



Research article

Nexus among foreign direct investment, financial development, and sustainable economic growth: Empirical aspects from Sudan

Mustafa Hassan Mohammad Adam*

Business Administration Department, Komar University of Science and Technology, Sulaimani city, Kurdistan Region, Iraq

* **Correspondence:** Email: mustafa.hassan@komar.edu.iq.

Abstract: This study examined the nexus between foreign direct investment (FDI), financial development, and sustainable economic growth in Sudan during the period of the structural adjustment program and the full Islamization of the banking and financial system that took place in the 1980s. The research provides a comprehensive analysis using the most recent time series secondary data from 1990 to 2020 and the study employed co-integration, Granger causality, and VAR error correction technique to estimate the models, to clarify the claimed relationship between FDI and its effect on the financial sector and subsequently attending a sustainable economic development in Sudan. In this research, Augmented Dickey-Fuller (ADF) unit root tests are applied to test the stationarity of data and the data was found stationary at first difference. The results of the ARDL bounds showed the existence of a long-term relationship between the FDI and other independent variables but the short-term showed otherwise. The Granger causality test implies that the past values of FDI don't significantly contribute to the prediction of sustainable economic growth. Also, results show that there's evidence of observed causality running from the country's trade openness and the financial sector's development. The implication of these results shows there is a complementary relationship between sustainable economic growth and both financial development and trade openness in the short run. Interestingly, the findings of the study show that the effect of financial development on economic growth is further enhanced by the inflows of FDI.

Keywords: FDI; financial development; sustainable economic growth; Sudan; empirical evidence

JEL Codes: C22, C33, E22, F21, F23, F43, O11, O55

1. Introduction

The processes of globalization, changes in the economic environment, trade liberalization, and technical development over many decades have led to the robust growth of international business activities and movements of foreign direct investments (FDIs) (Akbas et al., 2013; Asteriou and Moudatsou, 2014; Borensztein et al., 1995). The continuous inflows of international capital to developing countries, specifically those of FDIs, are expected to increase production efficiency and further increase opportunities in recipient countries in terms of, for example, technology gap transfer (Findly, 1978; Wang and Blomström, 1992), export development, human resources, technical skill creation, and upgrading of management knowledge and skills (Barro and Sala-i-Martin, 1995; Grossman and Helpman, 1991). However, from the perspective of Sudan, a sub-Saharan African developing country, given its savings rates and access to international capital markets compared to rich countries, its ability to invest is limited unless supplemented by other external benefits, such as FDIs. Asiedu (2002) revealed a country that received a smaller amount of attracting FDI is a widely recommended policy in developing countries because FDIs bring with them several positive externalities, such as productivity gains and technology transfers (Alfaro et al., 2010). Moreover, foreign investments, particularly in projects, can become valuable channels for the transfer of technology, knowledge, and modern practices (Findlay, 1978; Wang and Blomström, 1992). However, when comparing the distribution of FDI inflows across developing regions, Sudan has attracted only a small proportion of global FDI stocks compared to China, India, and Brazil (UNCTAD, 2003).

The main goal of this study is to investigate the inflow of FDI to Sudan (Abdallah et al., 2015; Ibrahim and Hassan, 2013). FDI flows are a sensitive subject for many developing nations; there is considerable controversy about the related costs and benefits of FDIs (Aliber, 1970). They can directly affect growth and development by contributing to gross fixed capital formation and through several indirect channels that constitute the externalities associated with FDIs. A direct channel does not favor FDIs over other types of investments and would not justify costly incentives for attracting FDIs without providing the same incentives for domestic direct and foreign portfolio investments. Through indirect channels, however, FDIs are often argued to affect various parts of the host economy and, in turn, spur growth (Hussain, 2009). The World Investment Report indicated that developing economies experienced FDI inflow growth. Consequently, FDI inflows to Africa increased from US \$ 2.845 billion (1990) to US \$ 45.678 billion for 2019, while FDI stock stands at US \$ 82.991 billion in 2021 (UNCTAD, 2021). Sudan was one of the leading recipient after South Africa for Chinese FDI inflow, for instance (UNCTAD, 2013). Sudan recorded around 7% GDP growth rate as the highest economic growth in Africa during the period 2005–2018 (World Bank, 2021). That means the FDI has increasingly become important globally and for Sudan, however, the domestic investment remained highly unpredictable during the studied period. Foreign direct investment inflows totaled less than \$150 million until the year 2000 before the full exploitation of the oil resources, then started to increase in line with the increase in oil production to reach US\$ 2.8 in 2008. However, after the secession of South Sudan and the loss of oil and the consequent economic instability FDIs started to decline by half from US\$ 2.3 billion in 2011 to 1.1 billion in 2018. Sudan has made some efforts to diversify the economy and attract FDI into new industries. Efforts included putting in place a relatively open investment legislative framework with several of the existing laws being modernized and in line with good practices. However, the instability of the macroeconomic situation, the difficulty of doing business in Sudan that being in the SSTL were all factors behind the weakness of realizing a good potential from FDIs.

1.1. Importance and objectives of the study

The importance of this study lies in its testing of the extent to which Sudan has recognized the importance of FDIs in the process of financial development and sustainable economic growth, and hence, the measures adopted to attract foreign capital and encourage foreign investment, particularly considering the relationships among FDIs, financial development, and economic growth (Abdalla et al., 2015). Campos and Kinoshila (2002) mentioned that FDIs' positive impact on sustainable economic growth seems to have acquired the status of a stylized fact in the literature. Therefore, the objectives of this study are as follows: (i) to contribute to the debate regarding the importance of FDIs in Sudanese economic growth and the related issues of strategy and policies and (ii) empirically analyze, determine, and examine the effects of foreign capital inflow on the dynamic relationships among financial development, trade-openness, and sustainable economic growth in Sudan.

1.2. Problem statement and rationale of the study

An FDI is the net inflow of investment aimed at acquiring a lasting management interest in an enterprise operating in an economy other than that of the investor (Abdalla et al., 2015). It is the sum of equity capital, reinvestment of earnings, and other long- and short-term capital, as shown in the balance of payments. This series shows the total net, that is, net FDIs from foreign sources in the reporting economy minus net FDIs made by the reporting economy in the rest of the world. An FDI plays a major role in the growth process of both developed and developing countries; it has long been a topic of intense debate. The relationship between FDIs and economic growth has been studied by explaining four main channels: (i) determinants of growth, (ii) determinants of FDIs, (iii) role of multinational firms in host countries, and (iv) direction of causality between the two variables. This nexus is one of the thorniest areas in the present debate. There is a wide spectrum of views on an FDI, from those who see it uncritically as contributing to economic growth in all circumstances to those, largely from the anti-globalization movement, who consider that an FDI is pernicious to national development. An FDI has many effects, which vary significantly by the sector in which it is made and by the type of the host country (Mohamed and Sidiropolous, 2010).

