P ISSN 2086-3128 | E ISSN 2502-180x

Economic Journal of Emerging Markets

Accredited by Kemenristek/BRIN No.: 79/E/KPT/2023

Volume 15 Issue 2, 2023, Pages: 115-225

Economic Journal of Emerging Markets

https://journal.uii.ac.id/JEP

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Economic Journal of Emerging Markets (EJEM) is a peer-reviewed journal which provides a forum for scientific works pertaining to emerging market economies. Published every April and October, this journal welcomes original quantitative research papers on economic issues and problems in emerging markets. The journal is fully open access for scholarly readers.
The journal was first published in 1993 as Jurnal Ekonomi (ISSN 0854-5723), which then changed to Jurnal Ekonomi Pembangunan (JEP) in 1996 (ISSN 1410-2641), and since 2009 has become Economic Journal of Emerging Markets (EJEM, ISSN 2502-180X). The journal is published by the Center for Economic Studies, Universitas Islam Indonesia, Yogyakarta, Indonesia.

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Economic Journal of
Emerging Markets

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Revisiting the nexus between remittances and financial sector development in Nigeria

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Article Info

Article history:
Received 03 March 2023
Accepted 02 September 2023
Published 31 October 2023

JEL Classification Code:
F24, G20, F10, E43, E51.

Author's email:
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DOI: 10.20885/ejem.vol15.iss2.art1

Abstract

Purpose — The study aims to investigate the impact of remittances on financial sector development in Nigeria using data from 1990 to 2021.

Method — The study examines the variables' relationship using the Autoregressive Distributed Lag (ARDL) and Toda Yamamoto (TY) Causality.

Findings — The study finds that remittances have a positive and significant long-run impact on financial sector development. Total reserves and imports of goods and services have a negative and significant long-run impact. In the short run, remittances and deposit interest rates positively and significantly impact financial sector development, while total reserves and total population have negative and significant impacts. The Toda-Yamamoto causality result indicates a two-way causal relationship between financial sector development and remittances.

Implication — The study recommends that the government employs policies encouraging channeling remittances through a formal banking system, as well as ensuring that such remittances received are channeled to finance productive investment, hence financial development.

Originality — The novelty of this research relates to the use of the three main indicators of remittances in an economy, which are the import of goods and services, total reserves, and deposit interest rates, to examine its impact on financial sector development in Nigeria.

Keywords — Remittances, financial development, interest rate, cointegration, Nigeria

Introduction

Migration has been a livelihood strategy among households in most developing countries. The World Bank reports that about 244 million migrants from developing countries lived and worked outside the country of their birth. Hence, only about 20 percent of sub-Saharan Africans educated abroad return home, and the remaining 80 percent stay in the country of their study as migrants (World Bank, 2018).

According to The World Bank Report, Nigeria is one of the top remittance recipients in Sub-Saharan Africa. The country was estimated to have received about 21 billion USD in remittances in 2012 compared to 2.3 billion USD in 2004. It also projected that up to 22 billion USD will flow into Nigeria 2017 through diaspora remittances. The European Union (2016) stated that more than 10 million Nigerians, representing more than 5% of the country's population, lived abroad, of which almost 50% were in Sub-Saharan Africa. The World Bank (2018) report has shown that remittances by Nigerians in the diaspora rose steadily in the last 13 years and recorded

P ISSN 2086-3128 | E ISSN 2502-180X

the highest at 71.3% in 2018. The remittance to Nigeria rose 11.2 percent in 2021 to $19.5bn from the $17.21bn recorded in 2020. The remittances are estimated to hit $20.9bn by the end of 2022. This represents a 75% increase from the prior year 2021.

Becker (1976), who propagated the theory of altruism, pointed out that the decision to remit relies on the income needs of the relatives of the emigrant worker. The migrant worker remits the money because his utility derives from that of his family members (Fullenkamp et al., 2008). In other words, the migrant worker gets satisfaction if the family's welfare left back home improves. This theory highlighted that the recipients received remittances through the financial sector; meanwhile, they do not have a positive relationship with private investment since they are primarily spent on consumption activities. Markowitz (1952) views remittances as a strategy by an emigrant worker to diversify their savings. Accordingly, remitting relies on the risk-return differential of assets in both the host and recipient countries. As such, the main determinants of the decision to remit include interest rate differential on deposit accounts in the host and recipient country, real estate return, and inflation rate, among others.

The roles of remittances in promoting financial sector development have received considerate attention in both theoretical and empirical literature (Aggarwal et al., 2011; Akkoyunlu, 2015; Attila et al., 2018; Fromentin, 2017; Gupta et al., 2009; Misati et al., 2019). Scholars have argued that remittance inflows boost demand for financial services and financial sector development. This notion is built on the premise that remittances encourage recipients to demand and gain access to financial products and services they would not otherwise have (Olowa, 2015; Orozco & Rouse, 2013). Thus, remittances encourage the recipients to use formal banking services to transfer funds and other financial services. Two, it is also assumed that remittance inflows enable the financial sector to reach the unbanked recipients or recipients with limited financial intermediation. Thus, it promotes financial inclusion activities in developing countries (Agarwal & Horowitz, 2002; Olowa, 2015). Third, since remittances usually involve large amounts, it is postulated that recipients often need financial products that will enable them to save such funds for future consumption as well as gain some amount of interest earnings from these savings (Aggarwal et al., 2011). This implies that remittance inflows could be a strong determinant of financial development.

Migrant remittances may lead to financial sector development in developing economies by increasing their aggregate volume of deposits and credit intermediated by the banking sector (Fromentin, 2017). He further stated that remittances might lead to a lower demand for credit and dampen the credit market development. Remittance can also pave the way for its recipients to demand and gain access to other financial products and services, which might tremendously lead to the development of the financial sector. At the same time, providing remittance transfer services allows banks to know and reach out to unbanked recipients or recipients with limited financial intermediation (Adams & Page, 2005; Bangake & Eggoh, 2020; Chowdhury, 2016; Chowdhury, 2011; Cooray, 2012; Gupta et al., 2009; Imai et al., 2014; Williams, 2017).

Remittances sent back home by migrants significantly impact the socioeconomic conditions of families left behind in the country of their origin (Ndlovu & Tigere, 2018). However, one of the areas of controversy in the literature is the need for one general acceptable definition of remittance. For instance, some of the early attempts to define remittances emerged from the work of Solimano (2003), who argued that Remittances are generally defined as that portion of migrants' earnings sent from the migration destination to the place of origin. Remittances can be sent in cash or kind. However, the issue with this definition is that remittance is not limited to monetary and other cash transfers by immigrants to their families in their home country. It also reflects local labor earnings in the global economy (Iheke, 2012).

