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INSURANCE AND ECONOMIC GROWTH IN SUB-SAHARAN AFRICA: INSTITUTIONAL QUALITY THRESHOLD EFFECT

ABSTRACT: *This paper examines the influence of institutional quality institutional quality on the relationship between the extent of both non-life insurance and life insurance and economic growth in sub-Saharan Africa. The paper employs a dynamic threshold model for the analysis of a panel of data consisting of 34 countries over the period 1990 to 2017. The findings of the research reveal that non-life insurance exerts an significant effect on economic growth when the level of institutional quality institutional quality is high, while the association becomes insignificant when the level of institutional quality institutional quality is low. In contrast, the effect of life insurance on economic growth is insignificant at both at high and low levels of institutional quality. The paper also considered the effect of the different types of insurance in both low- and middle-income countries in the sub-Saharan region. Overall, the paper emphasises the important role of non-life insurance in enhancing economic growth, and the dependence of this effect on the level of institutional quality in a country.*

KEY WORDS: *insurance development; institutional quality; threshold regression; economic growth*

JEL CLASSIFICATION: G10, O1, O2, O33

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1. INTRODUCTION

The contribution of insurance development to economic growth economic growth has been thoroughly examined in the literature across economies. Studies (e.g., Akinlo & Apanisile, 2014; Beck & Webb, 2003; Guochen & Wei, 2012; Haiss & Sümegi, 2008; Kugler & Ofoghi, 2005; Outreville, 2011) have documented the importance of insurance to economic growth. Past studies that investigated the connection between insurance and economic growth documented a positive effect of insurance on economic growth (e.g. Hou et al., 2012; Lee, Lee, & Chiu, 2013; Yinusa & Akinlo, 2013).

Some studies have begun taking into account mediating variables in the relationship between financial development financial development and economic growth based on theoretical results that advocated the joint consideration of the effects of financial development with other sectors that influence economic growth. For instance, the mediating role of the real sector between financial development and economic growth was examined by Ductor and Grechyna (2015). The level of human capital and per capita income were taken into account by Ibrahim and Alagidede (2018) as intermediary variables between financial development and economic growth. Another body of literature advocates for the consideration of institutional quality institutional quality in the relationship between financial development and economic growth. Some of these studies have attempted to incorporate financial development and institutional quality into the Solow growth model (e.g., Hausman et al., 2005; Nelson & Sampat, 2001; North, 1990; Pagano, 1993). The studies advocating for institutional quality as an intermediary variable between financial development and economic growth claim that the impact of financial development on economic growth might depend on the level of institutional quality. The argument is that when institutional quality is weak, the financial system cannot operate efficiently and the impact of financial development on economic growth will be affected. In contrast, a strong institutional quality enhances the efficiency of financial institutions by promoting efficient allocation of financial resources, which in turn enhances economic growth.

This line of reasoning implies that using institutional quality as an intervening variable between insurance and economic growth can alter the relationship between the two variables. That is, when insurance development is rooted in a

sound institutional framework, it might produce a greater impact on growth. For instance, there might be an increase in insurance development as captured by insurance premiums, but it may not lead to economic growth because of corruption and political interference in the sector. Likewise, the prevalence of information asymmetries, contract default and high-risk-taking behaviours will also limit the effect of insurance on economic growth. This implies that the intervention of strong institutional quality can result in a positive connection between insurance and economic growth. However, in the case of weak institutional quality, the reverse might be the case. Therefore, if institutional quality can alter the relationship between insurance and economic growth, could there be a threshold level of institutional quality above which insurance will promote growth and below which insurance will harm economic growth?

Earlier studies indicate that many concentrated on the impact of insurance on economic growth (e.g., Balcilar et al., 2018; Lee, Lee & Chiu, 2013; Outrevielle, 1996; Pradhan et al., 2015; Soo, 1996; Webb et al., 2002) while fewer studies focused on the relationship between institutions and insurance development (e.g., Beck & Webb, 2003; Lee, Chiu and Chang 2013; Ward & Zurbruegg, 2002). On the threshold effect of institutional quality on the insurance–economic growth nexus, Lee et al. (2016) is the only known study to have investigated this relationship but the study considered life insurance (LI) only. In sub-Saharan Africa (SSA), studies that examined the direct effect of insurance on economic growth or the effect of institutional quality on insurance development are rare. To date, there is no known study investigating the mediating impact of institutional quality between insurance and economic growth using threshold regression. This is the gap this study intends to fill.

Thus, the main focus of this study is to examine the threshold effect of institutional quality on the relationship between insurance development and economic growth in SSA. This study is different from earlier studies in the following ways. First, as earlier stated, this study will be the first to use institutional quality as an intervention variable between insurance and economic growth in the SSA region and among the income groups in the region. Second, this study considers both LI and non-life insurance (NLI) as well as total insurance (LI and NLI), unlike other studies, which considered only LI. Third, the study will be the first to identify the threshold point of institutional quality

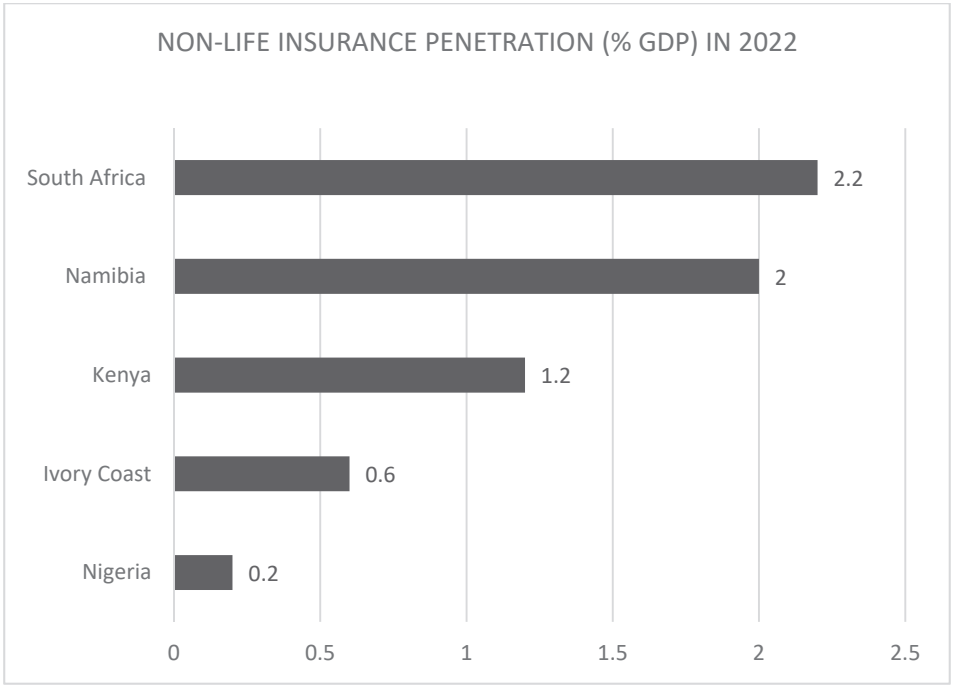
below and above which insurance will have a different effect on economic growth, thus enabling policymakers to make the decision necessary to raise the level of institutional quality to meet the threshold point. The remaining part of the study is arranged as follows. The second section offers an overview of insurance in SSA. The third focuses on the literature review. The fourth presents the methodology. The fifth discusses the data and the data source. The sixth focuses on the empirical analysis. The seventh discusses the findings. The eighth consists of the conclusion and implication of the findings.

2. OVERVIEW OF INSURANCE IN SSA

Many nations on the SSA continent are still building their insurance industries. Even though SSA is home to approximately 18% of the world's population, the region's insurance market accounts for less than 3% of all insured catastrophic losses globally. However, despite the low levels of insurance uptake, large multinational brokers, insurers and reinsurers continue to show greater interest and concentration in this area. In SSA, insurance premiums were worth a little over 50 billion USD in 2020.

According to Malabo (2023), in SSA, the level of insurance penetration is directly correlated with the level of a nation's development and economic growth. The largest and most developed insurance market in SSA is found in South Africa, which also accounts for a sizable portion of insurance premiums written on the African continent. The NLI contributions to GDP in five selected SSA nations in 2022 are shown in Figure 1. The five selected countries are those that have data regarding NLI and LI in 2022. South Africa had the highest NLI insurance premium contribution to GDP. NLI accounted for around 2.2% of South Africa's overall GDP in 2022. Regarding NLI's contribution to GDP, Namibia (2%), Kenya (1.2.%) and Coite d'Ivoire (0.6%) are ranked second, third, and fourth, respectively. This suggests that South Africa had the highest level of NLI development among the selected five SSA countries in 2022. The country that had the least contribution to GDP in terms of NLI is Nigeria. NLI constituted about 0.2 per cent of GDP in Nigeria in 2022.

Figure 1: Non-life insurance penetration in 2022

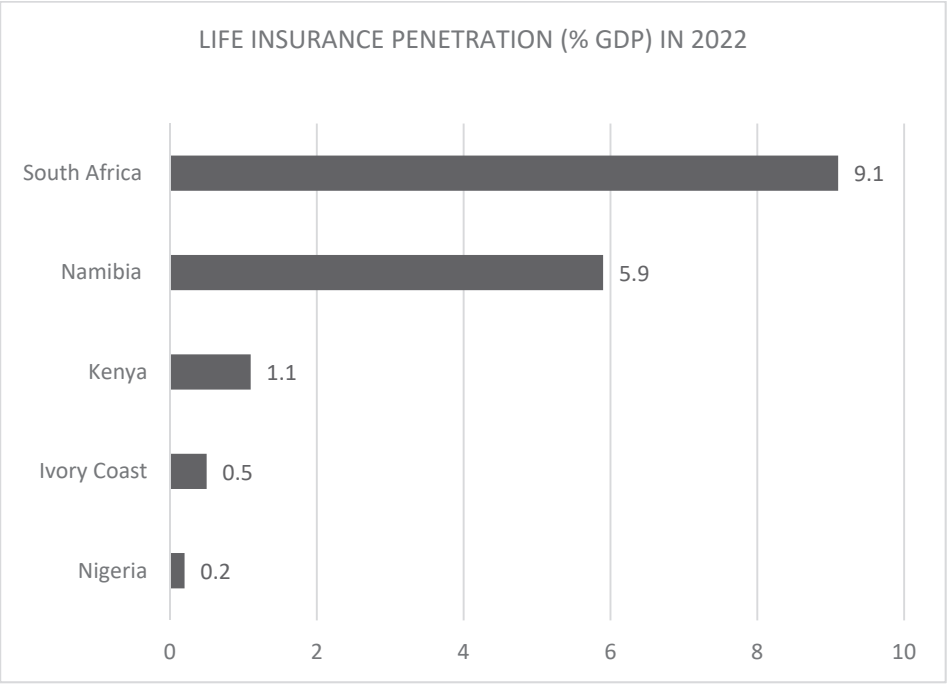


Source: Author's computation based on Swiss Re Institute Data 2023

The contribution of LI premium volume to GDP of these five SSA nations in 2022 is shown in Figure 2, according to which LI accounted for around 9.1% of South Africa's total GDP, the highest percentage among the five SSA countries. This shows that compared to other SSA nations, South Africa has a very high penetration of LI. According to KPMG (2015), South Africa is the market leader for LI, accounting for 88.6% of the continent of Africa's LI premiums in 2013. In 2022, Namibia ranked second to South Africa with an insurance premium volume contribution to GDP of 5.9%. The GDP share of LI in Kenya was approximately 1.2%, ranking third highest among the five countries in SSA. Unlike the situation in the top three nations (South Africa, Namibia and Kenya), LI makes up only a very small percentage of the GDP in Cote d'Ivoire and Nigeria. Figure 2 demonstrates that the LI insurance premium volume contributions to the GDP in Cote d'Ivoire and Nigeria are alarmingly low. They represent less than 1% of the total GDP. This suggests that the LI industry is weak in some of the SSA countries.

Comparing Figures 1 and 2, it can be seen that the markets for LI are bigger than for NLI in South Africa and Namibia, with their LI markets being sizable. According to KPMG (2015), the insurance penetration rate in South Africa is one the highest in the world and is far higher than one might anticipate given its per-capita GDP. The financial system in South Africa is quite advanced, which is frequently a key factor in the expansion of the insurance sector. In Kenya and Cote d'Ivoire, the percentage contribution of NLI to GDP is slightly bigger than that of LI, while the contributions of NLI and LI to GDP in Nigeria are the same.

Figure 2: Life insurance penetration in 2022



Source: Author's computation based on Swiss Re Institute Data 2023

The vast differences in SSA's economies are reflected in the region's various levels of insurance market maturity. The most established insurance market in the area is found in South Africa, which also provides reinsurance services to several of its nearby countries. In contrast, frameworks and institutions are far more recent in other nations. The insurance industry is thriving and expanding when strong regulatory frameworks are in place, but there is a substantial reliance on

facultative and treaty reinsurance from outside Africa. This presents unique difficulties.

3. LITERATURE REVIEW

In this section, a considerable number of previous studies that examined the link between insurance development and economic growth are reviewed. The previous empirical studies can be classified into four strands. The first strand consists of studies that examine insurance and economic growth. The second comprises studies that investigate the connection between institutions and insurance development. The third strand is made up of studies that focus on the causality between insurance and economic growth. The fourth strand consists of recent studies that consider intervening variables between insurance and economic growth. In the first strand, for instance, Outreville (1990) showed that the premium of property-liability insurance was positively related to economic growth in a sample of 55 developing countries. Beenstock et al. (1998), in a cross-sectional analysis covering 12 countries and spanning 1970–1981, found that property liability insurance premiums promote economic growth. Webb et al. (2005) concentrated on the effect of both banking and insurance on economic growth in a cross-country analysis that consisted of 55 countries. The study established that both banking and insurance contributed to economic growth. Haiss and Sumeji (2008) used panel data from 29 countries in Europe for the period 1992–2005 to analyse how insurance investment and premiums impact GDP growth. They found that LI contributed to economic growth in 15 countries. Studying how LI influences economic growth, Chen et al. (2012) found that this form of insurance enhanced economic growth. However, the impact of LI on low-income countries (LICs) is greater than on middle-income countries (MICs). Akinlo and Apanisile (2014) used panel data from 30 SSA countries to investigate the effect of insurance on economic growth. They found that insurance significantly impacted economic growth. Kozarević et al. (2013) examined the insurance market transition process in ten South-Eastern Europe (SEE) post-communist countries. They focused on determining the connection between insurance market development and the European Union (EU) integration process as well as overall economic development. Using Spearman coefficients, their study showed a very strong correlation between the transition of insurance markets and the level of economic development as well as between the transition

of insurance markets and the level of EU integration. Also, the study indicated that insurance penetration, insurance density and shares of life insurance tend to depend on the level of economic development, while aspects such as legal and institutional frameworks as well as solvency standards tend to depend more on the level of EU integration.

Regarding the second strand of literature, the studies that focused on institutions and insurance, Sepehrdoust and Ebrahimnasab (2015) used a sample of developing countries to analyse how LI was connected to economic political, and regulatory factors during the 1999–2011 period. They found that political measures such as political stability and democracy enhance LI. Furthermore, governance of law and quality of rules as regulatory measures and economic measures impact LI positively. In a similar study, Ward and Zurbruegg (2002) investigated the association between legal and political variables and LI in Asia and OECD countries using dynamic GMM estimations. The study found, in both Asia and the OECD region, that civil rights and political stability cause an increase in the demand for LI. The study by Ćurak et al. (2013) differs from earlier studies as they used primary data to investigate the social and demographic factors that determine LI in Croatia. The survey data used in the study were obtained from 95 respondents and they found that factors such as age, education and employment enhance the demand for LI in Croatia. However, the study found that gender, marital status and family size fail to significantly impact LI. Lee, Chiu, and Chang (2013) focused on the relationship between country risks and income elasticity demand for insurance. The study employed panel smooth transition regression for the analysis. In the full sample, the study found that lower country risks are associated with low-income elasticity demand for insurance. The analysis of income groups shows a similar result. Beck and Webb (2003) adopted panel data consisting of 68 nations from 1961 to 2000 in determining variations in LI consumption. The study found that inflation, income per capita and other economic variables are the major determinants of LI. Religious and institutional measures likewise are determinants of the use of LI. But other factors, such as education, life expectancy and the young dependency ratio, have a marginal association with LI consumption.

In the third strand, according to Lee, Lee and Chiu (2013), only a few studies focused on causality between insurance and economic growth as most focused on

insurance development and economic growth. Ward and Zurbruegg (2000) is among the few studies that examine this causality. They used a bivariate VAR method to determine the causal relationship between insurance and economic growth in nine OECD countries during the period 1961–1996. The study found varying results among the countries. For instance, they found that insurance leads to economic growth in Canada and Japan, while they found a bidirectional relationship in Italy. However, they found no evidence of a causal relationship in other countries. Kugler and Ofoghi (2005) were interested in the causal relationship between LI and economic growth in the U.K. Using varieties of LI premiums in the study, they found causality running from insurance to GDP in six cases, a single case of long-run causality from GDP to insurance was reported, and long-run bidirectional causality for the other two cases. Vadlamannati (2008) investigated the short-run causality between insurance and economic growth in India. Using the vector error correction model (VECM), the study found the existence of two-way causality between LI and economic growth. Adams et al. (2009) found that economic growth in Sweden has a one-way relationship from insurance to economic growth without a reverse effect. In their study consisting of 41 countries, Lee, Lee and Chiu (2013) found both short-run and long-run a bidirectional causality between insurance and economic growth. Balcilar et al. 2018 used a bootstrap panel causality test to confirm a feedback hypothesis between insurance and economic growth.

The last strand of studies consists of those that considered the intermediary between insurance and economic growth. These include Lee et al. (2016), who use an innovative dynamic panel threshold model to determine how institutional environments enhance the impact of insurance on economic growth. It was established that insurance is detrimental to economic growth in relatively weak institutional environments but above a certain level of institutional threshold, the negative significant relationship became insignificant. Lee et al. (2017) considered globalisation as an intermediary between insurance and economic growth for a pooled sample of 38 countries. Their study found that globalisation impacts economic growth positively at lower insurance activities, while the result was reversed at a higher level of insurance activities.

4. METHODOLOGY

4.1 A Dynamic Panel Threshold Model

A panel threshold estimator that is only appropriate for static and balanced panels was proposed by Hansen (1999). However, some macroeconomic factors, such as GDP growth, are incredibly persistent, making the use of a dynamic panel framework necessary. As a result, Bick (2010) and Kremer et al. (2013) developed a dynamic panel threshold for a non-linearity estimator by extending the threshold models of Hansen (1999, 2000), and Caner and Hansen (2004). The key issue is to adapt the panel threshold model in such a way that the country-specific fixed effects are eliminated without altering the distributional assumptions of both models. Fixed effects cause serial correlation when cross-section specific error terms are transformed and first-differencing, which is the standard fixed-effects removal in dynamic panels, is not possible. Hence, this is tackled by applying Arellano and Bover's (1995) forward orthogonal deviations transformation, which eliminates fixed effects while avoiding serial correlation in the converted errors. As a result, the forward orthogonal deviation transformation ensures that the threshold model's original distribution theory, as applied to static panels in Hansen (1999), is valid in a dynamic context as well.

4.2 Model Specification

This study adopts the dynamic panel threshold proposed by Kremer et al. (2013) in determining the threshold effect of institutional quality on the insurance–growth nexus. This method is preferred because it accommodates unbalanced panel data, unlike Hansen (1999) and studies such as Aydin (2017), which were applied to a small panel sample of eight countries. We specify the model as

$$GDP_{it} = \mu_i + \delta_1(ISQ_{it} \le \gamma_{it}) + \beta_1 (INS)_{it}(ISQ_{it} \le \gamma_{it}) + \beta_2 (INS)_{it}(ISQ_{it} > \gamma_{it}) + \sigma_1 GDP_{it-1} + \sigma_2 X_{it} + \varepsilon_{it}, \quad (1)$$

where GDP_{it} denotes GDP per capita growth, *ISQ* is the institutional quality, *INS* signifies insurance development, which is the threshold variable, GDP_{it-1} is lagged GDP per capita and X_{it} stands for all the control variables included. *i* denotes countries, while *t* represents time. Differences in the regime intercept suggested by Bick (2010) are taken into consideration by Kremer et al. (2013) and

captured in δ_1. The regime intercepts are included on the assumption that their differences across the countries are the same except for individual-specific ones. This will take care of the problems of omitted variables and making them the regime-dependent exogenous regressor for a given threshold is easier. Bick (2010) stated that the inclusion of regime intercepts has some implications statistically and economically. The statistical implication has to do with the reduction in the biasedness of the omission of variables and easy identification of the biased effect by the inclusion of regime intercepts. The economic implication is that the policy effect of the variables concerned becomes relevant, which relates to statistical results. Therefore, in this study, we consider regime intercepts.

By following Kremer et al. (2013) in estimating threshold value (γ_{it}), the first stage involves running a reduced form specification by regressing the endogenous variable, i.e., GDP_{it-1}, on instruments. By using the predicted values of the reduced form regression in the first step to replace the endogenous variable, Equation (1) will now be estimated by least squares for a fixed threshold value, and the associated sum of squared residuals can be produced. A set of sum of squared residuals is obtained by repeating the same procedures for a subset of the threshold variable (ISQ_{it}). The threshold value (γ_{it}) estimate with the least sum of squared residuals is used in future estimations, such as slope coefficients for various regimes.

5. DATA AND DATA SOURCE

Panel data are used in this investigation. The full sample is made up of an unbalanced panel sample drawn from 34 SSA nations between 1990 and 2017. The availability of data affected the selection of the time frame for this investigation. In line with the World Bank's classification, income classes are also taken into account in this study. 18 nations fall into the low-income category, whereas 16 belong to the middle-income category. In this study, middle-income countries are made up of lower-middle-income and upper-middle-income countries. The panel sample for both the LICs and MICs is also unbalanced. Due to the fact that only one nation in SSA belongs to the upper-income group, it is not included.

5.1. The Dependent Variable and Control Variables

The dependent variable in this study is economic growth. It is measured by the real GDP per capita growth rate. Seven control variables that are considered in the literature as determinants of economic growth are included in the study. The first control variable is lagged GDP per capita growth. This is included because Arellano and Bond (1991) and Arellano and Bover (1995) suggested using the lags of dependent and explanatory variables as tools to get around the endogeneity issue. According to the literature, lagged GDP per capita growth might be either positive or negative. The second control variable is gross capital formation. Gross capital formation as a percentage of GDP is the investment in physical capital. A positive relationship is expected between gross capital formation and economic growth because investment in physical capital increases productivity and reduces the cost of production. The third control variable is government expenditure as a percentage of GDP, which captures the consumption expenditure of the government. According to Apergis and Poufinas (2020), government expenditure can have a positive or negative effect on economic growth. Trade openness is the fourth control variable and is defined as the total of exports and imports as percentage of GDP. Trade openness is expected to impact positively on economic growth although its impacts on economic growth in the literature are mixed. The fifth control variable is inflation. Inflation is the consumer price index and measures macroeconomic stability. Inflation is expected to harm economic growth because it creates uncertainty in the economy and hence discourages investment. The sixth control variable is population growth which is defined as the annual growth rate of the population. Population growth is expected to promote economic growth because it constitutes the labour force in the economy. The last control variable is domestic credit to the private sector (DCP), which is used to proxy financial development. It is the domestic credit made available to the private sector by financial institutions. Due to important functions performed by financial institutions in the economy, financial development is expected to enhance economic growth. The data on the dependent variable and control variables are obtained from the World Bank Development Indicators (WDI) 2021.

5.2. Insurance

Insurance is measured by the insurance penetration, which is calculated as the total premium volume that the insurer earned or received during the preceding

fiscal year as a percentage of GDP. This study takes into account total insurance, NLI and LI. The NLI premium volume as percentage of GDP is used to measure NLI. The LI premium as a percentage of GDP serves as a measure for LI. The total insurance premiums collected, including both life and NLI, are added together. Data on LI and NLI are obtained from the Global Financial Development Database 2021.

5.3. Institutional Quality

Four institutional quality variables are included in the analysis. These include legal system and property rights, economic freedom index, polity2 and rule of law. The legal system and property rights is an index that captures the protection of individuals as well as their rightfully acquired property. The Economic Freedom Index (ECF index) measures the degree to which the institutions and policies of countries are compatible with economic freedom. Polity2 index is used to measure political institutional quality. Polity2 is from the polity iv dataset constructed by Marshall et al. (2018). Polity2 data is a modified version of polity data. It measures the degree of democracy and autocracy and scaled from -10 to 10. Data on the legal system and property rights and economic freedom are extracted from the Economic Freedom of the World index published in the 2019 annual report (Gwartney et al., 2019). Data on both the legal system and property rights and the economic freedom index are scaled between 0 and 10. A higher value represents a sound legal system, higher protection of life and property, and higher economic freedom, respectively. Scaled from -10 to 10, Polity2 measures the degree of democracy and authoritarianism. A score of 10 denotes a robust democracy, whereas a score of -10 indicates a high degree of dictatorship. The polity2 data is obtained from the Polity IV dataset constructed by Marshall et al. (2018). It is a modified version of polity data. The World Governance Indicator dataset created by Kaufmann et al. (2010) contains a dataset on the rule of law. The degree to which members of society uphold and trust established laws is reflected in the rule of law. The scale for the rule of law is roughly between -2.5 and 2.5. While 2.5 suggested a strong rule of law, -2.5 indicates a weak rule of law. It is a dataset that covers the period from 1996 to 2019. However, there are gaps for the years 1997, 1999 and 2001. Table 1 contains the descriptive properties of the variables. Appendix A3 contains the list of countries selected for this study.

Table 1: Descriptive statistics

Variables	Mean	Std. Dev.	Min	Max
GDP per capita growth	1.558	5.169	-47.503	37.536
NLI penetration	0.773	0.876	0.003	14.723
LI penetration	0.813	2.050	0.001	15.381
Total insurance penetration	1.312	2.465	0.004	17.023
Gross capital formation	22.188	8.955	-2.424	60.156
Government expenditure	14.165	5.955	0.911	40.444
Trade openness	61.555	31.638	11.087	165.646
Inflation	57.171	805.178	11.686	23,773.13
Population growth	2.539	1.003	-6.766	8.118
Domestic credit to private sector	18.873	24.415	0.491	160.125
Polity2	0.996	6.838	-28	10
Economic freedom	5.728	0.913	2.525	8.117
Legal system and property rights	3.990	1.220	1.217	7.321
Rule of law	-0.597	0.630	-2.130	1.077

6. EMPIRICAL ANALYSIS

The panel unit root tests employed are those of Levin et al. (2002), Im et al. (2003), and the ADF– and PP–Fisher chi-square (Maddala & Wu, 1999). The results of the unit root tests are shown in Appendix A2, and they demonstrate that some variables, such as GDP per capita growth, total insurance, NLI, government expenditure, gross capital formation, population growth, inflation, trade openness, polity2 and rule of law, are stationary at the level, but legal system and property rights, LI, DCP and economic freedom are stationary at first difference.

Tables 2 to 5 contain the results of the parameters and the estimated threshold values. In Table 2, we use polity2 as the institutional quality variable. The economic freedom index is used as an institutional quality variable in Table 3. In Tables 4, the legal system and property rights is used as institutional quality variable while in Table 5, the rule of law is used as institutional quality variable. Column 2 of each table contains the results of the NLI model, while columns 3 and 4 consist of the results of the LI and total insurance models, respectively.

In Table 2, the threshold values of 3.000, 5.000 and -7.000 are estimated for NLI, LI and total insurance, respectively. Below the threshold value, NLI and LI produce insignificant impacts on economic growth. The total insurance result differs as it enhances economic growth below the threshold level at 10%. The effect of NLI on economic growth above the threshold level is positive and significant at 1%. This indicates that NLI promotes economic growth when political rights are higher. The effect of LI is positive but insignificant, while the effect of total insurance is also positive and insignificant.

With respect to the control variable, the models produce similar results. Gross capital formation significantly impacts economic growth in all the models at 1%. Some studies, such as Akinlo (2020) and Ridha and Parwanto (2020), also found a positive effect of gross capital formation on economic growth. The coefficient of trade openness is positive but not significant in any of the models. Inflation exerts a negative effect on economic growth across the models as expected. The coefficient of population growth is positive and significant in the NLI model only, while it is insignificant in other models. Financial development enhances economic growth significantly in all the models at 10%. Concerning the regime intercept $\hat{\delta}_1$, Bink (2010) explained that it suggests that the difference in the regime intercepts is the same for all cross-sections rather than being individual-specific. This implies that within the same regime, the growth rate is indistinguishable. From the economic perspective in this study, it is a dummy of the low regime that represents the average economic growth rate of countries with weak institutional quality. Its inclusion in the model reduces the omission of variable bias from a statistical perspective. Also, in each of the models, its coefficient is significant and negative.

In Table 3, where we use the economic freedom index as institutional quality variables, the threshold values of 6.166, 5.904 and 4.579 are estimated for NLI, LI and total insurance, respectively. In the low regime, the coefficients of NLI, LI and total insurance are insignificant. This is an indication that a lower level of economic freedom limits the impact of insurance on economic growth. For the regime above the threshold, the coefficients of NLI and total insurance are positive and significant, whereas the coefficient of LI is insignificant. This suggests that higher economic freedom is advantageous to the growth impact of NLI and total insurance.

Table 2: Insurance, polity2 and growth result

Dependent variable: GDP per capita growth rate	Non-life insurance (NLI)	Life insurance (LI)	Total insurance
Threshold estimates			
$\hat{\gamma}$	3.000	5.000	-7.000
95% confidence interval	[2.014, 6.046]	[4.448, 13.630]	[-15.622,7.804]
Insurance development			
$\hat{\beta}_1$	0.188(0.206)	-0.203(0.279)	0.391*(0.205)
$\hat{\beta}_2$	0.923***(0.317)	0.093(0.086)	0.094(0.714)
Other variables			
Lagged GDP per capita growth	0.102***(0.032)	0.109***(0.032)	0.103***(0.032)
Gross capital formation	0.116***(0.198)	0.119***(0.020)	0.118***(0.019)
Government expenditure	-0.046(0.031)	-0.021(0.030)	-0.021(0.029)
Trade openness	0.004(0.006)	0.002(0.006)	0.003(0.006)
Inflation	-0.003*(0.002)	-0.004*(0.002)	-0.004*(0.002)
Population growth	0.330**(0.164)	0.245(0.164)	0.249(0.163)
Domestic credit to private sector	0.011*(0.006)	0.012*(0.007)	0.103*(0.007)
$\hat{\delta}_1$	-2.053***(0.722)	-1.941***(0.736)	-2.151***(0.714)
No of observations	952	952	952
No of countries	34	34	34

Note: Significance at 1%, 5% and 10% is indicated by ***, ** and *, respectively. The parentheses contain the standard error.