1.3. Brief review of the relevant literature:

Numerous studies, both empirical and theoretical, have been devoted to FDIs by economists and other writers, who have talked about the issue from different perspectives. While certain studies have shown that FDIs positively impact the economic growth of the host country, others believe that FDIs are neither necessary nor sufficient to boost economic growth. Generally, the following two main trends of thought are found on this issue: the first is based on the causality between FDIs and economic growth, and the second is based on FDI spillovers in the host country (Asteriou and Moudatsou, 2014). All these studies have serious weaknesses concerning the statistical methods that they have adopted. Some authors have analyzed investment flows between different countries and groups of countries, such as flows between developed and developing countries; others have focused on the reasons behind investors' decision to delocalize their production or invest in other countries, and another group has presented different effects of FDIs on the host country.

An extensive literature review showing that an FDI increases the gross domestic product (GDP) was conducted by Mohamed (2003), who examined the effect of foreign capital inflow on the savings, investment, and economic growth rate in Egypt. The regression results showed that foreign capital inflow has a significant positive effect on these three variables. In addition, a complimentary relationship between FDIs and domestic investment was established. The results indicated a strong positive effect of investment on economic growth in Egypt. Meanwhile, the main determinants of FDIs in MENA countries were analyzed by Mohamed and Sidiropoulos (2010), who covered a sample comprising 36 countries. Twelve of these were in the MENA region, and the remaining 24 were the major FDI recipients in their respective regions in developing countries. The authors employed panel data and revealed that the key determinants of FDI inflows in MENA countries are the size of the host economy, government size, natural resources, and institutional variables. They concluded that the countries receiving fewer foreign investments should make themselves more attractive to potential foreign investors. Therefore, policymakers in the MENA region should remove all trade barriers, develop their financial system, and build appropriate institutions.

The emerging literature on FDIs stipulates that an FDI's positive impact on economic growth depends on absorptive capacities, such as financial development. These studies have confirmed that in reformed countries, FDIs can cause financial development (Omran and Bolbol, 2003). Hermes and Lensink (2003), through an empirical investigation, found that financial system development is an important precondition of the recipient country for FDIs to positively impact economic growth, which can positively and strongly contribute to the process of technological diffusion associated with FDIs. They used data from 67 countries, of which 37 countries, such as Latin America and Asia, had a sufficiently developed financial system to let FDIs contribute positively to economic growth, while the remaining, such as African countries, lagged behind. Omran and Bolbol (2003) emphasized the same view in Arab countries, whose financial system is predominantly bank-based. They found that Arab countries' FDIs can have a favorable effect on economic growth if they interact with financial variables at a given threshold level of development. They concluded that domestic financial reforms should precede policies promoting FDIs, investment measures should enhance the environment for all investors, and liberal commercial policies should be designed as initial measures to attract FDIs. Meanwhile, Hussein (2009) examined the extent to which the Cooperation Council for the Arab States of the Gulf (GCC) countries has recognized the importance of FDIs in the process of growth and, hence, the measures adopted to attract foreign capital and encourage foreign investment. They used recent growth theories and statistical techniques to empirically investigate the association between FDIs and economic growth in these countries. The result supported the endogenous growth hypothesis, at least for this group of countries, and indicated a weak relationship between FDIs and GDP in the GCC panel.

Alfaro et al. (2004) examined the various links among FDIs, financial markets, and economic growth using cross-country data from 1975 to 1985 by investigating whether countries with better financial systems can exploit FDIs more efficiently. Their study indicators were financial development covering the credit market and that covering the equity market. The dataset related to the "credit market indicators" comprised 20 OECD countries and 51 non-OECD countries, while that related to "equity market indicators" comprised 20 OECD countries and 29 non-OECD countries. Their findings showed that an FDI makes a significant contribution to economic growth; however, the level of development of financial markets is crucial for these effects to be realized and achieved. In addition, Zakaria (2007) investigated the relationship between FDIs and financial development in 37 developing countries in a

multivariate framework. The results of their causality tests provided little support for the hypothesis that FDI inflows contribute to the development of the domestic banking sector in developing countries. In addition, they found that FDIs do not affect the development of the domestic banking sector. However, there is little evidence that the development of the domestic banking sector causes FDIs. In contrast, the author found strong evidence that FDIs affect the development of the domestic stock markets in developing countries and vice versa.

Lamine and Yang (2010) studied the contribution of FDIs to the economic growth proxies of the Guinea Republic by applying the Granger causality test. The results showed that the FDI level of this country is not high enough to promote economic growth. The results of the causality test demonstrated that the GDP can promote the level of FDIs, which means that if the GDP level increases in Guinea, FDIs will follow. In addition, they used other factors and concluded that the Guinean government must play a key role in employment promotion to attract foreign investments; they found that school enrollment can increase the GDP and indirectly impact FDIs positively. Pradhan (2010) explored the long-run equilibrium nexus among financial deepening, FDIs and economic growth in India from 1970 to 2007. Using Johansen's cointegration technique, the author found that financial deepening, FDIs, and economic growth are cointegrated, which indicates the continuation of the long-run equilibrium relationships among these variables. Applying ECM, they further confirmed the presence of bidirectional causality between FDIs and economic growth and unidirectional causality from financial deepening to FDI. They suggested that India needs a well-developed financial system to bring more FDIs, which may enhance economic growth. In the case of Pakistan, Najid et al. (2012) used co-integration and ECM to investigate the relationship between FDIs and GDP, taking GDP as the dependent variable and FDI, labor force, and domestic capital as the independent variables. The results suggested a positive relationship between FDIs and GDP, indicating that economic progress can be achieved by attracting FDIs.

Abu et al. (2010) employed co-integration and Granger causality techniques to analyze the relationship between FDI and economic growth in Nigeria during 1970–2008. Their results indicated a positive relationship between the variables. Meanwhile, the Nigerian scenario was also studied by Omankhanlen (2011), who investigated the effects of exchange rate and inflation on FDIs and the relationship of FDIs with economic growth by applying a linear regression analysis to a 30-year dataset. The findings revealed that FDIs follow economic growth occasioned by trade openness, which saw the entry of some major companies, especially telecommunication companies, while inflation does not affect FDIs; however, the exchange rate affects FDIs. The effects of financial development and FDI on economic growth in Nigeria were examined by Saibu et al. (2011), who adopted time-series data (1970–2009) and the ARDL technique to estimate the model. According to their findings, financial development and FDI have negative effects on economic growth. Furthermore, the effects of FDIs differ significantly when different measures of the financial market are used. In particular, FDIs are significant only when combined with stock market indices. In addition, economic growth is affected by financial market liquidity but not the size of the financial market.