On the other hand, since remittances might help relax households' financing constraints, the demand for and the overall level of credit might fall as remittances increase. Regardless of remittance recipients' demand for credit, overall credit levels might still increase in remittance-receiving areas if banks channel the increased liquidity from remittance deposits to previously unfunded or underfunded projects. However, a rise in remittances might not translate itself into an increase in credit to the private sector if these flows are instead channeled to finance the government or if banks are reluctant to lend and prefer to hold liquid assets. Similarly, remittances might not increase bank deposits if they are immediately consumed or if the recipients distrust financial institutions and prefer other ways to save this fund (Benhamou & Cassin, 2021).

Despite these plausible arguments in the theoretical literature, most existing studies have neglected the feedback relationship (Demirgüç-Kunt et al., 2011; Olayungbo & Quadri, 2019). Also, few studies that have addressed the issue of reverse causation have reported contradictory evidence (Ahamada & Coulibaly, 2013; Akkoyunlu, 2015; M. B. Chowdhury, 2011; Coulibaly, 2015; Fromentin, 2017; Karikari et al., 2016; Motelle, 2011). The existing empirical literature reviewed the impact of remittances on financial sector development in Nigeria and used GMM and OLS as the analysis method (Olowa, 2015). Furthermore, both OLS and GMM have limitations when employing them as analysis methods. The method cannot accommodate variables of I(0) and I (1). Also, the techniques could be more robust when the sample size is small. Hence, there exists a vital justification for using ARDL in this study. Also, on methodology, a more robust estimation technique, i.e., Autoregressive Distributed Lag (ARDL), will be used to explore the short-run and long-run relationship between the variables. The above literature has shown that some studies establish a positive impact of remittances on financial development. In contrast, others found a negative relationship between them, and very few of the findings report no relationship between the variables.

This study makes significant contributions to the existing literature on remittances and financial sector development by introducing important variables overlooked in previous research, particularly within the context of Nigeria. The study identifies crucial factors such as real interest rate, broad money supply, total population, and importing goods and services, which are pivotal in advancing financial development. Notably, the study emphasizes the vital role of a well-educated population in facilitating the effective functioning of the financial system, as highlighted by (Elsherif, 2015). Furthermore, this research employs contemporary and advanced data analysis techniques, specifically the ARDL model and Toda Yamamoto causality, to provide a novel perspective. This approach sets the study apart from earlier investigations in Nigeria that predominantly employed conventional estimation methods, as evidenced in works such as (Kumar, 2019; Oke et al., 2011; Oluwafemi & Ayandibu, 2014). By incorporating these previously unexplored variables and employing advanced analytical tools, this study expands our understanding of the intricate relationship between remittances, financial sector development, and these critical contributing factors in the Nigerian context.

Methods

This study adopts the portfolio theory approach coined by Markowitz (1952). In the Portfolio approach theory, remittances are viewed as a strategy by an emigrant worker to diversify their savings. The theory has the following assumptions: the desire to remit is based on the risk-return differentials of assets in both host and recipient countries, significant interest rate differential on deposit accounts, the desire to remit is purely motivated by investment opportunities and the relationship between private investment and remittances is positive since remittances are principally spent on investment activities.

Based on the theory, we assumed that the financial sector development has the following function:

$$FINDV = F(REMT) \tag{1}$$

Where $FINDV$ means financial development, and REMTS is remittances. Eq. 1, was transformed as:

$$FINDV_t = \beta_1 + \beta_2 REMT_t \tag{2}$$

Therefore, Equation 2 revealed that financial development depends on remittances. For this study, we follow the work of Barua (2007), and this equation was modified to include other variables of interest. For instance, scholars have argued that remittances impact credit to the private sector as a percentage of GDP (Karikari et al., 2016). In addition, credit to the private sector was used in many empirical studies to measure financial sector development. Hence, financial development was substituted with credit to the private sector (CPSGD). Thus, the equation is specified as follows:

$$CPSGD_t = \beta_1 + \beta_2 REMT_t + \mu_t \quad (3)$$

Also, the deposit interest rate (DPIRR) is very significant in determining credit to the private sector. Chowdhury (2011) argued that the deposit interest rate has a lasting impact on financial sector development. Furthermore, total gold reserves (TRSVG) are also an important determinant of financial sector development. Takyi and Obeng (2013) argued that a negative relationship between total reserves and financial sector development could be expected. In addition, it has been argued that population (TPOP) can influence financial sector development. The variables mentioned above are theoretically linked with remittances, so they are included in the remittance models. Therefore, the general framework of the study is presented below:

$$CPSGD_t = F(REMT_t, DPIRR_t, TRSVG_t, TPOP_t, IMPGS_t) \quad (4)$$

CPSGD is the credit to the private sector as a percentage of GDP, REMTS is personal remittances received, DPIRR is the deposit interest rate, TRSVG is a total reserve, TPOP is the total population, and IMPGS is the import of goods and services.

Model Specification

Having established the theoretical framework, the general model of credit to the private sector (CPSGD), including variable of interest along with other important determinants of financial sector development such as REMTS, DPIRR, TRSVG, TPOP, and IMPGS, is specified as follows:

$$CPSGD_t = \beta_1 + \beta_2 lnREMT_t + \beta_3 DPIRR_t + \beta_4 lnTRSVG_t + \beta_5 lnTPOP_t + \beta_6 lnIMPGS_t + \mu_t \quad (5)$$

Source of Data and Measurement of Variables

The study used secondary data obtained from World Development Indicators (WDI), all the data for variables remittances (REMT), domestic credit % of GDP (CPSGD), domestic interest rate (DPIRR), Total reserves (TRSVG), Total population (TPOP) and Imports of goods and services (IMPGS) are from WDI (2022).

