South Africa along with other countries that have different country-specific characteristics. This approach creates an aggregation bias in the panel estimates when generalized for all countries under investigation (Bahmani-Oskooee and Ltaifa 1992; Bahmani-Oskooee 1996; Sauer and Bohara 2001; Mukherjee and Pozo 2009; Omojimite and Akpokodje 2010; Musila and Al-Zyoud 2012; Vieira and MacDonald 2016; Meniago and Eita 2017; Bahmani-Oskooee and Arize 2020; Dada 2021). Secondly, we note that most previous studies conducted in South Africa have utilized cointegration techniques such

as FMOLS, DOLS, E-G, and VECM, which can produce biased estimates if the series are not mutually cointegrated and are sensitive to sample size biasedness (Pesaran, Shin, and Smith 2001). Interestingly, we observe that previous studies that employed the ARDL model, similar to our own study, tend to produce similar positive estimates on the exchange rate volatility variable (Todani and Munyama 2005; Ekanayake, Thaver, and Plante 2012; Ishimwe and Ngalawa 2015; Bahmani-Oskooee and Gelan 2018).

Regarding the practical and policy implications of our findings, we highlight two main points. Firstly, we suggest that the flexible exchange rate regime maintained by the SARB has not been detrimental to trade with South Africa's top trading partners. Contrary to the implications drawn from previous studies, we argue that the SARB does not need to intervene in currency markets to smooth out exchange rate fluctuations. Secondly, our findings indicate that firms are willing to undertake risk under currency uncertainty which, in turn, may reflect the high levels of confidence that trading firms have in the domestic forward markets. Furthermore, our QARDL estimates indicate that this confidence is more pronounced in the case of China compared to the US, possibly due to the success of the bilateral currency swap agreement signed between South Africa and China in 2015.

Conclusions

We examined the relationship between exchange rate volatility and export/import trade between South Africa and its top trading partners from 1994:q1 to 2022:q4, using ARDL and QARDL models. Conventional economic theory suggests that flexible exchange rate regimes create currency risk for trading firms, which can have a negative impact on export and import volumes. Moreover, most empirical literature conducted in South Africa supports the idea of an inverse relationship between exchange rate volatility and trade. However, a cursory examination of the time series data reveals that while exchange rate volatility has been increasing since 1994, particularly after the adoption of the inflation targeting regime in 2001, total export and import trade volumes between South Africa and its major trading partners have also been increasing. This observation prompts us to re-evaluate the relationship at a disaggregated level, considering specific products and trading partners using the QARDL model as a novel econometric technique used to capture location asymmetries and apply these methods to more extensive and recent data.

TABLE 4 ARDL and QARDL Long-run Estimates for Export Items

TRADE SECTORS	TRADE INDUSTRIES	China						US					
		ARDL	QARDL					ARDL	QARDL				
			0.10	0.30	0.50	0.70	0.90		0.10	0.30	0.50	0.70	0.90
Manufacturing Sector	Prepared foodstuffs	insig	insig	insig	insig	+	insig	+	insig	insig	insig	insig	insig
	Iron & steel	+	+	insig	insig	insig	insig	insig	insig	insig	insig	insig	insig
	Chemicals	insig	insig	insig	+	+	+	insig	insig	insig	insig	insig	insig
	Plastics & rubber	+	insig	insig	insig	+	insig	insig	insig	insig	insig	insig	insig
	Wood products	+	+	insig	insig	insig	+	+	insig	+	insig	insig	insig
	Wood pulp & paper	insig	+	insig	insig	insig	insig	insig	insig	insig	+	insig	insig
	Textiles	insig	insig	+	insig	insig	+	insig	insig	insig	insig	insig	insig
	Footwear	insig	insig	insig	+	+	insig	+	insig	insig	+	insig	insig
	Stone & glass	insig	insig	insig	insig	+	insig	+	+	insig	insig	insig	insig
	Toys & sports apparel	insig	+	+	+	insig	insig	-	-	-	-	insig	-
	Works of art	insig	insig	+	+	insig	insig	insig	insig	+	+	+	insig
	Other unclassified goods	+	insig	+	insig	insig	insig	insig	insig	insig	insig	insig	insig
	Equipment components	insig	insig	insig	insig	insig	+	insig	insig	insig	insig	insig	insig
	Machinery	+	+	+	+	+	+	+	insig	+	insig	insig	insig
	Vehicles, aircraft & vessels	+	insig	+	+	+	insig	insig	insig	insig	insig	insig	insig
	Photographic & medical equipment	+	insig	+	+	+	+	+	insig	insig	+	insig	insig
Agricultural Sector	Live animals	insig	insig	insig	insig	insig	insig	+	insig	insig	+	insig	insig
	Vegetables	insig	insig	insig	insig	insig	insig	+	+	insig	insig	insig	insig
	Animal or vegetable fats	insig	insig	insig	insig	insig	insig	insig	insig	insig	insig	insig	insig
	Raw hides & leather	insig	insig	insig	+	+	+	insig	insig	insig	insig	insig	insig
Mineral Sector	Precious metals	insig	insig	insig	insig	insig	insig	-	insig	-	-	insig	insig
	Mineral products	+	insig	insig	insig	insig	insig	insig	insig	insig	insig	insig	-

TABLE 5 ARDL and QARDL Long-run Estimates for Import Items

TRADE SECTORS	TRADE INDUSTRIES	China						US					
		ARDL	QARDL					ARDL	QARDL				
			0.10	0.30	0.50	0.70	0.90		0.10	0.30	0.50	0.70	0.90
Manufacturing Sector	Prepared foodstuffs	insig	insig	insig	insig	+	insig	insig	insig	insig	insig	insig	insig
	Iron & steel	+	+	insig	insig	insig	insig	+	insig	insig	insig	insig	insig
	Chemicals	insig	insig	insig	+	+	+	+	+	insig	insig	insig	insig
	Plastics & rubber	+	insig	insig	insig	+	insig	+	insig	insig	+	insig	insig
	Wood products	+	+	insig	insig	insig	+	+	insig	insig	insig	insig	insig
	Wood pulp & paper	insig	+	insig	insig	insig	insig	+	insig	insig	insig	insig	-
	Textiles	insig	insig	+	insig	insig	+	+	insig	+	+	insig	insig
	Footwear	insig	insig	insig	+	+	insig	+	insig	insig	insig	insig	insig
	Stone & glass	insig	insig	insig	insig	+	insig	+	insig	insig	insig	-	-
	Toys & sports apparel	insig	+	+	+	insig	insig	insig	insig	insig	insig	insig	insig
	Works of art	insig	insig	+	+	insig	insig	+	insig	insig	+	insig	insig
	Other unclassified goods	+	insig	+	insig	insig	insig	insig	insig	insig	insig	insig	insig
	Equipment components	insig	insig	insig	insig	insig	+	insig	insig	insig	insig	insig	+
	Machinery	+	+	+	+	+	+	insig	insig	insig	insig	insig	insig
	Vehicles, aircraft & vessels	+	insig	+	+	+	insig	insig	insig	insig	insig	insig	+
	Photographic & medical equipment	+	insig	+	+	+	+	+	insig	insig	insig	+	+
Agricultural Sector	Live animals	insig	insig	insig	insig	insig	insig	insig	insig	insig	insig	insig	insig
	Vegetables	insig	insig	insig	insig	insig	insig	+	+	insig	insig	insig	insig
	Animal or vegetable fats	insig	insig	insig	insig	insig	insig	-	insig	insig	-	-	insig
	Raw hides & leather	insig	insig	insig	+	+	+	insig	insig	insig	insig	insig	insig
Mineral Sector	Precious metals	insig	insig	insig	insig	insig	insig	insig	insig	insig	insig	+	insig
	Mineral products	+	insig	insig	insig	insig	insig	insig	insig	insig	insig	insig	insig

The results obtained from the conventional ARDL model provide little evidence of adverse effects of exchange rate volatility on most export and import items. In fact, most industries show either insignificant or positive effects. Moving beyond the ARDL models, our estimation of the QARDL models reveals the presence of hidden positive cointegration relationships at quantiles beyond the mean and median distributions, particularly for export items to China and import items from China. This finding suggests that exchange rate volatility has a more positive impact on trade with China compared to trade with the United States. Theoretically, this can be attributed to the willingness of traders to undertake currency risk in their trade activities with China and highlights the success of currency swap agreements signed between South Africa and China. This raises an important policy question as to whether a currency swap agreement with the United States could potentially improve trade relations between the two countries.