Sghaier and Abida (2013) studied the causal relationships among FDI, financial development, and economic growth in a panel of four North African countries: Algeria, Egypt, Morocco, and Tunisia (1980–2011). Their study moved away from the traditional cross-sectional analysis and focused on more direct evidence of the channels through which FDI inflows can promote the economic growth of the host country. They used the generalized method of moment's technique for panel data analysis and found strong evidence of a positive relationship between FDI and economic growth. They also found

that the development of the domestic financial system is an important prerequisite for FDI to positively affect economic growth. Another case related to the impact of FDI on economic growth in Africa was examined by Gui-Diby (2014), who presented estimations based on the panel data of 50 African countries during 1980–2009 by using the system-generalized method of moments' estimators. The author found that FDI inflows significantly impacted economic growth in the African region during the period of interest. In addition, while the low level of human resources did not limit the impact of FDI, the impact of FDI on economic growth was negative during 1980–1994 and positive during 1995–2009. Finally, Asteriou and Moudatsou (2014) investigated whether the contribution of FDI to economic growth is relatively more important in countries with well-developed financial markets than those with less-developed ones. The period of the empirical research spanned from 1988 to 2009, and the authors used yearly macroeconomic data for a sample of 73 developing countries. Their results suggested that the FDI contribute significantly to economic growth in countries whose financial systems function effectively, such as high-income countries, while the FDI impact is insignificant in countries with relatively weak financial systems.

The cases that are related to Sudan were studied by Ibrahim and Hassan (2013), who explored the determinants of foreign direct investments in the country during 1970–2010 by considering the market size, inflation rate, exchange rate, indirect taxes, trade openness, and investment incentive policy as factors influencing foreign direct investments. They used Johansen cointegration and error correction model techniques to identify the dynamics of the FDI determinants. The results of the long-run FDI equation indicated that FDI flows in Sudan were influenced by market size, inflation rate, exchange rate, and investment incentive policy. The error correction model results suggested that approximately 17% of the total disequilibrium in foreign direct investment flows was corrected each year. Moreover, the Granger causality results showed unidirectional causality running from each of the variables, that is, exchange rates, investment incentive policy, and market size, to FDI. Moreover, Abdalla et al. (2015) empirically evaluated some of the economic determinants of FDI in Sudan during 1990–2013. The OLS method was applied to estimate the along-linear relationship between FDI and a set of explanatory variables. The results suggested that exchange rate, transportation and communication, and oil exploration are the major determinants of FDI in Sudan, while GDP and trade openness play insignificant roles. These results are attributable to the formula of FDI in Sudan, which was adopted to encourage foreign investors to invest in re-exporting to markets at home or in third countries. They recommended setting a stable exchange rate, increasing the concentration of the energy sector, improving the infrastructure, concentrating FDI in the priority sectors, and facilitating procedures for foreign investors.

Another research was done by Yahia et al. (2018) who applied the ARDL Bounds test to cointegration and Granger Causality to examine the impact of foreign direct investment in Sudan (1976–2016). Empirical results show a crowd out effect of FDI on Sudan's domestic investment, and the results confirm the cointegration relationships. Economic growth, exchange rate, macroeconomic stability and natural resource rent have shown short and long-run significant association with domestic investment. Meanwhile, Ali (2018) empirically interpreted the role of FDI in promoting domestic investment in Sudan (1980–2013) applying co-integration and error correction vector techniques. The study indicated the existence of a complementary relationship between FDI and domestic investment in Sudan, supporting the argument of the giving hope hypothesis

Subsequently, Iamsiraroj (2016) investigated the nexus between FDI and economic growth using 124 cross-country datasets for 1971–2010. The results indicated that the overall effects of FDI are

positively associated with economic growth, and vice versa; in addition, labor force, trade openness, and economic freedom are other key determinants of FDI that further stimulate income growth. Plus to that Imen et al. (2016) investigated the interactions among FDIs, economic freedom, and economic growth in North African countries by employing GMM and observed a positive link between FDIs and economic growth. Meanwhile, Agbloyor et al. (2016) did the same in sub-Saharan Africa, applying a two-step GMM estimator with Weidmeijer-corrected standard errors and found a significant relationship between institutions and economic growth. The results suggested that the quality of institutions plays a direct role in spurring economic growth. In addition, a direct and positive relationship between FDIs and economic growth was found. Alvarado et al. (2017) examined the effect of FDIs on economic growth in 19 Latin American countries. Applying panel data econometrics, they found robust empirical evidence that the effect of FDIs on economic growth is not statistically significant in aggregated form. A sample of Central and Eastern European countries was studied by Gherghina et al. (2019), who tested the link between FDIs and economic growth by considering several institutional quality variables, as well as sustainable development, by estimating panel data regression models. The empirical outcomes evidenced a nonlinear relationship between FDI and GDP per capita. A different study was conducted by Qamruzzaman and Wei (2019) investigated the magnitude of financial inclusion and stock market development towards capital flows in the economy considering a panel of 58 developing countries for the span of 1993–2017. They applied a dynamic panel system-GMM and ascertained the asymmetric relationship between financial inclusion, stock market development, and cross-broader capital flows in developing countries, particularly development in financial inclusion in the financial system encourages foreign capital flows in the form of FDI.