Table 1. Definition of variables and data sources

Variables	Symbols	Description	Source of Data
Financial sector development	CPSGD	The dependent variable is Domestic credit to the private sector (CPSGD) and is measured as a percentage of GDP. Domestic credit to the private sector refers to financial resources provided to the private sector by financial corporations, such as through loans, purchases of non-equity securities, trade credits, and other accounts receivable that establish a claim for repayment.	World Development Indicators
Remittances	REMT	Personal remittances comprise personal transfers and compensation of employees. Personal transfers consist of all current transfers in cash or in kind made or received by resident households to or from non-resident households.	World Development Indicators
Deposit Interest Rate	DPIRR	The rate paid by commercial or similar banks for demand, time, or savings deposits. The terms and conditions of these rates differ by country, limiting their comparability.	World Development Indicators
Total Reserves	TRSVG	Comprise holdings of monetary gold, special drawing rights, reserves of IMF members held by the IMF, and holdings of foreign exchange under the control of monetary authorities.	World Development Indicators

Variables	Symbols	Description	Source of Data
Imports of Goods and Services	IMPGS	The value of all goods and other market services received from the rest of the world. They include the value of merchandise, freight, insurance, transport, travel, royalties, license fees, and other services, such as communication, construction, financial, information, business, personal, and government services. They exclude compensation of employees and investment income (formerly called factor services) and transfer payments.	World Development Indicators
Total Population	TPOP	The de facto definition of population is all residents regardless of legal status or citizenship.	World Development Indicators

Method of Analysis

The method of analysis is the Autoregressive Distributed Lag ARDL. Similarly, the study will employ the Toda Yamamoto Causality Test.

Unit Root Test

The analysis began with the unit root test to determine the time series properties of the data. Whether the time series data were stationary at level or first difference, the unit root test will be conducted on each variable of the model. An Augmented Dickey-Fuller (ADF) test and Phillips-Perron test will be employed to examine the order of integration of the variables. The ADF is conducted by augmenting the DF equations by adding the lagged Values of the dependent variable to avoid serial correlation of the error term.

The ARDL Approach to Cointegration

This study adopts the bounds-testing approach to cointegration based on the Autoregressive Distributed Lag (ARDL) model framework, as proposed by Pesaran et al. (2001). The uniqueness of the ARDL approach compared to other cointegration approaches is that the ARDL does not restrict the integration order of the variables, being all I(1). Consequently, the ARDL can be applied regardless of whether the variables are all I(0), I(1), or mutually cointegrated (Pesaran et al., 2001). The ARDL approach involves estimating a restricted error correction (EC) version of the ARDL model.

The ARDL model is therefore specified as:

$$\Delta(CPSGD)_t = a_0 + a_1 \ln CPSGD)_{t-1} + a_2 \ln(\text{REMT})_{t-1} + a_3(\text{DPIRR})_{t-1} + a_4 \ln(\text{TRSVG})_{t-1} + a_5 \ln(\text{TPOP})_{t-1} + a_6 \ln(\text{IMPGS})_{t-1} + \sum_{i=1}^{h} \beta_1 \Delta(CPSGD)_{t-i} + \sum_{i=0}^{o} \beta_2 \Delta \ln(REMT)_{t-i} + \sum_{i=0}^{j} \beta_3 \Delta(DPIRR)_{t-i} + \sum_{i=1}^{q} \beta_4 \Delta \ln(TRSVG)_{t-i} + \sum_{i=0}^{k} \beta_5 \Delta \ln(TPOP)_{t-i} + \sum_{i=0}^{l} \beta_6 \Delta \ln(IMPGS)_{t-i} + \mu_t \quad (6)$$

The meaning of variables remains constant, $\beta_1, \beta_2, \beta_3, \beta_4, \beta_5\ and\ \beta_6$ are short-run parameters estimated, Δ denotes differencing, lmeanslogarithm, and *h, o, j, q k, l* is the optimal lag length.
An error correction model (ECM) is estimated to get the short-run coefficients. The ARDL specification of the ECM is represented in Equation (7) below.

$$Increment\Delta(CSPGD)_t = \sum_{i=1}^{h} \beta_1 \Delta(CPSGD)_{t-i} + \sum_{i=0}^{o} \beta_2 \Delta \ln(REMT)_{t-i} + \sum_{i=0}^{j} \beta_3 \Delta(DPIRR)_{t-i} + \sum_{i=0}^{q} \beta_4 \Delta \ln(TRSVG)_{t-i} + \sum_{i=0}^{k} \beta_5 \Delta \ln(TPOP)_{t-i} + \sum_{i=0}^{l} \beta_6 \Delta \ln(IMPGS)_{t-i} + \mu_t \quad (7)$$

The error correction mechanism (ECM), first used by Sargan and later popularized by Engle and Granger (1987), corrects for disequilibrium. An important theorem, the Granger representation theorem, states that if two variables, Y and X, are cointegrated, the relationship between the two can be expressed as ECM.

Toda Yamamoto Causality

If the series are integrated of the same order, then Engle and Granger (1987), Johansen (1988), and Johansen and Juselius (1990) tests for causality are valid. However, since the variables are a combination of I(1) and I(0), the study used Toda Yamamoto's (1995) causality test to examine the impact of Remittances on financial sector development. Toda Yamamoto (1995) has suggested a solution by estimating a VAR for the series in levels and testing general restrictions on the parameter matrices even if the series are integrated. They offer a modified version of the Granger causality test that involves a modified Wald (MWald) test in an intentionally augmented VAR model. The procedure for Toda Yamamoto causality involves first establishing the optimal order of the VAR process k, using AIC, SBC, and HQC information criteria. Once the optimal lag order is confirmed, Toda and Yamamoto (1995) suggest estimating a VAR (k+dmax) model where dmax is the maximal order of integration that captures the data generation process. Once the estimation is carried out, linear or non-linear restrictions on the k coefficients of the model can be tested using standard Wald tests, ignoring the last dmax lagged variables.

the To test for Toda-Yamamoto causality between remittances and financial sector development (credit to the private sector), the following bivariate VAR (*k*) model is specified: $the\ \Delta CPSGD_t = \omega_X + \sum_{i=1}^{k+m} \in_x \Delta CPSGD)_{t_{t-1}} + \sum_{i=1}^{k+m} \tau_x \Delta LREMT_{t-1} + \mu_{tx}$

(8)$\Delta REMT_t = \omega_y + \sum_{i=1}^{k+m} \in_y \Delta REMT_{t-1} + \sum_{i=1}^{k+m} \tau_y \Delta CPSGD)_{t_{t-1}} + \mu_{ty}$(9)

In the equation, Δ is the first-deference operator, k is the maximum order of integration, m is the optimal lag length, $\omega_X\ and\ \omega_y$ are the intercepts (constants), $\in_x$ and $\in_y$ are the coefficients. The decision criteria for Toda Yamamoto causality is that if there is unidirectional causality from CPSGD to LREMT, the estimated coefficient of the CPSG must be statistically significant. In contrast, the estimated coefficient of the LREMTS is not statistically significant, and vice versa. Also, bi-directional causality is expected when the CPSGD and LREM coefficients are statistically significant. Finally, Independence causality is suggested when the CPSGD and LREMTS coefficients are not statistically significant.