Given the QARDL model's demonstrated efficacy in identifying hidden cointegration relationships among time series variables, we recommend for future research studies to replicate our empirical approach for different countries and their respective trading partners. Although there is a growing consensus regarding the nonlinear nature of this association, existing scholarly literature has predominantly concentrated on the NARDL model, which discerns the effects of ascending and descending levels of currency volatility on trade. In contrast, the QARDL model departs from this paradigm by highlighting spatial dissimilarities. Our investigation has demonstrated that this framework can be employed to discern the impact of currency volatility across various quantile distributions, encompassing both extremely low and extremely high degrees of volatility.

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The Shadow Economy, Mobile Phone Penetration and Tax Revenue in Sub-Saharan Africa

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This study investigates the effect of the shadow economy on tax revenue and the moderating effect of mobile phone penetration in Sub-Saharan Africa. Using data on 26 SSA countries over 11 years and employing the system General Method of Moments (GMM) approach, the study reveals that the shadow economy has a significant negative effect on tax revenue in SSA, whereas mobile phone penetration has a significant positive effect on tax revenue. Again, mobile phone penetration plays a moderating role in the shadow economy–tax revenue nexus in SSA. Governments in the SSA region need to update their tax administration systems, construct and enhance infrastructure linked to emerging mobile technology, and implement best practices in tax regulations. Lastly, governments and telecommunications companies should implement some kind of consumer education in the informal sector to raise awareness of the advantages of using mobile phones for business transactions and the simplicity of paying taxes using a mobile device.

Keywords: shadow economy, mobile phone penetration, tax revenue, sub-Saharan Africa
JEL Classification: E26, H25, H27, H30

Received 2023/12/01 · Revised 2024/03/10 · Accepted 2024/03/17
Published online 2024/09/30 https://doi.org/10.26493/1854-6935.22.279-308

Introduction

Every nation in the world aspires to economic development as a macroeconomic objective (Ayenew 2016). In most developing economies, there are still unresolved issues with economic development in particular. Despite having an abundance of natural resources, the majority

of developing nations have budget deficits that make it necessary for them to depend on foreign aid to pay for their development initiatives. Consequently, better control over the processes of economic development and poverty reduction as well as a reduction in the fiscal deficit may result from increased mobilization of domestic resources. Resource efficiency has remained poor in Less Developed Countries (LDCs), and these economies' governments are more actively involved in achieving economic stabilization using a range of policy tools, including fiscal policy (Ayenew 2016). Because economic resources are limited in society, an increase in government spending usually causes a drop in private spending. One way to transfer resources from the private to the public sector is through the implementation of fiscal policy, which involves raising tax revenue. Taxation is without a doubt the most significant source of government revenue; however, governments regularly raise money through a number of means, including borrowing, receiving aid, printing money, and taxing (Chaudhry and Munir 2010).

One of the most important tools that developing nations can use to mobilize their own resources for long-term development is taxation. It supports the core responsibilities of a functional state by allowing it to raise the funds required to carry out significant services and by creating an atmosphere that is favourable to economic expansion. It also acts as a catalyst for building state capacity and governments which are more responsive and responsible to their constituents (OECD 2008). In addition, to raise their tax revenues, several developing nations have implemented numerous reform initiatives during the past few decades, such as the implementation of value-added taxation (VAT). Even though tax revenue indicates how well the economy can support government spending, most developing nations still have low tax rates (Tanzi and Zee 2001).

In developing nations, tax revenue collection is still historically low, although being an essential tool for robust and inclusive state-building. Numerous authors have written about how developing nations perform poorly in terms of tax revenue. For instance, tax collection in developing nations is just 11 percent of GDP, while it is 20 percent in comparatively wealthy nations (Okunogbe and Santoro 2021). The Sustainable Development Goals specify a tax performance of 20 percent of GDP as the minimum required to build a strong state (to deliver on core citizens' rights and government promises), which raises significant development concerns in light of poor countries' low tax revenue. Numerous authors,

such as Okunogbe and Santoro (2023) and Basri et al. (2021), provide evidence of inadequate tax revenue mobilization in developing nations.

The majority of Sub-Saharan Africa (SSA) nations share a low tax-to-GDP ratio (Ayenew 2016). Many nations make great efforts but are unable to generate enough income to cover their governments' deficits and meet their development requirements. In order to meet the Sustainable Development Goals (SDGs), half of the SSA nations mobilized 16.8 percent of GDP from tax revenue, which is less than the 20 percent required by the UN. This information was reported by the United Nations Development Programme in 2013. However, less than 17 percent of GDP is collected in taxes by half of all SSA countries, and many Asian and Latin American nations fare little better (OECD 2014a). According to Coulibaly and Gandhi (2018), SSA has a large financing demand for investments, estimated at about $230 billion annually. The primary causes of this deficit are the low rates of savings inside the country and the persistent underperformance of tax revenue collection, even with the recent improvements. According to Coulibaly, Gandhi, and Senbet (2019), regional tax collections – aside from those pertaining to the natural resource sector – did in fact rise from 11 percent of GDP in the early 2000s to nearly 15 percent in 2015. Although the percentage has increased from 11 percent to nearly 15 percent, it still falls short of the desired level and is still lower than that of the OECD (24 percent) and other emerging and developing nations.

Official Development Assistance (ODA), a major source of funding for development in Africa, has been decreasing over time. This implies that for the continent to meet the SDGs, ways to improve internal resource mobilization must be found. The first SDG 17 target stresses the necessity for countries to improve internal resource mobilization and capacity building for tax and other revenue collection. The creation of tax income is vital to a nation's economic progress (OECD 2014b). In particular, higher revenue would fortify the fiscal capacity of the continent, allowing it to fund public goods and services that will lessen vulnerability, poverty, and inequality. Nonetheless, the average tax-to-GDP ratio in Africa is 17.1 percent, which is less than the 18.5 percent threshold needed to support growth and supply basic amenities like better public safety, healthcare, and road infrastructure in emerging countries (Aydin and Esen 2019). This contrasts sharply with the 34 percent of the OECD and the 22 percent of Latin America and the Caribbean, respectively (OECD 2019). The remaining 16 SDGs, as well as SDG 17, would be challenging to achieve if this problem is not fixed. Over time, low tax revenue mobilization in SSA

has been attributed to various factors, including poor economic development, the significant contribution of agriculture to economic activity, and the size of the informal economy, also known as the shadow economy (Coulibaly and Ghandi 2018). Since the informal sector generates less tax revenue than the formal sector, the governments of some states in the SSA region have implemented various mechanisms to curtail its large scale.

The informal sector's size has decreased over time in SSA, although not to the anticipated degree (Lum 2011; Medina and Schneider 2018). In SSA, 34 percent of GDP comes from the informal sector (Coulibaly and Ghandi 2018). Even while the informal sector is blamed for the region's low tax income, it does offer some job prospects. About 70 to 80 percent of non-agricultural workers are working in the informal sector, with the majority being self-employed people and micro-business owners, according to the International Labour Organization (2018). The bulk of these people who work for themselves and manage micro businesses have embraced using mobile phones for both daily tasks and company operations, according to Larsson and Svensson (2018). The informal economy is undergoing a shift, and this is reflected in the increasing use of mobile phones in this sector, which also serves as a means of raising taxes (Larsson and Svensson 2018).

Many lives have been transformed by the mobile revolution, which has made basic financial access and connectivity possible through phone-based money transfers and storage (Donner and Tellez 2008; Demombynes and Thegeya 2012). In order to accomplish some of the SDGs in the SSA region, mobile phones are essential due to their capacity to promote sustainable development and equitable growth. Theoretically, increases in a nation's tax revenue are the main indicators of growth and progress. According to the OECD (2014b), tax income is allocated to various projects, including but not limited to road construction, social amenities, and job creation, all of which contribute to growth and development.

Some studies have looked into how mobile phones affect economic development and growth (Aker and Mbiti 2010). Additionally, Asongu (2015) and Carabregu Vokshi et al. (2019) investigated the effect of the penetration of mobile phones on inequality. Furthermore, several studies conducted on mobile phones have been qualitative and theoretical in character (Donner and Tellez 2008; Maurer 2008; Merritt 2010; Thacker and Wright 2012). Research on the connection between taxes and mobile phones examined the impact of specific taxes and how the mobile

market is affected (Exelby 2011; Katz, Flores-Roux, and Mariscal 2011). For instance, Apeti and Edoh (2023) examine the effects of mobile money adoption on direct and indirect tax revenue in developing countries. Additionally, research on how the informal sector affects tax collection has been conducted in a number of different countries (Boltano and Abanto 2019; Mawejje and Munyambonera 2016).