In the case of Bangladesh, Sarker and Khan (2020) examined the causal nexus between FDI and real GDP in Bangladesh from 1972 to 2017. The annual series constitutes a nonstationary series considered a first-order integrated process, $I(1)$, according to the Dickey–Fuller unit root test results, and additional tests indicated similar results. The ARDL cointegration bound test indicated the presence of cointegration between the series logarithm of FDI and logarithm of real GDP—fulfilled even when the dependent variable is altered—as the F-statistic is higher than the band’s economies at the 5% significance level. Real GDP has an elastic behavior with regard to FDI in the long-term equilibrium. Moreover, FDI presents a negative long-term equilibrium income inelasticity. Also, Siddiquee and Rahman (2020) explored the short- and long-run impacts of FDIs, FD, capital formation, and labor forces on economic growth in Bangladesh by applying the Granger causality test and VECM; the results indicated a positive impact. They noticed that the effect of FDIs is approximately null in both the short and long runs, indicating that Bangladesh fails to achieve the benefits of FDIs. Qureshi et al. (2021) highlighted the dynamic associations among FDIs, corruption, and economic growth in 54 developed and developing countries during 1996–2018. They found that corruption affects inward FDIs and economic advancement in developing (developed) countries. Most recently, Tag et al. (2022) studied the role of economic institutions and policies in attracting higher levels of FDIs. They empirically examined 127 countries over a period of 19 years by using the SYS-GMM approach, and found evidence that FDIs increase in countries with institutions that ensure the rule of law, expand trade freedoms, and reduce regulatory barriers to investing and doing business. Doytch (2022) explored the responsiveness of sector-level FDI inflows and outflows to economic accelerations and decelerations in the wake of the Covid-19 economic crisis and anticipated a prolonged economic recession. The results suggested that financial service FDIs and both transport service FDI inflows and outflows are countercyclical, while manufacturing FDI outflows are procyclical. The results suggested

that the most vulnerable sectoral FDI flow to a potentially prolonged recession resulting from the COVID-19 pandemic crisis is manufacturing FDI.

The most recent studies pursued by Danky et al. (2022) explored the nexus of human capital development, FDI, and economic growth in West Africa on panel data from 1990 to 2017, the study suggests that the rate of human capital, foreign direct investment, CO₂ emissions, and urbanization affect economic growth. Another study was done by Lutfi et al. (2022) who investigated the effect of uncertainty, and financial development on the FDI in Pakistan. The ARDL estimations conclude that uncertainty and financial development have long-run as well as short-run effects on FDI inflow for Pakistan during the period of study. Uncertainty plays a strong part in decreasing the FDI inflow, whereas financial development plays a strong part in enhancing the FDI inflow in Pakistan during the period of study. Furthermore, Morina, and Grima (2022) analyze the impact of pension asset investments on the economic growth of selected non-OECD countries, taking into account the controlling effect of gross fixed capital formation, domestic credit to the private sector, inflation, public debt and population. Given that most non-OECD countries are emerging and transition economies, the importance of this study lies in the fact that the authors, through empirical findings, highlight the importance of pension fund investments in global financial markets and the effects of these investments on the economic growth of these countries. To conclude with was the work that was pursued by Osabuohien-Irabor, and Drapkin (2022) focused on how the host country's risk components affect investment inflow. But the effects of home country risk on investment outflow remain unexamined. Therefore, based on the conceptualization of FDI escapism and the combined frameworks of Dunning's eclectic paradigm and internationalization theory, Findings reveal that home country composite risk has a moderate adverse effect on investment flow abroad, contributed by both the political and financial risk components, which may give rise to escaping FDI. Lastly, Tanaya and Suynato (2022) examined the relationship between the variables, namely, real GDP and FDI inflows in Indonesia for the period 1970–2018. The results of the estimated ECM reveal an extremely significant and high short-term income elasticity of FDI equal to 76.74 and a significant income elasticity of FDI in the following period equal to 42.18. FDI has a significant negative and inelastic behavior with respect to its value in the previous period. Finally, this model confirms the cointegration between the series with a highly significant and negative coefficient of the error correction term.

In summary, many of the aforementioned studies confirmed the strong relationships between FDIs and financial development, trade openness, and sustainable economic growth in developed and developing countries; meanwhile, a weak relationship was noticed in sub-Saharan African countries. The empirical literature on the linkage among FDI, trade openness, financial development, and economic growth does not provide a consensus on the theoretical relationship. Many researchers have documented positive relationships among them, while others have not traced them or, at best, reported very weak relationships. These wide differences result from the authors' viewpoints, sample selection, methodologies, and analytical tools applied in their study (Chakrabarti, 2001). In addition, country-specific characteristics concerning economic, technological, infrastructural, and institutional developments play a significant role in gauging empirical relationships (Wang and Blomström, 1992). Thus, in the present study, we conducted a country-specific analysis to add knowledge to the empirical literature.

2. Research methods and model

The main purpose of this study is to quantify the nexus among FDI, financial development, trade openness, and sustainable economic growth. These variables are expected to reduce specification errors. Time-series data were used to determine the impact of FDIs on Sudan's GDP for the period 1990–2019. The data were collected from the annual reports of the Central Bank of Sudan (CBS), the Central Bureau of Statistics, the Ministry of Finance and National Economy (Government of Sudan), World Bank indicators, and International Financial Statistics. The Engle–Granger causality test and the vector-auto-regression framework were used to test the causal relationships among FDI, financial development, trade openness, and economic growth in Sudan. Many prerequisites must be satisfied, such as the unit root test and cointegration, to avoid invalid conclusions. The planned steps of this study are as follows: i) data description, ii) examination of data stationarity, iii) Johansen cointegration test (1988), iv) causality test, and v) vector-auto-regression error correction stability (Altaee et al., 2014). E-Views version 8.0 as a statistical package was utilized for the analysis.

2.1. Data collection, variable definition, and empirical modeling

Many studies have empirically confirmed the relationships among FDI, economic growth, and financial development (Pradhan, 2010). These researchers used different measurements to improve the relationship between FDI inflow and financial development. Thus, this study took net inflows of FDI to Sudan, financial development, and GDP per capita as economic growth proxies from 1990 to 2020. The use of net FDIs seems more appropriate for examining the effects of the host country. Here, FDI is measured as a ratio to GDP, GDP represents real per capita economic growth measured by GDP/population, and FDC represents financial development, which is measured by the credit offered by the banking sector divided by GDP and has been widely used in econometric models (Afaró et al., 2010; Altaee et al., 2014), which is measured as the ratio of the broad money supply to GDP. Trade openness (Openness) is measured by export and import as a ratio of GDP following Gries et al. (2009) and Yanikkaya (2003). To examine the impact of FDIs on GDP and achieving sustainable development in Sudan, this study used annual data collected from the World Bank's World Development Indicators database (<https://databank.worldbank.org>) and the CBS database (<https://cbos.gov.sd>) from 1990 to 2019. For econometric analysis, the first step was to apply unit root tests to check for the order of the integration of the variables. Second, the ARDL model was estimated to determine whether any long-run relationships existed between the independent variables and GDP. Third, a familiar Granger causality test was applied to determine the direction of causality. Finally, several diagnostic tests were conducted to check for the robustness and stability of the results. The basic theoretical model for the FDI economic growth nexus can be defined as follows:

$$GDP = f(FDI, OP, FDC) \quad (1)$$

where GDP indicates the gross domestic product, FDI indicates foreign direct investment inflows as a percentage of GDP, OP trade openness is measured as a ratio of the sum of export and import to GDP, and FDC indicates the financial development proxied by domestic credit provided to the financial sector as a percentage of GDP. There are many reasons for selecting the ARDL approach. One of the most important primates of this approach is that it is applicable in a situation in which the variables

have different orders of integration; however, they should not be stationary at the second difference. In addition, this model yields consistent estimation results with small and finite sample data sizes.