Diagnostic Tests

Diagnostic tests are conducted to ensure the goodness of fit of the models, enable the results to be relevant for policy recommendation, and verify the validity and reliability of the results. In this regard, serial correlation, normality, stability, functional form, and heteroscedasticity tests are performed. First, the study used the Breusch-Pagan-Godfrey test to test whether the error terms are homoscedastic. Heteroskedasticity is used to test whether the residual's size (either positive or negative) is related to any of the explanatory variables or combinations of explanatory variables. The null hypothesis is Homoscedastic errors.

Serial correlation is used to ascertain the relationship between observations of the same variable over a specific period. It happens when the errors associated with a given period carry over into future periods. Serial correlation is tested using the Breusch-Godfrey Serial Correlation LM Test. The null hypothesis of no correlation is tested. The Ramsey RESET test examines whether non-linear combinations of fitted values explain the response variable significantly at the 5% level. Similarly, as suggested by Pesaran and Pesaran (1997), the cumulative sum of recursive residuals (CUSUM) and the cumulative sum square of recursive residuals (CUSUMSQ) tests are executed to test for the stability of the parameters and model in the long run.

Results and Discussions

Table 2 reports the summary of descriptive statistics. The results show that the average (mean) value of credit to the private sector % of GDP is 10.128%, with the maximum value of credit to the private sector in a year being 22.289% and the minimum value of 4.958% received in a year. This indicates that domestic credit plays a significant role in financial sector development. The contribution of remittance in a year is $ 8.250 billion on average, with the minimum and maximum values being $2.20 million and $2.25 million, respectively. The mean value of the deposit interest rate is 12.085, the maximum value is 23.242, and the minimum value is 5.693. The average import of goods and services is 14.045, the maximum value is 22.811, and the minimum value is 3.887. The total population mean is 35.345, with a maximum value of 53.278 and a minimum of 9.136.

Table 2. Descriptive Statistics of the Variables

	CPSGD	REMT	DPIRR	IMPGS	TPOP
Mean	10.128	8.250	12.085	14.045	35.345
Median	8.242	1.260	12.339	13.087	36.540
Maximum	22.289	2.250	23.242	22.811	53.278
Minimum	4.958	2.200	5.693	3.887	9.136
Std. Dev.	4.452	9.490	3.906	4.756	10.627
Observations	31	31	31	31	31

Results of Diagnostic Tests

Two sets of diagnostic tests were conducted to verify the validity and reliability of the results. The first set deals with residual diagnostic tests comprising serial correlation, heteroscedasticity, and normality. In contrast, the second set focuses on the parameter's stability test consisting of the Ramsey reset test for functional misspecification. There are three tests conducted in this regard: Breusch-Pagan test for serial autocorrelation, which is conducted to establish whether the residual of the estimated model of the study is serially uncorrelated. The second test, the Breusch-Pagan-Godfrey test, is performed to investigate whether the residuals are homoscedastic. Third is the Jacque-Berra test, which is carried out to establish whether the residuals are normally distributed. Table 3 reports the results of these tests.

Table 3. Results of Diagnostic Tests

Test	Test Statistic
Heteroscedasticity CHSQ (14)	0.880 [0.784]
Serial correlation CHSQ (2)	0.905 [0.815]
Normality: Jarque-Berra	1.801 [0.406]
Functional form Ramsey Reset F statistic	0.759 [0.840]

Table 3 shows the Breusch-Godfrey serial correlation LM test to identify the residuals are not serially correlated because the Chi-square of the observed R-square and its associated p-value are statistically insignificant. The result shows that the residuals or the error terms are not serially auto-correlated. Moreover, the observed R-square and its p-value of the Breusch-Pagan-Godfrey test for heteroscedasticity turned out to be statistically insignificant, which suggests the acceptance of the null hypothesis of homoscedasticity in the residuals. In other words, the residuals are homoscedastic. In addition, the F-statistic and its p-value for the Jarque-Berra test for normality were statistically insignificant, hence the acceptance of the null hypothesis of normality in the residuals.

Unit Root Test

The unit root test results in Table 3 indicate that domestic credit to the private sector, remittances, domestic interest rate, and total reserves have unit roots at level, which means they are not stationary at level but stationarity at first difference. Therefore, the variables are integrated into degree 1 or I(1). However, total population, inflation, and import of goods and services are stationary at level. Therefore, the variables are found to be integrated of order zero or I(0). In summary, the variables of interest have a mixed order of integration. The mixed order of integration among these variables provides a vital justification for adopting the Autoregressive distributed lag ARDL approach for this study.

Table 3. Results of the Unit Root

Variables	Level				First Difference				Result
	ADF		PP		ADF		PP		
	Intercept	Trend & Intercept	Intercept	Trend & Intercept	Intercept	Trend & Intercept	Intercept	Trend & Intercept	
CPSG	-2.136	-3.631	-1.232	-1.850	-5.068***	-5.727	-4.951***	-4.806	I(1)
LREMT	-1.687	-2.066	-2.149	-1.986	-4.330***	-4.711	-8.828***	-8.593	I(1)
DPIRR	-1.337	-2.806	-2.743	-2.505	-4.048***	-4.892	-7.046***	-7.026	I(1)
TRSVG	-1.200	-2.066	-1.061	-1.603	-5.104***	-5.928	-7.374***	-21.857	I(1)
TPOP	3.411**	1.214	-3.411**	-0.051	-5.851	-6.215	-5.850	-13.520	I(0)
IMPGS	-3.393**	4.021	-3.289**	-3.817	-7.292	-7.176	-17.692	-18.593	I(0)

Note: *** and ** indicated statistically significant at 1%, and 5%, respectively.

Since the stationarity status has been established, the ARDL bound test for cointegration was employed to check for the long-run relationship among the variables. The results presented in Table 4 show that the computed F statistics (32.566) is greater than the upper bound critical value (3.99) I(1) at a 1% level. This finding suggests the long-run relationship between CPSGD, REMT, DPIRR, IMPGS, and TPOP. The next step is to estimate the long-run as well as short-run/ECM coefficient of the optimum model of the study.