As a result of the aforementioned literature, and to the best of our knowledge, no study has yet evaluated how widespread mobile phone use affects tax revenue and how it influences the tax revenue–informal sector nexus in SSA. The few empirical studies that are currently available rely on micro-level, nation-specific data that is primarily gathered through surveys (Demombynes and Thegeya 2012). Evidence from the literature shows that over time, actors in the informal sector have resorted to using mobile phones to run their businesses and also use them as a medium to pay their taxes, which in the long run increases the overall tax revenue; an examination of the moderating role of mobile phone penetration in the informal sector–tax revenue nexus is necessary for SSA (Larsson and Svensson 2018). Therefore, this gap in the literature offers a rare chance to enhance the body of work already done by adding a macroeconomic analysis of tax revenue, mobile phone penetration, and the shadow economy. Being one of the few, if not the only, empirical studies to look at the moderating effect of mobile phone penetration in the informal sector and tax revenue relationship in the SSA region, the study adds to the body of current literature.

The rest of the article is structured as follows. The literature is presented first, followed by the methodology and data in the third section, the results and discussions in the fourth section, and lastly, conclusions and policy recommendations in the fifth section.

Review of the Literature

A significant basis in the economics of taxes has been the optimal tax theory (see Atkinson and Stiglitz 1976; Mirrlees 1971). The idea of optimal taxation examines how taxes can be designed to produce the maximum social welfare outcomes (Opara 2014). In this sense, uniform vs differentiated taxation has dominated discussions over the best taxation policies. The literature on optimal taxes has grown quickly, although there is still disagreement in this area. Ramsey (1927) demonstrates in his groundbreaking work that, generally speaking, a uniform commodities tax system is not the best option because it does not alter relative

pricing. Feldstein (1978) supports the Ramsey tradition by pointing out that it is generally not ideal to tax some forms of capital evenly, as long as the revenue from those products is untaxed. Differentiated tax rates are therefore necessary for optimal taxation, according to these theoretical perspectives. However, according to Summers (1987), there is little potential efficiency gain from doing away with the differential taxation of different types of capital income. As a result, addressing this issue diverts attention from the overall level of capital income taxation, which is crucial for figuring out how efficiently the economy operates.

The macroeconomic applied tax models of Heller (1975) and Leuthold (1991) demonstrate the importance of the tax base's constituent parts, efficient institutional frameworks (such as those concerning corruption control), and affirmative economic policies (such as those aimed at luring foreign direct investment, or FDI) in terms of tax revenue performance. According to the models, measures aimed at increasing FDI will boost growth and hence broaden the tax base, opening up new avenues for increased tax collection. The economist Arthur Laffer has long proven the importance of tax rate (as a particular type of a general discretionary tax policy) to impact tax revenue (Kazman 2014; Trabandt and Uhlig 2011). Neoclassical supply-side economics, which is based on the Laffer curve, indicates that raising the tax rate first improves tax revenue; however, raising the rate further results in a decrease in tax revenue. According to supply-side economists, tax cuts boost the economy and raise tax receipts as a result. The curve's downward slope indicates that to increase total tax revenue, a tax rate reduction is required to broaden the tax base. These views are supported by theoretical studies by Mankiw, Weinzierl, and Yagan (2009) and Hines and Summers (2009), which emphasize how important it is to select the right revenue instruments or tax handles (tax bases) to affect tax performance.

Several authors have taken into consideration empirical research on the subject of the shadow economy and tax revenue. For example, Lukito and Adi (2023) use descriptive-exploratory and explanatory methodologies to empirically investigate the effects of the allocation, distribution, and stabilization variables on the shadow economy and their impact on tax revenues in Mojokerto City, Indonesia. Using a sample of 79 respondents, a population of 369 with a Slovin tolerance formula of 0.01 was identified. Version 3.3.7 of the SmartPLS software aided in data processing while a questionnaire was used for data collection. The outcomes demonstrate: (1) The shadow economy is significantly impacted by

allocations; (2) The shadow economy is significantly impacted by distribution; (3) Stabilization has no influence on the shadow economy; (4) Allocations have no effect on tax revenues; (5) Distribution significantly affects tax revenues; (6) Stabilization significantly affects tax revenues; (7) The shadow economy significantly affects tax revenues; (8) Allocations indirectly affect tax revenues through the shadow economy; (9) Distribution indirectly affects tax revenues through the shadow economy; (10) Stabilization indirectly affects tax revenues through the shadow economy. This study is, however, a micro-study of a city in Indonesia, the result of which cannot be used to generalize for the entire country. Furthermore, Ishak and Farzanegan (2020), for example, investigated the impact of the shadow economy on tax revenue and found that it had a negative influence on tax collection in both developed and developing nations.

The size of Peru's informal economy was examined in a Boltano and Abanto (2019) study concerning other Latin American countries and the Organization for Economic Cooperation and Development (OECD). The results showed that the average size of the informal economy in terms of tax collection as a percentage of GDP was projected to be 37.4 percent in Peru, 34 percent in Latin America, and 19.89 percent in OECD countries – less than half of the average for the region. The study's conclusions showed that tax revenue was negatively impacted by the unorganized sector. Additionally, Obara and Nangih (2017) looked into the effects of taxing Nigeria's informal sector, with a particular emphasis on Rivers State. The study's conclusions showed that taxing the informal sector improved revenue collection and benefited Nigeria's economic growth. Mawejje and Munyambonera (2016) looked into how public spending and sectoral growth affects tax revenue in Uganda. According to their results, the main obstacles to the performance of tax revenue are the dominance of the informal sector and agriculture. In his study of developing countries, Gnangnon (2023) investigated how tax reform was impacted by the shadow economy. The first category of tax reform is known as 'structural tax reform' (STR), which is defined by significant episodes of tax revenue mobilization. Akitoby et al. (2020) identified STR using the narrative approach, which enables the precise nature and timing of significant tax actions in a number of areas related to revenue administration and tax policy that actually resulted in increases in tax revenue. The term 'tax transition reform' (TTR) refers to the second kind of tax reform, which is a restructuring of the tax revenue structure that lessens reliance

on revenue from international trade taxes in favour of domestic tax revenue. The analysis, which made use of a variety of estimators, demonstrated that the shadow economy lowers the probability of STR (especially in low-income countries) in a number of domains related to tax policy and revenue management. In nations where the money from international trade taxes plays a significant role in the tax revenue system, the shadow economy also poses a threat to the TTR process. Lastly, it encourages the TTR process in nations with more liberalized trade.

The second approach in the literature looks at the factors that affect tax revenue. According to one body of research, the factors that statistically significantly explain the differences in the tax revenue-to-GDP ratio between nations are the per capita GDP, income level, foreign aid, share of agriculture, the structure of the economy, and the degree of openness (Addison and Levin 2012; Gupta 2007; Nnyanzi, Babyenda, and Bbale 2016; Zarra-Nezhad, Ansari, and Moradi 2016). The empirical research also focuses on the relationship between institutional characteristics and tax income. Research by Epaphra and Massawe (2017) shows that the creation of tax income is enhanced by governance indices such as government efficacy, regulatory quality, rule of law, voice, and accountability (see also Ngwakwe 2015; Lensink, Hermes, and Murinde 2000).