The control variables lagged GDP per capita growth and gross capital formation have a positive and significant effect on growth. Their coefficients are significant at 1% in the models. Neither government expenditure nor trade openness produces a significant effect on growth; however, while the coefficient of government expenditure is negative, it is positive for trade openness. Inflation has a detrimental effect on economic growth. The coefficient of population growth is insignificant in the models. financial development contributes to growth. The regime intercept is negative and significant across the models.

Table 3: Insurance, economic freedom and growth result

Dependent variable: GDP per capita growth rate	Non-life insurance (NLI)	Life insurance (LI)	Total insurance
Threshold estimates			
$\hat{\gamma}$	6.166	5.904	4.579
95% confidence interval	[6.003, 6.613]	[5.492, 5.975]	[4.217,7.254]
Insurance development			
$\hat{\beta}_1$	0.255(0.019)	-0.055(0.124)	1.067(0.205)
$\hat{\beta}_2$	0.899***(0.332)	0.158(0.104)	0.126*(0.069)
Other variables			
Lagged GDP per capita growth	0.104***(0.033)	0.120***(0.033)	0.105***(0.033)
Gross capital formation	0.114***(0.020)	0.118***(0.019)	0.117***(0.020)
Government expenditure	-0.030(0.029)	-0.021(0.030)	-0.019(0.030)
Trade openness	0.003(0.002)	0.004(0.006)	0.001(0.006)
Inflation	-0.0004*(0.0002)	-0.0003*(0.0002)	-0.0004*(0.0002)
Population growth	0.295(0.163)	0.249(0.163)	0.267(0.162)
Domestic credit to private sector	0.020*(0.007)	0.012*(0.007)	0.013*(0.007)
$\hat{\delta}_1$	-2.215***(0.718)	-2.048***(0.718)	-2.123***(0.714)
No of observations	952	952	952
No of countries	34	34	34

Note: Significance at 1%, 5%, and 10% is indicated by ***, ** and *, respectively. The parentheses contain the standard error.

In Table 4, the legal system and property rights is the threshold variable. The threshold estimate for NLI is 5.680, for LI 4.120 and for total insurance 3.065. The results show that a weak legal system and unsecured ownership of properties are barriers to the growth impact of insurance. This is based on the insignificant effect of NLI, LI and total insurance obtained in the lower regime. However, in the higher regime, a strong legal system and secured property rights enhance the effect of NLI and total insurance on economic growth. The coefficient of LI is insignificant in the higher regime.

The results of the control variables gross capital formation, government expenditure, trade openness, inflation and financial development are the same as

the results obtained in Tables 2 and 3. Population growth has a positive sign, but its coefficient is significant only in the NLI model. The coefficient of intercept is negative and significant in all the models. The significant negative sign of the intercept implies that the countries with weak legal systems and unsecured property rights experience a negative average growth rate.

Table 4: Insurance, legal system and property rights and growth result

Dependent variable: GDP per capita growth rate	Non-life insurance (NLI)	Life insurance (LI)	Total insurance
Threshold estimates			
$\hat{\gamma}$	5.680	4.120	3.065
95% confidence interval	[4.460, 5.595]	[4.094, 4.528]	[0.183, 6.205]
Insurance development			
$\hat{\beta}_1$	0.282(0.194)	-0.040(0.128)	-1.006(0.117)
$\hat{\beta}_2$	1.245***(0.441)	0.138(0.101)	0.172**(0.078)
Other variables			
Lagged GDP per capita growth	0.102***(0.036)	0.120***(0.033)	0.105***(0.033)
Gross capital formation	0.118***(0.020)	0.118***(0.020)	0.117***(0.020)
Government expenditure	-0.033(0.030)	-0.015(0.030)	-0.020(0.029)
Trade openness	0.002(0.006)	0.003(0.006)	0.003(0.006)
Inflation	-0.0004*(0.0002)	-0.0003*(0.0002)	-0.0004*(0.0002)
Population growth	0.316*(0.163)	0.252(0.164)	0.268(0.163)
Domestic credit to private sector	0.012*(0.007)	0.012*(0.007)	0.012*(0.007)
$\hat{\delta}_1$	-2.182***(0.718)	-2.095***(0.717)	-2.141***(0.715)
No of observations	952	952	952
No of countries	34	34	34

Note: Significance at 1%, 5% and 10% is indicated by ***, ** and *, respectively. The parentheses contain the standard error.

In Table 5, we use the rule of law as the threshold variable. We estimate a threshold value of -0.275 for NLI. The LI threshold estimate is -1.382, while the total insurance threshold estimate is -1.265. The results mean that below the threshold level, the coefficients of NLI and LI are insignificant, implying they have no effect on economic growth. However, total insurance contributes to

economic growth at 10% significance level. This suggests that a weak rule of law does not limit the effect of total insurance on economic growth.

In the higher regime, NLI significantly enhances economic growth at 1%. The results of the control variables are slightly different from the previous tables. Lagged GDP per capita growth is positive and significant. Gross capital formation and population growth contribute to economic growth. Government expenditure and inflation have negative signs but the coefficient of government expenditure is not significant. financial development promotes economic growth.

Table 5: Insurance, rule of law and growth results.

Dependent variable: GDP per capita growth rate	Non-life insurance (NLI)	Life insurance (LI)	Total insurance
Threshold estimates			
$\hat{\gamma}$	-0.275	-1.382	-1.265
95% confidence interval	[-1.427, -.0514]	[-1.295, -.0734]	[-0.151, -0.377]
Insurance development			
$\hat{\beta}_1$	0.207(0.205)	1.573(1.165)	0.350*(0.211)
$\hat{\beta}_2$	0.865***(0.312)	0.066(0.084)	0.099(0.073)
Other variables			
Lagged GDP per capita growth	0.103***(0.033)	0.111***(0.033)	0.104***(0.033)
Gross capital formation	0.116***(0.019)	0.121***(0.020)	0.118***(0.020)
Government expenditure	-0.042(0.031)	-0.014(0.301)	-0.021(0.030)
Trade openness	0.002(0.006)	0.003(0.006)	0.003(0.006)
Inflation	-0.0004*(0.0002)	0.0003*(0.0002)	-0.0004*(0.0002)
Population growth	0.312*(0.163)	0.286*(0.164)	0.262(0.163)
Domestic credit to private sector	0.013*(0.007)	0.009(0.007)	0.012*(0.007)
$\hat{\delta}_1$	-2.040***(0.724)	-2.258***(0.725)	-2.150***(0.715)
No of observations	952	952	952
No of countries	34	34	34

Note: Significance at 1%, 5% and 10% is indicated by ***, ** and *, respectively. The parentheses contain the standard error.

6.1 Investigation Among Income Groups

Generally speaking, both the level of income and the level of economic development are associated with institutional quality. Therefore, we extend the investigation to income groups in SSA. That is, we investigate if the threshold effect of institutional quality on the insurance–growth nexus differs among the income groups within SSA. The results of the income groups are presented in Table 6. Table 6 consists of both the results of LICs and MICs. However, due to limited space, this part of our study uses the legal system and property rights as institutional quality indicators.

As can be seen in Table 6, threshold values of 3.065 for NLI and total insurance are obtained in the low-income group, while the threshold value for LI is 2.689. NLI and LI impact economic growth negatively at the low regime in the LICs. This suggests that a weak legal system and property rights limit the effect of LI and NLI on economic growth. A weak legal system and property rights will discourage people from buying insurance products, as there will be no guarantee that they will get justice if there is a default. In the high regime, LI and NLI have no effect on economic growth, whereas total insurance promotes economic growth. In the MICs, 5.050 is the estimated threshold value for NLI and 5.102 for both LI and total insurance. The results show that NLI, LI and total insurance have no effect on economic growth in the low regime. In the high regime, NLI and total insurance contribute to economic growth. The coefficient of LI is not significant but positive. From these results, we observe that insurance development will contribute more to economic growth when the legal system and property rights are guaranteed.

Gross capital formation enhances economic growth in both LICs and MICs. Government expenditure and trade openness are unable to exert a significant impact on economic growth in LICs and MICs. Inflation and population growth have a significant effect on growth in the LICs. However, while the coefficient of inflation is negative, that of population growth is positive. In the MICs, on the other hand, the coefficients of inflation and trade openness are not significant. financial development is unable to promote growth in the LICs. This might be due to the small size of the financial system. In contrast, financial development is a determinant of economic growth in the MICs.

Table 6: Results of a dynamic threshold effect of the legal system and property rights on insurance–growth nexus

	Low-income countries			Middle-income countries		
Threshold estimates	Non-life insurance (NLI)	Life insurance (LI)	Total insurance	Non-life insurance (NLI)	Life insurance (LI)	Total insurance
$\hat{\gamma}$	3.065	2.689	3.065	5.050	5.102	5.102
95% confidence interval	[4.199, 5.115]	[2.246, 5.447]	[4.039, 5.276]	[-16.782, 26.166]	[-12.549, 19.062]	[-4.243, 11.486]
Insurance development						
$\hat{\beta}_1$	-3.296**(1.559)	-10.747*(6.201)	-0.632(1.102)	0.081(0.172)	-0.030(0.096)	-0.034(0.074)
$\hat{\beta}_2$	-0.030(0.821)	-0.694(0.700)	1.208*(0.669)	0.987***(0.298)	0.108(0.079)	0.128*(0.067)
Other variables						
Lagged GDP per capita growth	-0.028(0.045)	-0.024(0.045)	-0.033(0.045)	0.387***(0.045)	0.412***(0.044)	0.408***(0.045)
Gross capital formation	0.182***(0.031)	0.178***(0.031)	0.171***(0.031)	0.042**(0.023)	0.043**(0.023)	0.044*(0.023)
Government expenditure	-0.087(0.062)	-0.044(0.061)	-0.087(0.062)	-0.018(0.027)	-0.008(0.028)	-0.015(0.027)
Trade openness	0.007(0.014)	0.001(0.013)	0.001(0.014)	0.007(0.005)	0.008(0.005)	0.008(0.005)
Inflation	-0.001**(0.0002)	-0.001**(0.0002)	-0.001**(0.0002)	0.001(0.001)	0.001(0.001)	0.001(0.001)
Population growth	0.444*(0.228)	0.455**(0.226)	0.431*(0.227)	0.027(0.219)	-0.092(0.224)	-0.063(0.220)
Domestic credit to private sector	-0.002(0.017)	-0.0004(0.017)	-0.001(0.017)	0.014**(0.006)	0.011*(0.006)	0.011*(0.006)
$\hat{\delta}_1$	-2.296**(1.202)	-2.625**(1.182)	-2.364**(1.185)	-1.038(0.998)	-0.559(1.014)	-0.671(0.997)
No of observations	504	504	504	448	448	448
No of countries	18	18	18	16	16	16

Note: Significance at 1%, 5% and 10% is indicated by ***, ** and *, respectively. The parentheses contain the standard error.

7. DISCUSSION OF FINDINGS

In the case of all the institutional quality variables used in our study, we found that NLI does not significantly contribute to economic growth below the threshold level or in the low regime (see Tables 2-5). This is an indication that weak institutional quality limits the impact of insurance on economic growth in SSA. Weak institutional quality exposes insurance to the problems of adverse selection and moral hazards, resulting in the negative impact of insurance on economic growth. In the high regime, NLI significantly impacts economic growth (see Tables 2-5). This implies that a strong institutional quality enhances the impact of NLI on economic growth. This finding is in line with finance–growth studies (e.g., Demetriades & Law, 2006, Anwar & Cooray, 2012), which found that institutional quality boosts the impact of finance on economic growth. NLI will enhance economic growth as institutional quality reduces transaction costs and provides the mechanism for enforcing contracts that are necessary between the insurer and the insured. A strong institutional quality that provides information and a good environment for the efficient operation of insurance provides avenues for a greater impact of NLI on economic growth. In relation to this study, this implies that a high level of political rights, a high degree of economic freedom, and strong rule of law and protection of property rights provide a suitable environment for a greater impact of NLI on economic growth.

In contrast, LI has no observable impact economic growth below and above the threshold regime. This is in line with Nwani and Omankhanlen (2019), who found an insignificant effect of LI on economic growth. This finding is also consistent with Lee et al. (2016), who determined that LI does not significantly impact economic growth at a higher level of institutional quality. Lee et al. (2016) gave two possible reasons for this. First, they claimed that a sound institutional environment allows all the economic sectors within the economy to function very well and, as a result, the contribution of the LI might be insignificant. Second, since sound institutional quality is associated with developed economies in which the insurance sector is developed and not in the growth phase, the effect of insurance on economic growth might not be obvious in this situation. However, these two reasons might not apply to SSA. For example, the level of institutional quality is weak in SSA, so it cannot be said categorically that it allows all the

sectors to function very well. Furthermore, the economies of SSA countries are still underdeveloped and the effect of LI may not be obvious.

In the case of total insurance, we observe that its effect depends on individual institutional quality. For instance, at a low level of polity2 and rule of law, total insurance significantly contributes to economic growth. However, a higher level of political rights and rule of law does not have any influence on the impact of total insurance on economic growth. The reason for the significant impact of total insurance on economic growth at a low level of political rights and rule of law might require further investigation. In contrast, at a higher level of economic freedom and legal system and property rights, total insurance enhances economic growth.

Regarding income groups, the results reveal that a low level of institutional quality does not enhance the effect of insurance on economic growth in LICs and MICs. However, at a higher level of institutional quality, insurance had a better chance to enhance economic growth. This is in line with Demetriades and Law (2006), who found a greater effect of financial development on economic growth because the financial system was rooted in a better institutional framework. This result is expected, as weak institutional quality will prevent the insurance sector from operating efficiently and thereby limit the effect of the sector on economic growth both in LICs and MICs. Weak institutional quality will promote a high level of corruption and political interference in the insurance sector. High levels of corruption and political interference result in the waste of resources and also severely compromise the quality of insurance services. Likewise, information asymmetries, contract defaults, and high-risk-taking behaviours are products of weak institutional quality that hamper the efficiency and operations of the insurance sector.

The insignificant effect of LI and NLI on economic growth at a stronger level of institutional quality in low LICs might be due to the small size and the level of development of the insurance sector. The level of income in LICs affects the patronage of insurance products. The low patronage of insurance products affects the size of premiums in the insurance sector, and low premiums will limit the ability of the insurance sector to influence economic growth significantly. For instance, when the premium size is small, it will affect the ability of the insurance

sector to make long-term funds available for firms, businesses, and investors, thereby reducing the level of investment. Similarly, the ability of life insurance to promote economic growth at a stronger level of institutional quality in MICs indicates that life insurance might be bigger and more efficient in MICs than in low-income countries. The low level of development of the insurance sector in LICs can influence its efficiency in pooling premiums, the choice of technology, and access to modern facilities. Lack of access to modern facilities and technology will affect the operation efficiency of insurance companies by increasing the cost of operation and, as a result, making them unable to influence economic growth.

Gross capital formation contributed to economic growth in SSA. Studies like Asiedu et al. (2015) and Mputu (2016), have also found a positive influence of gross capital formation on economic growth. The capacity to produce in any economy depends on gross capital formation and its deficiency will hamper the growth rate. Government expenditure failed to significantly impact economic growth which is in line with Okungbowa and Ogbeide (2018). According to Sakyi and Egyir (2017), the outcome of the effect of government expenditure on economic growth depends on the direction of government spending. Trade openness did not exert a significant impact on economic growth in this study, which is in line with Ulaşan (2015). The connection between trade openness and economic growth is not free from controversy as some studies reported a growth-enhanced effect of trade while others reported contrary results. The inverse relationship found between inflation and economic growth is expected, as SSA countries have been unable to successfully keep inflation low over the years. Sakyi and Egyir (2017) and Zahonogo (2016) found an inverse effect of inflation on economic growth in the region. Kelsey and le Roux, (2017, 2018) stated that inflation creates uncertainty and ambiguity, which discourages investors who usually prefer a less ambiguous environment. Population growth and financial development contributed significantly to economic growth. Becker et al. (1999) and Headey and Hodge (2009) also established a positive relationship between population and economic growth .

8. CONCLUSION AND IMPLICATION OF FINDINGS

The target of this study is to investigate the threshold effect of institutional quality on the connection between insurance and economic growth in SSA from 1990 to 2017. Many studies have focused their attention on the insurance–economic

growth nexus without considering the intermediary role of institutional quality between insurance and economic growth, particularly in SSA. This paper has used dynamic panel threshold regression as the estimation method. Furthermore, it has used four institutional quality measures, including the legal system and property rights, polity2, the economic freedom index and the rule of law to provide a robust and comprehensive analysis. The study has also considered LI, NLI and total insurance for evidence to help policymakers make appropriate decisions for the improvement and expansion of the insurance sector in the region. For a more detailed and deeper analysis, the paper has extended the investigation to income groups within the region.

Generally, this paper discovered that an institutional quality threshold exists in the insurance–growth relationship, which calls for consideration of the level of institutional quality in policies aimed at improving insurance performance. The study has found that institutional quality influences the relationship between NLI and economic growth, while LI has a lesser effect on economic growth. The effect of total insurance on economic growth has also been considered. Several noteworthy policy implications have emerged from the findings of the study. At a low level of institutional quality, a positive and insignificant relationship exists between NLI and economic growth, which indicates that a weak institutional quality limits the impact of NLI on economic growth. A positive and significant effect of NLI is obtained at a higher level of institutional quality, which suggests institutional quality improves the contributions of insurance to economic growth. The policy implication from this is that there is a need for policies that will target both the development of institutional quality and NLI in the region. Any policy that targets the development of NLI without also targeting institutional quality might not achieve its objectives, as the growth effect of NLI depends on the level of institutional quality.

The study found that LI has no effect on economic growth whatever the level of institutional quality (although it may even be negative in low-income countries at low levels of institutional quality). This is an indication that the size and

improvement of LI is of little importance for enhancing economic growth in the region[1].

Another noteworthy discovery is that the effect of total insurance on economic growth depends on the institutional quality used. For instance, total insurance stimulates growth when the rule of law and political rights are weak but is unable to enhance growth at a strong level of the rule of law and political rights. However, the effect of total insurance on growth is positive and significant when economic freedom, the legal system and property rights are at a high level, and becomes insignificant when economic freedom, the legal system and property rights are at a low level.

With regard to income groups, the study found that a low level of institutional quality is not beneficial for the growth effect of insurance in both low- and middle-income countries. Specifically, LI and NLI harm economic growth in LICs while they have insignificant effect in MICs when institutional quality is low. However, a higher level of institutional quality enhances the growth impact of total insurance in LICs and LI and total insurance in MICs. This is an indication that the level of development is directly related to the level of institutional quality and that institutional quality is stronger in MICs than in the low-income group of countries. Policymakers need to target the development of institutional quality and NLI in both LICs and MICs, but especially in the former. The deployment of advanced technology and mobile phones can help to reach out to more people about insurance products. A large part of the population, particularly in rural areas, is not aware of the value of insurance and therefore need to be made aware of and educated about the benefits of insurance, especially non-life insurance. This might help to expand the size of the insurance market and improve the rate of economic growth and the level of development of the poorer countries of SSA.

[1] In most SSA countries, LI penetration is very low, which might be related to the low level of income and high levels of illiteracy. For instance, in 2013, South Africa accounted for 88% of total LI premiums in the region. In 2018, the total amount of LI premiums in SSA was 43.2 billion USD and South Africa accounted for 80% of these premiums. Aside from South Africa, the LI market is underdeveloped in SSA countries

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APPENDIX A2: UNIT ROOT RESULT

Variable	Levine *et al*		Im *et al*		ADF		PP	
	level	1st diff	level	1st diff	level	1st diff	Level	1st diff
GDP per capita growth	-7.469***	-19.605***	-10.498***	-25.970***	241.466***	611.935***	464.978***	816.235***
Non-life insurance (NLI)	-2.587***	-6.205***	-3.175***	-10.228***	115.212***	276.012***	120.924***	429.101***
Life insurance (LI)	-0.406	-1.486*	-1.608*	-10.243***	115.733***	260.069***	179.886***	411.820***
Total insurance	-3.090***	-9.429***	-4.446***	-13.041***	124.626***	291.743***	98.815***	449.368***
Government expenditure	-3.652***	-12.855***	-3.623***	-15.135***	107.332***	351.609***	120.930***	631.442***
Gross capital formation	-1.995**	-15.633***	-2.203**	-17.918***	87.216**	411.712***	111.004***	685.306***
Population growth	-17.376***	-21.917***	-22.743***	-25.584***	475.210***	515.972***	134.117***	150.365***
Inflation	-8.480***	-19.641***	-9.176***	-23.181***	208.749***	547.210***	264.456***	804.896***
Trade openness	-1.648**	-12.557***	-2.327**	-16.224***	83.247*	371.692***	106.591***	651.094***
Polity2	-4.982***	-7.500***	-5.829***	-14.214***	150.375***	265.844***	233.336***	376.471***
Domestic credit to private sector	-1.301*	-13.998***	0.374	-13.763***	85.342*	300.934***	50.239	477.755***
Economic freedom	0.405	1.0E+08	2.419	-12.088***	40.337	274.066***	50.491	467.562***
Legal system and property rights	0.113	4.3E+07	2.355	-12.123***	39.249	269.546***	43.624	480.190***
Rule of law	-3.283***	-8.7134***	-3.879***	-9.143***	135.414***	208.180***	173.768***	338.011***

Note: Significance at 1%, 5% and 10% is indicated by ***, ** and *, respectively. The parentheses contain the standard error.

Table A3: List of SSA Countries included

Full Sample		**Middle-income countries**	**Low-income countries**
Angola	Malawi	Angola	Benin
Benin	Mali	Cape Verde	Burkina Faso
Botswana	Mauritius	Botswana	Central African. Rep.
Burkina Faso	Mozambique	Cameroon	Chad
Cape Verde	Namibia	Congo, Rep.	Congo, Dem. Rep.
Cameroon	Niger	Cote d'Ivoire	Ethiopia
Central African Rep.	Nigeria	Gabon	Guinea
Chad	Rwanda	Ghana	Madagascar
Congo, Dem. Rep.	Senegal	Kenya	Malawi
Congo, Rep.	Sierra Leone	Lesotho	Mali
Cote d'Ivoire	South Africa	Mauritius	Mozambique
Ethiopia	Sudan	Namibia	Niger
Gabon	Tanzania	Nigeria	Rwanda
Ghana	Togo	South Africa	Senegal
Guinea	Uganda	Sudan	Sierra Leone
Kenya	Zambia	Zambia	Tanzania
Lesotho			Togo
Madagascar			Uganda

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ECONOMY-WIDE AND ENVIRONMENTAL BENEFITS OF GREEN ENERGY DEVELOPMENT IN OIL-RICH COUNTRIES: EVIDENCE FROM AZERBAIJAN

ABSTRACT: *Azerbaijan, which is an oil/gas-rich country, has been taking full advantage of its energy potential and taking steps towards creating green energy and turning it into an export. The Green Energy Corridor, in which Azerbaijan plays the main role, aims to connect Azerbaijan with Europe in its first stage. In the second stage, this corridor will connect Central Asia with Europe, which will involve the laying of an electric cable under the Black Sea and the Caspian Sea. This will allow Azerbaijan and other Central Asian countries to export zero-carbon electricity to the European market. If Azerbaijan is successful in this field, it will not only serve the sustainability of the country's economy in the post-oil era, but will also contribute to the reduction in carbon emissions, leading to global benefits. The aim of this article is to assess the socioeconomic, ecological, and political benefits of green energy deployment in Azerbaijan. An economic cost-effectiveness analysis was conducted for selected green energy projects (large-scale wind and solar power plants). We also argue that green transition projects, which seem expensive and difficult to realise today, will be justified in the near future.*

KEY WORDS: *green energy, Caspian Sea, wind energy, export of green energy, cost-effectiveness analysis.*

JEL CLASSIFICATION: Q42; Q47; Q48; Q49

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1. INTRODUCTION

Azerbaijan is a net energy exporter, exporting oil, natural gas, and electricity. It meets its own energy needs through domestic production, which currently relies largely on the exploitation of the country's hydrocarbon reserves. Azerbaijan has a 100% electrification rate (International Renewable Energy Agency [IRENA], 2019). The opening of the Serbia–Bulgaria gas interconnector in the Serbian city of Niš on December 10, 2023, has expanded the list of countries to which Azerbaijan exports gas (President of the Republic of Azerbaijan [PoA], 2023). Azerbaijan had been exporting its Caspian Sea gas to eight countries, six in Europe, and Serbia became the ninth country on this list. But Azerbaijan's main goal is related to renewable energy; it expects to export the green energy produced from its excellent wind resources in the Caspian Sea to Europe in the near future (IRENA, 2019).

Despite Azerbaijan's wealth in oil and gas, the country sees a future in the production and export of zero-carbon electricity. It is attempting to implement a mega-project that involves laying a pipeline under the Black Sea to export renewable energy to Europe after using it for oil and natural gas. At the same time, Azerbaijan is evaluating the possibility of green hydrogen production and export, as well as an increase in the supplying of gas through the Southern Gas Corridor, which will play a strategic role in diversifying gas supplies to Europe. By realising its green hydrogen potential, Azerbaijan may also support Europe's plans in this field. Also, it could play a role in Kazakhstan's hydrogen exports to Europe by taking advantage of transportation systems it develops. Consequently, Azerbaijan can play an important role in diversifying the energy supply for Europe. By the early 2030s, Azerbaijan aims to have installed production capacity for 7 GW of wind and solar energy and will start exporting green energy. Of this, 4 GW will be exported to Europe via the Caspian-European Green Energy Corridor, which will pass through the Black Sea, and 1 GW will be exported to Türkiye and Europe via Nakhchivan, which has been declared a *green energy zone*.

Azerbaijan is one of the countries with high potential for renewable energy sources. The technical potential of Azerbaijan's onshore renewable energy is 135 GW and offshore it is 157 GW (35 GW in shallow water and 122 GW in deep water) (World Bank [WB], 2022). However, 292 GW is a technical potential; the economic potential is the part of the technical potential that can be realised

economically (Azerbaijan Renewable Energy Agency [AREA], 2023). Azerbaijan aims to fully realise its green energy potential, meeting both domestic demand as well as exports to Europe. For this reason, it has planned to increase the percentage of renewable energy in its installed capacity of electricity production from 17.3% in 2021 to 30% in 2030. Other steps towards the creation of a green energy corridor with Europe include an agreement in 2022 on a strategic partnership in green energy development and transmission with Georgia, Romania, and Hungary (PoA, 2022b). This agreement references the undersea power cable planned for the Black Sea (capacity of 4 GW). Current plans aim to further expand this project, and Serbia and Bulgaria will also take part in it.

The Energy Transition Index of the World Economic Forum (WEF, 2023) shows that Azerbaijan was a top improver between 2022 and 2023 (rank 32, score 62) and was ahead of the global average. Azerbaijan has shown large improvements across several transition readiness parameters.

The purpose of this article is to examine the Caspian–European Green Energy Corridor, in which, in the first stage, the South Caucasus will be connected with the Balkans by laying the Black Sea cable and, in the second stage, Central Asia will be connected with the Balkans by laying a cable under the Caspian Sea. This article explains Azerbaijan's strategies for exporting zero-carbon electricity to the European market. Two green energy projects (wind and solar) in Azerbaijan have been chosen to evaluate their cost-effectiveness.

Following this introductory section, the potential of Azerbaijan in green energy will be discussed briefly. The literature review is in Section 2, and Section 3 provides the data and the methodology. Section 4 presents the results and discussion. Finally, Section 5 contains the conclusions and policy implications.

2. LITERATURE REVIEW

A wide range of studies exist that aim to measure green energy development and the economic, social, and ecological impacts on the selected country. Most scholars view renewable energy investments as an essential part of reducing greenhouse gas emissions, and they consider renewables as a positive. Scientists are studying the problems presented by the transition to green energy, and these studies are widely represented in the literature. For example, Dimitrov (2021) has

stressed that there are some considerations, which include economic and financial barriers, that need attention.

In particular, researchers have begun to pay particular attention to the development of green energy in resource-rich countries (Aslani et al., 2012; Bahrami & Abbaszadeh, 2013; Mohammed et al., 2013; Tlili, 2015; Zell et al., 2015; Noorollahi et al., 2021; Issayeva et al., 2023) and the opportunities and problems that exist. Ahssein Amran et al. (2020) examined green energy production in Saudi Arabia according to the Saudi Vision 2030; Almasri & Narayan (2021) researched green energy sector developments in the resource-rich Gulf Cooperation Council countries (Bahrain, Kuwait, Oman, Qatar, Kingdom of Saudi Arabia [KSA], and the United Arab Emirates). Almasri & Narayan (2021) show that the green energy sector has the potential to create jobs for a large portion of the population across the Gulf Cooperation Council countries, resulting in essential gains in terms of new employment opportunities, fuel savings, and emission reduction.

There are also a number of studies dealing with the potential, production, and consumption of green energy in the resource-rich countries of the Caucasus and Central Asia (Gulaliyev et al., 2020; Zhakupova et al., 2021; Mustafayev et al., 2022; Huseynli, 2022; Vakhguelt, 2017). Shakeyev et al. (2023) analysed renewable energy projects in fossil fuel-dependent Kazakhstan and stressed the urgent necessity to shift towards renewable energy sources.

There is also some research on renewable energy development in Azerbaijan. This research shows that Azerbaijan is a country with vast potential for renewable energy development. The country has excellent wind and solar resources and significant prospects for biomass, geothermal, and hydropower (IRENA, 2019). However, the issue of green energy export is also new for Azerbaijan. It is true that in the Strategic Road Map (SRM, 2016) of Azerbaijan the question of electricity exports and the European market are reflected. But these studies were not related to the export of green energy. For example, the issue of laying a cable along the bottom of the Black Sea and the Caspian Sea for the purpose of exporting green energy is new and has not yet been examined. The main discussion of this topic began in 2022 and is included in Gasimli's (2024) study.

In summarising the literature, it becomes evident that numerous researchers have examined the topic of green energy development. Since we do not have enough studies for Azerbaijan, we include studies from other areas. However, there is as yet no research on the green energy corridor that will connect Central Asia with Europe through Azerbaijan. Therefore, this article is one of the first studies written on this topic.

3. RESEARCH METHODS AND DATA

In this study, we use both qualitative and quantitative methodology to assess the benefits of the green transition. In the qualitative approach, we used focus group discussions to evaluate the potential benefits of green energy projects, also the cost-effectiveness and co-benefit analysis and a cost-effectiveness analysis has been used as a quantitative assessment of green energy-related projects.

3.1 Focus group discussion

Two focus group discussions took place to focus on the development potential of green energy in Azerbaijan. Discussions were organised at the Centre for Analysis of Economic Reforms and Communication in May and Septmember 2023. About 10 green energy experts participated in each focus group discussion.

It should be noted that the "Country of Green Energy" working group was established by the Azerbaijani government in June 2023. The members of this working group participated in the focus group discussion held in September.