Table 4. Results of Bounds Test Cointegration

Dependent Variables	Function						
CPSGD	F(REMT, DPIRR, IMPGS, TPOP)						
F-Statistic	Critical Value Bound	10%		5%		1%	
32.566***		I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
		1.99	2.94	2.27	3.28	2.88	3.99

Source: *** denotes statistical significance at a 1% level

Results of Selected Long Run and Short Run Model

The Akaike Information Criterion (AIC) is used in model selection to balance model fit and complexity, particularly in the Autoregressive Distributed Lag (ARDL) context. Its formula, AIC = 2*k - 2 ln(L), combines estimated parameters ('k') and the natural logarithm of the likelihood function (ln(L)). A lower AIC indicates a better compromise between fit and complexity. In comparison, the Schwarz Criterion (SC), also aids model selection by considering goodness of fit and complexity but imposes stricter penalties on complex models. Its formula, SC = k*ln(n) - 2*ln(L), introduces a complexity and sample size ('n') weighted penalty, promoting simpler models. Like AIC, a lower SC value highlights a better fit-complexity balance. In this model, the SC suggests the optimal lag order for the long and short-run models is 2.

Table 5. Results of Akaike Information Criterion (AIC) and Schwarz Criterion (SC)

Lag order	AIC value	SC value	F-statistic
0	100.0	100.0	1.0
1	95.0	95.0	2.0
2	90.0	90.0	3.0
3	92.0	92.0	4.0

The SC test results, including the AIC and F-statistic, are presented in Table 5. The lag order with the lowest AIC and SC values in the table is 2, indicating it is the best choice for the ARDL model. Furthermore, the F-statistic for the bounds test is significant at the 1% level, supporting the selection of the ARDL model with a lag order of 2 as the best model for the data.

Having confirmed the long-run relationship between the variables, the ARDL model was estimated. The long-run and short-run coefficients for the estimated optimum model chosen by Akaike information criteria are presented in Table 6. The results in the long-run ARDL model show that the coefficient of remittances is positive and statistically significant at a 1 percent significance level in the long run. This means that increases in remittances can stimulate financial development in Nigeria. A 1% increase in remittances leads to a 2.76% increase in CPSGD in the long run, while in the short run, remittances have a positive and significant effect on CPSGD at a 1% level. A 1% increase in remittances leads to a 1.05% increase in CPSGD. This finding is in line with the works of Coulibaly (2015) and Kakhkharov and Rohde (2020).

Table 6. Results of Short Run and Long Run ARDL model

Long run ARDL Model				
The dependent variable is CPSGD				
Variables	Coefficient	Standard error	t-statistic	Probability
LREMT	2.757	0.460	5.994	0.000
DPIRR	-0.063	0.118	-0.538	0.598
TRSVG	-0.000	0.000	-1.146	0.026
TPOP	-0.723	0.946	-0.765	0.455
IMPGS	-1.505	0.628	-2.398	0.028
C	44.752	6.595	6.786	0.000
Short-run ARDL Model				
The dependent variable is CPSGD				
Variables	Coefficient	Standard error	t-statistic	Probability
Δ LREMT	1.054	0.251	4.202	0.001
Δ LREMT-1	-1.762	0.296	-5.958	0.000
Δ LREMT-2	-0.947	0.268	-3.536	0.003
Δ DPIRR	0.243	0.076	3.212	0.005
Δ DPIRR-1	0.250	0.086	2.898	0.010
Δ DPIRR-2	0.524	0.101	5.196	0.000
Δ TRSVG	-0.000	0.000	-1.334	0.200
Δ TPOP	-3.435	0.863	-3.979	0.001
Δ IMPGS-1	-0.915	0.740	-1.237	0.233
CointEq-1	-1.058	0.156	-6.776	0.000

Source: Δ is the first difference operator.

Moreover, the results indicated that the deposit interest rate positively and significantly affects CPSGD at a 1% level in the short run. A 1% increase in deposit interest rate leads to a 0.24% increase in CPSGD in the short run. The findings are consistent with the results of previous studies (Khurshid et al., 2020; Tuuli, 2015). Furthermore, the total population negatively and significantly impacts CPSG at a 1% level in the short run. Also, the variable negatively and significantly impacts CPSGD at 1% in the short run. A 1% increase in total population leads to a 3.44% decrease in CPSGD in the long run, while in the short run, it leads to a 0.72% decrease in CPSGD. The finding supports the previous studies (Vanroose & Espallier, 2009). Moreover, importing goods and services as a percentage of GDP negatively correlates with CPSGD at 1% in the long and short run. A 1% increase in IMPGS leads to a 0.92% decrease in the long run and a 1.51% decrease in the short run. The results are consistent with the previous studies (Elsherif, 2015).

The estimation results show that an increase in remittances leads to a rise in domestic credit to the private sector in Nigeria. It is noted that migrant remittances or transfers help to ease the immediate budget constraints of the recipient and provide an opportunity for small savers to gain access to the formal financial sector. Remittances enable unbanked recipients to acquire certain financial products and services, improving financial sector development. The findings support the portfolio theory of private investment (or broad money), which states that increasing remittances tends to enhance the financial sector's development (Ajide, 2019).

This outcome is in line with the Nigerian context because remittances, from the empirical analysis, increased the saving pattern of recipients. Excess funds after consumption and use of other investments could be saved, introducing non-banked recipients to formal banking and investment systems. This is consistent with (Aggarwal et al., 2011; Gupta et al., 2009; Hussaini et al., 2021; Oke et al., 2011; Olowa, 2015). Also, the findings revealed that the domestic interest rate is an important determinant of financial sector development in such a way that a rise in domestic interest rate leads to an increase in domestic savings, hence more loanable funds for investors, leading to financial sector development in Nigeria.