The third aspect of the literature looks at electronic commerce. Duke et al. (2013) investigated the barriers to Nigerian electronic commerce functioning as a conduit for tax revenue. The results show that Nigeria's total tax revenue is greatly impacted by e-commerce activities. A comparable study conducted in Nigeria by Effiong and Nwangu (2020) also discovered that while Point of Sales (PoS) and mobile phone transactions had a large impact on tax revenue income, e-commerce and ATM transactions had a big impact as well. Apeti and Edoh (2023) examine how the use of mobile money has affected tax collection performance over the 1990–2019 period in 104 developing countries. Estimates derived from the entropy balancing method demonstrate that, in comparison to non-mobile money countries, mobile money dramatically boosts tax collection in mobile money countries. This result holds up well to a number of robustness tests and may be influenced by time perspective, the kind of mobile money service, and a few structural elements such as the degree of corruption, the size of the rural population, the inflation rate, the education level, the sample 25th percentile and average of tax revenue, the effectiveness of revenue administration, and mature markets. Mobile money raises both types of tax revenue, having a greater

influence on direct tax revenue, according to a first level of tax revenue disaggregation into direct and indirect tax revenue. When these two components are broken down into separate subcategories at a second level, it becomes clear that while taxes on goods and services determine indirect tax revenue, personal and corporate income taxes have the biggest impact on direct tax revenue. Ultimately, the key ways that mobile money adoption improves tax performance in developing nations are through a wider tax base (measured by GDP per capita), improved institutional quality, and streamlined tax payment procedures. Hanrahan (2021) also applies both static and dynamic panel data analysis approaches to analyse the impact of the rise in digitalization on tax revenues. Panel data spanning OECD countries from 1995 to 2018 is used. The results suggest that a nation with strong digital dynamics may find it more difficult to earn larger tax returns as a result of digitalization. With propensity score matching, Wandaogo, Sawadogo, and Lastunen (2022) evaluate the causal relationship between tax income and Peer-to-Government (P2G) mobile payments adoption. The matching estimates indicate that P2G service adoption results in a 1.2 to 1.3 percentage point increase in direct tax collection as a proportion of GDP. The adoption of P2G enhances corporate and personal income tax collection, having a greater impact on the latter. The outcomes hold up well to comparable quality assessments and different estimate techniques such as the system generalized method of moments, function control, and two-stage least squares. The average treatment effects are highest in lower-middle-income nations and those with low levels of urbanization, domestic loans to the private sector, and limited tax compliance and corruption control. According to the research, developing nations should encourage the adoption and use of mobile money services for tax transactions, especially those with weak institutions and low levels of financial inclusion. Adegboye et al. (2022) also examine the effect of Information and Communication Technology on government revenue mobilization for 48 Sub-Saharan African countries from 2004 to 2020 using the Generalized Method of Moments (GMM). Internet penetration rate, telephone penetration rate, and mobile phone penetration rate are the three measures of Information and Communication Technology used in the study. The study also estimates the thresholds for two of the three measures and reveals thresholds of 21.125 internet penetration (per 100 people) for the income from the tax on non-resource income, 16.333 (per 100 people) internet penetration for

total income from tax, and 21.959 (per 100 people) telephone penetration for total income from tax revenue.

More recent studies such as Jemiluyi and Jeke (2023) and Okunogbe and Santoro (2023) have discussed the effect of the adoption of Information and Communication Technology on tax revenue in Africa. Jemiluyi and Jeke (2023), for instance, analysed the role of Information and Communication Technology in mobilizing tax revenue in the Southern African Development Community between 2001 and 2020 within the Fully Modified OLS framework. The results of the study indicate that measures of Information and Communication Technology, namely mobile cellular and internet usage, have a statistically significant positive effect on all categories of taxes such as total tax revenue, taxes on goods and services, and taxes on income, profit, and capital gains. Okunogbe and Santoro (2023) also look at how African nations might use the latest technological developments to enhance tax management. It gives a general summary of the advantages and disadvantages of the various tax types in Africa, including income taxes, trade taxes, real estate taxes, and consumption taxes. The use of technological solutions to help identify the tax base, monitor compliance, and ease compliance is then discussed as a means of addressing these issues.

It is evident from the literature that research on tax revenue that has already been done has concentrated on different factors. Furthermore, the majority of research on the shadow economy is done at the micro level (Olabisi et al. 2020; Mawejje and Munyambonera 2016; Obara and Nangih 2017). Lastly, research on the adoption of mobile phones relies primarily on micro-level, country-specific data gathered through surveys (Demombynes and Thegeya 2012). The research has mostly overlooked the empirical connection between mobile phone penetration and the creation of tax revenue as well as the moderating effect that mobile phone penetration plays in affecting tax revenue through the informal sector.

Methodology and Data

THEORETICAL MODEL SPECIFICATION

This study extends and adopts the well-known tax framework created by Heller (1975) as the foundation for the theoretical model specification to investigate the impact of the shadow economy on tax revenue and the moderating role of mobile phone penetration in the shadow economy–tax

revenue nexus in the SSA region. According to Heller's (1975) model, public decision-makers in developing nations make fiscal decisions based on maximizing a welfare function while adhering to budgetary constraints. The public decision-maker utility function is given as:

$$U = (Y - T, G, D, F + L), \tag{1}$$

where $U_{Y\text{-}T}$ and $U_g > 0$; U_D and $U_{F+L} < 0$, if D and $F+L > 0$; U_D and if D and $F+L < 0$. Y-T (Y is GDP and T is tax revenue) is the disposable income of the private sector; G is total government spending, D is net domestic government borrowing (non-tax revenue), and (F+L) is net foreign financing made up of grants (F) and loans (L), including the accumulation or decumulation of external arrears (net amortization). The first derivatives of U with respect to D and (F+L) can be either positive or negative because the variables D and (F+L) can have either one of these values. Every variable in the model is expressed in real terms per capita. The decision maker's budget constraint is given by:

$$G = T + (F + L) + D \tag{2}$$

To determine the desired tax revenue, (1) is maximized subject to (2). The utility function is assumed to take the following quadratic form:

$$U = \varnothing_1 (Y - T - Y_s) - \frac{\varnothing_2}{2}(Y - T - Y_s)^2 + \varnothing_3 (G - G_S) - \frac{\varnothing_4}{2}(G - G_S)^2 - \varnothing_5 D - \frac{\varnothing_6}{2} D^2 - \varnothing_7 (F + L) - \varnothing_8 (F + L)^2, \tag{3}$$

where the ∅ s are positive constants. G_s and Y_s are subsistence levels of government expenditure and income, respectively. Since G_s and Y_s are not observable, it is assumed that they are simple linear functions of income such that:

$$G_s = g_0 + g_1 Y \tag{4}$$

$$Y_S = y_0 + y_1 Y \tag{5}$$

The following reduced form for the desired equation for the tax revenue–GDP ratio $(T/Y)^*$ is obtained by simultaneously solving the optimal equations and maximizing (3) with regard to T, G, and D after substituting for G_s and Y_s subject to the budget constraint (2):

$$\left(\frac{T}{Y}\right)^{*} = \left(\frac{\mu + \varnothing_4 g_0 - \pi Y_0}{\pi + \varnothing_4}\right)\left(\frac{1}{Y}\right) - \left(\frac{\varnothing_4}{\pi + \varnothing_4}\right)\left(\frac{F+L}{Y}\right) + \left(\frac{\varnothing_4 g_1 - \pi Y_1}{\pi + \varnothing_4}\right), \tag{6}$$

where

$$\mu = \left(-\varnothing_1 + \varnothing_3 - \frac{\varnothing_1 \varnothing_4}{\varnothing_6} + \frac{\varnothing_4 \varnothing_5}{\varnothing_6}\right) \text{ and } \pi = \frac{\varnothing_2(\varnothing_4 + \varnothing_6).}{\varnothing_6}$$

Variable *D* disappears while solving for the desired tax revenue GDP ratio. We now suppose that certain tax bases, the desired tax revenue to GDP ratio $(T/Y)^{*}$, and the state of macroeconomic policies all influence the actual tax revenue to GDP ratio (T/Y). In this study, the tax base is captured by the shadow economy (SHADOW) and mobile phone penetration (MPP). Thus:

$$\left(\frac{T}{Y}\right) = f\left[\left(\frac{T}{Y}\right)^{*}, SHADOW, MPP, M\right] \tag{7}$$

The expression for the actual tax shares is given by combining equations (6) and (7) as:

$$\left(\frac{T}{Y}\right) = f\left[\left(\frac{1}{Y}\right), \left(\frac{F+L}{Y}\right), SHADOW, MPP, M\right] \tag{8}$$

Since π is positive and μ can be either positive or negative, the actual tax revenue to GDP ratio (T/Y) is a negative function of $(F+L)/Y$ and an uncertain function of the inverse of GDP $(1/Y)$. Equation (8) determines the country's tax bases captured by shadow economy (SHADOW) and mobile phone penetration (MPP) (often referred to as tax handles), macroeconomic policies (M), and foreign financing as a ratio of GDP$((F+L)/Y)$.