3.2 Economic assessment

In this study, we focus on the cost-effectiveness of wind and solar power projects in Azerbaijan. While doing this, we follow the methodology applied by Ma et al. (2013), Xue et al. (2015), and Jiang et al. (2020) with some modifications. This analytical approach is instrumental in identifying the most economically efficient option to attain predefined objectives. Explicitly, the focus of this study was to quantitatively assess the economic efficiency of lowering emissions through wind and solar power deployment.

The net annual cost (NAC) of a project is composed of three elements. In particular, NAC equals the annual project cost (APC) plus the annual fuel

(natural gas) cost saving (CAFC) and the annual on-grid energy sales revenue (ASR). The equation is given below:

$$NAC = APC + CAFC + ASR \tag{1}$$

CAFC from equation (1) can be calculated using the following formula:

$$CAFC = AFA \times \mathrm{FP}, \tag{2}$$

where AFA is the annual fuel consumption amount of natural gas-fired power and FP is the natural gas price. According to the information provided by the Ministry of Energy of Azerbaijan, a wind project provides an opportunity to save 220 million cubic metres of natural gas per year whereas a solar power plant project has the potential to save 110 million cubic metres of natural gas per year.

The annual project cost (APC) is calculated using the figures for the annual maintenance cost including the average annual operating cost (AMC), discount rate (r), total investment cost (TIC), and a service life (n):

$$APC = \frac{TIC \times \mathrm{r}}{1-(1+r)^{-n}} + AMC. \tag{3}$$

Lasltly, the cost-effectiveness (CE) is calculated with the following equation, where the net annual cost of a wind power project (NAC) is divided by the wind power project's annual reduction in the amount of CO2 equivalent (ARA) compared to natural-gas-fired power:

$$CE = \frac{NAC}{ARA}. \tag{4}$$

In contrast to natural gas-fired electricity generation plants, wind and solar energy generation exhibits a remarkably lower release of CO2 equivalent. ARA is defined as per year saving of the CO2 equivalent in both projects times service life of the project. It is estimated that the annual CO2 equivalent saving from the wind and solar power plant would be 400 and 200 thousand tons of CO2 equivalent, respectively.

The main sources of data for the analysis were from the State Statistical Committee of Azerbaijan, the Ministry of Environment and Natural Resources of Azerbaijan, the Ministry of Energy of Azerbaijan, and the Central Bank of Azerbaijan. Two projects were selected as a case study: a 240 MW wind power project in the coastal region of the Caspian Sea and the 230 MW Garadakh solar power plant. The total investment cost of the first project is 300 million USD whereas the second project`s total cost is 262 million USD. The two projects are expected to have a lifespan of 25 years each. It is anticipated that, on an annual basis, the wind power plant will generate approximately 1 billion kWh of electricity, while the solar power plant is expected to produce around 0.5 billion kWh. This indicates that, throughout the duration of their separate operating periods, the wind project is expected to add a total of 25 billion kWh to the energy grid and the solar project roughly 12.5 billion kWh.

Using wind energy offers a practical way to address several environmental issues. This study measures the additional advantages of wind energy, looking at them from the standpoint of affordable mitigation techniques. The following formula summarizes the previously given analysis:

$$ECB = CE \times ARA. \tag{5}$$

where ECB is the economic co-benefits of wind power project.

4. RESULTS AND DISCUSSION

4.1. Realisation of green energy potential

Azerbaijan is taking its initial steps in expanding the development of renewable energy potential with its first large-scale onshore wind facility (the 240 MW Khizi-Absheron Wind Power Plant) and solar power plant (the 230 MW Garadag Solar Power Plant). In 2023, the Garadag Solar Power Plant, the largest solar power plant in the Caspian region, began operations, and in 2024, the Khizi-Absheron Wind Power Plant will begin operations.

The State Oil Company of Azerbaijan (SOCAR) and Masdar (Abu Dhabi Future Energy Company, an Emirati state-owned renewable energy company) have already signed a joint development agreement for a 2 GW offshore wind and

hydrogen project in Azerbaijan, as well as a joint development agreement for a 1 GW solar photovoltaic and 1 GW onshore wind project (Azertac, 2023). The cooperation with the company started with a 230 MW solar power station and is being expanded with wind, solar, and green hydrogen projects; the production of 3 GW of wind and 1 GW of solar energy is targeted for 2027. A public-private partnership with Fortescue Future Industries (FFI), an Australian company, is also planned for the production of 12 GW of wind and solar energy. An executive contract was signed with the company ACWA Power for the implementation of a wind project of up to 1.5 GW offshore and the creation of a 1 GW wind farm onshore. In addtion to these power generating plants, projects for the creation of energy storage systems in Azerbaijan are in the planning stages with this company. At the same time, Fortescue Future Industries has started research and implementation of renewable energy and green hydrogen projects in Azerbaijan with a capacity of up to 12 GW.

The company BP will participate in building a 240 MW solar power plant in the Jabrayil district. Negotiations are also under way for the construction of a 500 MW solar power plant in the Nakhchivan Autonomous Republic.

In addition, there will be a cooperation with the China Gezhouba Group Overseas Investment Co., Ltd on a 2 GW renewable energy project in Azerbaijan. In addition, the Turkish company Baltech is collaborating on a 50 MW solar power plant project in Nakhchivan and a 200 MW wind power plant project in the Eastern Zangezur and Karabakh economic regions.

The most important stage has now been reached in negotiations with investors regarding the production of 10 GW of the targeted 28 GW of green energy, and agreements and memoranda of understanding have been signed. Even the State Oil Company of Azerbaijan is interested in the field of green energy and has established the SOCAR Green Company for this purpose. This company aims to implement solar and wind energy projects together with Masdar, ACWA Power, BP, and Energy China. In particular, this company will implement a 1 GW onshore wind and solar energy project in the initial phase with Masdar and a 240 MW solar energy project with BP.

4.2. Advantages of the transition to green energy

4.2.1. Geo-political advantage

Leading the transition from oil and natural gas, Azerbaijan can become an exporter of renewable energy and green hydrogen for Europe. The new Memorandum of Understanding on a Strategic Partnership in the Field of Energy was signed between Azerbaijan and the European Union on July 18, 2022 (PoA, 2022a). According to this document, Azerbaijan aims to double the volume of gas exports to Europe by 2027. While Azerbaijan gas exports to Europe amounted to eight billion cubic metres in 2021, this reached 11.8 billion cubic metres in 2023. The realisation of Azerbaijan's green energy projects will allow gas intended for domestic electricity production to be saved, and this will create the conditions needed for fulfilling export obligations.

On December 17, 2022, the Agreement on a Strategic Partnership in the Field of Green Energy Development and Transmission was signed in Bucharest, the capital of Romania (PoA, 2022b), between the governments of Azerbaijan, Georgia, Romania, and Hungary, and this opens new prospects for Azerbaijan.

Figure 1: Caspian-European Green Energy Corridor

Source: Authors' work

The above agreement is expected to ensure Europe's energy security by enabling the export of green energy from Romania and Hungary to the European Union. It will also aid the transition to clean energy in our regions and will create additional opportunities for Azerbaijan's exports of green energy (see Figure 1).

A project proposed by Azerbaijan for these exports is related to the creation of the Azerbaijan–Turkey–Europe Energy Corridor, which will pass through the Zangezur Corridor (Zangezur and Nakhchivan) (AP, 2022). The development of the Caspian–Black Sea–European Green Energy Corridor project, which began within the framework of the creation of a green energy corridor between Azerbaijan, Georgia, Romania, and Hungary, also has on its agenda the inclusion of Serbia and Bulgaria in this Black Sea submarine power line project. Azerbaijan is making a significant contribution to Europe's energy security with the Southern Gas Corridor infrastructure project, which is 3,500 kilometers long. If the Caspian–Black Sea–European Green Energy Corridor is implemented, it can fulfill the mission of connecting Central Asia with the Balkan countries in the field of green energy in the near future. That is, this mega-project will include eight countries: Uzbekistan, Kazakhstan, Azerbaijan, Georgia, Bulgaria, Romania, Hungary, and Serbia. Thus this project will also serve the development of political and economic relations between those countries.

Of course, energy projects will further strengthen the geo-political position of Azerbaijan. In addition, the existence of political stability and dynamic economic development in Azerbaijan will attract investors.

4.2.2. Economy-wide advantage

Renewable energy can play a role in supporting Azerbaijan's drive for economic diversification (IRENA, 2019). In particular, building a cable under the Black Sea will make the country a zero-carbon electricity exporter. The plan is to finalise the feasibility study for this project by the end of 2024.

When the above project is realised, Azerbaijan will have sufficient potential to use it to export green energy. According to forecasts, Azerbaijan will produce 7 GW of green energy by the early 2030s and 4 GW of it can be exported. Azerbaijan, Kazakhstan, and Uzbekistan have initiated plans to utilise the corridor to transmit green energy from Central Asia.

In addition, Europe plans to obtain 20 million tons of hydrogen by 2030, and Azerbaijan expects to export hydrogen to the European Union.

Including Serbia and Bulgaria may increase the importance of this corridor, as Serbia is Azerbaijan's new partner for the diversification of the gas market in Europe. Azerbaijan will supply up to 400 million cubic metres of gas annually to Serbia, with this volume expected to increase in the coming years.

At the initiative of Azerbaijan, with the participation of Uzbekistan and Kazakhstan, a project to construct an energy cable connecting the shores of the Caspian Sea is being discussed (Ministry of Economy of the Republic of Azerbaijan [MoEconom], 2023). The projects implemented in the field of green energy provide an opportunity to expand electricity production and export, and open further opportunities for the transportation of electricity from Central Asian countries to Europe through Azerbaijan (MoEconom, 2023). On November 14, 2023, Azerbaijan, Kazakhstan, and Uzbekistan signed a joint communiqué on cooperation in the development and export of green energy.

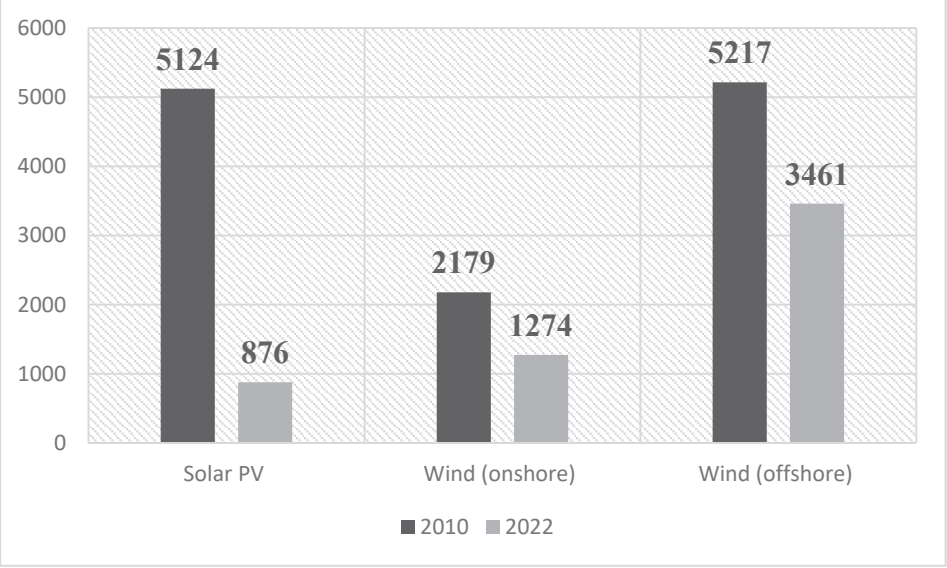
In 2022, the EU and Kazakhstan signed an agreement for the production and export of green hydrogen. The 50 billion USD deal calls for the construction of 20 GW of green power plants in Kazakhstan and the production of two million tons of green hydrogen through electrolysis. Kazakhstan will be able to supply 20% of the ten million tons of EU hydrogen imports in 2030 (Dezem, 2022). Its southern neighbor, Uzbekistan, is also taking major steps in the field of green hydrogen. And in Azerbaijan, the share of renewable energy sources in the installed electricity production capacity is expected to increase from 17.3% in 2021 to 30% in 2030 (Strategy of Socio-economic Development [SSED], 2022).

It is important to mention that Azerbaijan mainly uses natural gas in generating electricity. More broadly, total electricity generated in 2023 was about 29.3 billion kWh. A noteworthy 92.8% of this was generated from thermal power plants (TPPs). On the other hand, 1.8 billion kWh, or 6% of the total, came from hydroelectric power plants (HPPs). Furthermore, the share of other renewable energy sources was quite small, making about 1.2% or 359.0 million kWh of the total electricity produced in the same year (Ministry of Energy of the Republic of Azerbaijan [MoE], 2024).

In 2022, the production capacity of facilities utilising renewable energy was 131.2 watts per capita (State Statistical Committee of the Republic of Azerbaijan [SSC], 2023). The production capacity of hydroelectric power plants was 1,164.7 MW, the production capacity of solar power plants was 51.2 MW, and the production capacity of wind power plants was 64 MW (SSC, 2023). The share of renewable energy in the total final energy consumption was 1.3 % in 2022 (SSC, 2023).

For 2025, production of 28.3 billion kWh of electricity and consumption of 24.3 billion kWh of electricity is predicted for Azerbaijan. We think that after 2025 all new power generation in Azerbaijan will be created from renewable resources. Of course, it is important to note that the investment costs for renewable energy sources are quite high. However, the analysis shows that renewable energy installation costs by 2022 had decreased significantly compared to 2010 and that the downward trend is continuing.

Figure 2: Renewable energy installation costs, USD/kWh (2010/2020)



Source: IRENA (2023), Renewable Power Generation Cost, 2022

The decrease in the cost of electricity produced from renewable sources from 2010 to 2022 has begun to make these projects attractive.

The International Energy Agency (IEA, 2022) Stated Policies Scenario (STEPS) shows that the capital costs of solar photovoltaic (PV) and offshore wind installations in the EU and China are expected to more than halve by 2050 (Table 1).

Table 1: Electricity generation technology costs (Stated Policies Scenario)

	Capital costs (USD/kW) in the European Union			**Capital costs (USD/kW) in China**		
	2021	**2030**	**2050**	**2021**	**2030**	**2050**
Solar PV	810	530	410	630	410	300
Wind onshore	1,590	1,510	1,450	1,160	1,090	1,050
Wind offshore	3,040	2,000	1,500	2,860	1,840	1,380

Source: IEA (2022)

Note: All costs are expressed in year-2021 dollars and economic lifetime assumptions are 25 years for solar PV and onshore and offshore wind power.

Not only will succesful implimentation of the projects in green energy contribute to the stability of the country's economy in the post-oil era and create new jobs, these projects will also contribute to a reduction in carbon emissions, leading to global benefits.

Increasing attention to green energy and deepening global cooperation in this field will certainly lead to social benefits for Azerbaijan. Overall, implementing the mega-projects in this field will have a positive effect on unemployment and lead to an increase in the income level of the population.

The report by the International Renewable Energy Agency and the International Labour Organization (IRENA & ILO, 2023) finds that the global renewable energy sector employed 13.7 million people directly, as well as indirectly, in 2022. This report stressed that climate-safe pathways would create many millions of additional jobs in the next decades. The Global Wind Energy Council (GWEC, 2022) analysed the international experience of the onshore wind industry and found that typically a 1GW/year installation rate over five years could unlock nearly 100,000 new jobs and over the lifetime of onshore wind farms (25 years) could add 12.5 billion USD gross value to national economies. The calculation by GWEC (2022) shows that 5 GW of onshore wind farms could create 12,000 local jobs each year during the 25-year operational and maintenance phase; a total of

130,000 jobs would be created during the development, construction, and installation phase of these facilities.

The greater complexity of components like foundations, substations, cables, and installation vessels creates greater labour requirements for offshore wind farms than onshore installations. The World Bank (2022) low-growth scenario shows that by 2040, 19,000 full-time equivalent (FTE) years of employment will have been created by the offshore wind industry. In the high-growth scenario, it will be 3.9 times more and will provide employment to 69,000 people (Table 2).

Table 2: Impact of offshore wind in Azerbaijan under low- and high-growth scenarios, 2020 to 2040

Fraction of electricity supply in 2040	Low growth scenario 7%
	High growth scenario 37% (5.2 times higher)
Offshore wind operating in 2040	1.5 GW
	7.2 GW (4.7 times higher)
Electricity produced by 2040	55 TWh
	215 TWh (3.9 times higher)
Local jobs created by 2040	19 thousand FTE years
	69 thousand FTE years (3.6 times higher)
Local gross value added by 2040	2 billion USD
	7 billion USD (3.6 times higher)
CO2 avoided	27 million tonnes
	107 million tonnes (3.9 times higher)

Source: WB (2022)

Azerbaijan has been investigating the potential for solar energy along with onshore and offshore wind energy. According to the US Department of Energy (US DOE, 2022), 1 GW of production capacity (crystalline silicon [c-Si] modules) could generate between 1,085 and 2,020 direct jobs across the full value chain.

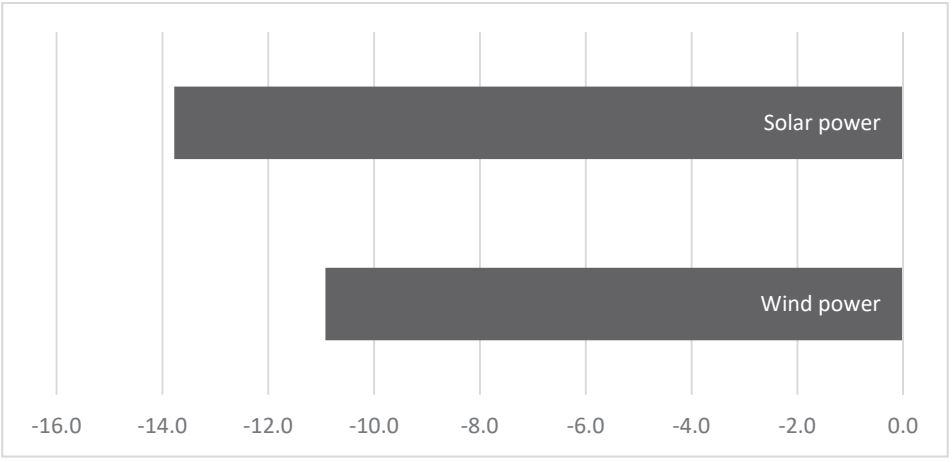
Thus, one can expect that, by implementing mega-projects in the green energy sector, Azerbaijan will also increase levels of employment. It is clear that the economic and social benefits of green energy projects are linked and will contribute to the realisation of Azerbaijan's strategy of socio-economic development (SSED, 2022). Furthermore, one of Azerbaijan's five national

priorities for socio-economic development in the period up to 2030 is "Country of Clean Environment and Green Growth".

When it comes to analysing cost-effectiveness (CE), it is critical to comprehend the consequences of the numerical values obtained from well-established equations in the above sections. An analysis of this kind that produces a positive CE (see equation 5) indicates that the project in question is probably going to cost the investor money. On the other hand, a negative CE indicates that the reduction in emissions in the project is economically beneficial.

From our analysis, wind power has a computed cost-effectiveness of -10.9 CO2 USD/ton, while solar power has a slightly larger economic advantage of -13.8 CO2 USD/ton (Figure 3). These numbers bear witness not only to the financial elements of these renewable energy sources, but also to their positive environmental effects. The economic benefits of reducing CO2 emissions are represented by the negative numbers in this context, highlighting the double advantages of such projects: economic feasibility and environmental sustainability.

Figure 3: Cost-effectiveness ratio of the wind and solar projects



Source: Authors' calculation

The study also adopts co-benefits analysis approach to adress several environmental problems, such as pollution and climate change. The equation (5)

indicates the financial benefits linked to the reduction of emissions of CO2 equivalent. Obviously, adoption of wind power reduces emissions and benefits the environment while simultaneously providing economic rewards. Projected contributions from wind and solar energy projects to the non-oil GDP generated in 2023 are estimated to be 0.11% and 0.07%, respectively. This certainly highlightes the dual advantages of wind energy for the environment and the economy.

4.2.4. Ecological advantage

Azerbaijan's greenhouse gas emissions were 79 million tons of CO2 equivalent in the base year of 1990, and according to the commitment under the Paris Agreement, it aims to reduce emissions by 35% by 2030, that is, a reduction to 51.3 million tons of CO2 equivalent in 2030. According to official information from 1990, greenhouse gas emissions decreased to 47 million tons of CO2 equivalent in 2010. However, as a result of the development of the energy sector in the following period, there was an increase in this area, and Azerbaijan's emissions amounted to 58.1 million tons of CO2 equivalent in 2021 (SSC, 2024). This means that in the coming years, Azerbaijan can achieve its commitment by reducing emissions of up to 6.8 million tons of CO2 equivalent. It will be the green energy projects that play an important role in Azerbaijan's achievement of this commitment.

Azerbaijan accounts for only 0.15 percent of global greenhouse gas emissions. It aims to reduce greenhouse gas emissions by 35 percent by 2030 and 40 percent by 2050 compared to 1990. In terms of installed capacity, this would require installing 1.2 GW of wind and 1.1 GW of solar by 2030 and 3.6 GW of wind and 4.1 GW of solar by 2050 (WB, 2023). In addition, Azerbaijan aims to create a "net-zero emission" zone in the liberated territories. Renewables also offer an important low-carbon solution to meeting Azerbaijan's climate targets (IRENA, 2019). According to the IEA (2022), solar PV and wind are the leading means of cutting electricity sector emissions: their global share of electricity generation will increase from 10% in 2021 to 40% by 2030 and 70% by 2050.

Among the national priorities of Azerbaijan, "green growth" is defined as an important issue in the coming decade. Therefore, in the next decade, as Azerbaijan realises its socio-economic developent according to the five national

priorities, "a Country of Clean Environment and Green Growth" will play an important role (SSED, 2022).

Considering the scale of global climate change, the national policy for this priority will reflect the importance given to the application of environmentally friendly technologies, the use of clean energy sources, recycling of waste, and the restoration of polluted areas. Within this priority, the achievement of two goals is of paramount importance: a *high quality ecological environment* and *spaces for green energy*. The research stresses that it is necessary to increase the share of alternative and renewable energy sources in primary consumption in all sectors of the economy and reduce their impact on climate change (SSED, 2022). The transition to green energy is of exceptional importance in this regard.

A great deal of work remains to be done when analysing the emission of greenhouse gases in Azerbaijan. A particular focus needs to be the energy sector, which has an 80 per cent share in the emission of greenhouse gases, and will thus require substantial investment in order to become low-carbon.

An increase in green energy production marks an important stage in Azerbaijan's transition to zero carbon emissions. One salient fact is that by the end of 2027, wind and solar power plants with a capacity of 1,862 MW are expected to be commissioned, which means a saving of more than one billion cubic metres of gas. On the other hand, SOCAR, which supports the implementation of green hydrogen projects, has accepted a voluntary commitment to reduce methane emissions to zero by 2035 and has signed the appropriate documents. Achieving net zero by 2060 would entail a major transformation of the energy system, and Azerbaijan would have to install approximately 30 GW of wind and solar photovoltaic power plants before 2060 (WB, 2023).

On the other hand, Azerbaijan is one of the countries facing water scarcity, and, in this regard, green energy production will be beneficial. The energy sector is currently the second largest water user in Azerbaijan (11 percent of total demand). A report by the World Bank (2022) stressed that wind farms required very little water and a 1 GW wind farm would save 65 billion litres of water per year (WB, 2022). A World Bank (2023) calculation shows that the large-scale deployment of wind and solar PV would lead to an 80 % reduction in the energy sector's water consumption over the period 2040–2060. A GWEC (2022)

calculation shows that the resulting 5 GW of wind energy should save 28.8 million litres of water annually. Among other benefits, over the lifetime of this onshore wind farm, 240 million metric tons of CO2 emissions would be saved (GWEC, 2022). Natural gas releases, on average, 500 metric tons of CO2 per GWh of electricity generated, and a typical 1 GW wind farm would save over 2.2 million metric tons of CO2 per year (WB, 2022).

4. DISCUSSION

Diversifying Europe's energy supply and ensuring its energy security are of strategic importance. The idea of laying an electric cable across the bottom of the Caspian Sea became relevant later as the discussion of laying an electric cable across the bottom of the Black Sea evolved. If this happens, the opportunities for Central Asian countries to export green energy to Europe will increase. Azerbaijan aims to implement mega-projects in the field of green energy and has been expanding its activities in this field since 2022. The involvement of the world's largest companies in this process and the start of cooperation with the European Union on the export of green energy increase the possibility of achieving these goals. The findings of our study indicate that the transition to green energy will bring multiple benefits for the country, including geo-political, socio-economic, as well as ecological benefits.

Azerbaijan has signed a memorandum with the EU, and one of the important points in this memorandum is the issue of cooperation in the field of green energy. Azerbaijan's goals are to implement large energy projects with its partners that will contribute to the development of the non-oil sector and, at the same time, will play a role in attracting foreign investment to the country and in creating new jobs. The above project is expected to attract foreign investors and increase non-oil export opportunities.

Group discussions on the projects have stressed that the investment costs for renewable energy sources are quite high. On the other hand, these costs will decrease over the next ten years. Another very important point is that the reduction in oil production, which is expected in future years, will have a negative impact on Azerbaijan's economic growth.

However, the increase in green energy production and exports of zero-carbon electricity are of great importance from the point of view of the development of the non-oil sector in Azerbaijan. Ensuring the political stability of Azerbaijan and having foreign currency reserves in the country are also important in terms of attracting foreign investors to green energy projects.

A question that may arise here: does Azerbaijan have the experience to implement such huge projects?

Azerbaijan commissioned and successfully completed the 3,500-kilometre gas pipeline that runs from the fields in the Caspian Sea to Europe on time and is currently exporting gas to the old continent. It exported 11.4 billion cubic metres of gas to Europe in 2022, and this volume reached 11.8 billion cubic metres in 2023. It should certainly be possible to realise green energy projects. In the near future, it is feasible that the countries of Central Asia will export green energy to Europe through the Green Energy Corridor. Access of Kazakhstan and Uzbekistan to these corridors will strengthen the development of markets for electricity in these countries, as well as cooperation in the production and supply of green hydrogen, ammonia, and other products. Partnerships will develop for energy security and green projects within the framework of the Middle Corridor. In the coming years, increased attention will also be focused on Azerbaijan's green hydrogen potential and its export to Europe.

5. CONCLUSIONS

As the host country for COP29, Azerbaijan is taking important steps in the transformation to a green energy economy by using the rich potential of solar and, especially, wind energy in the Caspian Sea and coastal areas. Projects are being initiated in this field for investment by many of the world's leading energy companies, and preliminary agreements have been reached for the production of 28 GW of wind and solar energy. In addition, cooperation between Azerbaijan, Georgia, Romania, and Hungary is moving toward the implementation of the 4 GW capacity Black Sea submarine power line. Serbia and Bulgaria are considering participating in the Caspian–Black Sea–European Green Energy Corridor project. Azerbaijan has started preparations for the export of 5 GW of green energy.

In addition, at the initiative of Azerbaijan and with the participation of Uzbekistan and Kazakhstan, the construction of the energy cable connecting the shores of the Caspian Sea is also being discussed. Thus, the issue of green energy trade with Europe through the Green Energy Corridor of Kazakhstan and Uzbekistan is also on the agenda. These projects in the field of green energy create opportunities to expand the production of electricity and increase export potential by opening significant prospects for the transportation of electricity from Central Asian countries to Europe via Azerbaijan. Green energy projects with a capacity of 28 GW, which Azerbaijan is trying to implement by attracting foreign investors, have already started to have regional importance and will also bring social and economic benefits, as well as ecological benefits.

A cost-effectiveness analysis of green energy projects in Azerbaijan suggests that there are numerous opportunities to cut greenhouse gas emissions through solar and wind power projects that are both economically and environmentally beneficial. This study also highlights the increasing understanding that making investments in renewable energy can be a wise strategic move that balances financial gain with environmental responsibility. This change in perspective represents a major advancement in the fight against climate change and in the direction of sustainable development.

This study emphasizes how important renewable energy initiatives are to improving the country's economic climate, especially in industries unrelated to the production and distribution of oil and gas.

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HETEROGENEOUS DETERMINANTS OF ENVIRONMENTAL SUSTAINABILITY: ASSESSING THE ROLES OF ENERGY CONSUMPTION, ECONOMIC GROWTH, AND FINANCIAL DEVELOPMENT

ABSTRACT: *This study offers unique insights into the heterogeneous influence of energy consumption, economic growth, and financial development on environmental sustainability in Sub-Saharan African (SSA) countries. Basically, the scarcity of evidence on this issue, especially in the context of SSA, motivates this new assessment. Thus, on the basis of the annual panel series for 22 SSA countries over the period 1999–2019, the novel quantile-based method of moments (MM-QR), and system-generalisation method of moments (sysGMM) provide the following results. First, financial development significantly degrades the region's environmental quality. Second, energy utilisation provides varying significant increasing effects. Whereas it largely increases carbon emissions at the upper quantiles, the influence at the middle and low quantiles is inconsequential. This highlights the fact that high levels of energy use in the region significantly increase carbon emissions, which in turn reduces the region's environmental sustainability. Third, the empirical result confirms the inverted U-form hypothesis in the region. Policy options to enhance and maintain sustainable growth in the region without compromising environmental quality have been highlighted.*

KEY WORDS: *environmental sustainability, economic growth, financial development, energy consumption, MM-QR, SSA*

JEL CLASSIFICATION: Q4, Q5, O4

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1. INTRODUCTION

The determination to comprehend, adapt, project, and streamline the main economic and noneconomic components impacting climate change has recently taken centre stage in world discussions. In particular, the United Nations espoused Sustainable Development Goals (SDGs) in 2015, with rigorous frameworks to guarantee that the world is more flourishing, more environmentally friendly, and inclusive by the year 2030. The SDGs' 11th, 12th, and 13th targets, respectively, delineated plans to ensure worldwide ecologically sound communities and cities, sustainable production and consumption structures, and environmentally conscious ecological actions. Furthermore, the Paris Convention in 2015 and the Intergovernmental Panel on Climate Change (IPCC) in 2018 recommended comprehensive blueprints for combating climate change and ensuring the development of less polluted environments worldwide. Additionally, the remarkable Paris conference (COP21) proposed well-thought policy targets, such as keeping the global temperature within 2°C above preindustrial levels while aiming for a further drop in the world temperature to at least 1.5°C. Regardless of how optimistic these global designs are, the bigger challenge is to properly pinpoint the elements driving climatic changes and the pathways on which they enter ecological systems and to ensure environmental sustainability. In particular, a number of variables, including economic growth (Shahbaz et al., 2014; Ali et al., 2016; Arshad et al., 2020; Rafindadi & Usman, 2019;Mesagan & Olunkwa, 2022; Osuntuyi & Lean, 2022; Akadiri et al., 2022), population (Opuala et al., 2022), energy use (Mohiuddin et al., 2016; Asumadu-Sarkodie & Owusu, 2016; Shahbaz et al., 2014; Rafindadi, 2016; Rafindadi & Usman, 2019; Adebayo et al., 2022; Opuala et al., 2022), exhaustion of natural resources (Dingru et al., 2023), financial development (Musah et al., 2022; Boutafeh & Saadaoui, 2020; Ye et al., 2020; Nwani & Omoke, 2020; Uche & Effiom, 2021, Anochiwa et al., 2022), urban sprawl (Opuala et al., 2022), structural transformations, technological advancements (Ahmed & Le, 2021), foreign direct investments (Opuala, et al., 2022), migration, institutions, and remittance inflows (Brown et al., 2020; Yang et al., 2021; Ahmad et al., 2022; Nwani et al., 2022; Uche, 2022) have been identified as potential determinants of environmental degradation.