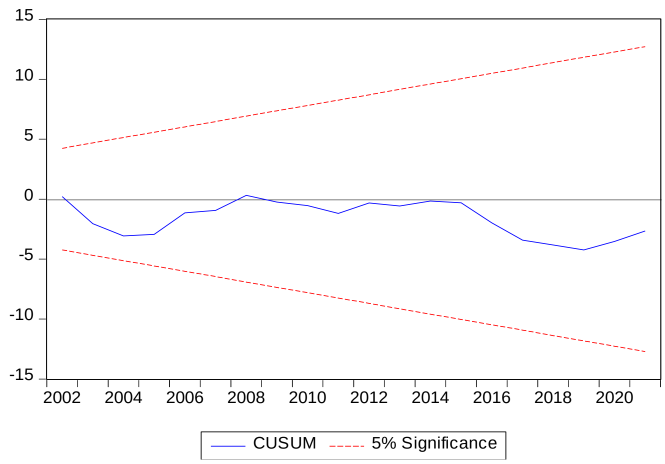
The negative sign of the coefficient of import of goods and services revealed that the more imported goods and services, the more the financial sector is underdeveloped in Nigeria. The situation shows the current circumstances in Nigeria, where it imports most of the goods and services needed for consumption and production purposes which retard the industries in Nigeria that produce the same goods and services, resulting in workers' retrenchment and subsequently reducing savings which will reduce financial sector development in the country (Ajide, 2019).

In addition, the empirical findings show that as total reserves increase, financial sector development also increases. It is real that the more the country's foreign reserves are appreciated, the more the financial sector develops, as the reserves serve as a mirror for future investors in the country. Similarly, the empirical result reveals that a country's population can improve financial sector development. Productive individuals can save their income in the financial sector, making loanable funds available for investment (Onyeisi et al., 2020).

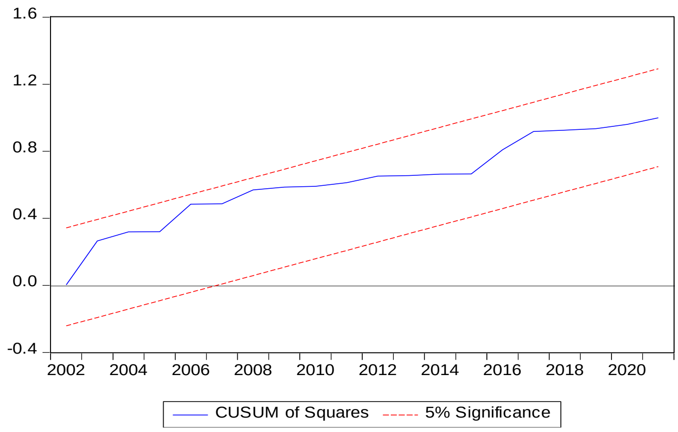
The equilibrium correction coefficient takes the value of 1.05 and is highly significant, thus having the correct sign and implying a very high speed of adjustment to equilibrium after a shock. About 105 % of disequilibria from the previous year's shock converge back to the long-run equilibrium in the current year. Banerjee et al. (1998)state that a highly significant error correction term further proves a stable long-term relationship.

Stability Test

The cumulative sum of recursive residuals (CUSUM) and the cumulative sum square of recursive residuals (CUSUMSQ) tests are executed to test for the stability of the parameters and model in the long run. The result of CUSUM and CUSUMSQ is shown in Figure 1.



CUSUM



CUSUM of Square

Figure 1. Stability Test using CUSUM and CUSUM of Square

The stability test (CUSUM) results show that the plots do not exceed the bounds at a 5% significance level, indicating that the long-run parameters and the model are stable. This shows that the parameters and the model are stable in the long run and, therefore, are relevant for policy recommendations.

Results of Toda Yamamoto Causality Test

The presence of cointegration among the variables does not show the direction of causality between them. Hence, this justifies examining the existence of a causal relationship between the variables using Toda Yamamoto's (1995) approach to causality. The summary of the results of the Toda Yamamoto causality test is presented in Table 7.

Table 7. Results of Toda Yamamoto Causality

Null hypothesis	df	MWALD	Prob	Decision	Direction of causality
CPSGD→LREMT	2	21.826	0.000	Reject	Unidirectional
LREMT→ CPSGD	2	2.332	0.312	Do not reject	No causality
CPSGD →DPIRR	2	0.006	0.937	Do not reject	No causality
DPIRR→ CPSGD	2	1.980	0.996	Do not reject	No causality
CPSGD →TPOP	2	15.184	0.005	Reject	Unidirectional
TPOP→ CPSGD	2	8.389	0.015	Reject	Unidirectional
CPSGD →GCFG	2	0.001	0.991	Do not reject	No causality
GCFG→ CPSGD	2	0.087	0.768	Do not reject	No causality
CPSGD →TROP	2	3.079	0.215	Do not reject	No causality
TROP→ CPSGD	2	1.752	0.416	Do not reject	No causality

Note: → denotes 'does not Granger cause'; df indicates degrees of freedom, and MWALD is the modified Wald chi-square of the Toda-Yamamoto (1995) causality test.

Table 7 shows a bidirectional causality running from CPSGD to remittances (LREMT) and a unidirectional causality from domestic credit to the private sector (CPSGD) to total reserves (DPIRR) in Nigeria. The results of the remaining variables indicate that there is no causality among the variables. The results of the Toda Yamamoto causality revealed the presence of causation between domestic credit to the private sector and remittance is bidirectional. This is consistent with the Nigerian context; broad money may cause an inflow of remittances (Keho, 2020).

Conclusions

Given the preceding findings, this study makes the following recommendations. First, having established that remittances inhibit financial sector development, the government should employ policies encouraging the channeling of remittances through formal banking and ensuring that such remittances are channeled to finance productive investment, hence financial development.

In addition, through financial inclusion measures, policymakers may consider providing financial services and products to rural areas to facilitate and reduce transaction costs associated with receiving remittances. Doing so will inculcate banking habits among rural dwellers and ensure that remittances make them important sources of loanable funds to investors or entrepreneurs in the country. From the results, there exists a negative relationship between real interest rates and financial sector development. This implies that policymakers should maintain positive real interest rates to encourage more saving deposits and loanable funds in the financial sector.

The growth rate of Gross capital formation was found to have a positive impact on financial sector development, and this implies that policies should be designed to boost the growth rate of gross capital formation, which will enhance the performance of Nigeria's financial sector development. Lastly, the study found a positive relationship between trade openness and financial sector development. This demonstrates the importance of trade openness in promoting financial sector development, hence the need to implement policies to support more trade openness as a financier of promoting financial sector development in Nigeria.

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Economic Journal of Emerging Markets, 15(2) 2023, 129-142

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Labor market distortions in major emerging-market economies: Some CGE estimates

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Article Info

Article history:
Received 11 August 2023
Accepted 23 October 2023
Published 31 October 2023

JEL Classification Code:
C68, D57, E24.