Finally, we can express the theoretical model as follows using the general determinants of the model:

$$\left(\frac{T}{Y}\right) = f(YP, \ Tax\ Base, M, \ Ext\ Env) \tag{9}$$

where *YP* is GDP per capita representing the size of the economy, *Tax Base* is the tax base of handles, captured by shadow economy (SHADOW) and mobile phone penetration (MPP), M is the macroeconomic policies captured by inflation with the reason that economic policies

that emphasize a prudent financial stance can be expected to raise tax revenue, and *Ext Env* denotes external environment factors that may affect tax revenue, such as control of corruption.

EMPIRICAL MODEL SPECIFICATION

The variables of interest, shadow economy and mobile phone penetration are added to equation (9) above in accordance with the literature (see, for instance, Feger (2014) and Terefe and Teera (2018)). Equation (10) specifies the baseline model, which is the empirical form of equation (9) above:

$$(T/Y)_{i,t} = \beta_0 + \beta_1 (T/Y)_{i,t-1} + \beta_2 SHADOW_{i,t} + \beta_3 MPP_{i,t} + \beta_4 X_{i,t} + \eta_i + \mu_t + \varepsilon_{i,t}$$

$$i = 1,2,3,\ldots,26;\ t = 1,2,\ldots,11, \tag{10}$$

where T/Y represents tax revenue as a percentage of GDP, SHADOW represents the shadow economy as a percentage of GDP, represents mobile phone subscriptions (per 100 people), which is a proxy for mobile phone penetration, and X is a vector of control variables. The control variables include TOT, which indicates Trade Openness as a percentage of GDP; AGRIC, which also represents the share of agriculture value added (% of GDP); INF, representing inflation, consumer price index (annual %); SER represents the share of service value added (% of GDP); and AID represents net Official Development Assistance (ODA) received (% of GNI). YP represents GDP per capita (constant 2015 US$), COC represents control of corruption, μ_t is a dummy for time-specific effects and is country-specific unobserved effect and $\varepsilon_{i,t}$ idiosyncratic error term. The subscripts t and i denote country and time period, respectively.

To examine the effect of the shadow economy on tax revenue in general, the model includes the lag of tax revenue which is specified below:

$$(T/Y)_{i,t} = \beta_0 + \beta_1 (T/Y)_{i,t-1} + \beta_2 SHADOW_{i,t} + \beta_3 X_{i,t} + \eta_i + \mu_t + \varepsilon_{i,t}$$

$$i = 1,2,3,\ldots,26;\ t = 1,2,\ldots,11, \tag{11}$$

where $(T/Y)_{i,\,t-1}$ is the lag of tax revenue as a percentage of GDP. The lag of T/Y is taken in order to assess whether the previous year's tax revenue has any impact on the current year's tax revenue. Moreover, since this is

a dynamic analysis, there is a need to specify the lag of the tax revenue in the model. All other variables remain as defined earlier.

To examine the effect of mobile phone penetration on tax revenue in general, the model includes the lag of tax revenue which is specified below:

$$\begin{aligned}(T/Y)_{i,t} &= \beta_0 + \beta_1 (T/Y)_{i,\,t-1} + \beta_2 MPP_{i,t} \\ &\quad + \beta_3 X_{i,t} + \eta_i + \mu_t + \varepsilon_{i,t} \\ \text{i} = 1,2,3,\ldots,26;\ \text{t} = 1,2,\ldots,11,\end{aligned} \tag{12}$$

To examine the moderating role mobile phone penetration plays in the shadow economy–tax revenue nexus, model (13) is specified as follows:

$$\begin{aligned}(T/Y)_{i,t} &= \beta_0 + \beta_1 (T/Y)_{i,\,t-1} + \beta_2 SHADOW_{i,t} \\ &\quad + \beta_3 MPP_{i,t} + \beta_4 X_{i,t} + \beta_5 (SHADOW_{i,t} * MPP_{i,t}) \\ &\quad + \eta_i + \mu_t + \varepsilon_{i,t} \\ \text{i} = 1,2,3,\ldots,26;\ \text{t} = 1,2,\ldots,11,\end{aligned} \tag{13}$$

where ($SHADOW_{i,t}$*$MPP_{i,t}$) denotes an interaction term between shadow economy and mobile phone penetration. All other variables remain as defined earlier, β_0 represents the intercept term, β_1, β_2, β_3, β_4, *and* β_5 are our parameters or coefficients of interest and is the error term in the model.

The study makes use of panel data from 26 SSA nations that spans the years 2009 through 2019. Data availability influenced the selection of the time period and the countries. The study uses a dynamic panel system GMM methodology proposed by Blundell and Bond (1998) to account for the autoregressive component dependent variable and address the endogeneity that could occur from regressors. The lagged dependent variable's presence and the correlation between it and the error term can cause various endogeneity issues. The system GMM can handle these issues, as well as omitted variable bias, measurement error correction, and the generation of effective internal instruments. Two requirements must be met in order to determine the consistency and validity of our system's GMM estimator: the instruments must be valid and the error term cannot be serially correlated. To meet these requirements, the Arellano-Bond test for serial correlation and the Hansen test for over-identifying restrictions were employed.

DATA, SOURCE AND EXPECTED SIGNS

Table 1 presents the summary of the descriptions of the variables and their expected signs as well as the data sources.

TABLE 1 Variables, Description, Expected Sign and Data Source

Variable	Description	Expected Sign	Data Source
Tax Revenue (T/Y)	Tax revenue as % of GDP		World Bank Database
Shadow Economy (SHADOW)	Size of the informal sector measured as a % of GDP	-	Medina and Schneider (2018)
Mobile Phone Penetration (MPP)	Mobile cellular subscriptions (per 100 people)	+	World Bank Database
Trade Openness (TOT)	Trade Openness, defined as the sum of imports and exports as a % of GDP	+/-	World Bank Database
Agriculture Sector (AGRIC)	Share of agriculture, value added as a % of GDP	-	World Bank Database
Inflation (INF)	Consumer price index (annual %)	-	World Bank Database
Service Sector (SER)	Share of service, value added as a % of GDP	+	World Bank Database
Aid (AID)	Net Official Development Assistance (ODA) received (% of GNI)	+/-	World Bank Database
GDP Per Capita (YP)	GDP per capita (constant 2015 US$)	+/-	World Bank Database
Control of Corruption (COC)	Index for the control of corruption [−2.5 (weak) to 2.5 (strong)]	+	World Governance Indicators

We anticipate seeing a negative relationship between tax revenue and the shadow economy once tax revenue has been regressed on the model's sets of control variables because the informal sector is thought to be difficult to tax and also evades taxes (Nnyanzi, Babyenda, and Bbale 2016; Mawejje and Munyambonera 2016). Tax revenue is anticipated to benefit from the increased use of mobile phones. Because there are several taxes associated with using mobile phones, their use provides a means of income generation for governments. Additionally, it is now a method for people to pay their taxes (Koyuncu, Yilmaz, and Ünver 2016; Effiong and Nwanagu 2020).

Theoretically, there is uncertainty about how GDP per capita affects tax revenue. A nation's share in the formal economy rises with its level of development, increasing tax revenue (Ángeles-Castro and Ramírez Camarillo 2014). The impact of GDP per capita level, a proxy for economic development, varies depending on the kind of tax. For example, while

a higher level of GDP per capita raises the indirect tax ratio, trade taxes are likely to decrease. Farhadian-Lorie and Katz (1989) state that trade tariffs were a significant source of funding for governments in both the pre-structural adjustment era and the early phases of development. In such cases, it is anticipated that rising GDP per capita will result in declining shares of total tax collection. Other control factors, such as trade openness, the agriculture and service sectors, inflation, aid, and the control of corruption are also included in the study with reference to the literature.

Results and Discussion

The findings from the econometric estimations are covered in this section. The study begins by summarizing the descriptive statistics of the variables it utilized. The impact of the shadow economy and the widespread use of mobile phones on tax revenue comes next. We then go on to discuss how mobile phones moderate the impact of the informal sector on tax revenue. The system GMM findings are shown for each case. However, two requirements must be met in order to determine the consistency and validity of the system GMM estimator: the instruments must be legitimate and the error term cannot be serially correlated. Due to this, the study must use the Arellano-Bond test for serial correlation AR (2), which measures second-order serial correlation with the null hypothesis that there is no second-order serial correlation. The second test is the Hansen test for over-identifying restrictions with the null hypothesis that the instrumented variables are exogenous and not correlated with the error term. Instrument validity is indicated by rejecting the null.