Theoretically. the increased exploitation of petroleum-based energy sources as a significant component of energy resource availability, amongst other reasons, has

been directly related to the increasing carbon dioxide emissions, which is seen as a major determinant of environmental sustainability (Owusu & Asumadu-Sarkodie, 2016; Owusu, et al., 2016). Furthermore, the momentous role of financial development (FD) in driving economic growth has been established (Levine et al., 2000; Levine, 2005), although some researchers believe that financial development can only strike a win-win balance between economic growth and environmental sustainability (M. Kahn et al., 2022); yet others argue that it is the backbone of economic growth because an organised and functional financial sector can provide economic stability (Odionye & Okorontah, 2014; Katircioglu & Taspinar, 2017). However, financial development is accompanied by an increase in energy consumption, which obviously leads to undesirable environmental degradation. The sudden rise in CO_2 emissions has been attributed to the increase in the production and consumption rate of industrially manufactured goods enhanced by financial development in the developed and developing countries. Many countries, especially developing ones, including African countries, have neglected the adverse environmental effects of CO_2 emissions in order to promote economic growth (Nwani et al., 2022).

Although the detrimental environmental effect of the use of energy is a worldwide concern, tackling the menace is critical in the context of CO_2 emissions because the African continent is reported to be at higher risk of the consequences of environmental degradation with very little adaptation capacity (International Energy Agency [IEA], 2019; United Nations Environment Programme, [UNEP], 2020). Considering the adaptability issues, and the importance attached to improving quality of life and also maintaining environmental quality, it is imperative in the context of SSA to explore what drives environmental sustainability. Furthermore, the trajectory of carbon emissions in Sub-Saharan Africa has increased significantly in the previous few decades. World Bank data (2021) indicate that carbon emissions in SSA increased by more than 380% between 1960 and 1990. They increased by 26.1% between 1990 and 2000, rising from 1,213,589.1 kt to 1,529,884.4 kt. Between 2000 and 2020, they climbed by around 47.6%, from 1,529,884.4 kt to 2,258,595.5 kt. This shows the substantial upsurge in carbon emissions in the region, given that the region's energy use is among the lowest in comparison to other regions.

According to WMO (2022), the region's temperature, as an indication of elevated carbon emissions, rose faster than the rest of the world in 2021. WMO (2022) indicates that between 1991 and 2021 Africa continued warming, exhibiting a mean rate of change of roughly +0.3 °C/decade, compared to +0.2 °C/decade between 1961 and 1990, 0.04 °C/decade between 1931 and 1960, and +0.08 °C/decade between 1901 and 1930. Africa has warmed faster than the rest of the world (WMO, 2022). According to the IPCC AR6, rising average temperature trends across Africa are caused by human-caused climate change. Between 1901-1930, and 1991-2021, all six African sub-regions witnessed a rising trend in temperatures.

Not with standing the increasing number of studies on drivers of ecological systems, there is still a dearth of studies focusing on the heterogeneous influence of energy use, financial development, and economic growth on environmental sustainability in the context of Sub-Saharan African countries. The existing studies on SSA, which include Opuala et al. (2022), Uche and Effiom (2021), Nwani et al. (2022), and Dingru et al. (2023), did not consider the heterogeneous determination of environmental sustainability, except Anochiwa et al. (2022), which examined the distributional link between financial deepening and CO_2 emissions. While Nwani, et al. (2022) focused on the relationship between remittances and CO_2 emissions in SSA, Dingru, et al (2023) centered on the renewable energy influence of trade and natural resources in SSA. Opuala et al. (2022) examined the interconnection between financial development, energy use, and environmental quality in the West African region. Furthermore, extant studies reveal two exceptional features in the literature on the connection between environmental quality and growth. Some studies found a bidirectional link between the series of data (see Rafindadi, 2016; Rafindadi & Usman, 2019; Mesagan et al., 2022; Musibua et al., 2021; Mung et al., 2021). Moreover, the impact on environmental quality can be influenced by the size of the growth rate, in line with the environmental Kuznets curve (EKC), as well as the developmental stage of a nation in line with the environmental transition (ET) theory. The environmental transition theory posits that the environmental challenge changes as the developmental stage of a city changes (McGranahan et al., 2001; Shahbaz, et al., 2014; Rafindadi, 2016; Rafindadi & Usman, 2019). The above strands of empirical evidence point to the econometric issues of endogeneity and heterogeneity on the interaction between the series of data. So far, reliance on

empirical evidence to resolve the heterogeneous determinants of environmental sustainability issues has yet to yield the much-needed result, thus leaving the empirical question open for further investigation.

This study contributes to the existing energy-environmental economics literature in the following ways: first, it utilises the novel quantile-based GMM (MM-QR) approach developed by Machado and Silver (2019) to assess the heterogeneous determinants of environmental sustainability in 22 selected countries in SSA; second, it extends the study of Anochiwa et al. (2022) by using total CO_2 emissions, rather than consumption-based emissions; third, while Anochiwa et al. (2022) was limited to 19 countries in SSA, this study extends the cross-sectional units to 22 SSA nations, with the selection of nations based on data availability; fourth, a newly modified version of GMM that permits nonlinear moments and improves efficiency and robustness of the estimates as suggested by Kripfganz (2020) was utilised for robustness estimates.

In the light of the foregoing, the study employed the novel MM-QR with the fixed effects method, which takes into account the econometric issues of heterogeneity and endogeneity, to estimate the size-based influence of the listed explanatory variables on environmental sustainability in SSA. In addition to the introductory section, the remaining parts of the study are organised as follows: section two reviews the literature, section three discusses the methodological framework, section four discusses the empirical results, and section five concludes with policy implications and recommendations.

2. LITERATURE REVIEW

2.1 Theoretical literature

Some theories have linked environmental sustainability with some economic and non-economic factors such as economic growth, energy consumption, financial development, urbanisation, and others, which in turn demands appropriate policies and their effective implementation to enhance a sustainable environment. The two main theories guiding this study are the environmental Kuznets curve and the environmental transition theory (McGranahan et al., 1996, 2001). The EKC postulates that economic growth and development initially harm the environment, but after some progressive level of economic growth, there is an

improvement in the relationship between society and its environment which results in a reduction in societal environmental degradation. The EKC hypothesises that production activities and economic growth results in persistent environmental pollution which is detrimental to environmental sustainability. Structural transformations to facilitate economic growth increase carbon emissions and green development is not adequate to offset the overall environmental damage. There is a rise in demand for energy and massive use of natural resources as nations seek higher growth and development. Consequently, there is excess waste generation, carbon dioxide emissions, and so on, resulting in environmental degradation (Iheonu et al, 2022). The EKC is generally represented as an inverted U-shape curve. On the other hand, the ET theory posits that there exist diverse environmental issues linked with progress that do not follow the EKC trend (McGranahan et al., 1996, 2001). McGranahan et al. (2001) show that as cities get wealthier, their environmental effects move from being a localised menace to a worldwide ecosystem problem. The ecological menace changes from the rural-level problems of water accessibility and sanitation problems to urban problems of air and water pollution as certain areas grow from rural to urban areas. For cities grappling with "green" concerns, the most substantial ecological effects of urban-based activities are regional, if not global (e.g., greenhouse gas, acid rain, and ozone depleting chemical emissions). The theory states that nations experience a number of environmental problems as they grow and develop, and such growth and development are mainly functions of industrialisation, which demands higher energy consumption and financial development, resulting in higher CO_2 emissions (Iheonu et al., 2022) Thus, the scale of the ecological problem is development-dependent.

2.2 Empirical review

Many researchers in developed and emerging nations of Asia have conducted empirical studies linking financial development, energy utilisation, economic growth, and other economic and non-economic variables with environmental sustainability, while very few studies on countries of the African continent exist. Amongst the prior studies on African countries are, notably, Shahbaz et al. (2014) on Tunisia, Asongu et al. (2019) for 13 African countries, Rafindadi and Usman (2019) for South Africa, Rafindadi (2016) and Uche and Effiom (2021) on Nigeria, Musah et al. (2022) on selected countries of West Africa, Boutafeh and

Saadaoui (2020) on 22 African countries, and Mesagan and Olunkwa (2022) on 18 African countries.

Shahbaz et al. (2014) and Rafindadi and Usman (2019) adopted the vector error correction model (VECM) and the causality estimation technique to evaluate the EKC supposition in Tunisia and South Africa, respectively. Both studies support the EKC view for the investigated nations. While the study of Rafindadi and Usman (2019) indicates an inverse impact of globalisation on environmental quality, Shahbaz et al. (2014) favours trade openness as a co-driver of environmental quality. Rafindadi and Usman (2019) also detected a one-way direction of influence of energy utilisation on environmental sustainability. Similarly, in the context of Nigeria, Rafindadi (2016) examined the effect of economic growth and financial development on carbon emissions. The study adopted diverse dynamic estimation techniques such as autoregressive distributed lag model (ARDL), VECM, and causality approaches in its data analysis. The study's outcome indicates that financial development significantly increases energy utilisation but improves environmental quality, while economic growth reduces energy utilisation but worsens environmental quality in Nigeria. A similar study was conducted by Asongu et al. (2019) in selected African countries using a pooled mean group (PMG) version of ARDL and the study's result confirms the environmental Kuznets curve postulation.

Anochiwa et al. (2022) focused on the distributional influence of financial development on consumption-based carbon emissions in 19 selected SSA countries. The study employed the quantile-based version of the generalised method of moments analytical approach in its estimation. The study's outcome indicates that financial development significantly worsens the region's environmental sustainability through CO_2 emissions. In addition, it refutes the EKC hypothesis. Similarly, S. Khan et al. (2021) used dynamic econometrics estimation techniques in the context of 184 nations and observed that financial deepening significantly worsens the environmental quality of the selected nations, while energy utilisation significantly increases CDE and hence leads to a deterioration of environmental sustainability. In contrast, Omoke et al. (2020), in the case of Nigeria, examined the symmetric and asymmetric reaction of environmental deterioration to positive and negative changes in financial development. The study employed an ARDL framework and its nonlinear version

in its data analysis and observed a short-term asymmetric link between the investigated series. The study also observed a direct link between elevated financial development and environmental deterioration through increased carbon emissions in Nigeria.

Musah et al. (2022) utilised the cross-sectional autoregressive distributed lag (CS–ARDL), cross-sectional augmented error correction (CAEC), as well as the cross-sectional augmented distributed lag (CS–DL) methods of estimation to explore the relationship between financial development and environmental sustainability in West Africa. The study's outcome shows that financial development is detrimental to environmental quality in West Africa through increased carbon emissions. Researchers with the same result are Boutafeh and Saadaoui (2020), who adopted the ARDL–PMG estimation method in 22 African countries, Ye et al. (2021) in Malaysia, Nwani and Omoke (2020) in Brazil, and Ahmed et al. (2021) in Japan, all with the ARDL technique.

However, Boutafeh and Saadaoui (2020) as well as Mesagan and Olunkwa (2022), using ARDL–PMG and pooled mean group estimation methods in 22 and 18 African countries, respectively, examined the long-term and short-term effects of financial development on environmental sustainability, and their findings show that financial development has a long-term inverse influence on environmental sustainability. However, it indicates that financial development in the short run enhances environmental sustainability.

A few studies have looked at how energy utilisation influences environmental sustainability. Mesagan and Olunkwa (2022) examined how energy consumption affects environmental pollution in 18 African countries using the PMG estimation method while Osuntuyi and Lean (2022) used ARDL–PMG and heterogeneous causality test estimation methods to investigate the effect of energy consumption on environmental degradation in 92 countries. Their empirical results indicate that energy consumption has a negative effect on environmental pollution and environmental degradation, respectively, in the short run, whereas Mesagan and Olunkwa (2022) found that environmental pollution was positively and significantly affected by energy consumption in the long run. Similarly, Shahbaz et al. (2013) used the VECM estimation technique to obtain the same

result in the South African economy using CO_2 emissions as a proxy for environmental sustainability.

Omojolaibi (2010) determined how economic growth affects environmental sustainability in West Africa. He used carbon emissions as a proxy for environmental sustainability and the result from his panel data estimation research indicates that economic growth negatively affects environmental sustainability. The study suggests that governments of West African countries should adopt energy conservation policies in the economic production process to avoid environmental degradation. S. Khan et al. (2021), using an ARDL estimator, obtained a similar result in Pakistan: economic growth increases carbon emissions, which is detrimental to environmental sustainability. In addition, the outcome of Marques et al. (2018), using dynamic ordinary least square (OLS) and an autoregressive distributed lag model, affirms that economic growth had a significant negative long-run effect on carbon emissions in Australia. Farhani et al. (2014) tested the environmental Kuznets curve hypothesis in ten North African and Middle East countries using a panel data method. The result indicates that economic growth and human development negatively affect environmental sustainability. Ondaye et al. (2021) studied the influence of economic growth on CO_2 emissions in the Republic of Congo from 1980 to 2015 using ARDL modelling and showed that economic growth has no significant effect on CO_2 emissions in the period under review. Similarly, Shahbaz et al. (2014) utilised the VECM estimation technique to investigate the effect of energy consumption and economic growth on environmental sustainability in the Tunisian economy and demonstrated that CO_2 emissions increased as a result of an increase in energy consumption and economic growth.

Mesagan et al. (2022) studied the effect of carbon emissions and energy consumption on economic growth in West African countries using Granger causality and full maximum OLS estimation techniques. Their findings indicate that increased energy consumption and carbon emissions enhanced economic growth in West Africa. A unidirectional causal relationship from environmental pollution to energy consumption as well as bidirectional causality between carbon emissions and output growth were found in Ghana while, economic growth Granger causes carbon emissions in Gambia. Their study differs from our own in the sense that it looked at the effect of carbon emissions (a proxy for

environmental sustainability) and energy consumption on economic growth while our work will look at how energy consumption and economic growth affect environmental sustainability. Similarly, Musibua et al. (2021) empirically investigated the effect of environmental performance on economic growth of West African. They used two stage least square (2SLS) and moment quantile research methods to find that environmental performance positively affects economic growth in ECOWAS nations.

Our study departs from existing studies by adopting the novel quantile-based GMM (MM-QR) approach developed by Machado and Silva (2019) to assess the heterogeneous determinants of environmental sustainability in 22 selected SSA countries. Closest to this study in terms of approach is that of Anochiwa et al. (2022), which employed MM-QR to examine the connection between financial development and consumption-based CO_2 emissions in 19 SSA nations. Our study extends Anochiwa et al. (2022) by examining the heterogeneous drivers of environmental sustainability, the roles of economic growth, financial development, and energy use, utilising production-based carbon emissions as well as extending the cross-sectional units to 22 nations in SSA, carefully selected on the basis of data availability. In addition, we used two-step GMM, as suggested by Blundell and Bond (1998), and its newly modified version, which permits nonlinear moments and improves the efficiency and robustness of the estimates, as suggested by Kripfganz (2020).

3. METHODOLOGY

3.1 Data description

To uncover the intricacies surrounding the interactions of the relationship under study, the investigation harvests annual balanced panel series covering the period 1999–2019 drawn from 22 selected SSA countries. The choice of the selected countries was based on data availability. Furthermore, the choice of techniques is predicated on a short-panel framework with a larger cross-sectional (N) dimension and a smaller time (T) dimension (N=22 >T=21). Additionally, due to the study's objectives of assessing the heterogeneous influence of energy consumption, economic growth, and financial development on environmental quality, relevant macroeconomic series were extracted from the World Bank's

data repository for empirical estimations. Table 1 provides a detailed explanation of the composition of these identified panel series.

Table 1: Data descriptions

Series	Notation	Unit of measurement	Source
CO2 Emissions	Cdm	CO2 emissions, (metric tons per capita)	WDI
Energy Consumption	Erc	Energy used (kg of oil equivalent per capita)	WDI
Gross Domestic Product	Gdp	GDP at market prices (current USD)	WDI
Growth Rate of GDP per capita	GrGDP	The annual percentage growth rate of GDP per capita based on constant USD	WDI
Financial Development	Fdt	Domestic credit to private sector (% GDP)	WDI
Population	Ppu	Population (total)	WDI
Urban Population	Ubn	Urban population (% of total population)	WDI
Selected SSA countries: Benin, Botswana, Cameroon, Côte d'Ivoire, DR Congo, Congo Republic, Eritrea, Ethiopia, Gabon, Ghana, Kenya, Mauritius, Mozambique, Namibia, Niger, Nigeria, Senegal, South Africa, Tanzania, Togo, Zambia, and Zimbabwe			

Note: WDI denotes World Development Indicators, World Bank data repository (WDI, 2022).

3.2 Model specification

Consistent with the Kuznets environmental curve (EKC) hypothesis and in line with relevant prior studies (Osuntuyi & Lean, 2022; Mesagan & Olunkwa, 2022), our investigation considers a dynamic panel estimation process, namely MM-QR, to evaluate the heterogeneous influences of energy consumption, economic growth, financial development, and other control variables on environmental quality in SSA countries. The inclusion of the control variables is premised on their critical roles in affecting environmental sustainability, which is consistent with the relevant prior studies (Shahbaz et al., 2014; Rafindadi, 2016; Rafindadi & Usman, 2019). Consequently, the following equation describes the model linking environmental quality with the explanatory variables.

$$lcdm_{it} = b_0 + b_1lerc_{it} + b_2lgdp_{it} + b_3lgdp^2_{it} + b_4lfdt_{it} + b_5lppu_{it} + b_6lubn_{it} + \varepsilon_{it} \quad (1)$$

In Equation 1, *lcdm, lerc, lgdp, lgdp², lfdt, lppu* and *lubn* represent the natural log of CO_2 emissions, energy consumption, gross domestic product, squared GDP, financial development, total population, and urban population, respectively. Two different measures of growth were used in the study, namely growth rate of GDP per capita (2010 constant USD) and GDP at market prices. The reason is to validate the result that was obtained using nominal GDP and to serve as a robustness check. Growth rate of GDP per capita has been widely used as a proxy for growth in environmental studies (Rafindadi, 2016; Rafindadi & Usman, 2019; S. Khan et al., 2021; Anochiwa et al., 2022). Additionally, the subscripts *i* and *t* denote the cross-sectional and time dimensions, respectively, while *ε* indicates the stochastic error component. Instructively, all the series used were transformed to natural logarithmic values essentially to minimise the chances of serial correlation and to allow for consistent estimates based on point elasticities.

3.3 Estimation techniques

Method of Moments Quantile Regression (MM-QR)

As highlighted earlier, the study utilised the newly introduced MM-QR panel in the evaluation of the interactions of the listed series on environmental sustainability in SSA. It is interesting to note that this procedure was performed primarily to generate novel perspectives and improve understanding of the heterogeneous influence of the listed series on environmental sustainability in SSA, given that such empirical accounts are uncommon in previous studies. Aside from the apparent, the choice of the MM-QR is also based on the significant characteristics of this recently suggested panel estimator. As a result, these benefits include its capacity to expose the implications of changes in variables on the response variable throughout a range of distributions in a more complete manner using moment (quantile regression via moments) stages (Machado & Silva, 2019). Moreover, while the approach is robust in the presence of heteroscedasticity and outliers, it also reveals distributional heterogeneity along the conditional distributions of the outcome variable (Bista & Khan, 2022). Remarkably, unlike previous convectional quantile regression approaches, the MM-QR method takes into account unique country-specific fixed effects that are resistant to incidental parameter challenges over its entire distribution (Bista &

Khan, 2022). In addition, the MM-QR, which can handle irregularly distributed data, is based on both location and scale effects. The baseline location-fixed effects quantile technique was inspired by Machado and Silva (2019) and several similar recent investigations (Adeleye et al., 2022; Boikos et al., 2022). This procedure is thus represented in Eqn. (2).

$$Q_{\Upsilon}(\tau \mid \mathrm{X}_{it}) = (\alpha_i + \theta_i \delta_i) + \mathrm{X}'_{it}\beta + \mathrm{K}'_{it}\gamma\rho(\tau) \quad (2)$$

In Eqn. (2), $Q_{\Upsilon}(_{\tau}|\mathrm{X}_{it})$ shows the conditional quantile distributions of the outcome variable, which is determined by the explanatory variables; X_{it} represents the vector of all the listed predicting variables; $\alpha_i(\tau) = \alpha_i + \theta_i\delta_i(\tau)$ represents the scalar coefficient of the $\tau - th$ quantile of the individual *i* specific fixed effects; K'_{it} describes the *K*-vector; $\rho(\tau)$ represents the $\tau - th$ quantile, which has been expressed through an optimisation process illustrated in Eq. (3).

$$\min_{\theta} \sum_{i}\sum_{t} \sigma_{\tau}(F_{it} - (\delta + K'_{it}\gamma)\theta) \quad (3)$$

where $\rho_{\tau}(A) = (\tau - 1)AI\{A \le 0\} + \tau AI(\{A > 0\})$ symbolises the quantile conditional check-function. Following Eqn 1, in specific form, the MM-QR is expressed as:

$$Qlcdm(\tau \mid \mathrm{X}_{it}) = \beta_0 + \beta_1 lerc_{it} + \beta_2 \lg dp_{it} + \beta_3 \lg dp_{it}^2 + \beta_4 lfdt_{it} + \beta_5 lppu_{it} + \beta_6 \mathrm{lub}n_{it} + \varepsilon_{it} \quad (4)$$

The variables are defined as in Eqn 1.

System Generalized Methods of Moments (sysGMM)

As a robustness check, two-step GMM, as suggested by Blundell and Bond (1998), and its modified version that permits nonlinear moments (Ahn & Schmidt, 1995) and improves the efficiency and robustness of the estimates (Kripfganz, 2020) were used. Given the composition of the relevant panel series on the basis of which the estimated outcomes of this study are predicted, the method of moments (GMM) procedures and their related extensions are preferred. This choice of the GMM panel estimator is also premised on the fact that it remains the predominant technique in several studies with similar frameworks. It is

worthwhile to highlight that, in contrast with the steps taken in the prior literature, the current investigation took advantage of both the linear and nonlinear variants of the system generalised methods of moments (*sys*GMM) techniques. Instructively, the choice of the GMM dynamic panel estimator introduced by Arellano and Bond (1991) and its extension by Arellano and Bover (1995) is justified in several respects. First, the study used a micro-dynamic panel framework where the number of the cross-sections surpasses the number of observations (N>T), which ultimately controls for dynamic panel bias (Bond, 2002; Omri, 2020; Roodman, 2009). Given the N>T framework, the precondition to adopt the GMM procedure is fulfilled. Second, the preference for the sysGMM is predicated on the fact that it controls for infinite sample bias more efficiently than the difference GMM (Baltagi, 2009). Likewise, the model produces more robust estimates; hence, it efficiently controls the endogeneity bias associated with such a dynamic panel framework. In addition, the sysGMM estimator also accounts for reverse causality and at the same time ensures that cross-sectional exigencies are not precluded in the regression (Khan & Ozturk, 2021). Additionally, unlike the estimates of related prior studies that emerged through the *xtabond2* Stata command, this study preferred the *xtdpdgmm* command that generates robust nonlinear estimates within the sysGMM process (Kripfganz, 2020). Furthermore, the *estat serial, (1/2)* and the *estat overid* commands were relied upon for Arellano–Bond's first-differenced residuals autocorrelation test and Sargan–Hansen's overidentifying restriction test, respectively.

4. RESULTS AND DISCUSSION

4.1 Descriptive statistics and correlation matrix

Empirical presentations often start with some rudimentary descriptive test that sets the way for more robust estimations. Therefore, summary statistics and correlation tests were applied to the necessary series for the purpose of this study. These tests, among other things, indicate the form of the distributions, the series' behavioural trends, as well as the strength of the relationships. Specifically, descriptive statistics provide information that highlights whether the series are typically distorted whereas the correlation matrix divulges any likely multicollinearity issues. Table 2, therefore, summarises the test results.

Table 2: Descriptive statistics and correlation matrix

	LCDM	LERC	LFDT	LGDP	GrGDP	LGDP^2	LPPU	LUBN
	Panel A: Descriptive Statistics							
Mean	-0.946	6.237	2.699	23.13	2.431	536.72	16.28	4.081
Maximum	2.149	8.048	5.076	27.07	12.41	732.73	19.01	14.65
Minimum	-3.429	4.728	-0.710	20.18	-9.421	407.17	13.91	2.627
Std. Dev.	1.404	0.669	0.957	1.283	2.872	60.65	1.331	2.305
Skewness	0.364	0.662	-0.148	0.758	0.632	0.953	-0.129	4.154
Kurtosis	2.316	3.708	4.404	3.980	3.104	4.307	2.098	18.91
Jarque–Bera	19.19**	43.44**	39.64**	62.76**	30.27* *	102.9**	16.91**	620**
Probability	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Observations	462	462	462	462	462	462	462	462
	Panel B: Correlation Matrix							
LCDM	1							
LERC	0.699	1						
LFDT	0.603	0.545	1					
LGDP	0.117	0.457	0.262	1				
LGDPPC	0.245	0.356	0.123	0.345	1			
LGDP2	0.119	0.461	0.271	0.799	0.674	1		
LPPU	-0.586	-0.148	-0.192	0.636	0.234	0.637	1	
LUBN	0.283	0.145	0.216	-0.080	-0.211	-0.084	-0.373	1

Note: ** and * depict statistical significance at the 1% and 5% significance levels, respectively

Table 2 demonstrates that the series deviates from the normal distribution on the basis that the Jarque–Bera statistics are significant. It is worth noting that these outcomes justify the application of GMM approach within the quantile framework, which is capable of producing robust estimates amidst an abnormal distribution (Koenker & Bassett, 1987; Ullah et al., 2022; Bista & Khan, 2022; Uche, Odionye & Ngepah, 2023; Uche et al., 2023; Odionye et al., 2023; Odionye, Ojiake & Uba, 2023; Odionye et al., 2024). The correlation matrix (Panel B) indicates the absence of multicollinearity as the correlation coefficients between the explanatory variables are less than 0.8.

4.2 The methods of moment quantile regression (MM-QR) estimates

As stated earlier, the MM-QR is the baseline estimation relied upon to explain the heterogeneous influence of energy consumption, economic growth, and financial development on environmental sustainability in SSA. Instructively, the relevant outcomes are summarised in Table 3 for brevity.

Based on the abridged outcomes in Table 3 (Panel A and B) generated from the MM-QR, it is important to emphasise that, among other interesting results, financial development (lfdp) largely increases carbon emissions in the SSA across all the quantiles. The outcome also demonstrates that the influence of financial development on environmental sustainability via CO_2 emissions increases heterogeneously along the upper quantile change. The results were not different when GDP per capita was used as a proxy for economic growth (Panel B). What this means is that financial development significantly worsens region environmental sustainability; as the region's financial sector deepens, it increases CO_2 emissions, and thereby enervates the environmental quality in the SSA region. This outcome aligns with the results of Musah et al. (2022) for West African countries, Boutafeh and Saadaoui (2020) for 18 selected African countries, Ye et al. (2020) for Malaysia, Nwani and Omoke (2020) for Brazil, and Ahmed et al. (2021) but contradicts the finding of Mesagan and Olunkwa (2022) for 18 African countries.

Pertaining to energy consumption (lerc), the computations demonstrate that its influence is heterogeneous in both models (Panels A and B). Categorically, with regard to location and scale, as well as at the upper quantiles (qtile_70–qtile_90), energy consumption provides varying significant increasing effects. Whereas at the upper quantiles (qtile_70–qtile_90) it largely increases carbon emissions by 0.269%, 0.288%, and 0.298%, respectively, at the middle and low quantiles (qtile_10–qtile_60) the influence is inconsequential. This highlights the fact that the high level of energy used in the region significantly increases carbon emissions, which in turn reduces the region's environmental sustainability. The implication of this outcome is that high-energy-consuming nations experience high carbon emissions, hence increasing the environmental sustainability problem. This corroborates the results of Rafindadi and Usman (2019) for South Africa, Mohiuddin et al. (2016) for Pakistan, Asumadu-Sarkodie and Owusu (2016) for Ghana, Shahbaz et al. (2014) for Tunisia, and Rafindadi (2016) for Nigeria.