The ARDL model used in this study is specified as follows:

$$\begin{aligned} \Delta \ln(GDP)_t = & \beta_0 + \sum_{k=1}^p \beta_{1k} \ln(GDP_{t-k}) + \sum_{k=0}^q \beta_{2k} \ln(FDI_{t-k}) + \sum_{k=0}^q \beta_{3k} \ln(FDC_{t-k}) \\ & + \sum_{k=0}^q \beta_{4k} \ln(OP_{t-k}) + \beta_5 \ln(GDP_{t-1}) + \beta_6 \ln(FDI_{t-1}) + \beta_7 \ln(FDC_{t-1}) \\ & + \beta_8 \ln(OP_{t-1}) + u_t \end{aligned} \quad (2)$$

where Δ is a difference operator, p indicates the optimal lag length of the dependent variable; q is the optimal lag length of the regressors, $\ln(\cdot)$ is the logarithm operator, the parameters β_{1k} to β_{4k} represent the short-run dynamic coefficients; β_5 to β_8 are the long-run coefficients in the FDI–growth nexus; and μ_t is the error term. Following Pesaran et al.’s (2001) procedure, we test $H_0: \beta_5 = \beta_6 = \beta_7 = \beta_8 = 0$ (nonexistence of the long-run relationship) against the alternative one, $H_a: \beta_5 \neq \beta_6 \neq \beta_7 \neq \beta_8 \neq 0$ (a long-run relationship) using the F-test.

3. Empirical results and analyses

3.1. Descriptive statistics

Table 1 delineates the descriptive statistics of the time series, and Figure 1 presents the trends of FDIs and economic growth in a line plot. Summary statistics are provided in Table 1, which shows the mean growth of 4.66%, with a maximum of 11.5 and a minimum of -2.50 with a standard deviation of 3.6. All series are normal distributions, as indicated by the significance of Jarque–Bera statistics. Openness and financial development have low volatility, as indicated by the values of standard deviation and the behavior of economies in Sub-Saharan African countries; therefore, sustainable economic development has to be attended to.

Table 1. Descriptive statistics and correlation coefficient.

Variable	Mean	Max	Min	Std. Dev.	Jarque-Bera	P-value
GDP	4.6637	11.5219	-2.5035	3.5999	0.5125	0.7739
FDI	2.9316	7.6457	-0.0054	2.0353	0.6040	0.7393
OP	3.2043	3.8624	2.4394	0.3875	1.0872	0.5807
FDC	1.7420	2.6362	0.4797	0.7100	3.0191	0.2210
Correlation coefficient						
	RGDP	FDI	OP	FDC		
RGDP	1.00000					
FDI	0.03911	1.00000				
OP	0.31919	0.73236	1.00000			
FDC	-0.16901	0.41810	0.54962	1.00000		

Source: computed by the author.

Panel B of Table 1 shows that GDP is negatively correlated with financial development and positively correlated with the other variables. The correlation coefficient of GDP with FDI is relatively low compared to that of other variables.

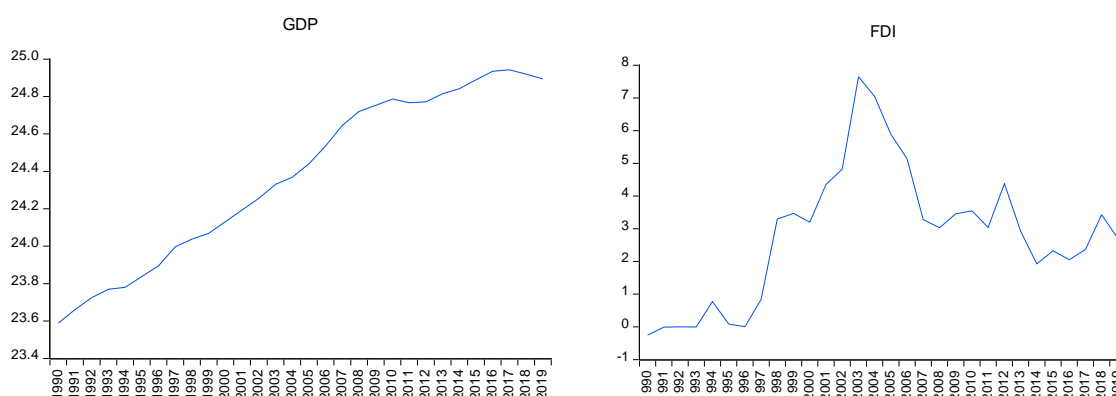


Figure 1. GDP and FDI inflows in Sudan from 1990 to 2019.

3.2. Tests for Stationarity

Before ore the ARDL approach, a unit root test for the concerned data series is necessary to confirm that none of the variables are integrated of order two. The augmented Dickey–Fuller (ADF) test is employed to test for the unit root. The test was carried out with three specifications: no constant, constant, constant, and trend. Table 2 presents the results of the stationarity tests.

3.2.1. Tests for stationarity

Table 2. ADF unit root test results.

Constant/Trend	Level	GDP	FDI	OP	FDC
None	t-Stat.	-1.6988	-0.5948	0.1405	0.0608
	(prob.)	-0.0842	0.4509	0.7192	0.6939
Constant	t-Stat.	-2.1441	-1.7842	-1.9433	-1.0126
	(prob.)	-0.2300	0.3805	0.3089	0.7346
Constant & Trend	t-Stat.	-2.6542	-1.4467	-1.2378	-2.7583
	(prob.)	-0.2614	0.8246	0.8832	0.2240
Constant/Trend	First difference	D(GDP)	D(FDI)	D(OP)	D(FDC)
None	t-Stat.	-5.7591***	-4.6983***	-6.3589***	-4.1078***
	(prob.)	0.0000	0.0000	0.0000	0.0002
Constant	t-Stat.	-5.7221***	-4.6419***	-6.2353***	-4.0755***
	(prob.)	0.0001	0.0010	0.0000	0.0039
Constant & Trend	t-Stat.	-5.6798***	-4.7218***	-6.9067***	-4.0083**
	(prob.)	0.0004	0.0040	0.0000	0.0202

Note: ** Significant at 5% and ***significant at 1%; Source: computed by the author.