SUMMARY STATISTICS

According to table 2, the total tax revenue (T/Y) for the 26 sub-Saharan African countries is averaged at about 15 percent of GDP. The maximum and minimum values are approximately 39 percent and 4 percent, respectively, with a variance of 6.8 percent. When expressed as a share of GDP across the period, the informal sector (SHADOW) averages roughly 34 percent of GDP. With a minimum of roughly 18 percent of GDP, the maximum figure is roughly 54 percent of GDP. Within the region, the informal sector deviates from the mean by about 7.7 percent annually. The mean value of mobile cellular subscriptions (per 100 persons), which is used as a proxy for mobile phone penetration (MPP) over the period, is 78.86, with the regional variance being 38.85. In the SSA region, there are

TABLE 2 Summary Statistics of Variables from 2009 to 2019

Variable	Obs.	Mean	Std. Dev.	Min	Max
Tax Revenue (T/Y)	286	15.5880	6.7700	4.0985	39.2576
Shadow Economy (SHADOW)	286	33.5458	7.6600	17.8	54
Mobile Phone Penetration (MPP)	286	78.8562	38.8531	4.7536	173.811
Trade Openness (TOT)	286	79.2191	28.9353	28.8153	155.999
Agriculture Sector (AGRIC)	286	17.4960	12.8915	1.0535	58.0357
Inflation (INF)	286	6.1892	13.2135	−2.4096	200.367
Service Sector (SER)	286	47.4676	10.1024	22.1315	67.6503
Aid (AID)	286	6.7825	8.1905	0.0035	77.8681
GDP Per Capita (YP)	286	2690.469	3034.459	345.635	15906.5
Control of Corruption (COC)	286	−0.5375	0.6525	−1.8264	1.0269

173.81 mobile phone subscriptions at the greatest level (per 100 persons) and 4.75 at the lowest. Within the region, trade openness (TOT) as a percentage of GDP ranges from a minimum of 28.82 to a maximum of 156.0. As a percentage of GDP, trade openness has a mean value of 79.22 and a variation of 28.94. Agriculture's average GDP share (AGRIC) is 17.50, with a deviation of 12.89. Agriculture's GDP share ranges from a low of 1.05 to a maximum of 58.04.

The consumer price index (annual %), which is used to quantify inflation (INF), has a mean value of 6.19 percent and a deviation of 13.21 percent from the mean. For the SSA nations included in the study, the highest inflation rate is 200.37 percent, while the minimum inflation rate is −2.41 percent. Some countries such as Burkina Faso, Cameroon, Equatorial Guinea, Liberia, Mali, Togo, Zambia and Zimbabwe recorded negative inflation values and this may be as a result of a fall in prices of goods and services, supply exceeding demand, or reduction in money supply, among other factors. Zambia had the highest inflation rate of 200.37, which could be caused by a number of factors, including a rise in the money supply and a demand that exceeds supply. Within the region, the service sector's GDP share (SER) ranges from a minimum of 22.13 to a maximum of 67.65. As a percentage of GDP, the service sector's mean value is 47.47, varying by 10.10 from the mean. The net official development assistance received as a percentage of GNI is used in this analysis as

a proxy for (AID). The SSA region's mean value is 6.78, with a deviation of 8.19 from the mean for the member countries. The highest and lowest reported values are 77.87 and 0, respectively. Within the SSA region, the mean value of real per capita GDP (YP) is 2690.47 US dollars, with an average deviation of 3034.46 from the mean. Within the region, the highest and lowest recorded amounts are 15906.5 and 345.64 US dollars, respectively. The Control of Corruption measure has a mean of −0.54 and a standard deviation of 0.65. The values are 1.03 at the highest and −1.83 at the minimum, respectively. A low control of corruption score indicates that the region is not doing well in controlling corruption, whereas a high score indicates that the region is performing well. The mean score of −0.54 indicates that in general the region is not doing well in the fight against corruption.

THE SHADOW ECONOMY, MOBILE PHONE PENETRATION AND TAX REVENUE

The system GMM results for the effect of mobile phone penetration and the shadow economy on tax collection are displayed in table 3. In particular, Model 1 does not include mobile phone penetration and instead shows results for the effect of shadow economy on tax revenue with other control variables. Excluding shadow economy, Model 2 displays the effect of mobile phone penetration on tax revenue. The outcomes of Models 1 and 2 demonstrate that the lagged value of tax revenue is significant at the 10 percent and 1 percent alpha levels, respectively. This confirms that the tax revenue for the current period is influenced by that of the preceding period, necessitating the specification of a dynamic model. At the 10 percent alpha level, the primary variable of interest, the shadow economy, was shown to be statistically significant and negatively correlated as depicted in Model 1. Therefore, in the sub-Saharan Africa region, a percentage rise in the shadow economy will result in a 0.18 percent drop in tax revenue, all other things being equal. This outcome is in line with the research of Nnyanzi, Babyenda, and Bbale (2016) and Mawejje and Munyambonera (2016), who similarly discovered a negative correlation between tax revenue and the informal sector. This makes sense intuitively since the informal sector includes all activities not reported to tax authorities with the express purpose of evading payment of income taxes arising from legal or illegal activities, and that do not adhere to any laws. Because the informal sector's operations are not subject to legal regulation, it evades and avoids paying taxes, which

TABLE 3 Effects of the Shadow Economy and Mobile Phone Penetration on Tax Revenue

Variable	Model 1	Model 2
Tax Revenue (T/Y)−1	0.4353*	0.7611***
	(0.2434)	(0.1059)
Shadow Economy (SHADOW)	−0.1763*	
	(0.0966)	
Mobile Phone Penetration (MPP)		0.01922**
		(0.0090)
Trade Openness (TOT)	0.0364*	0.0208**
	(0.0197)	(0.0099)
Agriculture Sector (AGRIC)	−0.3127***	−0.0927**
	(0.1248)	(0.0457)
Inflation (INF)	0.0833	0.0354
	(0.1298)	(0.0990)
Service Sector (SER)	0.0144	0.0201
	(0.0721)	(0.0233)
Aid (AID)	−0.0932	−0.0414
	(0.0978)	(0.0325)
Log of GDP Per Capita (Log YP)	−4.9506***	−2.0318***
	(1.9009)	(0.7583)
Control of Corruption (COC)	2.2566**	0.7737**
	(1.0428)	(0.3890)
Constant	54.4205***	16.6587***
	(18.5783)	(6.5947)
Diagnostics		
F Stat	170.17	827.69
Prob > F	0.000	0.000
AR (1)	0.024	0.013
AR (2)	0.690	0.697
Hansen test	0.155	0.232
Number of Obs.	260	260

NOTE Robust standard errors are in parentheses. *$p<$ 0.1, **$p<$ 0.05, and ***$p<$ 0.01 indicates significance at 10%, 5% and 1% levels, respectively.

lowers tax revenue. In addition, the informal sector is one of the difficult sectors to tax because it is difficult to track its activities, which reduces tax revenue.

Model 2 indicates that the mobile phone penetration variable, another important variable of interest, was estimated to be positive and statistically significant at 5 percent. Therefore, in sub-Saharan Africa, a unit increase in the prevalence of mobile phones will result in approximately a 0.02 percent increase in tax revenue, all other things being equal. This outcome is in line with research by Effiong and Nwanagu (2020) and

Koyuncu, Yilmaz, and Ünver (2016), which demonstrated how increased mobile phone adoption raises overall sustainable tax revenue. This makes sense intuitively as mobile phone penetration is growing and it is also a means of mobilizing tax revenue, which will raise the total amount of tax revenue in sub-Saharan Africa. Additionally, there are various taxes levied on using mobile phones, and the amount of tax revenue rises along with the level of mobile saturation.

EFFECT OF OTHER CONTROL VARIABLES ON TAX REVENUE

In Models 1 and 2, trade openness was found to be positive and significant at the 10 percent and 5 percent alpha levels, respectively. Ceteris paribus, for Models 1 and 2, a rise in trade openness is linked to increases in tax revenue in SSA of about 0.04 and 0.02 percent, respectively. This outcome, as anticipated, agrees with the research by Nnyanzi, Babyenda, and Bbale (2016), and Terefe and Teera (2018). The positive coefficient for trade openness suggests that administrative complexity is low for import and export taxes, making them simple to collect and administer within the region. Sub-Saharan African nations, therefore, engage in open economies with one another, which has the knock-on effect of raising tax revenue from these trade interactions.