Table 3. Estimates of MM-QR

VARIABLES	(1) Location	(2) Scale	(3) qtile_10	(4) qtile_20	(5) qtile_30	(6) qtile_40	(7) qtile_50	(8) qtile_60	(9) qtile_70	(10) qtile_80	(11) qtile_90
Panel A: GDP at market value											
Lerc	0.240**	0.113**	0.170	0.195	0.213	0.227	0.242	0.255	0.269***	0.288**	0.298**
	(0.081)	(0.043)	(0.207)	(0.163)	(0.154)	(0.162)	(0.185)	(0.212)	(0.046)	(0.097)	(0.116)
Lfdt	0.194***	0.090**	0.129**	0.152***	0.169***	0.182***	0.197***	0.209***	0.222***	0.239***	0.258**
	(0.0546)	(0.0433)	(0.0625)	(0.0493)	(0.0465)	(0.0489)	(0.0559)	(0.0640)	(0.0742)	(0.0893)	(0.107)
Lgdp	0.143**	0.0611	0.0437	0.0795	0.105**	0.124**	0.147**	0.165**	0.184**	0.211**	0.239**
	(0.0616)	(0.0489)	(0.0705)	(0.0557)	(0.0525)	(0.0512)	(0.0631)	(0.0721)	(0.0835)	(0.101)	(0.120)
lgdp2	-0.103**	0.107**	-0.0037	-0.0015	-0.105	0.124**	0.147**	-0.44***	-0.452**	-0.47***	-0.46***
	(0.0416)	(0.0409)	(0.0405)	(0.0557)	(0.352)	(0.0552)	(0.0631)	(0.1101)	(0.160)	(0.101)	(0.096)
Lubn	-0.126	0.0456	-0.200	-0.173	-0.154	-0.139	-0.123	-0.109	-0.0944	-0.0748	-0.0535
	(0.302)	(0.240)	(0.345)	(0.273)	(0.257)	(0.271)	(0.310)	(0.355)	(0.412)	(0.497)	(0.595)
Lppu	-0.0431	-0.294	0.434	0.262	0.141	0.0461	-0.0614	-0.150	-0.244	-0.370	-0.507
	(0.267)	(0.212)	(0.306)	(0.242)	(0.228)	(0.239)	(0.274)	(0.313)	(0.362)	(0.436)	(0.522)
Constant	-5.055	2.963	-9.860***	-8.126***	-6.906**	-5.953**	-4.870	-3.981	-3.035	-1.763	-0.381
	(3.278)	(2.602)	(3.751)	(2.964)	(2.793)	(2.938)	(3.357)	(3.840)	(4.448)	(5.358)	(6.417)
Observations	462	462	462	462	462	462	462	462	462	462	462
Fixed effect	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

Panel B: Growth rate of GDP per capita

Lerc	0.242**	0.116**	0.172	0.191	0.196	0.213	0.222	0.245	0.25***	0.291**	0.296**
	(0.091)	(0.043)	(0.207)	(0.163)	(0.172)	(0.222)	(0.195)	(0.212)	(0.046)	(0.097)	(0.116)
Lfdt	0.189**	0.092**	0.109**	0.121***	0.15***	0.18***	0.19***	0.19***	0.201**	0.22***	0.23**
	(0.0646)	(0.0411)	(0.0425)	(0.0421)	(0.037)	(0.046)	(0.062)	(0.061)	(0.084)	(0.0793)	(0.101)
Lgdp	0.101**	0.06**	0.036	0.079**	0.085**	0.101**	0.106**	0.112**	0.112**	0.17***	0.19**
	(0.038)	(0.029)	(0.071)	(0.036)	(0.0325)	(0.041)	(0.041)	(0.0421)	(0.0435)	(0.044)	(0.042)
lgdp2	-0.11**	0.10**	-0.011	-0.015	-0.096	0.105**	-0.15**	-0.19**	-0.19**	-0.23**	-0.24**
	(0.039)	(0.044)	(0.041)	(0.036)	(0.052)	(0.035)	(0.061)	(0.060)	(0.060)	(0.06)	(0.077)
Lubn	-0.124	0.031	-0.181	-0.164	-0.167	-0.144	-0.133	-0.141	-0.195	-0.175	-0.153
	(0.302)	(0.240)	(0.421)	(0.273)	(0.117)	(0.171)	(0.271)	(0.312)	(0.251)	(0.217)	(0.495)
Lppu	-0.123	-0.164	0.401	0.311	0.141	0.0461	-0.0614	-0.150	-0.244	-0.370	-0.507
	(0.231)	(0.212)	(0.356)	(0.282)	(0.228)	(0.239)	(0.274)	(0.313)	(0.362)	(0.436)	(0.522)
Constant	-5.055	2.963	-9.86***	-8.13***	-6.91**	-5.94**	-4.82	-3.97	-3.03	-1.76	-0.381
	(3.278)	(2.602)	(3.751)	(2.964)	(2.793)	(2.938)	(3.357)	(3.840)	(4.448)	(5.358)	(6.417)
Observations	462	462	462	462	462	462	462	462	462	462	462
Fixed effect	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Regarding the economic growth variable (lgdp) and its square ($lgdp^2$), the results in Table 3 (panels A and B) confirm the inverted U-form hypothesis that at the initial developmental stage, elevated economic growth increases CO_2 emissions (degrades environmental quality) but at a later stage, after some progressive level of economic growth, there comes a relationship enhancement between society and its environment which results in a reduction in societal environmental degradation. This obvious outcome is exemplified by the positive and significant influence of lgdp on CO_2 with regard to location as well as at the middle and upper quantiles (qtile_30–qtile_90), while the location, scale, and various quantiles of $lgdp^2$ demonstrate the varying nature of the influence of the square of economic growth ($lgdp^2$), with negative coefficients at the 60^{th}, 70^{th}, 80^{th}, and 90^{th} quantiles. When the growth rate of GDP per capita was used as a proxy for growth (Panel B), the outcome further verifie the U-shape hypothesis as both the level and square of GDP are significant. These outcomes, irrespective of the measure of GDP utilised, align with those of Shahbaz et al. (2014) for Tunisia, Rafindadi (2016) for Nigeria, Mesagan and Olunkwa (2022) for selected African countries, S. Khan et al. (2021) for 184 selected, Marques et al. (2018) for Australia, Farhani et al. (2014), and Osuntuyi and Lean (2022) for 92 countries. Shahbaz et al. (2014) found that as the square of GDP reduces carbon emissions, GDP increases them. The result also indicates that population (lppu) and urbanisation (lubn) insignificantly affect environmental sustainability in the region.

Table 4: Impact of the explanatory variables on the environmental sustainability using the GMM approach

	GDP at Current Prices			Growth Rate of GDP per capita		
VARIABLES	**SGMM[1]**	**SGMM**	**DGMM**	**SGMM[1]**	**SGMM**	**DGMM**
Lcdm	0.634***	0.87***	0.755***	0.59***	0.731***	0.821***
	(0.1199)	(0.106)	(0.153)	(0.116)	(0.261)	(0.323)
Lerc	0.141**	0.25***	0.318*	0.111**	0.231***	0.256*
	(0.0673)	(0.087)	(0.168)	(0.0373)	(0.078)	(0.148)
Lfdt	0.241**	-0.0181	0.148*	0.241**	-0.0171	0.118*
	(0.105)	(0.032)	(0.0880)	(0.105)	(0.0617)	(0.080)
Lgdp	0.0601***	0.049**	0.0668**	0.04***	0.055**	0.058***
	(0.0194)	(0.024)	(0.026)	(0.010)	(0.024)	(0.019)
Lgdp2	-0.020**	-0.023	-0.134**	-0.01**	-0.04*	-0.10**
	(0.0094)	(0.045)	(0.051)	(0.0044)	(0.027)	(0.049)
Lubn	0.0139	-1.28**	-0.123	0.0139	-1.177**	-0.123
	(1.5565)	(0.403)	(0.0924)	(1.5565)	(0.523)	(0.0924)
Lppu	0.149	0.466	-0.0341	0.149	0.466	-0.0341
	(0.8264)	(0.297)	(0.144)	(0.8264)	(0.297)	(0.144)
Constant			0.0193			0.0193
Observations	460	460	460	460	460	460
No. of crossid	22	22	22	22	22	22
country effect	YES	YES	YES	YES	YES	YES
year effect	NO	NO	NO	YES	YES	YES
YE_WT				0.981	0.07	1.230
Hansen_test		15.6	11.33		8.268	10.33
Sargan_test		16.25	16.44		8.437	6.337
AR(2)_test	-1.248	-1.236	-1.27	-0.894	0.676	-1.231
AR(3)_test	0.279			1.499		
S-H (OIR) test	18.944			-2.313		
No. of Instruments		18	19		17	19

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Instruments used are the lag values of the explanatory variables, S-H (OIR) represents the Sargan–Hansen (OIR) test. YE_WT is the Wald test of the year effect.

Accordingly, the estimated outcomes of the GMM (Table 4) provide several pieces of empirical evidence that, if used as a basis for policy measures, are capable of reducing carbon emissions and, by extension, enhancing environmental sustainability in the SSA if painstakingly implemented. What is crucial among such outcomes and similar to the estimates of the MM-QR is the influence of economic growth and the square of GDP, which confirms the hypothesis of the inverted U-form popularly known as the EKC. Judging from the three GMM-related estimation procedures – the linear and non-linear augmented sysGMM (SGMM[1]) as proposed by Kripfganz, 2020, the sysGMM (SGMM), and the differenced GMM (DGMM) – the results indicate that economic growth (lgdp) largely increases CO_2 emissions and hence degrades environmental sustainability in the region. However, economic growth expansion ($lgdp^2$) largely reduces CO_2 emissions and hence improves the SSA region's environmental sustainability. The result obtained when the growth of GDP was used as a measure of economic growth further confirms the EKC supposition. This outcome, with the findings generated from MM-QR, supports the popular EKC hypothesis in line with the findings of Shahbaz et al. (2014), Rafindadi (2016), Mesagan and Olunkwa (2022), Khan et al. (2020), Marques et al. (2018), Farhani et al. (2014), and Osuntuyi and Lean (2022). Similarly, energy consumption significantly degrades environmental quality, as the increase in energy used elevates CO_2 emissions in the region. In specific terms, a one per cent increase in energy consumption increases CO_2 emissions by 0.141%, 0.245%, and 0.318% for the SGMM1, SGMM, and DGMM models, respectively. Obviously, DGMM exacerbates the environmental degradation the most following the increase in energy consumption. This result supports the observations of Rafindadi and Usman (2019) for South Africa, Mohiuddin et al. (2016) for Pakistan, Asumadu-Sarkodie and Owusu (2016) for Ghana, Shahbaz et al. (2014) for Tunisia, and Rafindadi (2016). Regarding financial development (lfdt), judging by the modified version of sysGMM (SGMM1), environmental quality is worsened, as CO_2 emissions increase following the increase in financial development in the region. This outcome substantiates the research outcomes of Musah et al. (2022) for West African countries, Boutafeh and Saadaoui (2020) for 18 selected African countries, Ye et al. (2020) for Malaysia, Nwani and Omoke (2020) for Brazil, and Ahmed et al. (2021) but contradicts the finding of Mesagan and Olunkwa (2022) for 18 African countries. The robustness checks carried out validate these outcomes reliably for policy implementation given the post-estimation tests; the

tests show that the model is robust to AR (1) and AR (2) for the absence of first and higher-order autocorrelation and to the Sargan and Hansen tests as well as the Sargan–Hansen test *(OIR)* for instrument over-identification. The outcome from the Wald test of the year effect (YE_WT) indicates no joint effects of year in the panel models and this further validates the estimated outcomes.

5 CONCLUSIONS AND POLICY IMPLICATIONS OF THE FINDINGS

This study offers fresh insights into the heterogeneous determinants of environmental sustainability in the SSA region: the roles of energy consumption, economic growth, and financial development. Amidst other motivations, the dearth of updated empirical narratives from the above perspective as well as the twin econometric issues of heterogeneity and endogeneity inherent in the extant literature on the connection between environmental quality and growth compel the current evaluation. Based on this premise, our study used the novel MM-QR panel estimation procedure, which takes into account these dual econometric issues to estimate the magnitude-based influence of the listed explanatory variables on environmental sustainability. The relevant series from 22 SSA countries were analysed. Additionally, the sysGMM and its modified version, which captures non-linearity, were adopted for empirical estimates of the relevant series.

Our study demonstrates interesting outcomes, notably: Financial development significantly worsens the region's environmental quality; as the region's financial sector deepens, CO_2 emissions increase and thereby weakens environmental sustainability in the SSA region. The implication of this outcome is that while financial development as a driver of growth is worthwhile, its pursuit should not be to the detriment of environmental quality, so as to ensure environmental sustainability. As a result, authorities in the region must address both financial modernisation and programmes aimed at encouraging investment in environmentally friendly energy sources to improve energy conservation in the region, particularly in industrialised towns. Given the aforementioned, it is critical that regional policymakers include financial development initiatives in national environmentally friendly policy frameworks. Additionally, given that financial development via domestic financing to the private sector has a positive impact on carbon emissions, authorities in the region should give priority to such credit facilities. That is to say, only private companies who have integrated environmental protection techniques into their business operations and are

ecologically conscientious should be eligible for such loan arrangements. This is to make sure that financial facilities of this kind do not encourage activities that negatively impact environmental quality.

In terms of our results, energy consumption has varying effects. Whereas at the upper quantiles, it increases CO_2 emissions substantially, the influence at the middle and low quantiles is inconsequential. This highlights the fact that the high level of energy use in the region significantly increases CO_2 emissions, which in turn reduces the region's environmental sustainability. The implication is that high-energy-consuming nations generate high CO_2 emissions and hence diminish environmental sustainability. Our empirical results also demonstrate that economic growth (lgdp) and its squared value ($lgdp^2$) confirm the inverted U-form hypothesis that at an initial developmental stage, economic growth increases carbon emissions (and degrades environmental quality) but at a later stage, after some progressive level of economic development, further economic growth results in a reduction in environmental degradation.

The potential for ecologically friendly resources, such as solar, wind, and perhaps geothermal energy, present the region with a significant natural edge. Instead of concentrating on generating energy from fossil resources, which has been shown to increase carbon emissions and eventually jeopardise environmental sustainability, Africa's large renewable potential in the form of solar and wind energy can be an environmental asset. Additionally, the region's nations must prepare green infrastructure development plans for vital economic sectors with high energy consumption, such as the industrial and transport sectors. If implemented in both urban and rural settings, such plans would benefit the region in two ways. Investment choices in environmentally friendly projects would first benefit the environment by guaranteeing a less polluting and higher-quality environment through the reduction of greenhouse gas emissions. Second, they would help the region counteract the increasing strain that rural-urban migration is placing on urban infrastructure, improving the general standard of living in urban settlements, and assisting in the achievement of SDG 11, which emphasises the need for sustainable cities and communities.

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REVISITING THE EFFECT OF FINANCIAL CRISIS AND BANKING REFORMS ON THE EFFECTIVENESS OF MONETARY POLICY TRANSMISSION MECHANISM IN NIGERIA

ABSTRACT: *Understanding the effect of the extent of financial intermediation on the performance of monetary policy transmission channels is crucial to the formulation of monetary policy. To this end, the paper tested the validity of the above statement in the Nigerian context using quarterly data between 2005Q1 and 2019Q4. The data was analysed using a dynamic stochastic general equilibrium approach. Results of the estimation showed that the financial crisis experienced in the country led to the depression of the Nigerian capital market and a decrease in the amount of credit provided by banks for trading in the capital market, exchange rate risk tightening of liquidity, and greater loan-loss provisioning. It was revealed that recent changes and reforms in the industry have positive impacts on all the monetary policy transmission channels (exchange rate, interest rate, expectation, and credit) considered in the study. However, the credit channel appeared to be the most active as it transmits the largest impact of shocks to the financial sector (88.06 per cent on average) to the real economy. This demonstrates that the private sector depended on the financial sector for financing their expenditures, which later induced an increase in the level of investment and increased output.*

KEY WORDS: *financial intermediation, transmission mechanism, financial crises, DSGE*

JEL CLASSIFICATION: G21; E52; G01; C11

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1. INTRODUCTION

The world economy has experienced four major crises since the Great Depression of 1929: the Asian financial crisis of 1997, the Argentina financial crisis of 2001, the global financial crisis of 2007, and the Russian crisis of 2014. The global financial crises undermined banks' ability to play their developmental role. The resultant effect was a decline in the growth prospects for many economies of the world. In addition, the World Bank's global economic growth expectations also declined considerably from 2.5 to 0.9 per cent (Okonkwo & Godslove, 2015). This global financial meltdown led to a dwindling in the fortune of the once blossoming Nigerian banking industry (Okonkwo & Godslove, 2015; Ashamu & Abiola, 2012). The industry, during this period, was characterised by undercapitalisation of deposit-taking banks, weakness in the regulatory and supervisory framework, weak management practices, and tolerance of deficiencies in the corporate governance behaviour of banks. It was against these conditions that the Central Bank of Nigeria (CBN) announced a major reform in the entire banking industry in 2005. The reform included the involvement of banks in the foreign exchange market, banks were permitted to take deposits from the public sector, transaction costs were minimised, and banking rules and regulations were revised and updated to make the banking system more flexible, effective, and transparent (Okonkwo & Godslove, 2015). The primary objective of the reform initiative was to have an efficient and effective banking industry that could guarantee rapid economic growth and sustainable development. In response to this, the financial sector in Nigeria has undergone important structural and institutional changes. The restructuring exercise had a significant impact on the banking sector in that commercial banks' capital base was increased from ₦2 billion to ₦25 billion. This affected the sector to a large extent with the number of banks decreasing from 89 to 25 at first, and later further decreasing to 23 with the merger of some banks. The number of operating banks later increased to 24 with the emergence of Citibank in 2004. This radical change in market structure was to stabilise the national financial markets and consolidate the remaining banks to promote global competitiveness. The number of banks dropped to 22 in 2019. Jaiz Bank was not listed because the bank is a non-interest bank and cannot be categorised as a commercial bank.

However, the global financial crisis of 2007 presented further significant challenges to the recuperation of Nigeria's banking system. The effects of the crisis

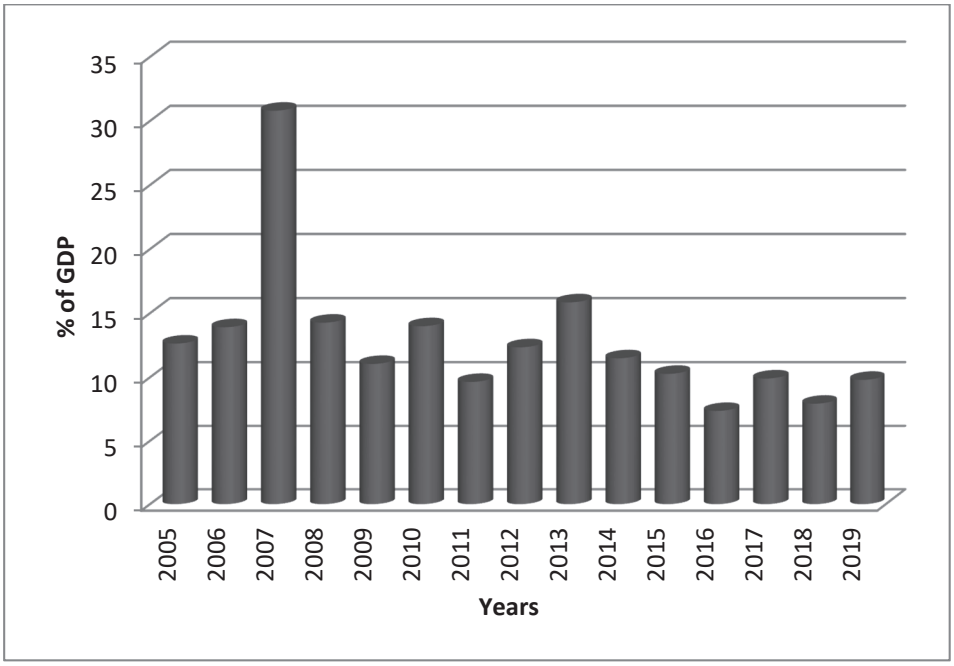
became evident in Nigeria because it happened when the country was making progress in economic performance and management. The Nigerian banking sector, after these incidents, was characterised by uncertainty and anxiety. Investors' and depositors' funds were not guaranteed, and public confidence was eroded with many of the banks becoming distressed due to capital inadequacy. These problems greatly impaired the quality of the banks' assets as non-performing assets became unbearable and became huge burdens on many of the banks. The financial intermediation role of the banks became weakened while the macroeconomic activities were seriously slowed down.

To cushion the negative effect of the global financial crisis of 2007, the CBN implemented a 2009 banking reform through which liquidity was provided for the ailing banks. The major highlights of the 2009 reform include the removal of chief executive officers (CEOs) and executive directors of banks found wanting, the injection of bailout funds (₦420 billion) to stabilise affected banks and another ₦200 billion to other banks, publication of names of outstanding debtors of affected banks, implementation of tenures for CEOs in the banking sector, and the approval of all potential CEOs by the CBN. The four pillars of the 2009 banking reform are to enhance the quality of banks, establish financial stability, enhance healthy financial sector evolution, and ensure that the financial sector contributes to the real sector.

Figure 1 shows the market capitalisation of banks as a percentage of GDP between 2005 and 2019. As can be seen from Figure 1, the banking reform of 2009 proved to be a buffer against the subsequent effects of the global financial crisis experienced in the country. The reform resulted in stronger Nigerian banks that are better able to withstand financial crisis. It had a dramatic effect on the size and health of the Nigerian banking system through improvement in banks' market capitalisation. It can be seen in Figure 1 that, after the 2009 reforms, banks' market capitalisation exhibited an upward trend, relatively speaking, throughout the period under study. This in turn increased their savings mobilisation and helped them effectively play their intermediation role. The post-recapitalisation experience in the Nigerian banking system included the injection of ₦620 billion in bailout funds to save most of the recapitalised banks, the sacking of indicted banks' CEOs and the appointment of advisers to these banks, the restructuring of banks and huge impaired shareholders' funds, huge exposure to non-performing

loans, and the establishment of the Asset Management Corporation of Nigeria (AMCON).

Figure 1: Banks' Market Capitalisation as a percentage of GDP in Nigeria 2005–2019.



However, towards the end of 2019, there was the outbreak of the COVID-19 pandemic. This affected all the economies of the world, with Nigeria being no exception. COVID-19 threatened the economy of Nigeria through forced lockdown of economic activities and disruption to the workings of the financial system. These led to gross economic loss and withdrawal of funds by portfolio investors from the stock market. The resultant effect was another financial crisis that wiped out the benefits of banking reforms in the country.

The developmental roles of banks are felt in the economy through monetary policy transmission channels. These define the various channels through which policy-induced changes in the nominal money stock or the short-term nominal interest rate affect prices and output in the economy. Not only do the transmission mechanism of monetary policy work through various channels, but

their functioning and effectiveness vary across countries due to differences in the extent of financial intermediation, the development of domestic capital markets, and structural economic conditions (Cevik & Teksoz, 2012). During the period under investigation, the Central Bank of Nigeria used short-term interest rates, open market operations, and short-term liquidity tools as the instruments of monetary policy. Furthermore, the monetary policy transmission channels included interest rate, exchange rate, and credit channels. It was also observed that there wm jere certain changes in the implementation of monetary policy during this period. These included the extension of the repayment of loans under a federal government scheme by one year, interest rate reduction on all intervention loan facilities from 9% to 5%, an offer of a ₦50 billion (US$131.6m) targeted credit facility to the service sector, strengthening of the loan to deposit ratio (LDR) policy, which allowed banks to extend more credit to the economy, and provision of credit support to the healthcare industry to meet the increasing demand for healthcare services during the outbreak. In addition, the Central Bank of Nigeria implemented the Central Bank Digital Currency (CBDC), also known as eNaira. The eNaira provides the Nigerian monetary authority with a new and more effective means of monetary policy transmission.

Several authors (Cecchetti, 1999; Dabla-Norris & Floerkemeier, 2006; Kovanen, 2011; Cevik & Teksoz, 2012) have argued that the extent of financial intermediation affects the performance of monetary policy transmission channels across countries. Their main point of contention is that the size and the structure of financial intermediation play a critical role in the performance of transmission channels. Following several major developments in financial intermediation in Nigeria as a result of the 2009 reforms, it is therefore important to examine the effect of improved financial intermediation on the performance of these channels in Nigeria. The research questions are: (1) Did the financial crisis affect the performance of the Nigerian financial system?; (2) What were the effects of improved financial intermediation on the performance of the monetary policy transmission channels in Nigeria? To achieve this objective, our study uses the small open economy version of the dynamic stochastic general equilibrium (DSGE) in the analysis of the four transmission channels (exchange rate, interest rate, expectation, and credit) in Nigeria. The use of the DSGE models provided several advantages over all other approaches to analysing macroeconomic policy in the literature. This was explained by Peiris and Saxegaard (2007), Apanisile and

Osinubi (2020), Akinlo and Apanisile (2019), and Apanisile and Akinlo (2022). First, DSGE models contain structural equations that can be explained using economic interpretations. The effect of macroeconomic policy and its transmission channels are traceable, thereby enabling the use of another policy to achieve the same objective if the other one is not forthcoming. Second, DSGE models are formulated on the basis of the interaction of microeconomic agents. This implies the models describe the activities of microeconomic agents using structural parameters that will remain the same as economic policies change. This property validates the use of alternative policies. Third, the models explain, in detail, how random shocks such as monetary and fiscal policy shocks are transmitted to the economy. Last, the models predict and explain the future performance of the economy based on the interactions among the economic agents.

This study is similar to Apanisile and Akinlo (2022) because they both use DSGE and quarterly data in estimating the effectiveness of monetary policy transmission channels in Nigeria. However, this study is different from Apanisile and Akinlo (2022) in various ways. First, it considers an inflation targeting framework in a small open economy using DSGE as against Apanisile and Akinlo (2022), which employed a DSGE for a closed economy with two different policy frameworks (inflation targeting and monetary aggregates). Second, while Apanisile and Akinlo (2022) examined the effectiveness of monetary policy transmission channels using two monetary policy frameworks, this study differs by explaining the response of monetary policy channels to the financial crisis and reforms after the crisis in Nigeria. Third, the scope of the two studies is not the same. While Apanisile and Akinlo (2022) covered the period 2000Q1 and 2019Q4, our study employs quarterly data on macroeconomics and financial variables between 2005:1 and 2019:4 to achieve the objectives of the paper. The choice of 2005 is informed by the financial crisis experienced in Nigeria in the same year.

Our results are in line with the finding of Ashamu and Abiola (2012) that the financial crisis affected "the quality of part of the credit extended by banks for trading in the capital market, exchange rate risk tightening of liquidity, greater loan-loss provisioning, slower growth rate of banks' balance sheet in response to the crisis and higher provisioning leading to lower profitability among others" (Ashamu & Abiola, 2012, p. 251). Furthermore, it was discovered that recent

changes and reforms have positive impacts on exchange rates, interest rates, expectations, and credit channels. However, the credit channel appears to be the most active channel as it transmits the largest impact of shocks to the financial sector (88.06 per cent on average) to the real economy.

The paper contains six sections. Section one, the introduction, explains the objective of the paper. Section two presents the extant literature on the subject matter and the need for this study. Section three discusses the fundamentals of the methodology used and section four explains data employed for the analysis, the technique of data estimation, and the description of the variables. In section five, the estimation technique is employed to examine the effect of the financial crisis on the channels of transmission of the monetary policy in Nigeria. The last section, section six, concludes the study.

2. LITERATURE REVIEW

There is a body of literature on banking reforms and the performance of transmission channels of monetary policy. Of the studies in the literature, the paper of Ogun and Akinlo (2010) investigated the effect of the newly adopted deregulation measures on the performance of the bank credit channels of monetary policy in Nigeria. The study employed quarterly data between 1986Q1 and 2006Q4. The data were analysed using a structural vector autoregressive model (SVAR). It was discovered that during the period under study, financial assets such as bank deposits, total loans, and advances were rigid in their response to monetary policy shock. Furthermore, the results showed that the effect of monetary policy shock on the forecast error of bank balance sheet variables is independent. It was concluded that the bank credit channel is not effective in Nigeria.

In the same vein, Butkiewicz and Ozdogan (2013) examined the role of reforms on the performance of Turkish monetary policy transmission channels using monthly data spanning between 1996:07 and 2007:06. The sample period was divided into two because of the presence of a structural break in the year 2001 and the two models were estimated separately. The first sample represented the pre-crisis period and contained 42 observations. The period ran between 1996:07 and 1999:12. The results showed that the structural break of 2001 boosted the strength of the monetary policy transmission channels in the country in the post-

crisis period. It was also revealed through the estimation of the baseline model that an unanticipated increase in the interest rate has a significant impact on economic activities before and during the crisis in an unusual manner.

Mohanty and Rishabh (2016) reviewed the implications of three key post-2008 crisis developments in financial intermediation – the role of banks, the globalisation of debt markets, and the sustained decline in global long-term interest rates – for various transmission channels of monetary policy in emerging market economies using quarterly data from 1996Q2 to 2014Q4 and a structural vector autoregressive framework. The paper argued that the globalisation of debt markets means that monetary policy can no longer be conducted through the short-term interest rate alone. The study concluded by requiring the central bank to use other instruments (such as foreign exchange intervention, bond market operations, and macro-prudential tools) to reduce risks to price and financial stability.

In the same vein, the paper by Abdel-Baki (2010) investigated the significance of the role of the Egyptian monetary policy agent in mitigating the negative impact of the multifaceted financial crisis on the interest rate and exchange rate channels in the country. The objective of the study was achieved by using structural VAR to examine the effect of the crisis on the economy and on the ability of the agents to mitigate the effect of the economic meltdown caused by the financial crisis. The study differs from existing studies by introducing an expectation channel to the analysis of the effectiveness of monetary policy transmission channels in the country. Data on the expectation channel were obtained from a field survey administered for 21 months. This inclusion was necessary given the failure to consider future inflation and the effect of the proposed removal of subsidies in the country. The results showed that the Central Bank of Egypt did not respond appropriately to the negative effect of the shocks inflicted by the inflation expectation. In addition, it was discovered that the apex bank needed to improve on the implementation of policy to combat the effect of negative shocks on the economy.

Furthermore, following the collapse of Lehman Brothers in late 2008, Islam and Rajan (2009) investigated the effectiveness of bank lending channels in India given the global financial crisis of 2007–2009. The results of the study

contradicted the outcome of studies in the United States and popular perceptions. While other studies found a negative effect of the global financial crisis on bank lending channels, this study found that bank credit in India maintained stable growth even in the face of the financial crisis. This was due to an aggressive effort by the Reserve Bank of India to ease monetary measures in the country. The study, however, differentiated between public and private banks' behaviour towards lending and confirmed that the bank lending channel is an important channel for transmitting monetary policy actions to the economy of India.

Kubo (2013) investigated whether reforms established a transmission channel of exchange rates from the formal to parallel markets in Myanmar. To investigate the question, the study examined the relationship between the Central Bank reference rate and the informal broker selling price of the US dollar banknote in the parallel market. The sample period of daily exchange rates spanned from 2 April 2012 through 13 March 2013. The empirical results of a VAR analysis with the daily exchange rates indicate that the Central Bank had been following the parallel rate rather than guiding it, implying that a transmission channel had yet to be established.

Furthermore, Chileshe (2018) explored the effect of changes in banking structure on the monetary policy channel of transmission with emphasis on the bank lending channel in Zambia. Using panel data that spanned between 2005:1 and 2016:4 and the dynamic one-step GMM proposed by Arellano and Bond (1991), the study showed that larger banks with more market power and liquidity respond less to monetary policy tightening. In addition, Jannsen et al. (2019) investigated the claim that the effects of monetary policy on output and inflation during the financial crisis differ significantly from those in normal times. The study employed panel data from 20 developed countries and the VAR model. The results showed that monetary policy has larger and quicker effects on inflation and output during financial crises and that the effects of monetary policy on output and inflation depend on the state of the economy.

To examine the effect of anticipated and unanticipated monetary policy shocks on the effectiveness of the transmission mechanism in Nigeria, Akinlo and Apanisile (2019) generated two policy shocks from the policy reaction function. The study covered the period between 1986Q1 and 2013Q4 and, using DSGE,

discovered that unanticipated monetary policy shocks had a short-run impact on transmission channels while anticipated ones had a long-run impact on them. Based on its findings, the study concluded that the government should announce its policy at the beginning of every year to reduce unanticipated policies in the economy.

Apanisile and Osinubi (2020) also investigated the effects of the recent development in the financial system of Nigeria on the effectiveness of the transmission mechanism in the country. The study employed a sticky-price DSGE model and estimated the model using the Bayesian approach. Their results showed that financial development had positive effects on all the transmission channels considered within the period 2004Q1 to 2016Q4. The credit channel was found to be the most active channel in stimulating output while the expectation channel was determined to be the most active channel in stabilising prices in the economy.