Before using the ARDL approach, a unit root test for the concerned data series needs to be conducted to confirm that none of the variables are integrated with order two. The augmented Dickey–Fuller (ADF) test is employed to test for the unit root and is carried out with three specifications: no constant, constant, and trend. Table 2 presents the results of the stationarity test.

The results indicate that all variables are stationary at their first difference.

3.2.2. Test for cointegration

The ARDL bound test was employed to scrutinize the presence of a cointegrating relationship among the variables under investigation. The test results are presented in Table 3. The existence of a long-run relationship between the dependent and independent variables is established when the calculated F-statistic is over and above the upper critical values at a certain level of significance. The figures presented in Table 3 show that the F-statistic (6.702) is greater than the upper bound critical value of 4.84.

Table 3. ARDL bound test for cointegration results.

Test-Stat.	F-value	k
F-statistic	6.702085	3
<i>Critical value bounds</i>		
Sig. level	I(0)	I(1)
10%	2.01	3.1
5%	2.45	3.63
2.5%	2.87	4.16
1%	3.42	4.84

Note: computed by the author.

3.2.3. Long-run relationship results

The long-run estimated results are listed in Table 4. The estimates indicate that the FDI variable is positive but not statistically significant ($p > 0.05$). This result is in contrast with that obtained by Abdalla et al. (2015), who found that FDIs have a long-run effect on economic growth in Sudan. Nevertheless, one should consider the indirect contributions of FDIs in enriching the overall knowledge of the host economy, including productivity and export spillovers.

Table 4. Long-run coefficient estimation.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
FDI	0.624966	0.468591	1.333714	0.2022
OP	3.375141***	0.706438	4.777690	0.0002
FDC	-4.533244***	1.408760	-3.217896	0.0057

Note: *** indicates statistical significance at 1%.

Sources: computed by the author, $EC = RGDP - (0.6250*FDI + 3.3751*OP - 4.5332*FDC)$.

Trade openness has a significant positive effect on economic growth. This suggests that openness is imperative for growth in the long run. Keeping all other independent variables fixed, a unit percentage change in trade openness is expected to result in a 3.4% change in economic growth. In addition, financial development negatively affects economic growth, even though insignificantly.

3.2.4. Short-run relationship results

Table 5 displays the results for the short-run relationship between economic growth and FDI, OP, and FDC. The estimation of the short-run dynamics of the model showed that approximately 72% of the variations in economic growth can be explained by the regressors. The Durbin–Watson statistic is 2.32, which is high enough to disregard the evidence of serial correlation in the model. The error correction term is negative, as expected, and is statistically significant at the 1% significance level. This means that the model is stable and returns to equilibrium when the regressors are subjected to unexpected shocks. In addition, the error correction coefficient is quite high. Approximately 97% of the disequilibria from the previous year’s shock converge back to the long-run equilibrium in the current year. This result implies that, in the long run, causality runs interactively through the error correction term from FDI, OP, and FDC to GDP growth. The short-run relationship results reveal a negative and significant relationship between FDI and GDP. Considering the impact of FDI, it is significant at a 5% probability and has a positive impact on economic growth in its first lag.

Table 5. Short-run coefficient estimation.

Variable	Coefficient	Standard error	t-Statistic	P-value
D(RGD(-1))	0.109063	0.151211	0.721264	0.4818
D(FDI)	-0.721266*	0.375968	-1.91842	0.0743
D(FDI(-1))	-1.785248***	0.460751	-3.874644	0.0015
D(FDI(-2))	-1.479766**	0.511969	-2.890342	0.0112
D(OP)	5.363639*	2.640369	2.031397	0.0603
D(OP(-1))	3.632689	2.388991	1.520595	0.1492
D(FDC)	-3.995677*	2.040924	-1.957778	0.0691
D(FDC(-1))	4.24981**	1.785369	2.380353	0.0310
CointEq(-1)*	-0.970911***	0.17118	-5.671861	0.0000
<i>R-squared</i>	0.725420			
<i>Durbin-Watson stat</i>	2.320882			

Note: *, **, and *** indicate statistical significance at 10%, 5%, and 1% levels, respectively.

Sources: computed by the author.

3.2.5. Diagnostic and stability tests of the ARDL model

The appropriateness of the ARDL model is noticeable by its statistical properties. The results of the different stability and diagnostic tests are reported in Table 6, all of which confirm the statistical adequacy of the estimated model. The results of the Breusch–Godfrey serial correlation LM test show that there are no problems with autocorrelation. The results of the Breusch-Pagan-Godfrey heteroscedasticity test show no evidence of heteroscedasticity. Moreover, the residuals are distributed normally according to the Jarque-Bera normality test. The Ramsey RESET test also suggests that the

model is well-specified. The stability of the coefficients of the ARDL model using the CUSUM and CUSUMQ tests shows that the estimated coefficients do not indicate any problem with stability.

Table 6. Model diagnostic and stability tests.

Test	LM Version	Decision
Autocorrelation	0.885506 (0.4762)	No Autocorrelation
Normality	0.861863(0.6499)	Normally distributed
Heteroscedasticity	0.758850(0.6807)	No Heteroscedasticity
Specification	0.164866(0.9180)	No misspecification
CUSUM		Stable
CUSUMQ		Stable

Note: Results were generated using version Eviews 12. Probability values are in parenthesis.

Sources: computed by the author.

3.2.6. Granger causality test results

The Granger causality test results for the variables included in this study are listed in Table 7. Given the probability of 0.1388, the null hypothesis that FDI does not cause economic growth is not rejected. This implies that the past values of FDI do not significantly contribute to the prediction of a country's economic growth. The results indicate that OP does Granger cause GDP at a 10% significance level. Similarly, causality is observed running from FDI to GDP. These results imply that there are complementary relationships between economic growth and both financial development and trade openness in Sudan in the short run.

Table 7. Results of the pairwise Granger causality test.

Null Hypothesis	F-Statistic (Prob.)
FDI does not Granger cause GDP	2.1332(0.1388)
OP does not Granger cause GDP	2.6586(0.0860) *
FDC does not Granger cause GDP	4.772 (0.0157) **

4. Conclusions

The main objective of this study was to investigate and measure the claimed nexus among FDI, financial development, trade openness, and sustainable economic growth in Sudan. The models were estimated using time-series data for 1990–2020. The results indicated that although Sudan has improved in attracting FDIs, considerable work is still required to make the country a more attractive location. As regards the national policy framework, advances have been made toward ensuring more economic stability and sustainability and a general trend toward more open trade regimes has been observed. However, privatization still does not seem to be attractive to foreign investors, and perhaps the most distressing factor in the Sudan economy is the continuing civil conflict and political unrest. The results of our study are in line with those of Abdalla et al. (2015), according to which economic growth and openness have insignificant effects on FDIs. In addition, trade openness and the growth rate of the real gross domestic product play insignificant roles in affecting FDI. This result indicates

that improving the work environment and economic stability can have a significant positive effect on FDI inflow.