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DOI: 10.20885/ejem.vol15.iss2.art2

Abstract

Purpose — In the present study, the effects of labor market distortions on economic structure and efficiency are estimated for seven emerging-market countries: Brazil, China, Indonesia, India, Mexico, Russia, and Turkey.

Methods — The estimates are based on a computable equilibrium (CGE) model that allows simulation of the inter-industry links of 56 industries plus a sector representing the rest of the world from data collected in the World Input-Output Database (Release 2016) for the period 2000-2014.

Findings — The results show that wage differentials appear to be distortionary, especially in the cases of countries with high wage-income inequality. Moreover, it seems that labor market distortions in emerging-market countries are subject to the rural-urban dichotomy and urban labor-market imperfections. Finally, the results show that the removal of wage differentials affects the terms of trade, which are improved in most but not all cases.

Implication —The conclusions of the present study have policy implications. In countries where the rural-urban dichotomy is the main distortion in labor markets, increasing urbanization can stimulate efficiency; when this is not the case, further reform of urban labor markets is needed. However, it cannot be ruled out in advance that a policy aimed at enhancing labor mobility may have a negative impact on the terms of trade.

Originality — The estimation method used in the present study presents certain advances over others found in the literature, as it becomes possible to estimate the effects of labor-market distortions while considering the interdependencies between different sectors, as well as to plausibly estimate the effects on trade. The present study also uses a large quantity of data, which is expected to add robustness to the study's conclusion.

Keywords — Emerging-market countries, labour market distortions, input-output tables, computable general equilibrium models.

Introduction

In the competitive society assumed by economic theory, homogeneous labor units are paid equally, regardless of the industry or firm that employs them. In the absence of market imperfections, arbitrary differences in wages are not expected to last as laborers move from one job to another. However, significant differences exist across all societies among the wages paid within distinct industries and firms, and these differences are especially large in less-developed countries (Freeman & Oostendorp, 2002; Liboreiro, 2022a).

P ISSN 2086-3128 | E ISSN 2502-180X

Sometimes, the large wage differences observed in less-developed countries are considered 'endogenous' (i.e., due to market imperfections in a 'laissez faire' context). Thus, many studies have found wage differentials to be caused by unobserved differences in the skills of laborers or the disutility associated with particular industries or regions (Pratap & Quintin, 2006; Rosenzweig, 1988). However, wage differentials can also be 'exogenous' (i.e., due to non-market imperfections, as they result from institutional elements typical of less-developed countries), whether 'autonomous' in origin or 'policy-imposed.' The causes of these differentials include the lack of freedom of registration, monopoly power through unionism, and/or the urban-rural dichotomy, among other factors (Günther & Launov, 2012; Jha & Hasan, 2022; Magee, 1973).

Ever since the existence of large wage differentials in less-developed countries became known, and data was made available, scholars have wondered about their effects on efficiency. Given the emphasis of economic theory on the allocation of resources, it seemed reasonable to consider that the existence of wage differentials would lead to a misallocation of labor among industries and firms, thereby reducing efficiency. Wage differentials in less-developed countries were therefore expected to be distortionary –especially when regarding 'exogenous' wage differentials.[1] However, the earliest theoretical studies on this matter showed that the effects of wage differentials on efficiency might prove insignificant (Fishlow & David, 1961; Johnson, 1966) and that their removal may even have perverse effects (Bhagwati, 1968; Bhagwati & Ramaswami, 1963) in the event of foreign trade or economic rigidities. Subsequently, pioneering empirical studies concluded that wage differentials appear to have a negative (but small) impact on efficiency in less-developed countries (de Melo, 1977; Kwon & Paik, 1995).

Lately, the initial skepticism among scholars has given way to effusive optimism. Indeed, recent contributions have led to some consensus on the hypothesis that factor-price differentials explain a significant part of the income differences between countries (Hopenhayn, 2014; Restuccia & Rogerson, 2017). Studies, both theoretical and empirical, that offer evidence in favor of this hypothesis are based on models of monopolistic competition involving heterogeneous firms, in which a large set of firms are assumed to use primary inputs for the provision of differentiated goods. As long as the elasticity of substitution between varieties of the same good is assumed to be great, and the use of intermediate inputs and other rigidities are not regarded, it has been found that the impact of factor-price differentials on efficiency can be considerable. Specifically, based on these assumptions, certain empirical studies estimate that the removal of wage differentials in emerging-market economies such as India or China can increase efficiency by a factor of two (Aoki, 2012; Hsieh & Klenow, 2009; Zhang et al., 2023).

Given the astonishing results obtained by this recent framework, a question arises: Is it possible to obtain similar results from different assumptions and data sets? Recent studies in this regard have focused on analyzing firm-level data for a single industry (typically manufacturing) and have heavily relied on evidence provided by the 'love-of-variety models' (Broda & Weinstein, 2006; Hendel & Nevo, 2006). In the present study, an alternative perspective is proposed by estimating the effects of wage differentials from a computable general equilibrium model, relying on evidence gathered using recent developments in input-output accounting (Dietzenbacher et al., 2013; Liboreiro, 2022b).

The proposed computable general equilibrium model is formulated in such a way that allows simulation of the inter-industry links of many industries plus an additional sector that represents the trade relations between each country and the rest of the world, assuming that a given country's exports are all intermediate goods. In addition, the demand is modeled as a linear expenditure system with a basic consumption basket composed of goods according to their income elasticity. To calibrate the model and perform simulation exercises, data were taken from the 2016 Release of the World Input-Output Database (Timmer et al., 2015) for seven emerging market countries (Brazil, China, Indonesia, India, Mexico, Russia, and Turkey) and 56 industries plus a composite sector comprising the rest of the world, for the period 2000-2014. The effects of removing wage differentials on efficiency, output, employment, and trade were then estimated using U.S. wages as a 'benchmark.'

[1] It is worth noting that 'differential' is a purely descriptive term, while 'distortionary' denotes that a differential has implications for efficiency (Bhagwati & Ramaswani, 1963).