Furthermore, Apanisile and Akinlo (2022) examined the effectiveness of the monetary policy transmission mechanism in Nigeria within the frameworks of inflation targeting and monetary aggregate using a closed economy DSGE. The monetary aggregate uses money supply as the policy instrument while the interest rate is used as a nominal anchor under the inflation targeting framework. The study was necessitated by the implicit nature of inflation targeting in the country, where the interest rate is augmented by the use of money supply. The study employed quarterly data between 2000Q1 and 2019Q4 and discovered that the monetary aggregate framework dampens the achievement of the inflation-targeting framework in the country.

Based on the reviewed literature, it can be seen that ample studies on this subject matter exist. However, most of the studies failed to include expectation channels. Furthermore, vector autoregressive (VAR) and structural vector autoregressive (SVAR) models were most commonly used. This study contributes to the extant literature by including the expectation channel and using a more robust approach to the study of the effectiveness of the transmission mechanism of monetary policy in Nigeria. This is because the implementation of monetary policy is a major determinant in formulating expectations and expectation plays an important role in transmitting policy impulses to the real sector of the country.

3. METHODOLOGY

The New Keynesian model was derived by extending the standard real business cycle framework. The model is employed for a small open economy such as the Nigerian economy. One of the attributes of the standard framework is the neutrality of money, which is a result of flexible prices and wages. However, the New Keynesian model introduces such Keynesian features as imperfect competition and sticky prices. These, therefore, provide a platform that enables monetary policy to be at the centre of discussions on macroeconomic fluctuations. The New Keynesian model assumes that there is a goods market characterised by imperfect competition and that firms in the market produce differentiated goods for which they set their prices. Furthermore, the model assumes the majority of firms in the market find it difficult to adjust their prices at any given point in time. This forms the major constraint of the model. Lastly, key players in the set-up of the model include an individual household that consumes goods produced and renders labour services. It also demands money and bonds. Others are firms that hire labour for production and the government, which implements policy.

3.1 Households

The model contains a set of identical and long-lived households that seek to optimise the utility function:

$$max_{C_t,\ N_t, \frac{M_t}{P_t}} E_0 \sum_{t=0}^{\infty} \beta^t U\left(C_t, N_t, \frac{M_t}{P_t}\right) \tag{1}$$

The constraints are $C_t \leq Y_t; B_{t+j} \leq 0; N_t \leq \int_{t=0}^{1} N_{it} d_t$; and the no-Ponzi game. E_0 is the conditional operator of expectation given the level of information in time 0, β represents the factor that discounts the model, and $\frac{M_t}{P_t}$ represents the real money demand. The utility function is subject to:

$$P_t C_t + Q_t B_t + M_t \leq M_{t-1} B_{t-1} + W_t N_t + J_t \tag{2}$$

where $C_t(i)$ is the quantity of household consumption of commodity *i* in time *t* for $i \ \forall[0,1]$ and $t = 0, 1, 2, \ldots$, $P_t(i)$ represents the commodity of good *i*, N_t represents the number of hours worked, W_t represents nominal wage, B_t is the amount of bond purchased in one period at a price Q_t, B_{t-1} is the amount of bond bought the previous year, M_t represents demand for money, and J_t is the component of income held as a lump sum. $\in$ captures the intertemporal elasticity of substitution that differentiates the goods. This is equal to the degree of responsiveness of change in consumption to change in price. To optimise the utility function subject to its constraint, we use the Kuhn-Tucker approach to derive the FOC conditions from equations (1) and (2).

Following Akinlo and Apanisile (2019), Apanisile and Osinubi (2020), and Apanisile and Akinlo (2022), the marginal utility derived from the optimisation of equations (1) and (2) is log-linearised. Representing the log-linearised variables with small letters, the equations become:

$$c_t = E_t c_{t+1} - \frac{1}{\sigma}\left(i_t - \rho - E_t \pi_{t+1}\right) \tag{3}$$

$$w_t - p_t = \sigma c_t + \varphi n_t \tag{4}$$

$$m_t - p_t = c_t - \eta i_t \tag{5}$$

Equation (3) is the first-order Taylor expansion of the Euler equation around the steady state. Equation (4) is the log-linearised version of the labour supply equation while equation (5) is the log-linearised version of the money demand equation. η in equation (5) is defined as interest rate elasticity in the money demand equation and is defined as $\frac{1}{v}\frac{1}{(1+i)i}$.

3.2 Firms

The model contains a set of individual firms that produce different goods using the same technology. The production function of the firms is given by:

$$Y_{it} = A_t N_{it}^{1-\alpha} \tag{6}$$

Y_{it} represents the output of each of the firms in time *t*, A_t represents the level of technical input available to all the firms, and N_{it} captures the amount of labour supply employed by each firm. The major feature of this model is the rigidity of price level. The rigidity of a firm's prices implies that although firms could freely set their prices, they are not sure when the next opportunity to change the prices will arise. The likelihood of not knowing when it is the right time to change their prices is given by θ. This represents the proportion of firms that are unable to change their last year's price. The rest, 1 – θ, can reset their prices. The firms in the market have similar demand schedules with an elasticity of price ϵ and the total level of price P_t. In addition, the total consumption index C_t is as given above. Finally, the total dynamics of price are given by:

$$\pi_t^{1-\epsilon} = \theta + (1-\theta)\left(\frac{P_t^*}{P_{t-1}}\right)^{1-\epsilon} \tag{7}$$

where $\pi_t \equiv \frac{P_t}{P_{t-1}}$ represents the gross price level and P_t^* represents the price set by firms in time *t*. The firms optimise their prices during this period,. Also, within this period, all firms will choose the same price because they have an identical problem. Therefore, the steady-state value with zero inflation becomes π = 1. Given this, $P_t^* = P_{t-1} = P_t$. Linearising this yields:

$$\pi_t = (1-\theta)\left(P_t^* - P_{t-1}\right) \tag{8}$$

Equation (8) explains that the value of inflation of a re-optimising firm in the current period is due to the fact that such firms select a price that varies from the average price of the economy in the past period. Therefore, to understand the evolution of inflation over a period, analysing the factors underlying a firm's price-setting decision is important. This is achieved by examining a re-optimising firm in period t that chooses a P_t^* that satisfies the condition for attaining the current market value of the profits generated when the price is still effective. The optimisation problem is solved subject to the constraints posed by the ordering of demand as presented by Akinlo and Apanisile (2019), Apanisile and Osinubi

(2020), and Apanisile and Akinlo (2022). The optimal price P_t^* , derived from the optimisation problem becomes:

$$p_t^* = \mu + (1-\theta\beta) E_t \sum_{k=0}^{\infty} \theta^k \beta^k [mr_{t+k|t}^r + p_{t+k}] \tag{9}$$

Solving for equilibrium in the goods market, the equilibrium condition becomes:

$$Y_{it} = C_{it} \tag{10}$$

The total output level is given as:

$$Y_t = \left(\int_0^1 Y_{it}^{\frac{\epsilon-1}{\epsilon}} di \right)^{\frac{\epsilon-1}{\epsilon}} \tag{11}$$

Substituting equation (10) into (11) and taking the logarithm of the result yields:

$$y_t = c_t \tag{12}$$

Equation (12) is the market-clearing condition for the entire market. In the same vein, the market-clearing condition in the labour market is:

$$N_t = \int_0^1 N_{it} di \tag{13}$$

From equation 6, we have N_{it} , the subject of the formula. Thus,

$$N_{it} = \left(\frac{Y_{it}}{A_t} \right)^{\frac{1}{1-\alpha}} . \tag{14}$$

By substituting (12) and (14) into (13) and log-linearising, equation (13) becomes:

$$y_t = a_t + (1-\alpha) n_t \tag{15}$$

3.3 Monetary Authority

The central bank employs the rate of interest as the monetary instrument in the short run. A decrease in the rate of interest increases the demand for consumption goods. An increase in demand will increase the firms' marginal cost and, consequently, their prices. The outcome of this action is inflation. The reverse is the case when there is an increase in the rate of interest. Therefore, the use of interest rates follows the Taylor rule type. Taylor's rule model is given as:

$$i_t = \beta_r i_{t-1} + (1-\beta_r)(1+\beta_\pi)\pi_t + \alpha_x(\hat{y}) + \varepsilon_t \tag{16}$$

where

$i_t = rate\ of interest\ in the\ short\ run$

$i_{t-1} = rate\ of\ interest\ in the\ previous\ period$

$\pi_t = consumer\ price\ index$

$y_t = output\ gap$

$\varepsilon_t = shock\ to the\ monetary\ policy$

3.4 The World Economy

The world economy, which is defined as the foreign economy in the model, is very large. It is represented by an unrestricted VAR (1) of output, inflation, and the nominal interest rate. This follows the approach of Jääskelä and McKibbin (2010). The VAR model is presented as follows:

$$\begin{pmatrix} Y_t^* \\ \pi_t^* \\ r_t^* \end{pmatrix} = M \begin{pmatrix} Y_{t-1}^* \\ \pi_{t-1}^* \\ r_{t-1}^* \end{pmatrix} + \varepsilon_t^* \tag{17}$$

ε_t^* captures the vector of the external shock and Y_t^*, π_t^*, and r_t^* are foreign output, foreign inflation, and foreign nominal interest rates, respectively. The variables are proxied by the output, inflation, and nominal interest rate of the United States of America. They are expressed as the percentage deviations from their sample means. The world economy is treated as exogenous to the domestic

economy. Therefore, the coefficients of matrix M are estimated separately. They enter the system of equations through an autoregressive model of order one (AR (1)).

3.5 Log-linearised Model

Log-linearisation is a process of linearising the system of complex equations in terms of the log deviation around their steady state. Linearising Euler equations and substituting them into the goods clearing condition under the resource constraints, the dynamic IS curve (equation 18) is obtained. Also, by log-linearising intermediate goods firms' first-order conditions, using the aggregate law of motion for prices stated, and substituting in the household intra-temporal condition and the market-clearing conditions, the forward-looking Phillips curve (equation 18) is obtained.

$$y_t = E_t y_{t+1} - \sigma\left(i_t - E_t \pi_{t+1}\right) \tag{18}$$

$$\pi_t = \beta E_t\left(\pi_{t+1}\right) + k\,\check{y}_t \tag{19}$$

$$i_t = \beta_r i_{t-1} + \left(1-\beta_r\right)\left(1+\beta_\pi\right)\pi_t + \alpha_x\left(\hat{y}\right) + \varepsilon_t \tag{20}$$

Equation (18) is the expectational IS curve. The equation presents the current output as a function of the expected value together with its prior rate of interest. The prior interest rate is achieved by deducting the future interest rate from the nominal interest rate. The mathematical expression represents a logarithm version of the Euler equation. This equation links the optimising household's inter-temporal rate of marginal substitution to the real rate of interest. The second equation is referred to as the New Keynesian Phillips curve. The mathematical expression shows a log-linearised FOC that explains the optimum behaviour of monopolistically competitive firms that are affected by explicit costs of nominal price adjustment as explained by Rotemberg (1982), or set the random prices in a staggered fashion as suggested by Calvo (1993). The third equation follows the monetary policy rate of interest rule as explained by Taylor (1993). Following this equation, the central bank uses interest rates as the policy instrument to control changes in the value of inflation and the output gap. The

three equations have three important variables. These are the output gap (y_t), inflation (π_t), and the short-term rate of interest measured in nominal terms (r_t).

Considering the New Keynesian model, the operation of monetary policy follows the old rate of interest channel. A contractionary monetary policy increases the nominal rate of interest in the short term and yields an increase in the real rate of interest when the nominal price is rigid as a result of a random price setting. The increase in the rate of interest thereby leads to a decrease in spending patterns as explained by the IS curve. Finally, the decrease in output through the Phillips curve puts downward pressure on inflation. This adjusts sluggishly after the shock. In addition, the expectation terms in the equation imply that the actions of monetary policy are not the same quantitatively. Their effects depend on whether the actions are anticipated or unanticipated.

4. TECHNIQUES OF ESTIMATION, DATA DESCRIPTION, AND VARIABLE MEASUREMENT

The literature contains different approaches for estimating the DSGE model. Some of these approaches include the full-information likelihood-based, minimum distance generalised method of moments (GMM), on the one hand, and the Bayesian, on the other. The Bayesian approach has been found superior to all other available techniques (Adjemian, 2013; Akinlo & Apanisile, 2019; Apanisile & Osinubi, 2020; Apanisile & Akinlo, 2022). The major reason for this is that there exists an identification problem which is due to the non-informative nature of data when the maximum likelihood method is used. Furthermore, the use of maximum likelihood and other approaches lead to a lack of precision in estimating the DSGE model. The Bayesian approach, however, makes the comparison of models possible. Therefore, we employ the Bayesian approach to estimate our model.

The use of the Bayesian estimation technique calls for the calibration of the parameters of interest. This is important because it resolves the identification problem that is associated with the estimation of the DSGE models. The process of calibrating the parameters in the Bayesian tradition involves fixing the initial value of the parameters. This process is known as the imposition of prior. The advantages of this exercise are that it enables the steady-state equilibrium to be established and provides the basis for determining how best the data fits the

economy. The selected prior is informed by the theoretical knowledge of the researcher and the likelihood function that must be included in the Bayesian method. The posterior distribution needed for generating the outcomes of the estimation is obtained by combining the prior and the likelihood function.

4.1 Data

Quarterly data on the eight macroeconomic variables were employed. The data cover the period between 2005:1 and 2019:4. The macroeconomic variables include the output gap, nominal interest rate, domestic inflation rate, nominal exchange rate, commercial bank credit to the private sector, anticipated monetary policy, unanticipated monetary policy, and terms of trade. If the real variables are used with domestic inflation as one of the independent variables, then there is a likelihood of collinearity among the independent variables. This will in turn produce spurious results since inflation is an important variable in the DSGE estimation and it cannot be eliminated. The New Keynesian Phillips curve in the DSGE estimation is proxied by inflation. Therefore, to avoid this problem, the nominal values of all the variables were used. This approach follows the work of Akinlo and Apanisile (2019), Apanisile and Osinubi (2020), and Apanisile (2021). The foreign economy was proxied by the output, inflation, and nominal interest rate of the USA. The output gap is the natural log of the ratio of the trend of output to real output. (Ajilore & Ikhide, 2013; Apanisile & Ajilore, 2013). The Hodrick-Prescott filter was used to extract the trend of real output from the output data. We generated anticipated and unanticipated monetary policies by estimating the monetary policy function. The predictive component of the model represents the anticipated monetary policy while the residual represents the unanticipated monetary policy. Outliers, trends, and non-stationarity of the selected variables were filtered. This was done to ensure the stability of the model. As a robustness check, two periods were considered, 2007:1–2019:4 and 2011:1–2019:4. The first period was considered to establish the effect of the financial crisis that started in the USA in 2007. The latter sample was considered as a post-consolidation era. Following Li and Liu (2017), the study considered four observable variables so that the model could be free from a stochastic singularity.

4.2 Methodology

This study employs the Bayesian approach in estimating the DSGE models. We simulated the posterior kernel for each model specification using the random-

walk Metropolis-Hastings (MH) algorithm. This simulation method is commonly used in the current literature of Bayesian estimation of DSGE models. The popular Matlab package and Dynare, version 4.3.3, were used to estimate our model.

4.3 Calibration

The choice of priors was based on the observations and facts emanating from the extant literature. Therefore, factors such as the validity of the economic theory, stylised facts about the economy, observation, and the literature were considered in the selection of priors for the parameters to be estimated. This study benefited from such studies as Adebiyi and Mordi (2011), Mordi et. al. (2013), Akinlo and Apanisile (2019), Apanisile and Osinubi (2020), and Apanisile and Akinlo (2022). The initial values (priors) and the standard errors selected are shown in Table 1.

Table 1: Priors of the Estimated Parameters

Parameter	Description	Density	Mean	Std Deviation
α_3	Measures impact of inflation expectation on the output gap	beta	0.300	0.050
α_4	Measures impact of anticipated monetary policy on the output gap	beta	0.670	0.050
α_5	Measures impact of unanticipated monetary policy on the output gap	beta	0.320	0.050
α_7	Measures impact of interest rate on the output gap	beta	0.200	0.049
α_8	Measures impact of bank loans on the output gap.	beta	0.300	0.050
β_1	Intercept	beta	0.990	0.051
β_2	Measures output persistence	beta	0.125	0.050
β_4	Measures impact of anticipated monetary policy on inflation	beta	0.300	0.050

β_5	Measures impact of unanticipated monetary policy on inflation	beta	0.250	0.050
β_7	Measures impact of interest rate on inflation	beta	0.260	0.050
β_8	Measures impact of bank loan on inflation	beta	0.310	0.050
φ_1	Measures policy persistence	gamma	0.220	0.050
φ_2	Measures weight put on inflation by policymakers	gamma	0.240	0.051
φ_3	Measures weight put on output gap by policymakers	gamma	0.300	0.050
eps_v	Measures unanticipated monetary policy shocks	invg	0.063	0.0267
eps_k	Measures shock to commercial bank credit to the private sector	invg	0.035	0.0301
eps_x	Measures output gap shocks	invg	0.488	0.0426
eps_u	Measures inflation shocks	invg	0.060	0.0098
eps_a	Measures anticipated monetary policy shocks	invg	0.500	0.0455

Our study went further to simulate the model to confirm the existence of the steady-state and obtain the steady-state values of the endogenous variables. To achieve this, we calibrated the stochastic shocks of the model. The calibration shocks are presented in Table 1. Based on the simulation result, the steady state, its values, and responses of the variables to orthogonal shocks were derived. The results show that the steady-state exists and the model has a unique solution.

5. DISCUSSION OF RESULTS

Table 2: Correlation Matrix

	Anticipated	Credit	Exchange	Inflation	Interest	Output	Trade	Unanticipated
Anticipated	1.00							
Credit	0.22	1.00						
Exchange	0.15	-0.30	1.00					
Inflation	-0.18	0.13	-0.50	1.00				
Interest rate	0.02	-0.21	0.42	-0.81	1.00			
Output	0.15	0.99	-0.35	0.14	-0.21	1.00		
Trade	-0.04	0.55	0.38	-0.08	-0.12	0.53	1.00	
Unanticipated	0.22	-0.54	0.43	-0.53	0.48	-0.55	-0.06	1.00

Table 2 presents the degree of relationship between the variables. The purpose of this analysis is to show the correlation between the independent variables used in the study. This analysis is a way of detecting the existence of collinearity among the independent variables. The rule of thumb is that the degree of correlation must not be greater than 0.6. A correlation coefficient that is greater than 0.6 signifies a strong relationship between the two variables; therefore, they must not be included in the same model. The independent variables in Table 2 include credit to the private sector, exchange rate, terms of trade, anticipated monetary policy, and unanticipated monetary policy. Looking at the results in Table 2, it can be seen that there is no evidence of collinearity as the degree of relationship between the independent variables is less than 0.6.

Furthermore, the posterior density of the estimation was derived from the calibration process using a random walk MH algorithm-generated posterior density of 10,000 draws. 94 out of the available 112 data points were used in generating the posterior density. The logarithm of the data used in generating the posterior density is -215.036470. The result is presented in Table 3, which shows the values of the prior mean, posterior mean, prior standard deviations, and confidence interval. The values are for the estimated parameters and shocks.

Table 3: Priors and Posteriors of the Estimated Parameters

Parameter	Density	Prior Mean	Posterior Mean	Standard Deviation	Confidence Interval at 90%
α_3	beta	0.300	0.3025	0.050	0.2940 0.3108
α_4	beta	0.670	0.6705	0.050	0.6619 0.6785
α_5	beta	0.320	0.3206	0.050	0.3118 0.3286
α_7	beta	0.200	0.1955	0.049	0.1875 0.2029
α_8	beta	0.300	0.3006	0.050	0.2928 0.3081
β_1	beta	0.990	0.9880	0.051	0.9791 0.9974
β_2	beta	0.125	0.1263	0.050	0.1177 0.1352
β_4	beta	0.300	0.2996	0.050	0.2919 0.3080
β_5	beta	0.250	0.2500	0.050	0.2418 0.2587
β_7	beta	0.260	0.2603	0.050	0.2527 0.2682
β_8	beta	0.310	0.3116	0.050	0.3036 0.3204
φ_1	gamma	0.220	0.2300	0.050	0.2218 0.2385
φ_2	gamma	0.240	0.2442	0.051	0.2361 0.2524
φ_3	gamma	0.300	0.3115	0.050	0.3029 0.3208
eps_v	invg	0.063	0.3441	0.267	0.2986 0.3857
eps_k	invg	0.035	0.4176	0.301	0.3665 0.4687
eps_x	invg	0.488	0.5910	0.426	0.5185 0.6648
eps_u	invg	0.060	0.0385	0.098	0.0140 0.0651
eps_a	invg	0.500	0.2042	0.455	0.1108 0.2905

It can be seen from the results in Table 3 that the posterior means and the prior means are not the same. This implies the available data does indeed provide information about the Nigerian economy. Looking at the output gap equation, one can see the consistency in Nigeria's household consumption and that the posteriors are higher than the priors. These results corroborate the findings of Adebiyi and Mordi (2011) and Mordi et. al. (2013)

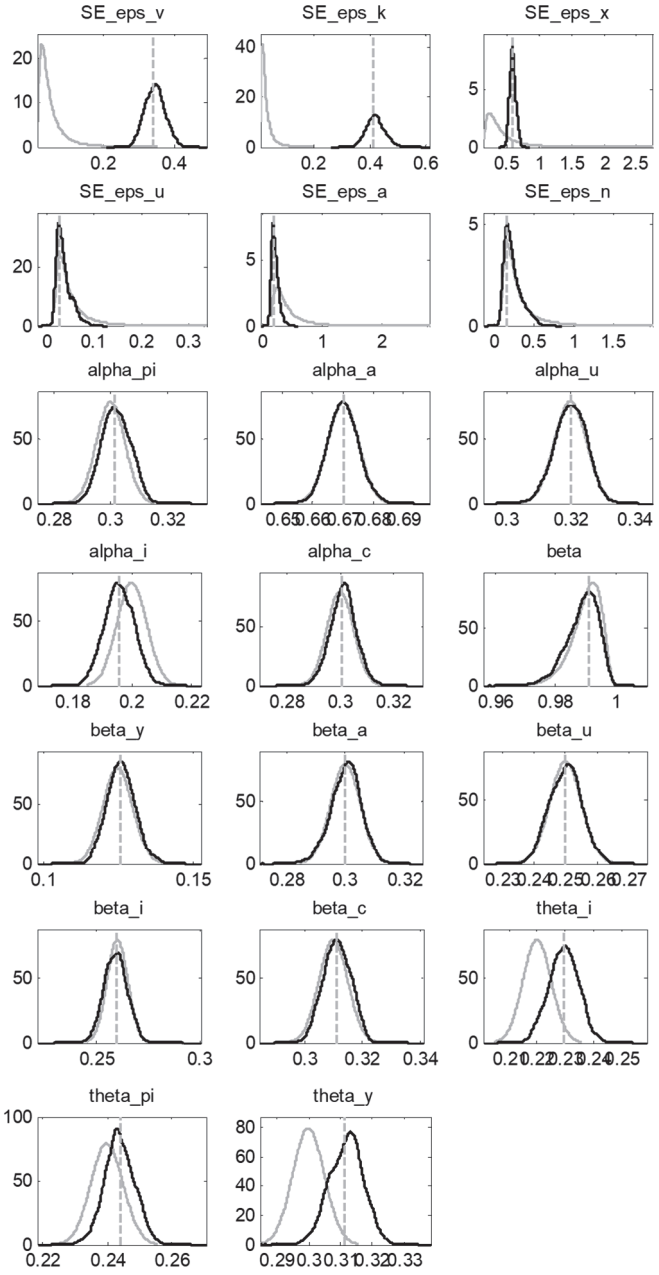
Furthermore, the results of the Phillips curve equation reveal basic information about the pattern of inflation in Nigeria as evident in the results of the prior and posterior estimation of this equation. Measures of output gap expectation (β_2), anticipated monetary policy (β_4), unanticipated monetary policy (β_5), and

measures of interest rate (β_7) determine the behaviour of the economy. The posterior value of β_4 (0.2996) shows that 29 per cent of the firms in the economy failed to re-optimise their prices in the quarter under consideration. The posterior value of $\beta_5(0.2500)$ reveals that 25 per cent of the available firms re-optimised their prices in quarter two. This result implies that firms in the country have the average price re-optimisation within the second quarter. This supports the studies of Adebiyi and Mordi (2010), Mordi et. al. (2013), and Garcia (2010). The effect of monetary policy on inflation is measured by the posterior value of output and exchange rate parameters, which must be greater than zero. The output gap (β_2 = 0.1263) and exchange rate (β_6 = 0.15) satisfy this condition. This implies that the Central Bank of Nigeria has effective tools for the output gap and exchange rate to control inflation. The estimates of the reaction function of the monetary policy provide adequate information about the design of monetary policy in the country in the period under investigation. Following the estimation of the Taylor-type reaction function, monetary policy is active and shows a strong effect on the output gap. This shows the operation of monetary policy is in tandem with the Taylor-type. In addition, the operation of the Central Bank is concerned with output stabilisation as against price stability in the long run.

The posterior value of the lag of interest rate (φ_1 = 0.2300) is greater than its prior value (0.2200). This indicates that the short-term interest rate follows a smoothing path. The result of this estimate differs from that of Adebiyi and Mordi (2010), 0.623, and that of Mordi et. al (2013), 0.43. The policy reaction function results reveal that monetary policy design is effective in achieving the primary objective of price stability and economic growth as its supporting objective. Examining the posterior estimate of the standard deviations, the output gap shock is the most volatile shock (0.5910) and the shock to the commercial bank credit to the private sector (0.4176) is the least volatile. The results of these parameters indicate that they are driven by the data.

The diagram of the prior and the posterior of the parameters is presented in Figure 2. Grey represents the prior while black represents the posterior. The green line in each chart is the posterior mode generated from the numerical optimisation of the simulations. It can be observed from the result that both the prior and the posterior estimates are the same except in a few cases. This result validates the likelihood of our estimation. In addition, the posterior values are close to normality. The implication is that our model accurately models the Nigerian economy.

Figure 2: Prior and Posterior Distributions



5.1 Estimating the Viability of the Model

Our study employed a set of diagnostic tests to examine the statistical integrity of the whole estimation process. The diagrams in the results of our sensitivity analysis contain the historical and smoothed graphs of the estimated parameters. In each diagram, the length of the period in each sample is plotted on the horizontal axis. In addition, the study used the univariate and the multivariate MCMC test to verify how sensitive the Metropolis-Hastings algorithm is. The sensitivity level of the MH algorithm calls for the similarity of the simulation's result both within and across the chain. The lines are expected to vary for a while and later converge at the end of the process (Griffoli, 2007; Mordi et. al., 2013). The diagrams show that the lines of all the estimated parameters satisfy the conditions.

The results of the multivariate MCMC test are summarised in three graphs. Each graph represents two different lines that show the within and between-chain results. The results explain the analysis of parameters mean (interval), variance (m2), and third moment (m3). The condition requires that both lines converge to their steady state at the same time. The results affirmed the stability and convergence of all the models.

5.2 Result Sensitivity

The sensitivity of the selected priors was confirmed by changing the prior means and standard deviation by one per cent and re-estimating the model. The results of the re-estimated model are shown in Table 4. The results, when compared with the benchmark result in Table 3, show that the changes noticed in the re-estimated model were not significant.

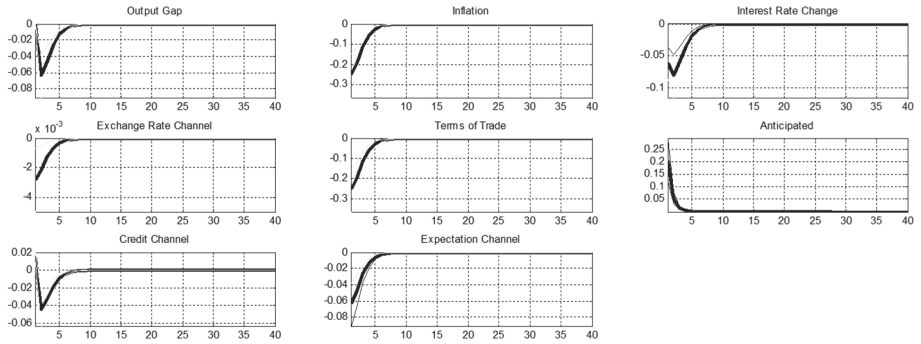
Table 4 Sensitivity Result with 1% Increase in Prior Mean and Standard Deviation

Parameter	Density	Prior Mean	Posterior Mean	Standard Deviation	Confidence Interval at 90%	
α_3	beta	0.303	0.2990	0.0505	0.2897	0.3078
α_4	beta	0.6767	0.6704	0.0505	0.6617	0.6783
α_5	beta	0.3232	0.3204	0.0505	0.3127	0.3291
α_7	beta	0.202	0.1967	0.04949	0.1879	0.2044
β_1	beta	0.9999	0.9905	0.05151	0.9838	0.9977
β_2	beta	0.12625	0.1284	0.0505	0.1206	0.1370
β_4	beta	0.303	0.3003	0.0505	0.2918	0.3084
β_5	beta	0.2525	0.2502	0.0505	0.2417	0.2572
β_7	beta	0.2626	0.2604	0.0505	0.2518	0.2692
φ_1	gamma	0.2222	0.2215	0.0505	0.2129	0.2292
φ_2	gamma	0.2424	0.2334	0.05151	0.2261	0.2412
φ_3	gamma	0.303	0.3013	0.0505	0.2936	0.3098
eps_v	invg	0.063125	0.0239	0.26967	0.0142	0.0334
eps_k	invg	0.035754	0.1579	0.304011	0.1382	0.1787
eps_x	invg	0.49288	0.3334	0.43026	0.2880	0.3779
eps_u	invg	0.0606	0.2773	0.09898	0.0158	0.0394
eps_a	invg	0.505	0.1414	0.45955	0.0977	0.1821

5.3 Impulse Response Results

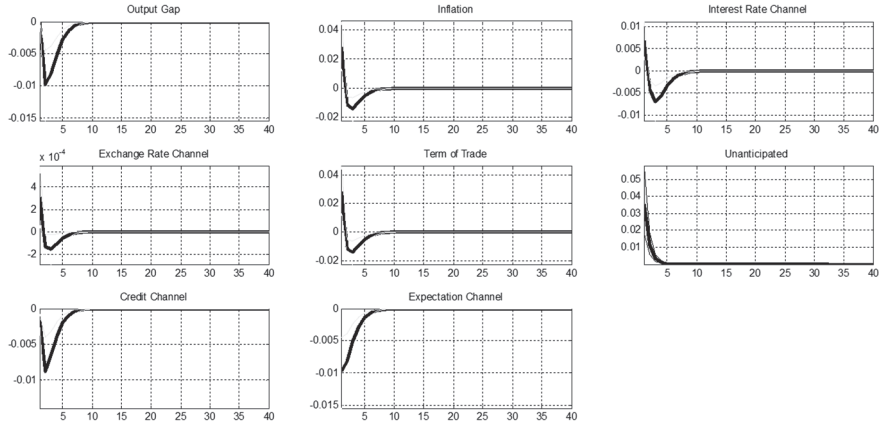
The impulse response of the estimated model reveals the propagation of the steady-state shocks within the economy. The results of the impulse response are presented in Figures 3 to 6.