4.1. Policy implementations

This study recommends maintaining a stable exchange rate, increasing the concentration of the energy sector, implementing institutional reforms, and improving the infrastructure. In addition, it recommends creating an attractive environment for FDIs, with clear policies that consider channelizing FDIs toward the productive sectors (i.e., agricultural, manufacturing, information technology, and health), which can improve welfare and foster sustainable economic growth. Policymakers must remove barriers to trade, develop sound financial institutions, reduce corruption levels, improve a conducive environment, and build appropriate economic institutions. Then, the government size must be reduced through a true step of privatization and control macroeconomic instability. Lastly, the foreign direct investment could stimulate human resources development via investment in modern education and institutional training, therefore, the concerned authority must pay attention to it. The study suggests some policy measures to design effective policies for macroeconomic stability; controlling inflation, flexible exchange rate spurring economic growth, and as well as developing effective strategies to encourage the mode of FDI that can create technological and market share spillover.

Acknowledgments

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. An earlier version of this paper was presented at the International Conference on Applied Economics and Policy (July 2017), held at the Faculty of Economics and Administration (University of Malaya – Kuala Lumpur, Malaysia). I thank the participants for their comments. Also, the author gratefully acknowledges the help and comments and help made by Prof. Dr. Hatem H. A. Altae. Any remaining errors are the responsibility of the author.

Conflict of interest

The author declares no conflicts of interest in this paper.

References

- Abdalla OA, Mohamed AA, Abdelmawla MA, et al. (2015) Evaluation of foreign direct investment inflow in Sudan: An empirical investigation (1990–2013). *J Bus Stud Quart* 7: 149–168.
- Abu N, Gobna WO, Usman A (2010) On the causal links between foreign direct investment and economic growth in Nigeria, 1970–2008: An application of Granger causality and co-integration techniques. *Romanian Stat Rev* 3: 57–76.
- Alfaro L, Chanda A, Kalemlı-Ozcan S, et al. (2004) FDI and economic growth: the role of local financial markets. *J Int Econ* 64: 89–112. [https://doi.org/10.1016/S0022-1996\(03\)00081-3](https://doi.org/10.1016/S0022-1996(03)00081-3)
- Alfaro L, Chanda A, Kalemlı-Ozcan S, et al. (2010) Does foreign direct investment promote growth? Exploring the role of financial markets on linkages. *J Dev Econ* 91: 242–256. <https://doi.org/10.1016/j.jdeveco.2009.09.004>

- Akbas YE, Senturk M, Sancar C (2013) Testing for causality between the foreign direct investment, current account deficit, GDP and Total credit: Evidence from G7. *Panaeconomicus* 60: 791–812. <http://dx.doi.org/10.2298/PAN1306791A>
- Ali MAM (2018) Impact of foreign direct investment on domestic investment in Sudan: Giving Hope Hypothesis. *J Econ Coop Dev* 3: 39–64.
- Aliber RZ (1970) *A theory of foreign direct investment*. International Cooperation MIT press.
- Altaee HHA, Saied SM, Esmaeel ES, et al. (2014) Financial development, trade openness and economic growth: Evidence from Sultanate of Oman (1972–2012). *J Econ Sustain Dev* 5: 64–75.
- Asiedu E (2002) On the determinants of foreign direct investment to developing countries: Is Africa different? *World Dev* 30: 107–119. [https://doi.org/10.1016/S0305-750X\(01\)00100-0](https://doi.org/10.1016/S0305-750X(01)00100-0)
- Asteriou D, Moudatsou A (2014) FDI, finance, and growth: Further empirical evidence from a panel of 73 countries. *Appl Econ Financ* 1: 48–57. <https://doi.org/10.11114/aef.v1i2.480>
- Barro RJ, Mankiw, NA, Sala-I-Martin X (1995) Capital mobility in neoclassical models of growth. *Am Econ Rev* 85: 103–115.
- Borensztein E, De Gregorio J, Lee JW (1998) How does foreign direct investment affect economic growth? *J Int Econ* 45: 115–135. [https://doi.org/10.1016/S0022-1996\(97\)00033-0](https://doi.org/10.1016/S0022-1996(97)00033-0)
- Central Bank of Sudan (CBS) Economic and Financial Statistical Review data (various issues). Available from: <https://cbos.gov.sd/en/periodicals-publications>.
- Chakrabarti A (2001) The determinants of foreign direct investment: Sensitivity analysis of cross-country regression. *Kyklos* 54: 89–113. <https://doi.org/10.1111/1467-6435.00142>
- Dankyi AB, Abban OJ, Yusheng K, et al. (2022) Human capital, foreign direct investment, and economic growth: Evidence from ECOWAS in a decomposed income level panel. *Environ Chall* 9: 1–13. <https://doi.org/10.1016/j.envc.2022.100602>
- Dickey DA, Fuller WA (1981) Likelihood ratio statistics for autoregressive time series with a unit root. *Econometrica* 49: 1057–1072. <https://doi.org/10.2307/1912517>
- Engle RF, Granger CWJ (1987) Cointegration and Error Correction: Representation, Estimation, Testing. *Econometrica* 55: 1057–1072. <https://doi.org/10.2307/1913236>
- Findlay R (1978) Relative backwardness, foreign direct investment and the transfer of technology: A simple dynamic model. *Quart J Econ* 92: 1–16. <http://dx.doi.org/10.2307/1885996>
- Granger CWJ (1988) Some recent developments in a concept of causality. *J Econ* 39: 199–211. [http://dx.doi.org/10.1016/0304-4076\(88\)90045-0](http://dx.doi.org/10.1016/0304-4076(88)90045-0)
- Gui-Diby SL (2014) Impact of foreign direct investments on economic growth in Africa: Evidence from three decades of panel data analyses. *Res Econ* 68: 248–256. <https://doi.org/10.1016/j.rie.2014.04.003>
- Hussein MA (2009) Impacts of Foreign Direct Investment on Economic Growth in the Gulf Cooperation Council (GCC) Countries. *Int Rev Bus Res Pap* 5: 362–376.
- Hermes N, Lensink R (2003) Foreign Direct Investment, Financial Development, and Economic Growth. *J Dev Stud* 40: 142–163. <https://doi.org/10.1080/00220380412331293707>
- Ibrahim OA, Hassan HM (2013) Determinants of foreign direct investment in Sudan: an econometric perspective. *J North Afric Stud* 18: 1–15. <http://dx.doi.org/10.1080/13629387.2012.702013>
- Iamsiraroj S (2016) The foreign direct investment-economic growth nexus. *Int Rev Econ Financ* 42: 116–133. <https://doi.org/10.1016/j.iref.2015.10.044>