Moreover, agriculture was found to be significant and negative for Models 1 and 2, respectively, at the 1 percent and 5 percent alpha levels. Other things being equal, a percentage increase in the share of agriculture to GDP will result in approximately a 0.09 percent drop in tax revenue in the sub-Saharan Africa region and about a 0.31 percent decrease in tax revenue in Model 1. This conclusion is in conflict with the findings of Terefe and Teera (2018), but it is consistent with the investigations of Addison and Levin (2012), and Coulibaly, Gandhi, and Senbet (2019). Agriculture's negative coefficient suggests that this industry is sometimes referred to as 'the hardest sector to tax', owing to its prevalence of large-scale informal players and underground economies driven by subsistence farmers. Fiscal authorities are under pressure from inefficient tax administration, which increases the likelihood that enterprises would evade paying taxes and so lowers tax collection.

For both Models 1 and 2, the log of GDP per capita was likewise found to be significant and negative at the 1 percent alpha level. It shows that, in the sub-Saharan Africa region, a dollar rise in GDP per capita is linked, all other things being equal, to about a 0.05 and 0.02 percent decrease in tax revenue in Models 1 and 2, respectively. This conclusion

contradicts the findings of Ayenew (2016) and Besley and Persson (2013), but it is consistent with the work by Nnyanzi, Babyenda, and Bbale (2016). In theory, higher GDP per capita indicates development and increased taxability. But over the years, although most sub-Saharan African countries are growing and developing, they have been characterized by difficult-to-tax informal sectors and subpar tax administration systems, consequently causing the SSA region's tax revenue to decline.

With a coefficient of about 2.26 and 0.77 for Models 1 and 2, respectively, and at a significance level of 5 percent for all models, the control of corruption has a positive effect on tax revenue. This suggests that higher tax revenues in the SSA region follow improvements in the fight against corruption. This outcome agrees with Nnyanzi, Babyenda, and Bbale (2016)'s findings. The region's tax revenue will rise when measures to combat corruption are implemented, such as states using collected funds for their intended purposes, refraining from embezzlement, and punishing corrupt offenders. This is indicated by the positive coefficient of control of corruption.

The results of the Hansen over-identification test, which are also approximately 0.16 and 0.23 as well as AR (2), which are approximately 0.69 and 0.70 in Models 1 and 2, are not significant. The model is therefore valid and consistent.

MODERATING ROLE OF MOBILE PHONE PENETRATION

The study now proceeds by analysing the moderating role mobile phone penetration is playing in the shadow economy–tax revenue nexus in SSA. Finding the moderating effect of mobile phone penetration gives

$$\frac{\delta(T/Y)_{i,t}}{\delta SHADOW_{i,t}} = \beta_2 + \beta_5 MPP_{i,t}$$

$$\frac{\delta(T/Y)_{i,t}}{\delta SHADOW_{i,t}} = \beta_2 + \beta_5 \overline{MPP}.$$

From Model 3 in table 4, we get

$$\frac{\delta(T/Y)_{i,t}}{\delta SHADOW_{i,t}} = 0.2427 + (-0.0029)(\overline{MPP}).$$

Placing the mean value of mobile phone penetration of 78.8562 (from table 2) gives

$$\frac{\delta(T/Y)_{i,t}}{\delta SHADOW_{i,t}} = 0.2427 + (-0.0029)(78.8562)$$

$$= 0.2427 - 0.22868298$$

$$= 0.0140.$$

On the other hand,

$$\frac{\delta(T/Y)_{i,t}}{\delta MPP_{i,t}} = \beta_3 + \beta_5 SHADOW_{i,t}$$

$$\frac{\delta(T/Y)_{i,t}}{\delta MPP_{i,t}} = \beta_3 + \beta_5 \overline{SHADOW}$$

Placing the mean value of shadow economy of 33.5458 (from table 2) gives

$$\frac{\delta(T/Y)_{i,t}}{\delta MPP_{i,t}} = 0.1084 + (-0.0029)(33.5458)$$

$$= 0.1084 - 0.0973$$

$$= 0.0111.$$

The earlier result (0.0140) indicates that on average, with mobile phone penetration, a percentage increase in the informal sector would increase tax revenue by about 0.01 percent. This implies that with mobile phone penetration the effect of the informal sector on tax revenue changes from negative (−0.1763 as shown in Model 1) to positive. On the other hand, the estimated result of 0.0111 indicates that given the level of the shadow economy, an increase in mobile phone penetration increases tax revenue. These results show that mobile phone penetration, once increased, has a positive and significant impact on tax revenue as a variable on its own and even in the presence of the shadow economy. It also moderates the effect of the shadow economy on tax revenue, changing it from negative, as shown in Model 1, to positive. In other words, mobile phone penetration positively influences the informal sector to increase tax revenue. Hence, for the SSA region to achieve much in terms of the shadow economy impacting tax revenue positively, mobile phone penetration in the informal sector must be given greater attention.

Since the value of the AR (2) from the model is about 0.72, we fail to reject the null hypothesis that there is no second-order serial correlation,

TABLE 4 How Mobile Phone Penetration Moderates the Effect of Shadow Economy on Tax Revenue

Variable	Model 3
Tax Revenue $(T/Y)_{-1}$	0.8659***
	(0.0848)
Shadow Economy (SHADOW)	0.2427*
	(0.1396)
Mobile Phone Penetration (MPP)	0.1084**
	(0.0533)
Trade Openness (TOT)	0.0276*
	(0.0153)
Agriculture Sector (AGRIC)	−0.0017
	(0.0345)
Inflation (INF)	−0.0071**
	(0.0028)
Service Sector (SER)	0.0108
	(0.0212)
Aid (AID)	−0.0395*
	(0.0217)
Log of GDP Per Capita (Log YP)	−0.5935
	(0.4132)
Control of Corruption (COC)	−0.1703
	(0.3519)
SHADOW*MPP	−0.0029*
	(0.0015976)
Constant	−4.9806
	(6.5695)
Diagnostics	
F Stat	1798.07
Prob > F	0.000
AR (1)	0.017
AR (2)	0.721
Hansen test	0.628
Number of Obs.	260

NOTE Robust standard errors are in parenthesis. *$p<$ 0.1, **$p<$ 0.05, and ***$p<$ 0.01 indicates significance at 10%, 5% and 1% levels, respectively.

leading to the conclusion that the model does not suffer from serial correlation. The value of the Hansen over-identification test is about 0.63, therefore we fail to reject the null hypothesis of no over-identification restrictions. From the post estimations, it can be concluded that the results are consistent and valid.

Conclusions and Recommendations

The Sustainable Development Goals emphasize the need to strengthen internal resource mobilization and enhance tax collection in relation to SDG 17's first target. However, because of the sizeable informal sector in each of the region's economies, sub-Saharan Africa is losing a substantial portion of its revenue. This study takes a look at how tax revenue in 26 SSA nations is affected by the shadow economy and the widespread use of mobile phones, in particular, the impact that the shadow economy has on tax revenue and the moderating function that the widespread use of mobile phones plays in the relationship between the shadow economy and tax revenue. The study analysed panel data on 26 African countries from 2009 to 2019 using the GMM methodology. The study's conclusions showed that in the SSA region, the shadow economy had a detrimental impact on tax revenue. As a result, tax revenue decreases as the size of the informal sector grows. Since the informal sector makes up a larger percentage of most sectors in emerging economies and is also one of the hardest sectors to tax, it cannot be disregarded when it comes to revenue collection. Additionally, the use of mobile phones increased tax collections. Therefore, higher rates of mobile phone adoption translate into higher tax receipts. Finally, in SSA, the effect of the shadow economy on tax income is positively moderated by the proliferation of mobile phones. This outcome is not unexpected because there has been an increase in the informal sector's usage of mobile phones over time, and some participants in the informal sector utilize them to conduct business and make payments of taxes.

The study suggests that to help the informal sector feel acknowledged and encourage voluntary compliance with regard to tax payment, governments should strengthen the special agencies that are tasked with identifying, registering, training, and advising all operators in this sector on how to market their goods, keep accurate records, and obtain affordable funding, among other things. Governments in the SSA region also need to update their tax administration systems and construct and enhance infrastructure linked to emerging mobile technology. To fully benefit from mobile phone usage, they must, however, also implement best practices in tax regulations. Lastly, the study suggests that governments and telecommunications companies implement some kind of consumer education in the informal sector to raise awareness of the advantages of using mobile phones for business transactions and the simplicity of paying taxes using a mobile device.