Figure 3: Response to 1% Anticipated Monetary Policy Shock



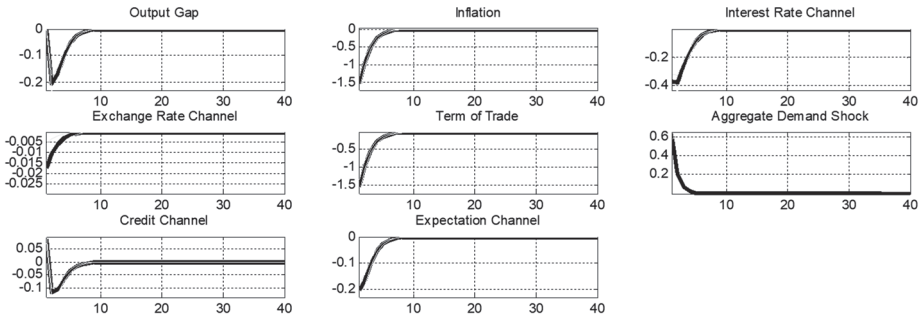
Anticipated monetary policy harmed transmission channels such as the interest rate, exchange rate, expectation, and credit channels. It impacted negatively on the interest rate, exchange rate, and credit to the private sector. It reduced the rate of interest from 0.06 per cent in quarter one to 0.009 in quarter eight. The credit channel also demonstrated a negative response to the anticipated shock, though the effect is insignificant over the periods. This confirmed the argument of rational expectation theory that the anticipated shock would increase the price at the expense of other macroeconomic objectives. It could also be observed that the variables return to a steady state after their responses to shock.

Figure 4: Response to 1% Unanticipated Monetary Policy Shock



The interest rate responded positively to the unanticipated monetary policy shock while the exchange rate, credit, and expectation channels responded negatively. The interest rate channel transmitted 0.31 per cent in quarter one and this decreased to 0.004 per cent in quarter eight. Pressure from the unanticipated monetary policy shock subdued the performance of the exchange rate as the percentage of shock transmitted by the channel decreased from 0.002 in quarter one to zero in quarter eight. The same trend is noticed in the performance of the credit channel as the percentage of shock transmitted decreased from 0.07 per cent in quarter one to 0.003 per cent in quarter eight. Finally, the expectation channel performance followed the same trend. This result showed the pro-cyclicality of monetary policy in Nigeria. These results reasonably captured the effectiveness of monetary policy as it showed how to achieve its basic objectives, with some nominal tradeoffs, in terms of output decline and exchange rate appreciation. In the medium to long run, all the variables converged to their equilibrium levels.

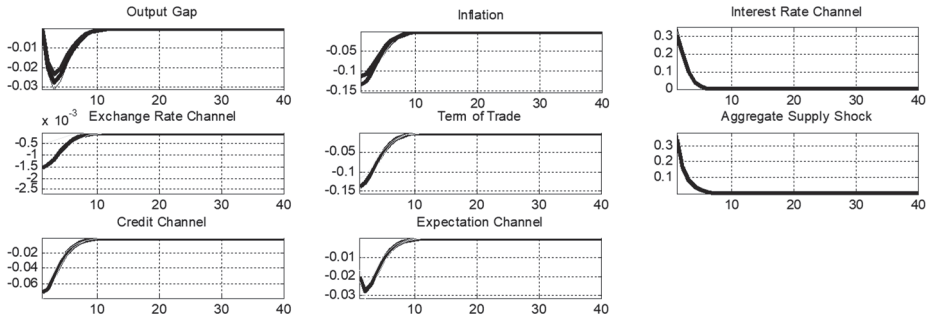
Figure 5: Response to 1% Aggregate Demand Shock



A shock to aggregate demand could either be positive or negative. The interest rate, exchange rate, credit, and expectation channels responded negatively to a one per cent positive aggregate demand shock. Although the response of the exchange rate to a positive demand shock is negative, the results are different both in the long-run and short-run periods. In the short run, the response is negative and significant. However, in the long run, it is negative and insignificant. The percentage of shock transmitted by interest rate and exchange rate channels fell from 0.36 per cent and 0.08 per cent in quarter one to 0.009 per cent and 0.003 per cent in quarter eight, respectively. The expectation channel also decreased

from 0.20 per cent in quarter one to 0.002 per cent in quarter eight. For the exchange rate, the percentage of shock fell from 0.01 per cent in quarter one to zero in the last quarter. All the variables converged to a steady state in the long run.

Figure 6: Response to Aggregate Supply Shock



The transmission channels differ in their responses to an aggregate supply shock. The credit and expectation channels responded negatively to the shock while interest rate and exchange rate responded positively both in the long- and short-run periods. The overall results showed that the supply shock produced short-term effects as against the demand shock. Given that the supply shock led to temporal supply adjustment problems, it pushed credit to the private sector upward from 0.001 per cent in the first quarter to 0.003 per cent in the fourth quarter. The interest rate and expectation channels responded negatively and the percentage of shocks transmitted fell from 0.06 per cent and 0.09 per cent in quarter four to 0.004 per cent and 0.002 per cent in quarter eight, respectively. The exchange rate produced an insignificant result as its values fizzled out over the entire period. The variables eventually converged to their steady state in the long run.

5.4 Robustness Check

Following Li and Liu (2013), the robustness of our empirical results was checked in the following two ways. First, we slightly altered the beginning and ending quarters of the samples, in addition to trying samples other than the baseline samples. For instance, 2007:1 to 2019:4 was taken as the longest sample instead of

2005:1 to 2019:4. Furthermore, the samples were extended to a more recent quarter i.e. 2011:1 to 2019:4. Second, some of the observable variables were changed and different measures for the existing observable variables were also used. For example, one of the observable variables was replaced by credit to the private sector as a measure of the credit channel. Furthermore, the short-term interest rate was used to represent the nominal interest rate against the treasury bill. The official exchange rate was also used to represent the exchange rate channel against the fixed effective exchange rate. It turns out that our baseline results do not change qualitatively in this robustness check.[1]

6. CONCLUSION

Our study examines the financial crisis, banking reforms, and effectiveness of monetary policy transmission channels in Nigeria by estimating a sticky-price dynamic stochastic general equilibrium model using quarterly data from 2005:1 to 2019:4. Our results are in line with the finding of Ashamu and Abiola (2012) and showed that the financial crisis "caused a drop in the quality of part of the credit extended by banks for trading in the capital market, exchange rate risk tightening of liquidity, greater loan-loss provisioning, slower growth rate of banks' balance sheet in response to the crisis and higher provisioning leading to lower profitability among others" (Ashamu & Abiola, 2012, p. 251). Furthermore, it was discovered that recent changes and reforms have positive impacts on all the monetary policy transmission channels considered in the study (exchange rate, interest rate, expectation, and credit). However, the credit channel (proxied by credit to the private sector) appears to be the most active channel as it transmits the largest impact of shocks to the financial sector (88.06 per cent on average) to the real economy. This demonstrates that the private sector depended on the financial sector for financing its expenditures which later induced an increase in the level of investment and increased output. Mengesha and Holmes (2013) argued that the effectiveness of credit channels, however, is an empirical issue that varies from one country to another. In line with their argument, most of the findings in the literature indicate the ineffectiveness of the credit channel through the private sector. Their argument is based on the fact that the effectiveness of the credit channel comes from credit issued to the government sector and not the

[1] The results of the robustness check are available upon request.

private sector (Mengesha & Holmes, 2013; Ravn, 2014; Gambacorta & Signoretti, 2014; Badarau & Popescu, 2014).

In addition, the data were found to be informative as the posterior means are different from the prior means. Furthermore, the prior and posterior estimations of the hybrid Phillips equation show that the data provide useful information in explaining inflation behaviour in Nigeria. Our study concluded that structural weaknesses such as a weak legal framework, poor governance, and insufficient infrastructure, which have contributed to inadequate financial intermediation and heightened risks, must be eliminated because they hamper the transmission mechanism of monetary policy.

Data Availability Statement

The datasets generated during and/or analysed during the current study are available in the World Bank data repository.

(https://databank.worldbank.org/reports.aspx?source=2&series=NY.GDP.MKTP.CD&country=)

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THE IMPACT OF EDUCATIONAL TECHNOLOGIES ON LEARNING OUTCOMES IN HIGHER BUSINESS EDUCATION

ABSTRACT: *The paper examines the impact of alternative ways of teaching and the use of various educational technologies on students' performance. Our survey was conducted on a sample of actively enrolled students of Business Informatics at the Faculty of Economics, University of Belgrade, in December 2022. Our results suggest that utilisation of communication and learning platforms (Viber, WhatsApp, Facebook, Moodle and course sites), although widely accepted and favoured by students, has no significant impact on their performance. Students' performance was measured by their average grades and the share of passed examinations in the total number of attended courses (i.e., success rate). We have found evidence that students' performance can be related to the teaching approach. Furthermore, attending classes online worsens students' chances of improving their average grade and their success rate in business informatics courses. On the other hand, the data suggests that students' chances of improving their total average grade improve if they attend classes online.*

KEY WORDS: *business education, educational technologies, learning platforms, distance learning*

JEL CLASSIFICATION: O31, O33, A22, C12, M15

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1. INTRODUCTION

In welfare economics, theoretical education is an important factor for both economic and human development (Barr, 2001). When it comes to prospective economists, modern economic education is faced with numerous challenges due to the global challenges which are emerging in the 21st century (Shakharova et al., 2022). Some of the main issues are: keeping up with the rapidly changing economic trends and technologies, addressing the increasing complexity of global markets, politics and economic factors, adapting new teaching methods and technologies to the teaching process, pedagogical preparations for dealing with new generations and students' new way of life, ensuring that students have the necessary skills to navigate a dynamic and competitive job market, satisfying a growing need for incorporating real-world applications and practical experiences into economic education in order to prepare students for the career challenges they may face in their careers, etc. Over the years there have been many attempts by researchers to address these issues. Our research deals with one of them – utilisation of technologies in the education process.

Since February 2020, the COVID-19 pandemic has had a significant impact on educational systems all over the world, as well as on the global society. The Internet, communication platforms, smart devices and numerous other novel digital and electronic resources (referred to as "Educational Technologies" or "EdTech" – Mirrlees & Alvi, 2019) helped sustain both teaching and learning during the pandemic. Simultaneously, educational technologies brought additional benefits into education (class flexibility, time efficiency, extension of student–teacher communication time, etc.). Nowadays, although the pandemic is over, teachers still use these technologies to supplement traditional teaching. Naturally, the question of how the changes introduced in the educational process affect students as the key beneficiaries of the educational system arises. Addressing this issue is vital for the future of education systems around the world. Given their benefits for the teaching process and positive experiences of students from schools in which some EdTech are already implemented, it is expected that EdTech would have a positive impact on students' performance as well. If this is the case, they should be incorporated into the teaching process globally. Conversely, if EdTech do not contribute to or have a negative effect on students' performance, there is no need to change the existing educational systems. Examining this question could be particularly helpful for the Serbian educational

system, where traditional teaching is still dominant in schools with little to no presence of EdTech. Furthermore, investigating this issue could be beneficial for the future development of Serbian academic business and economic education, especially bearing in mind the fact that in the Serbian context, similar academic surveys and research have not yet been conducted, to the best of our knowledge.

The main goal of this research was to quantify and examine the impact of different EdTech types on students' learning outcomes in Serbian higher business education. More precisely, this paper aims to examine and quantify the impact of three digital resources from the EdTech family on students' performance: communication platforms (Viber, WhatsApp and Facebook), learning platforms (Moodle and course websites) and online education. All of these resources were available to the students of the Business Informatics Department at the Faculty of Economics, University of Belgrade when our survey was conducted in December 2022. Each student had the opportunity to decide whether or not to use these EdTech. It covered a sample of 108 actively enrolled students participating on a voluntary basis who were asked to identify the EdTech they used, their attitudes toward theEdTech and their final performance. The results obtained were analysed using logistic and linear regression along with the Mann-Whitney U test. We found a high level of student satisfaction with implemented EdTech (analysis of student satisfaction was the secondary goal of this research). However, only one of them had a statistically significant impact on students' performance – online education.

The remainder of this paper is organised as follows: Section 2 gives a review of the relevant literature, Section 3 presents the EdTech analysed in this research, Section 4 deals with the data, applied methodology and research hypotheses, while in Section 5 we present our empirical findings. Finally, Section 6 provides the conclusion.

2. LITERATURE REVIEW

A detailed review of the literature on economics students' education was given by Miragaya-Casillas et al. (2023), who discussed 29 studies on this topic and students' self-interest. Among the earliest published papers on the impact of COVID-19 on teaching is Watermeyer et al. (2021), in which the authors discussed the rapid migration to online teaching and utilisation of digital

pedagogy in the UK. 1,148 academics working in the UK universities participated in the research. The results showed that not all fields were equally ready for a quick transition to online teaching. Computer science proved to be the readiest. Birdi et al. (2023) discussed recent economics pedagogy literature in the first period of the pandemic (2020–2021). They noticed a significant impact of the pandemic on scholarly articles, but not to the extent that they expected after 2021. The authors paid special attention to the impact of technologies on overcoming the issues brought on by the pandemic. Zhang and Ramse (2021) also dealt with the impact of the pandemic on economics and handling the problem in teaching practice.

There have been several papers on the impact of the COVID-19 pandemic on education in individual countries. For example, Roman and Plopeanu (2021) discussed the education of economists in Romania. They found that psychological distress and increased concerns about the pandemic had a negative effect on learning effectiveness. They also concluded that the university infrastructure for online activities decreased the likelihood of students perceiving online education as less effective. Conrad et al. (2022) examined education in Canada. They found that students' experience with online education can be negatively affected by information overload and additional technical skill requirements. Their evidence suggested a lack of social interactions, class format and ambiguous communication, which also affected perceived learning. Engel et al. (2023) analysed the situation in Germany. Based on various regression analyses, the results of Engel et al. (2023) show that several (digital) frameworks must be created at both teacher and student levels to achieve sufficient learning success. The strongest predictors of students' learning success were teachers' digital competencies. This supports the argument that teachers must be qualified to address the very specific challenges of teaching in digital contexts and a need for universities to implement more teacher qualification programmes. Rudolph et al. (2023) discussed the situation in Singapore, presenting students', lecturers' and academics' perspectives. They discussed the practical implications of their research for current university students during and after the pandemic. Engzell et al. (2021) analysed a large sample (n=350,000) of pupils in primary schools in the Netherlands. Their findings imply that students made little or no progress while learning from home and suggest even greater losses in countries with weaker infrastructure or school closures of longer durations.

González et al. (2023) showed that teachers who used EdTech to maintain content delivery and promote interaction expanded their understanding of course design and developed an empathetic disposition to understand students' situations. Rapanta et al. (2021) interviewed experts and discussed issues related to the possible role of EdTech and distance learning after the COVID-19 pandemic and what the teachers had learned from it. Engelhardt et al. (2021) compared students' performance in the COVID-19-affected semester to the performance in the previous three semesters. They considered both students' grades and performance on standardised tests in introductory macroeconomics, microeconomics and statistics and concluded that there were no significant differences in performance across the semesters. Orlov et al. (2021) concluded that students' gender, race and first-generation status had no significant association with a decline in students' performance in the pandemic semester. In contrast, they found that prior online teaching experience and teaching methods that encouraged active engagement (e.g., small group activities and projects) played an important role in mitigating negative effects of the pandemic. Adedoyin and Soykan (2023) concluded that online education is different from emergency remote teaching as it is more sustainable while instructional activities are more hybrid. Generally, the literature on the efficacy of online teaching is divided and inconclusive. There are authors claiming that one of two teaching methods is more efficient (online teaching was favoured by Bi et al., 2023; Dutton et al., 2002; Hamdan & Amorri, 2022; Zheng et al., 2021; amongst others; whereas face-to-face teaching was favoured by Brown & Liedholm, 2002; Helms, 2014; Jiang et al., 2021;amongst others), while there are also those who claim that online and face-to-face teaching are equally efficient (e.g., Fisher et al., 2022; Paul & Jefferson, 2019; Westhuis et al., 2006; amongst others).

Researchers apply different methods to analyse the EdTech impact on students' performance. There are also researchers who try to assess the EdTech impact via multiple statistical methods. Here, we will briefly address some of the commonly used methods in the recent literature. Authors such as Rapanta et al. (2021) and González et al. (2023) used qualitative methods based on interviews with research respondents. One such popular method is a hybrid thematic analysis which combines inductive and deductive codes (concepts) in order to draw a common conclusion (i.e., common narrative) from all the held interviews. Some authors tested whether average students' performance would be the same among students

who had been exposed to some EdTech and those who had not via two-independent-samples T-tests (Bi et al., 2023; Fisher et al., 2022; Helms, 2014) or via its non-parametric alternative, the Mann-Whitney U test (Fisher et al., 2022; Westhuis et al., 2006). Some others used other non-parametric tests to check whether the distribution of students' performance among exposed and unexposed students is the same. One of the most commonly applied non-parametric tests is the chi-square test (Dutton et al., 2002; Helms, 2014; Paul & Jefferson, 2019; Zheng et al., 2021). Among parametric statistic procedures, researchers typically use ANOVA or MANOVA depending on the number of students' performance metrics utilised. Some good examples are Bi et al. (2023), Jiang et al. (2021), Paul and Jefferson (2019). Finally, many researchers have used different econometric models to study the impact of EdTech. The most common among them is simple linear regression (Brown & Liedholm, 2022; Dutton et al., 2002; Engelhardt et al., 2021). Authors typically regress students' performance on a dummy variable which indicates whether a student is exposed to EdTech or not and on some controlling variables (such as gender, age, race, previous performance, employment, homework performance, teacher demographics). Apart from linear regression, authors have used the fixed effect panel model to test performance on multiple courses at the same time (Orlov et al., 2021), or logistic regression to model discrete metrics of students' performance (Roman & Plopeanu, 2021).

In analytical terms, the study by Roman and Plopeanu (2021) is closest to our work. The authors used ordinal logistic regression to assess the impact of multiple factors on students' attitudes towards different teaching methods in five major economics faculties in Romania during the COVID-19 pandemic. Thematically, the studies by Valverde-Berrocoso et al. (2022) and Palaroan et al. (2023), who examined the impact of ICT (Information and Communication Technologies) and Viber on students' performance, is the most similar to our work. All of these authors found significant improvement when EdTech were utilised.

3. EDUCATIONAL TECHNOLOGIES

Educational technologies have existed and been in development for many years. However, their use was not so widespread before the pandemic. It was left to teachers and students to use them as they chose. The Business Informatics department at the Faculty of Economics of the University of Belgrade recognised

the potential of EdTech and implemented some of them even before the pandemic. This primarily refers to the course websites and communication platforms for immediate information exchange (Viber, WhatsApp and Facebook). Both resources were initially used solely to supplement the teaching process, but they gained additional importance during the pandemic. Here we will briefly discuss each of them.

Course websites are learning platforms used for dissemination of teaching materials and information. Materials used in classes, additional exercises, notifications, announcements, instructions, relevant updates, etc. are commonly distributed to students via the respective course websites. The sites are not interactive. Consequently, they serve as general support for students in the learning process. Their main advantage lies in their availability since they are easily accessed from any place and any device with an Internet connection. Moreover, when course websites are built, designed, updated and maintained by teachers alone, they are usually better adapted to the needs of a specific course and each individual generation of students.

Viber and WhatsApp are communication platforms for instant information exchange. By using them, students have the opportunity to participate in a direct group conversation. Questions posted by each student can be answered by either a teacher or other students who are group members. Teachers can simultaneously monitor students' common questions, weak points in knowledge, point of interests, etc. In this way, the transmission of incorrect information is significantly reduced, while the response time is significantly shortened. Another important benefit of these platforms is that received information can be in text, audio, image, or video format. A non-negligible advantage of instant messaging applications is their popularity. They represent a preferred way in which students and young people want to communicate these days, which can encourage students to participate in discussions.

Facebook is a specific communication platform. It operates more as a hybrid between a communication platform and a course website. Facebook groups are basically a shared Facebook wall. A person can post content, reply to other posts, create polls and even start live streams. Compared to major community platforms, this is not much. In addition to this, students need to have an account

with Facebook, which reduces the range of students a teacher can reach. In the remainder of this study, Facebook is considered separately from other communication platforms since it is a hybrid platform.

During the pandemic, the exigencies of sustaining the teaching and learning process paved the path for two additional widely accepted EdTech. In the first months of the pandemic, Moodle was the dominant electronic learning platform. Moodle was especially helpful for courses that did not have their own websites and had to be transferred into virtual space in a very short time. Moodle is an open-source electronic learning platform for LMS (Learning Management System). It provides a space for teaching materials, posting information, checking knowledge (sitting tests), etc. Access to the platform is made easy by assigning user access rights.

In the autumn of 2020, using the video conference platform Zoom became the predominant approach for distance teaching and learning. Teachers use Zoom to stream their classes online, allowing the students to attend classes digitally. In addition to streaming, Zoom also offers a large number of supplementary features: direct conversation, messaging, "whiteboard" writing, screen sharing, defining multiple "rooms" for work (breakout rooms), meeting recording, file sharing, among others. Furthermore, Zoom allows large numbers of participants to attend, which sets it apart from its main competitors.

4. METHODOLOGY, DATA AND RESEARCH HYPOTHESES

We surveyed Business Informatics students from the Faculty of Economics of the University of Belgrade who had experience with the EdTech analysed. The research was anonymous and voluntary. The prepared survey consisting of a questionnaire with 15 questions in total was conducted in December 2022. The data was analysed by the commercial statistical software IBM SPSS. The research questionnaire and the dataset of survey results are available upon request.

The question regarding grades is traditionally considered to be a sensitive piece of information among the Serbian student population. Students prefer to keep information about their average grade private and they even tend to lie when asked about it. To avoid receiving false answers to this question, we reduced its sensitivity load by asking students to point out the range in which their average

grade could be found. In the Serbian higher education grading system, grades are awarded on a scale from 5 to 10, with 5 being a failing grade. We decided to group average grades in four intervals: 6–7, 7–8, 8–9 and 9–10. This makes the target (i.e., dependent) variable "average grade" categorical. Consequently, we analysed the EdTech impact on average grade (AG) using the proportional odds ordinal logistic regression model:

$$\ln\left(Odd_k\left(AG_i\right)\right) = \beta_{0,k} + \beta_1 online_i + \beta_2 moodle_i + \beta_3 viber_i + \beta_4 facebook_i + \beta_5 site_i + \varepsilon_i, \quad (1)$$

where $online_i$, $moodle_i$, $viber_i$, $facebook_i$ and $site_i$ are dummy variables indicating whether a student has been exposed to the given EdTech or not, $\beta_{0,k}$ is a regression intercept, β_j represent regression slope parameters and ε_i represent random errors. Note that slope parameters are the same for all categories, while the intercept, $\beta_{0,k}$, varies across categories. In a proportional odds ordinal regression, a dependent variable is a logarithm of category deterioration odds. In our case, it translates into grade deterioration odds, i.e., the ratio of the probability that a student will get the same or worse grade, $P\left(AG_i \le k\right)$, to the probability that a student's grade will be improved, $P(AG_i > k)$:

$$Odd_k\left(AG_i\right) = \frac{P\left(AG_i \le k\right)}{P\left(AG_i > k\right)}, \quad (2)$$

where k is some grade category. The higher this ratio is, the lower the students' chances of getting better grades are, and vice versa.

As suggested by Hosmer and Lemeshow (2000), we tested the model's proportional odds assumption by using a parallel lines test, which compares the log-likelihood function of the given proportional odds model and a baseline ordinal regression model. If the parallel lines assumption is violated, the baseline ordinal regression model is used instead.

$$\ln\left(Odd_k\left(AG_i\right)\right) = \beta_{0,k} + \beta_{1,k} online_i + \beta_{2,k} moodle_i + \beta_{3,k} viber_i + \beta_{4,k} facebook_i + \beta_{5,k} site_i + \varepsilon_i \quad (3)$$

Note that in the baseline model, the slope parameters vary across categories and the odds are defined in a different way. Here, we consider the odds of not belonging to a referent category for each of the dependent variable categories. In other words, the model defines the odds as a ratio of the probability of belonging to the same group, i.e., $p(AG_i = k)$, to the probability of belonging to a chosen reference group, i.e., $p(AG_i = m)$, where *m* is some chosen referent category:

$$Odd_k(AG_i) = \frac{p(AG_i = k)}{p(AG_i = m)}. \quad (4)$$

We use the category 9–10 as the referent category. Consequently, for each student the modelled likelihood will tell us whether it is more probable that the student will have grades in the lower grade ranges (6–7, 7–8 or 8–9) or the highest possible grades (9–10). The higher this likelihood is, the lower the probability of a student having the highest grades. Note that in both models, the increase in the modelled odds indicates a deterioration of the student's performance.

By testing the statistical significance of the regression slope parameters (β_j), we examined whether students' odds of improving (or worsening) grades could be explained by exposure to some EdTech:

$$H_0 : \beta_j = 0$$

$$H_1 : \beta_j \neq 0$$

If slope parameters are statistically significant and positive, the EdTech they represent increase the chances of students' bad performance (since $e^{\beta} > 1$). Conversely, if slope parameters are statistically significant and negative, the EdTech associated with them decrease the chances of students' bad performance (since $e^{\beta} < 1$). EdTech impacts are examined separately for the total average grade (average grade of all courses the students completed) and the Business Informatics average grade (average grade of all Business Informatics courses the students completed).

The second target variable which was considered was the Business Informatics success rate (SRBI). It is a ratio of the total passed (i.e., completed) Business Informatics courses to the total number of Business Informatics courses that students took. The Faculty of Economics at the University of Belgrade allows students to attend up to 10 Business Informatics courses (some courses are elective). To analyse the EdTech impact only on the Business Informatics success rate, we used the multinomial linear regression model, since the dependent variable is continuous.

$$SRBI_i = \beta_0 + \beta_1 online_i + \beta_2 moodle_i + \beta_3 viber_i + \beta_4 facebook_i + \beta_5 site_i + \varepsilon_i \quad (5)$$

Naturally, we used the same set of regressors (i.e., the EdTech) as in the case of the previous ordinal regression. By testing the statistical significance of regression slope parameters, we examined whether students' Business Informatics success rate could be explained by their exposure to some EdTech:

$$H_0 : \beta_j = 0$$

$$H_1 : \beta_j \neq 0$$

In the case of finding a statistically significant result in any of the previous three regressions, a supplementary nonparametric test was to be carried out to strengthen our conclusions. For this purpose, we used the Mann-Whitney U test complemented with the analysis of Cohen's effect size index (Fritz et al., 2012):

$$r = \frac{|Z|}{\sqrt{N}}, \quad (6)$$

where Z represents a standardised test statistic, while N is the total sample size. The idea was to test whether the distribution of the target variable (total average grade, Business Informatics average grade or Business Informatics success rate) was the same for the students who were exposed to some EdTech and for those who were not exposed to it. If the distribution (labelled as F) of the target variable for these two groups of students proved to be the same, then the grouping variable (i.e., EdTech exposure) did not affect the target variable (i.e., students' performance). Formally, we tested the following hypotheses:

$$H_0 : F_{Yes} = F_{No}$$

$$H_1 : F_{Yes} \neq F_{No}$$

Provided this test verified the existence of the identified statistical significance, the impact of the studied EdTech on students' performance was measured by Cohen's effect size index. For $0.1 \leq r < 0.3$, the effect is weak; for $0.3 \leq r < 0.5$, the effect is moderate; for $0.5 \leq r$, the effect is strong.

The secondary goal of our research was to examine the students' attitudes towards the implemented EdTech. The research findings are presented via graphs and descriptive statistics of our survey results.

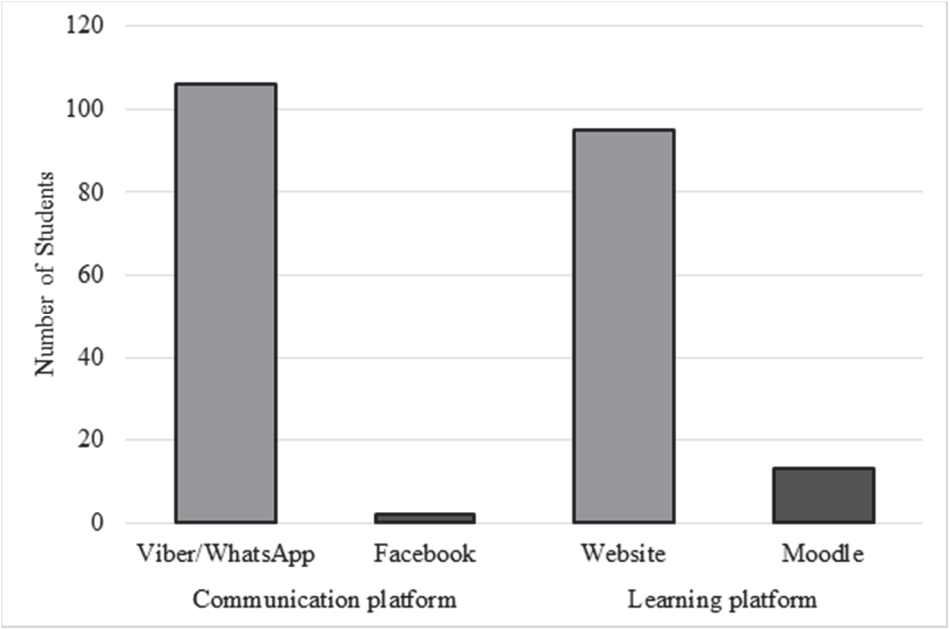
5. RESULTS

108 students (roughly 40% of the student population) voluntarily participated in our survey. The majority of these students were in their final year of studies (66.7%), while the smallest number of participants were in the second year of studies (1.8%). We first focus on examining the students' attitudes towards the utilised EdTech. We then analyse the EdTech impact on the students' performance.

5.1. Students' Attitudes towards Educational Technologies

The end users of the educational process are students, and therefore their opinions on how this process operates are very important. Keeping this in mind, in addition to the benefits of a particular EdTech, it is good to know what students think about them. We asked students to compare the learning and communication platforms used in Business Informatics courses. The results are displayed in Figure 1. In both cases, one of two alternatives is strongly preferred. Regarding the learning platforms, the vast majority of students consider the course website to be a more appealing learning platform than Moodle. One possible explanation for this result is that Moodle is a general, widely accepted learning platform, while course websites are tailor-made. Since the websites considered in this research are specifically designed for the needs of each individual course (i.e., customised), students may find them more helpful in learning a particular subject than Moodle (a more general alternative).