- Johansen S, Juselius K (1990) Maximum likelihood estimation and inferences on cointegration with application to the demand for money. *Oxford B Econ Stat* 52: 169–210. <https://doi.org/10.1111/j.1468-0084.1990.mp52002003.x>
- Lamine KM, Yang D (2010) Foreign direct investment effect on economic growth: Evidence from the Guinea Republic in West Africa. *Int J Financ Res* 1: 49–54. <https://doi.org/10.5430/ijfr.v1n1p49>
- Lutfi A, Ashraf M, Watto WA, et al. (2022) Do Uncertainty and Financial Development Influence the FDI Inflow of a Developing Nation? A Time Series ARDL Approach. *Sustainability* 14: 12609. <https://doi.org/10.3390/su141912609>
- Mohamed MA (2003) The impact of foreign capital inflow on savings, investment and economic growth rate in Egypt: An econometric analysis. *Sci J King Faisal Univ* 4: 279–308.
- Mohamed SE, Sidiropoulos MG (2010) Another look at the determinants of foreign direct investment in MENA countries: An empirical investigation. *J Econ Dev* 35: 75–95. http://dx.doi.org/10.35866/caujed.2010.35.2.005_
- Morina F, Grima S (2022) The impact of pension fund assets on economic growth in transition countries, emerging economies, and developed countries. *Quant Financ Econ* 6: 459–504. <https://doi.org/10.3934/QFE.2022020>
- Najid A, Hayat MF, Luqman M, et al. (2012) The causal links between Foreign Direct Investment and Economic Growth in Pakistan. *Eur J Bus Econ* 6: 20–21. <https://doi.org/10.12955/ejbe.v6i0.137>
- Omankhanlen AE (2011) The effect of exchange rate and inflation on foreign direct investment and its relationship with economic growth in Nigeria. Annals of “Dunarea de Jos” University of Galati Fascicle I. *Econ Appl Inform* 1: 5–16.
- Omran M, Bolbol B (2003) Foreign direct investment, financial development, and economic growth: evidence from the Arab countries. *Rev Middle East Econ Financ* 1: 231–249. <https://doi.org/10.2202/1475-3693.1014>
- Osabuohien-Irabor O, Drapkin IM (2022) FDI Escapism: the effect of home country risks on outbound investment in the global economy. *Quant Financ Econ* 6: 113–138. <https://doi.org/10.3934/QFE.2022005>
- Pesaran MH, Shin Y, Smith JR (2001) Bounds testing approaches to the analysis of level relationships. *J Appl Econ* 16: 289–326. <https://doi.org/10.1002/jae.616>
- Philips PCB, Perron P (1988) Testing for a unit root in time series regressions. *Biometrika* 75: 335–346. <https://doi.org/10.2307/2336182>
- Pradhan RP (2010) Financial deepening, foreign direct investment, and economic growth: Are they cointegrated. *Int J Financ Res* 1: b37–b43. <https://doi.org/10.5430/ijfr.v1n1p37>
- Qamruzzaman Md, Wei J (2019) Do financial inclusion, stock market development attract foreign capital flows in developing economy: a panel data investigation. *Quant Financ Econ* 3: 88–108. <https://doi.org/10.3934/QFE.2019.1.88>
- Saibu MO, Nwosa IP, Agbeluyi AM (2011) Financial deepening, foreign direct investment and economic growth in Nigeria. *J Emerg Trends Econ Manag Sci* 2: 146–154. <https://journals.co.za/doi/10.10520/EJC133886>
- Sarker B, Farid K (2020) Nexus Between Foreign Direct Investment and Economic Growth in Bangladesh: An Augmented Autoregressive Distributed Lag Bounds Testing Approach. *Financ Innov* 6: 10. <https://doi.org/10.1186/s40854-019-0164-y>
- Sghaier IM, Abida Z (2013) Foreign direct investment, financial development, and economic growth: Empirical evidence from North African countries. *J Int Glob Econ Stud* 6: 1–13

- Sirag A, SidAhmed S, Ali HS (2018) Financial development, FDI and economic growth: evidence from Sudan. *Int J Soc Econ* 45: 1236–1249. <https://doi.org/10.1108/IJSE-10-2017-0476>
- Sjöholm F (1999) Technology gap, competition, and spillovers from foreign direct investment: Evidence from establishment data. *J Dev Stud* 36: 53–73. <https://doi.org/10.1080/00220389908422611>
- Tanaya O, Suyanto S (2022) The causal nexus between foreign direct investment and economic growth in Indonesia: An autoregressive distributed lag bounds testing approach. *Period Polytech Soc Manage Sci* 30: 57–69. <https://doi.org/10.3311/PPso.16799>
- UNCTAD (2003) World Investment Report 2003—FDI Policies for Development: National and International Perspectives.
- UNCTAD (2014) World Investment Report 2008 Data. Available from: <https://unctadstat.unctad.org/EN/>.
- Wang JY, Blomström M (1992) Foreign investment and technology transfer: A simple model. *Eur Econ Rev* 36: 137–155. [https://doi.org/10.1016/0014-2921\(92\)90021-N](https://doi.org/10.1016/0014-2921(92)90021-N)
- World Bank (2021) World Development Indicators. Washington, D.C: World Bank. Available from: <https://datatopics.worldbank.org/world-development-indicators>.
- Yahia YE, Haiyun L, Khan MA, et al. (2018) The impact of foreign direct investment on domestic investment: Evidence from Sudan. *Intl J Econ Financ Iss* 8: 1–10. <https://doi.org/10.32479/ijefi.6895>
- Yanikkaya H (2003) Trade openness and economic growth: a cross-country empirical investigation. *J Dev Econ* 72: 57–89. [https://doi.org/10.1016/S0304-3878\(03\)00068-3](https://doi.org/10.1016/S0304-3878(03)00068-3)
- Zakaria Z (2007) The causality relationship between financial development and foreign direct investment. *Jurnal Kemanusiaan* 14: 1–23.



AIMS Press

© 2022 the Author(s), licensee AIMS Press. This is an open access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0>)