The study was based on 26 out of 46 countries in sub-Saharan Africa. The choice of the 26 countries was purely based on the availability of data for those countries. The results could have been more representative if all 46 sub-Saharan African countries had been used. However, the use of 26 out of 46 countries does not in any way render the findings and conclusions invalid.

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Appendix A: List of Selected Sub-Saharan African Countries

Angola, Botswana, Burkina Faso, Cabo Verde, Cameroon, Central African Republic, Congo Republic, Côte d'Ivoire, Equatorial Guinea, Ethiopia, Gabon, Ghana, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritius, Mozambique, Namibia, South Africa, Tanzania, Togo, Zambia and Zimbabwe

Appendix B: Pairwise Correlation Matrix

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(1) T/Y	1									
(2) SHADOW	−0.459*	1								
(3) MPP	0.433*	−0.201*	1							
(4) TOT	0.406*	−0.176*	0.158*	1						
(5) AGRIC	−0.412*	0.145*	−0.524*	−0.375*	1					
(6) INF	−0.0003	0.063	−0.064	−0.057	−0.020	1				
(7) SER	0.526*	−0.309*	0.292*	0.129*	−0.373*	0.114*	1			
(8) AID	−0.158	0.149*	−0.431*	0.072	0.598*	−0.010	−0.041	1		
(9) Log YP	0.244*	−0.240*	0.613*	0.321*	−0.803*	−0.084	0.205*	−0.579*	1	
(10) COC	0.606*	−0.515*	0.505*	0.215*	−0.251*	0.010	0.518*	−0.067	0.258*	1

Ali digitalizacija povečuje gospodarsko rast? Dokazi iz držav SADC

Simbarashe Mhaka in Lovemore Taonezvi

Četrta industrijska revolucija je znatno prispevala k rastočim globalnim tehnološkim transferjem, ki krepijo produktivnost, zaposlenost in življenjsko raven. Izbruh pandemije covida-19 je nedvomno povzročil motnje v življenju v globalnem svetu; je pa po drugi strani okrepil tehnološko preobrazbo z nenadnim porastom rabe digitalne tehnologije. Pričakovati je, da bosta razvoj in razpršitev digitalizacije poganjala gospodarsko rast na poti k Agendi trajnostnega razvoja 2030. Pričujoča raziskava z uporabo modela fiksnih učinkov proučuje učinke digitalizacije na primeru 14 držav Južnoafriške razvojne skupnosti (SADC) med letoma 2000 in 2029. Rezultati kažejo, da vsi uporabljeni pokazatelji digitalizacije kažejo na pozitiven učinek na gospodarsko rast. Spremembe posameznikove rabe informacijsko-komunikacijskih tehnologij, fiksnih širokopasovnih naročnin in naročnin na mobilno telefonijo za odstotek vodijo k 0,17-, 0,11- in 0,12-odstotnemu povišanju BDP na prebivalca. Zato lahko rečemo, da raba in dostop do digitalnih tehnologij stimulirata gospodarsko rast v regiji SADC. Javne politike bi morale spodbujati zasebne investicije v tehnološko infrastrukturo ter liberalizacijo trga telekomunikacij in inovacij. To pospešuje digitalizacijo in posledično vodi k višji gospodarski rasti ter razvoju v regiji SADC.

Ključne besede: digitalizacija, gospodarska rast, model fiksnih učinkov, SADC
Klasifikacija JEL: O33, O1, O47, R11, C5
Managing Global Transitions 22 (1): 201–229

Raziskovalna sinteza o prookoljskem vedenju v izobraževanju: pristop rudarjenja besedil

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Izpeljanih je bilo veliko znanstvenih raziskav o izobraževanju, ki naj spodbuja človekovo vedenje v prid trajnostnemu razvoju. Kljub temu pa zasledimo le omejeno število preglednih člankov, ki povzemajo ključne ugotovitve tega zelo pomembnega področja. Pričujoča raziskava uporablja bibliometrični pristop in pristop rudarjenja besedil, da bi kot prva proučila prookoljsko vedenje v izobraževalni literaturi. S

pomočjo bibliometrične analize osvetlimo različna omrežja v sodobni literaturi. Ta omrežja pokažejo vpliv družbene blaginje na prookoljsko vedenje, pri čemer želijo dvigniti okoljsko zavest, poudarjajoč vrednost človekove prirojene okoljske ozaveščenosti. Z uporabo posteriorne verjetnosti in latentne Dirichletove alokacije (LDA) rudarjenje besedil identificira 12 različnih tematskih modelov prek ocene logaritmične verjetnosti, pri čemer obravnava številne teme, povezane z okoljskim izobraževanjem in vedenjem, kot so, kako obiskovalci in trajnostnost v okoljskem izobraževanju učinkujejo na prookoljsko vedenje, kako šole in univerze izobražujejo za trajnostnost, kako je upoštevana teorija načrtovanega vedenja, kako sta povezana izobrazba in prookoljsko vedenje ter kako se skozi različne kanale raziskuje trajnostno izobraževanje.

Ključne besede: prookoljsko vedenje, izobraževanje, rudarjenje besedil, bibliometrična analiza
Klasifikacija JEL: I20, I24, I25
Managing Global Transitions 22 (1): 231–252

Učinek volatilnosti menjalnih tečajev na trgovino med Južno Afriko in njenima glavnima trgovinskima partnericama: sveži vpogledi s pomočjo modela ARDL in kvantilnega ARDL modela

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Na primeru 22 uvoznih in izvoznih industrij proučujemo učinek volatilnosti menjalnih tečajev na uvoz in izvoz med Južno Afriko ter njenima glavnima trgovinskima partnericama, Združenimi državami Amerike in Kitajsko. Raziskava uporabi kvantilni ARDL model in analizira četrtletne podatke iz obdobja od 1994Q1 do 2022Q4. Naše izhodiščne ARDL ocene kažejo, da volatilnost valute večini trgovinskih sektorjev obeh držav ne škoduje znatno. Pravzaprav veliko industrij izkazuje neznatno ali pozitivno korelacijo z volatilnostjo valute. Ob ponovni oceni regresij z uporabo kvantilnega ARDL modela pa odkrijemo obstoj razmerij »skrite kointegracije« nad kvantili povprečja in mediane, ki jih tradicionalni ARDL modeli ne zaznajo. Z upoštevanjem teh lokacijskih asimetrij zaključimo, da volatilnost menjalnih tečajev bolj koristi trgovinski aktivnosti s Kitajsko kot tisti z Združenimi državami Amerike. Na splošno naše ugotovitve implicirajo, da monetarnim oblastem morda ne bi bilo treba posegati v valutne trge, da bi s tem stimulirale trgovino z glavnimi trgovinskimi partnerji, saj kaže, da so podjetja pripravljena soočiti se z valutnimi tveganji, povezanimi z volatilnostjo menjalnih tečajev južnoafriške valute.

Ključne besede: volatilnost menjalnih tečajev, izvoz, uvoz, trgovina, ARDL model, kvantilni ARDL model, Južna Afrika, Združene države Amerike, Kitajska
Klasifikacija JEL: F31, F10
Managing Global Transitions 22 (1): 253–277

Siva ekonomija, prodor mobilne telefonije in davčni prihodki v Podsaharski Afriki

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Pričujoča raziskava proučuje učinke sive ekonomije na davčne prihodke in ublažitveni učinek prodora mobilne telefonije v Podsaharski Afriki (PSA). Z uporabo podatkov iz 26 držav PSA, ki zajemajo obdobje 11 let, in pristopa splošne metode trenutkov (GMM) raziskava razkrije, da ima siva ekonomija pomemben pozitivni učinek na davčne prihodke. Poudarjamo, da igra prodor mobilne telefonije ublažitveno vlogo v odnosu siva ekonomija – davčni prihodki v PSA. Vlade v regiji PSA bi morale posodobiti svoje sisteme davčne administracije, vzpostaviti in okrepiti infrastrukturo, povezano s porajajočo se mobilno tehnologijo, ter vpeljati najboljše prakse davčne regulacije. Kot zadnje pa bi morale vlade in telekomunikacijska podjetja implementirati izobraževanje potrošnikov v neformalnem sektorju z namenom ozaveščanja o prednostih uporabe mobilne telefonije za poslovne transakcije ter enostavnosti plačevanja davkov z uporabo mobilnih naprav.

Ključne besede: siva ekonomija, prodor mobilne telefonije, davčni prihodki, Podsaharska Afrika
Klasifikacija JEL: E26, H25, H27, H30
Managing Global Transitions 22 (1): 279–308