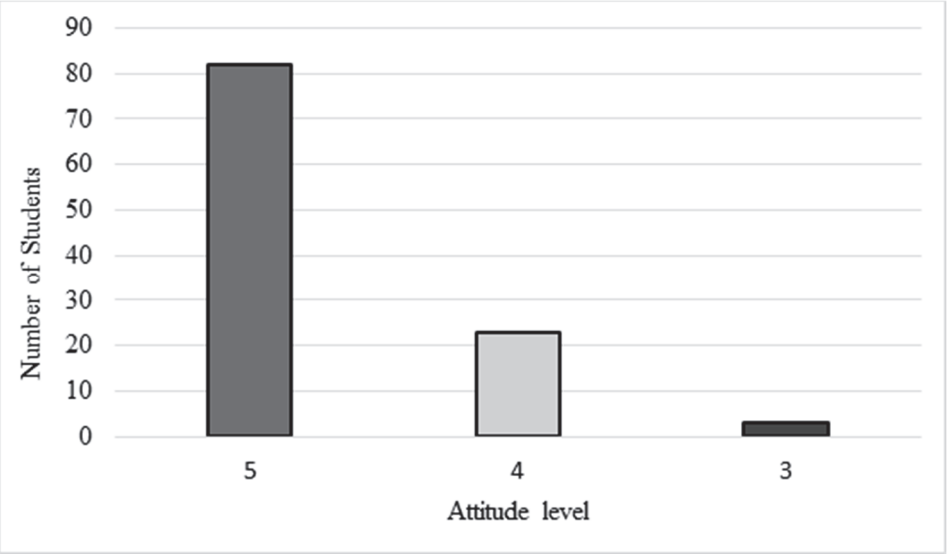
Figure 1. Students' preferred communication and learning platforms



Source: Authors' calculation

Students' preferences concerning communication platforms are shown on the left-hand side of Figure 1. The students almost unanimously selected Viber/WhatsApp as a more useful communication platform than Facebook. We anticipated this result, since teachers have constantly gained positive feedback from students regarding the idea of incorporating Viber/WhatsApp in the educational process. Figure 2 shows the distribution of students' attitudes towards the implementation of Viber and WhatsApp in the educational process. The highest level of satisfaction is associated with grade 5, while the lowest satisfaction level is represented by grade 1. The majority of students displayed the highest level of satisfaction. The average satisfaction level is high (the mean is 4.73) and the students' satisfaction does not vary too much within our sample (standard deviation is 0.5). This proves that a positive attitude is pervasive among students.

Figure 2. Students' attitude towards incorporation of Viber and WhatsApp in educational process



Source: Authors' calculation

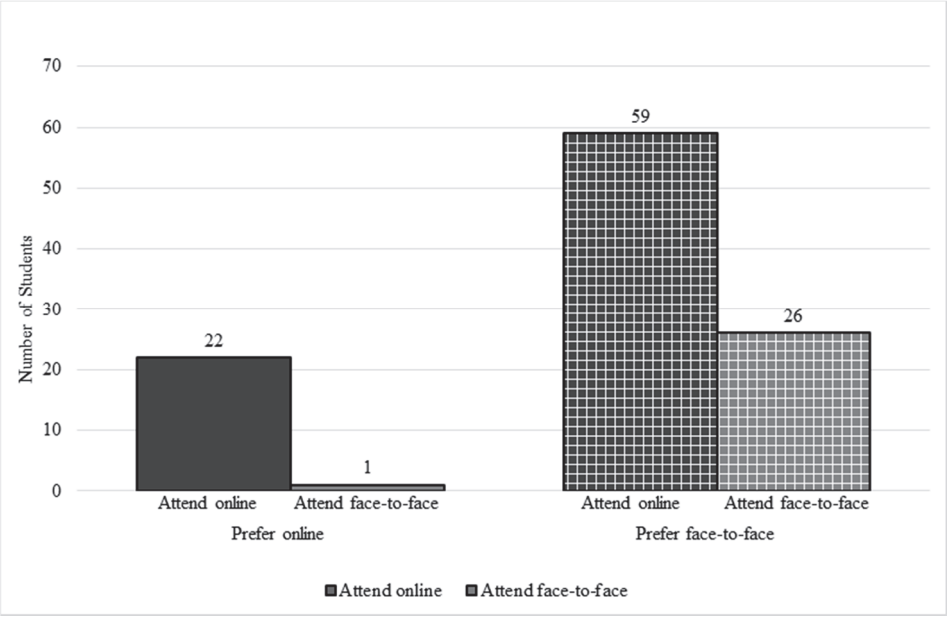
When it comes to teaching methods (online vs. face-to-face), we contrasted students' opinions and choices. More precisely, we examined whether students chose to attend classes online or face-to-face and which of these two was more efficient in their opinion. Our results are summarised in Table 1 and depicted in Figure 3. Interestingly, the majority of students chose to attend classes online (78.7%), while the majority of students considered face-to-face teaching a better teaching method regardless of the way in which they chose to attend classes. The obtained results also indicate that only 25% of the students considered online teaching as a more efficient alternative and they almost unanimously preferred attending classes online. The evidence presented implies that students generally prefer to attend classes online although they consider it to be a less efficient teaching method. One possible explanation for this could be that online education provides students with a certain dose of comfort and flexibility. It would appear that (these) Serbian students were willing to trade their learning efficiency for such benefits.

Table 1. Distribution of students by teaching method and their attitude towards it

		Used method:		Grand total (teaching method)
		Online	F2F	
Preferred method (attitude):	Online	26	1	27
	F2F	59	22	81
Grand total (attitude)		85	23	108

Source: Authors' calculation

Figure 3. Distribution of students by teaching method and their attitude towards it



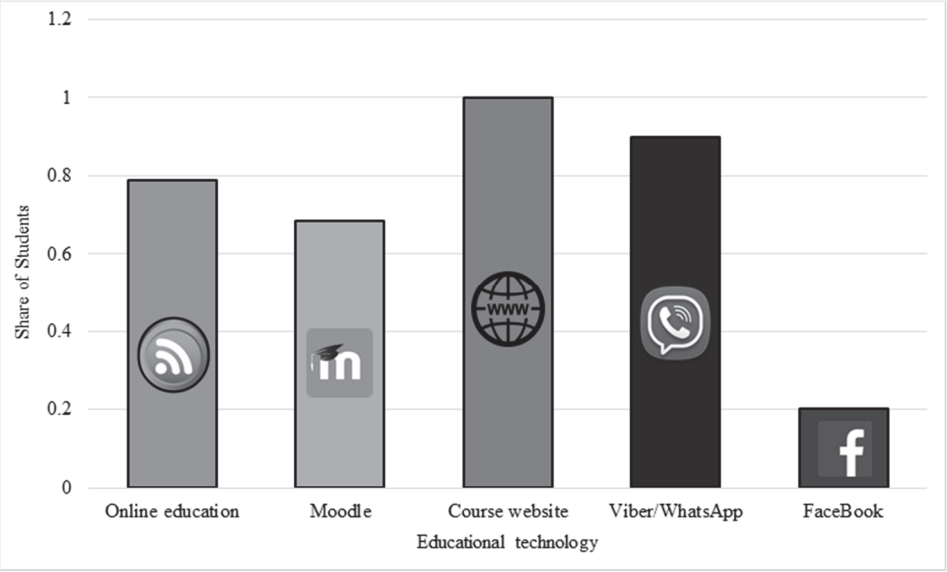
Source: Authors' calculation

5.2. Students' Performance

The primary goal of EdTech is to boost students' performance. This aspect of EdTech is also investigated in our study. Students' performance is measured via the total average grade (TAG), the average grade on Business Informatics courses (BIAG) and the success rate in the Business Informatics Department (SRBI). The examined EdTech included online teaching, Moodle, course websites, Facebook and Viber/WhatsApp. However, we were only able to examine the impact of four of them. After conducting the survey, an issue with the variable "course website"

arose. Namely, it turned out that all participating students used course websites during their learning process. Without the sub-sample of students who did not use course websites, we could not compare performance with and without this EdTech. Alternatively, we can say the utilisation of a course website is not a variable, but rather a constant within our sample. Since students' answers to the question whether they used course websites or not did not vary, we could not use it to explain the variations in students' performance. Furthermore, keeping it within a model would create a perfect multicollinearity issue (the intercept and variable "utilisation of website" are the same). Consequently, we excluded "course website" from this part of the research. The shares of the participating students who had the opportunity to use different EdTech are presented in Figure 4. The majority of the participating students were evidently open to trying the implemented EdTech. The only exception is Facebook, which was utilised by only 20% of students.

Figure 4. Shares of students who experienced different educational technologies

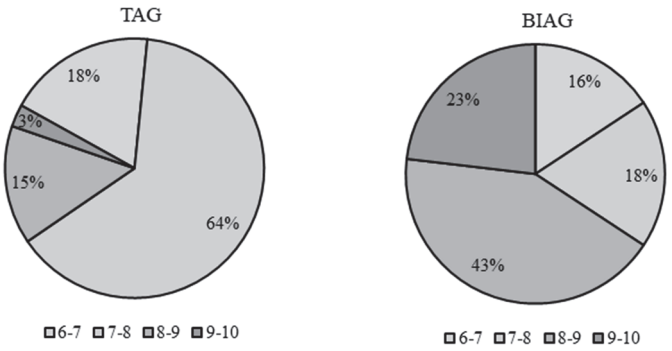


Source: Authors' calculation

The distribution of the first two performance matrices is shown in Figure 5. Interestingly, the results show that a significant number of students had better average grades in the informatics course group. This may indicate that the

EdTech used in the Business Informatics courses helped students master the course requirements more efficiently. Of course, since EdTech are not the only differentiating factors between these two groups and since they are not perfectly separated (BIAG is the subsample of the TAG), this assumption has yet to be verified.

Figure 5. Distribution of average grade (Total and Business Informatics)



Source: Authors' calculation

We first analysed the impact of EdTech on the TAG. With the exception of the teaching method, all other EdTech considered were implemented only in the Business Informatics Department. However, they still had an impact on students' TAG since the grades obtained in Business Informatics courses are included in it. This allowed us to estimate the ordinal logistic regression by regressing the TAG on four selected EdTech. The test of parallel lines asserted the proportional odds model. The results are displayed in Table 2.

Table 2: Test of parallel lines in the case of full model for TAG

-2 Log-likelihood		Chi-Square	df	p-value
Null hypothesis	Proportional odds			
55.961	49.815	6.146	8	.631

Source: Authors' calculation

The estimated model parameters are given in Table 3. Apart from the intercepts, the only statistically significant parameter at the significance level of 10% is the teaching method (i.e., online vs. face-to-face education). However, even the

teaching method is on the very edge of statistical significance. The results lead to the conclusion that the use of the other three EdTech (Moodle, Facebook and Viber/WhatsApp) cannot explain the variations in the students' TAG. Since the full model incorporates irrelevant regressors (which may affect estimates of relevant regressors), the reduced model is estimated prior to interpreting the impact of the teaching method on the TAG.

Table 3: Parameter estimates in case of full model for TAG

Variable	Estimate	Std. error	Wald	p-value
online	-0.805	0.489	2.712	0.100
moodle	0.474	0.433	1.2	0.273
viber	0.357	0.651	0.3	0.584
fb	0.301	0.493	0.373	0.541
Limit points				
[TAG = 1]	-1.460	0.839	3.030	0.082
[TAG = 2]	1.677	0.845	3.937	0.047
[TAG = 3]	3.720	0.994	13.999	0.000

Source: Authors' calculation

In the reduced model, the TAG is regressed only to the teaching method and intercept. The test of parallel lines (reported in Table 4) indicated that the proportional odds model was an appropriate framework for our analysis. This time, the statistical significance was much lower and close to the significance level of 10%.

Table 4: Test of parallel lines in the case of reduced model for TAG

-2 Log-likelihood		Chi-Square	df	p-value
Null hypothesis	Proportional odds			
22.613	18.022	4.591	2	.101

Source: Authors' calculation

Table 5 exhibits the estimates of the parameters in the reduced models. With the irrelevant regressors removed, there was a noticeable improvement of statistical significance for the variable "teaching method", which was previously on the very edge of statistical significance.

Table 5: Parameter estimates in case of reduced model for TAG

Variable	Estimate	Std. error	Wald	p-value
online	-0.823	0.483	2.907	0.088
Limit points				
[TAG = 1]	-2.154	0.479	20.177	0.000
[TAG = 2]	0.938	0.426	4.849	0.028
[TAG = 3]	2.960	0.667	19.693	0.000

Source: Authors' calculation

The negative value of the parameter next to the variable "teaching method" indicates that online teaching enhances students' chances of improving their TAGs. Attending classes online leads to a 0.44 times reduction in the likelihood of a deterioration in grades ($e^{\beta} = e^{-0.823} = 0.44$), *ceteris paribus*. Although there are other studies which found evidence in favour of online teaching efficiency, the obtained result was surprising. Given students' poor attitudes towards online teaching, previous inexperience with it and traditional benefits that face-to-face teaching provides, it was expected that students who attended classes in person would perform better. This issue is addressed later.

The intercept estimates show the chances of grade deterioration for the students who attend classes in person (i.e., face-to-face teaching). The intercepts vary from group to group, thus indicating that different groups of students who attend classes in person have different chances of deteriorating and improving their grades. The chances of grade deterioration for the students who attend classes in person are the lowest among the students who have the lowest grades. In other words, face-to-face teaching is the most beneficial for the students with the lowest grades. The chances of grade deterioration during face-to-face teaching are the highest among students who have high grades. In other words, the better the student, the less face-to-face teaching contributes to their performance.

Table 6: Test of parallel lines in the case of full model for BIAG

-2 Log-likelihood		Chi-Square	df	p-value
Null hypothesis	Proportional odds			
72.655	55.795	16.861	8	0.032

Source: Authors' calculation

Our results suggest that learning and teaching platforms do not affect students' performance as measured via TAG. We examined their effect on Business Informatics courses, i.e., on the students' BIAG, where they are directly implemented. To test whether the proportional odds ordinal logistic regression is an appropriate framework for this analysis, we conducted the test of parallel lines. The test results presented in Table 6 indicate that this is not the case. Consequently, the impact of the utilised EdTech on BIAG was modelled with the baseline ordinal logistic regression model.

Table 7: Parameter estimates in the case of full model for BIAG (reference category: 9–10)

BIAG	Variable	Estimate	Std. error	Wald	p-value
6–7	Intercept	-0.384	1.256	0.094	0.759
	online	1.158	0.770	2.259	0.133
	moodle	-0.784	0.687	1.303	0.254
	viber	-0.521	1.073	0.236	0.627
	fb	0.819	0.869	0.890	0.346
7–8	Intercept	-1.533	1.471	1.086	0.297
	online	2.695	1.116	5.831	0.016
	moodle	0.186	0.727	0.065	0.798
	viber	-1.272	0.963	1.744	0.187
	fb	0.507	0.873	0.337	0.562
8–9	Intercept	-1.062	1.210	0.770	0.380
	online	1.265	0.571	4.903	0.027
	moodle	0.010	0.579	0.000	0.987
	viber	0.691	1.055	0.430	0.512
	fb	0.719	0.733	0.963	0.326

Source: Authors' calculation

The estimated parameters in the case of the full model for the BIAG are given in Table 7. Once again, we have the situation in which the teaching method is the only EdTech with a significant impact. It is significant in two out of three equations. However, even in the first equation it is close to statistical significance. The test's failure to recognise its significance may be due to the presence of the

irrelevant regressors. The other three utilised EdTech (Moodle, Facebook and Viber/WhatsApp) cannot explain the variations in the students' BIAG. Although the participating students showed a high level of satisfaction with the utilised EdTech, their implementation in the educational process did not help the students improve their grades.

Before interpreting the significant parameters, the estimated full model was gradually reduced until the final reduced model with statistically significant parameters alone was obtained. The estimates of its parameters are presented in Table 8. After the impact of the irrelevant regressors is excluded, the teaching method proves to have a statistically significant impact in all three equations. In contrast to the results obtained for the TAG, in this case, online teaching had a positive impact on the modelled odds ratio.

Table 8: Parameter estimates in the case of reduced model for BIAG (reference category: 9–10)

BIAG	Variable	Estimate	Std. error	Wald	p-value
6–7	Intercept	-1.299	0.651	3.979	0.046
	online	1.299	0.753	2.977	0.084
7–8	Intercept	-2.398	1.044	5.271	0.022
	online	2.703	1.102	6.015	0.014
8–9	Intercept	-0.318	0.465	0.470	0.493
	online	1.317	0.560	5.530	0.019

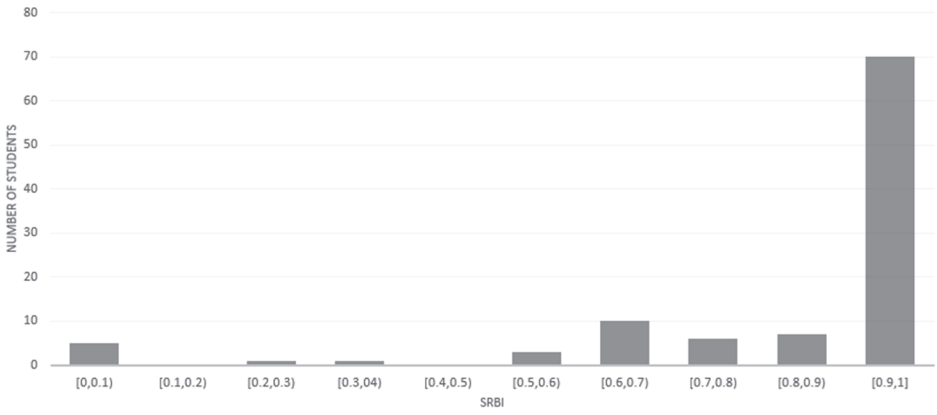
Source: Authors' calculation

In all three equations, the estimated slope parameter was positive. This indicates that attending classes online increases the chances of not getting the highest grade in Business Informatics courses for each group of students. The impact of online teaching on this likelihood was the highest for the students who had a BIAG between 7 and 8. For these students, attending classes online resulted in an almost 15-fold increase in the likelihood of not getting the highest grade in Business Informatics courses ($e^{\beta} = e^{2.703} = 14.929$), *ceteris paribus*. The impact of online teaching on the remaining two groups of students (6–7 and 8–9) was almost the same. In their case, attending classes online led to an almost 3.5 times increase in

the likelihood of not getting the highest grade , *ceteris paribus*. The results obtained in this part of our research are consistent with the findings of the other strand of the current literature.

The intercept estimates show the chances of not getting the highest grades for each group of students who attended classes in person. The students from category 7–8 had the highest likelihood of getting the highest grades (i.e., the lowest likelihood of not getting them) when attending classes in person. This indicates that they benefited the most from face-to-face teaching in Business Informatics courses. Underachievers (students from group 6–7) also felt the benefits of face-to-face teaching, given that their intercept was negative and statistically significant. Students from category 8–9 did not have statistically significant benefits from attending classes in person. However, some small and insignificant benefit still existed since the obtained point estimate was negative.

Figure 6. Distribution of students by their SRBI



Source: Authors' calculation

As the final performance metric, we considered the students' success rate in Business Informatics courses (SRBI). Survey participants typically attended 4 courses (the mean is 3.68 and the median is 4) while only 2 students decided to attend all 10 available Business Informatics courses. When it comes to their success in mastering these courses, the distribution of SRBI is depicted in Figure 6. The majority of 63% were able to pass all courses they attended (SRBI of 1).

The lowest success rate (0) was observed in just 5 cases. In addition, an average SRBI of 0.88, along with a median of 1 and a standard deviation of 0.26, also speaks in favour of excellent student performance in Business Informatics courses. The question remains whether the utilised EdTech had something to do with these students' performance in Business Informatics courses.

Since the success rate is a continuous random variable, here we fitted the linear regression model with the SRBI as a dependent variable and used EdTech as regressors. The estimated regression parameters are displayed in Table 9. Once again, we can observe that all utilised EdTech, with the exception of online teaching, did not have a significant impact on students' performance. We removed them from the model by estimating the reduced model with only significant parameters. The estimates of the reduced model are presented in Table 10.

Table 9: Parameter estimates in the case of full model for SRBI

Variable	Estimate	Std. error	t	p-value
Intercept	1.061	0.111	9.577	0.000
online	-0.131	0.065	-2.017	0.046
moodle	-0.038	0.057	-0.663	0.509
viber	-0.059	0.089	-0.661	0.510
fb	-0.001	0.067	-0.013	0.989

Source: Authors' calculation

The estimated slope parameter in the reduced model is statistically significant and negative. This indicates that online teaching had a negative impact on students' success rate. By attending classes online, students reduced their SRBI by 0.127, *ceteris paribus*. When it comes to the intercept, it was once again associated with the performance in face-to-face teaching. The students who attended classes in person had an average SRBI of 0.978, *ceteris paribus*. This success rate is high and favours face-to-face teaching. Thus, based on our results, face-to-face teaching seems to have had a positive impact on both analysed students' performance metrics.

Table 10: Parameter estimates in case of reduced model for SRBI

Variable	Estimate	Std. error	t	p-value
Intercept	0.978	0.056	17.425	0
online	-0.127	0.063	-2	0.048

Source: Authors' calculation

Finally, we display the statistical properties of the estimated final reduced model. Based on the F-test, the whole regression is statistically significant. The results presented in Table 11 imply that utilisation of the teaching method can explain 3.8% of the variations in students' success rates. When it comes to heteroscedasticity, autocorrelation and normality diagnostics, the usual statistical tests are reported in Tables 11 and 12. There is no heteroscedasticity (based on the Breusch–Pagan and Goldfeld–Quandt tests) nor autocorrelation (the Durbin–Watson test for order 1 and the Box–Ljung test for orders up to 10).

Table 11: Results of F-test for the model's statistical significance along with usual statistical heteroscedasticity, autocorrelation and normality diagnostics

	R^2 (F-test)	Jarque–Bera	Breusch–Pagan	Goldfeld–Quandt	Durbin–Watson
Statistic	0.038	152.664	.148	.904	2.228
p-value	.048	.000	.700	.637	- [a]

a. Critical values (intercept + k=1, n=100): [2.438, 2.478]

Source: Authors' calculation

Table 12: Results of Box–Ljung test

Lag	1	2	3	4	5	6	7	8	9	10
BL	1.406	2.864	2.929	3.311	3.490	4.996	10.596	10.760	12.898	13.075
p-value	.236	.239	.403	.507	.625	.544	.157	.216	.167	.219

Source: Authors' calculation

The only violated assumption is the assumption of normality. Under these circumstances, in order to be able to rely on the results of the statistical tests, we bootstrapped the estimated p-values. The bootstrap results were based on 10,000

bootstrap samples, and they are presented in Table 13. The simulated p-value is still below the significance level of 10%, thus indicating that the statistically significant teaching method can explain the variations in the students' SRBI.

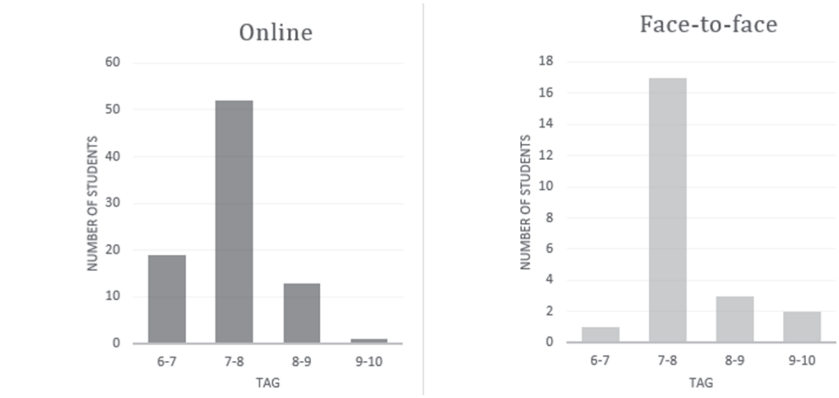
Table 13: Bootstrapped parameter estimates in the case of reduced model for SRBI

Variable	Estimate	Std. error	p-value	90% Confidence interval	
Intercept	0.978	0.061	0	0.874	1.074
online	-0.127	0.067	0.055	-0.235	-0.015

Source: Authors' calculation

In all our models, one EdTech in particular displays a statistically significant impact on the students' performance. In order to verify that result, the nonparametric Mann-Whitney U was carried out. Before the test itself, the distributions of all three performance metrics for online and face-to-face attending students considered were visually analysed in Figures 7 to 9. In each of the three figures, the performance metrics displayed a different distribution for the online and face-to-face attending students. Consider, for example, Figure 8. While the majority of the students who attended classes in person ended up with the BIAG between 9 and 10 and a small number of them ended up with lower grades, this was not the case with the students attending online. Faced with this evidence, we conducted the Mann-Whitney U test accompanied by Cohen's effect size diagnostics. The results are presented in Table 14.

Figure 7. Distribution of Total average grades by teaching method

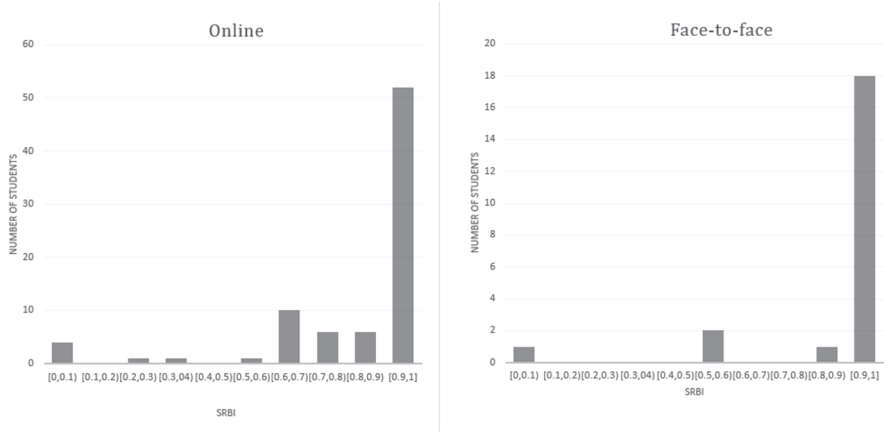


Source: Authors' calculation

Figure 8. Distribution of BI average grade by teaching method

Source: Authors' calculation

Figure 9. Distribution of students' success rates by teaching method



Source: Authors' calculation

In all three cases considered, the Mann-Whitney U test reported a statistically significant impact of the teaching method on the students' performance. Also, the size of this impact was rather small in all three cases based on Cohen's index. However, in the case of SRBI, it was close to the upper bound of 0.3, thus hinting that in some broader research it may show some moderate impact on this performance metric.

Table 14: Results of Mann-Whitney U test for three performance metrics

	TAG	BIAG	SRBI
Mann-Whitney U	779.000	636.500	603.000
Z	-1.744	-2.697	-2.747
Cohen's r	.16782	.25952	.26433
p-value	.081	.006	.005

Source: Authors' calculation

6. CONCLUSION

We conducted an experiment aiming to examine whether the three groups of educational technologies utilised the most during the COVID-19 pandemic affected students' performance (the average grade and success rate). Our paper considered the following EdTech: learning platforms (Moodle and customised

course websites), communication platforms (Facebook and Viber/WhatsApp) and online teaching. We explored their effects on a sample of 108 volunteer students from the Department of Business Informatics at the Faculty of Economics, University of Belgrade.

Our research has shown that students share a high level of affection towards the implemented EdTech. We were also able to identify some of the students' preferences. Students strongly preferred the customised course websites to a more general and widely used Moodle platform. The customised course website was the only EdTech used by all the students in our sample. We have also found that students strongly preferred Viber and WhatsApp to Facebook as communication platforms. Students' level of satisfaction with smartphone messaging (chatting) apps was very high, while the Facebook group was mainly neglected. Furthermore, we have found that the vast majority of students consider face-to-face teaching more efficient than online teaching. However, when it comes to class attendance, most students decided to choose online teaching although they themselves recognised that it is a less efficient learning method. One possible explanation for this result could be that these students were willing to consciously trade their learning efficiency for the comfort of online learning. The factors contributing to this are yet to be explored in some broader research.

Using linear and ordinal regressions, we demonstrated that the use of learning and communication platforms in teaching does not lead to a significant improvement in students' performance. We have found that the teaching method (online vs. face-to-face) is statistically significant and can explain variations in students' performance. Attending classes online boosts students' chances of improving their total average grade, while it worsens their chances of improving their average grade and their success rate in Business Informatics courses. In explaining this we suggest that the nature of the courses might influence the observed difference in the impact of online teaching on students' performance. Most courses in the field of economics are conceptualised as oral presentations of theoretical and empirical facts. On the other hand, informatics courses require practical demonstrations (e.g., working with some software, programming, web design, database editing). Active contact with students and control of their in-class performance is essential under these circumstances. There are also some student-oriented drawbacks. Some students may not possess the necessary

resources to follow informatics courses from their homes (e.g., some software). In addition, it may be difficult for inexperienced students to follow the professor and repeat the same procedure on their own computers at the same time. Consequently, face-to-face teaching might be more relevant for informatics than for classical economics courses. From the students' perspective, face-to-face teaching is recognised as the most beneficial for underachievers (average grade 6–7) and low-to-average-achievers (average grade 7–8). The Mann-Whitney U test provided support for previous claims, confirming that the analysed impacts exist, but are of minor significance.

Finally, we also acknowledge the limitations of this study and identify avenues for future research in this domain. Our study was organised as an anonymous pilot experiment. We decided to use the shortest possible questionnaire and collect the minimal set of information necessary for us to conduct the research. In this way, we obtained just enough data to gain a preliminary picture of the impact of the utilised EdTech on students' performance as a preparation for a wider study that we would like to conduct on this topic. In addition, since students are reluctant to participate in long surveys, one of the goals of giving a short questionnaire was to increase the number of students willing to participate. Finally, the absence of personal and demographic questions contributed to the anonymity of the survey and the establishment of a sense of security and trust among students with the aim of obtaining as honest answers as possible. Unfortunately, the negative side of this trade-off is that we lost controlling variables for our regression models. However, we would like to address this issue once we are able to conduct broader research on this topic by examining EdTech on a larger sample of students and faculties. At this point, a general impression is that communication and learning platforms can be helpful for all students and that overall students' performance does not directly depend on the platform used. In our opinion, it is noticeable that they are all good additions to the teaching process, but that no platform can replace high-quality live teaching for now. We hope that this research will motivate other researchers (from the fields of both economics and pedagogy) to continue in our footsteps and experiment with EdTech, which could prove to be beneficial for Serbian higher education and new generations of students.

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