The main conclusion of the study is that wage differentials in emerging-market countries appear to be distortionary, although they appear to be less distortionary than certain recent studies conclude (Aoki, 2012; Hsieh & Klenow, 2009; Zhang et al., 2023). Indeed, the efficiency gains of removing wage differentials appear higher for countries with high wage-income inequality. Furthermore, in many emerging-market countries, the main distortion in the labor market remains the urban-rural dichotomy, while major labor market distortions in other economies involve imperfections within urban labor markets. Additionally, the removal of wage differentials has effects on the terms of trade, which are improved in most but not all cases. In countries where the rural-urban dichotomy is the main distortion in labor markets, increasing urbanization can stimulate efficiency; when this is not the case, further reform of urban labor markets is needed. However, it cannot be ruled out in advance that a policy aimed at enhancing labor mobility may have a negative impact on the terms of trade, giving rise to a process of 'immiserizing growth.

The novelty of this study, compared to others found in the literature, lies in its estimation of the effects of wage differentials in emerging-market economies in view of empirical evidence recently gathered using input-output accounting. To date, and to the author's knowledge, only a few relevant studies have employed this methodology. Indeed, since the seminal contributions of de Melo (1977) and Paik (1995), no new progress has been made in estimating the effects of wage differentials using data from input-output tables in computable general equilibrium models. In addition, the estimation method used in this study presents certain advances over former methods, as the model endogenizes the relations of the economic system with the rest of the world. Then, employing this method, it becomes possible to estimate the effects of removing labor-market distortions while considering the interdependencies between different sectors, as well as to plausibly estimate the effects on trade. The present study also uses a large quantity of data, calculating estimates for seven countries across 15 years and considering the inter-industry links of 56 industries plus a composite sector comprising the rest of the world for each country and year. This breadth of purview is expected to add robustness to the study's conclusions and to permit generalization of the results obtained.

Methods

The method employed for estimating the effects of removing labor market distortions is to use a computable general equilibrium model capable of analyzing the data available in a standard input-output table. For this, it is first necessary to characterize the market behavior of the different agents that coexist in the economic system so that a system of equations can be obtained and solved using the fixed-point method.

Suppose, then, an economic system composed of $j = 1, \dots, N$ industries, producing $j = 1, \dots, N$ homogeneous commodities, plus $N + 1$ sector representing the rest of the world and producing a single composite good whose composition does not change with small changes in output. Both the N domestic industries and the $N + 1$ rest-of-the-world sector use as inputs the production factors and commodities produced by any of the $N + 1$ sector According to the available estimates derived from data from input-output tables, the values of the substitution elasticities between capital and labor σ_{KM}, between factors of production and intermediate inputs σ_{VM}, and between different intermediate inputs σ_{MM} are all between 0 and 1 for almost all the industries and countries analyzed (Kemfert, 1998; Koesler & Schymura, 2015; Okagawa & Kanemi, 2008; van der Werf, 2008).[2] Therefore, the most flexible production technology that can be expected is one in which $\sigma_{KL} = \sigma_{VM} = \sigma_{MM} = 1$, so it is reasonable to represent the behavior of the producers in the following manner:

[2] In the estimate by Koesler and Schymura (2015), still among the most complete using input-output tables, the authors found that the elasticity of substitution between capital and labor is significantly greater than 1 in only two of 35 sectors (Water Transport and Post & Telecommunications). Also, these authors found that the elasticity of substitution involving intermediate inputs is significantly greater than 1 in only one of 35 sectors (Water Transport) and only for the case of substitution between energy and primary factors.

$$X_j = \Xi_j K_j^{\beta_{Kj}} L_j^{\beta_{Lj}} X_{1j}^{\alpha_{1j}} \dots X_{ij}^{\alpha_{ij}} \dots X_{Nj}^{\alpha_{Nj}} X_{N+1j}^{\alpha_{N+1j}} \quad (1)$$

In this configuration, X_j is the output of industry j, K_j is the capital stock of industry j, L_j is the amount of labor employed in industry j, and X_{ij} is the output of industry I, which is used as an intermediate input in industry j. This is a Cobb-Douglas production function, including both primary factors of production and intermediate inputs. It represents the case in which substitution between capital and labor is possible, as is substitution among intermediate inputs and between intermediate inputs and production factors.

According to the available empirical estimates, actual technologies will be at most as flexible as (1). Therefore, it seems reasonable to use such production functions to find plausible estimated values. Assuming profit maximization and perfect competition, the input demand expressions corresponding to such a specification of the production function can then be deduced. Thus, when considering (1), the demand for production factors and intermediate inputs is:

$$L_j = \beta_{Lj} \left(\frac{W_j}{P_j}\right)^{-1} X_j, X_{ij} = \alpha_{ij} \left(\frac{P_i}{P_j}\right)^{-1} X_j \quad (2)$$

where P_j is the commodity price produced by industry j, and W_j is the wage of laborers employed in industry j.

Additionally, it is assumed that the relative wages $j = 1, \dots, N$ are exogenously given and can be expressed as a premium over the farm wage (industry 1), so that the wage paid in industry j can be expressed as:

$$W_j = \pi_j W_1 \quad (3)$$

where π_j represents the premium or discount paid to workers employed in industry j over the farm wage (W_1). The wage paid by the rest of the world can also be represented as the premium or discount over the farm wage:

$$W_{N+1} = EW_1 \quad (4)$$

The symbol E represents the exchange rate in this model, and, unlike the $j = 1, \dots, N$ wage differentials, it is not assumed to be exogenously given.

The set of equations (1) to (4) characterize the market behavior of producers according to two alternative assumptions regarding the technologies they use. To characterize the market behavior of consumers, a stylized fact can be accepted: the existence of a minimum consumption basket that is insensitive to changes in relative prices. Therefore, it is assumed that the welfare of consumers can be represented as:

$$U = \sum_{i=1}^{N+1} \mu_i \, log(C_i - \theta_i)$$

Under the assumption of welfare maximization, the result is a linear expenditure system:

$$C_i = \theta_i + \frac{\mu_i(D - \sum_k P_k \theta_K)}{P_i} \quad (5)$$

where C_i is the consumption demand of commodity i, θ_i represents an absolute minimum level of consumption of commodity i, μ_i is the marginal budget share of commodity i, and D is the total consumption expenditure ($D = \sum_i P_i C_i$). In actuality, there is an important relationship between μ_i and θ_i:

$$\theta_i = \left(\frac{D}{P_i}\right)[\phi_i - \mu_i \sigma_C]$$

where ϕ_i is the budget share of commodity i ($\phi_i = \frac{P_i C_i}{D}$), and σ_C is the supernumerary-income ratio. In addition, the marginal budget shares result from:

$$\mu_i = \eta_i \phi_i$$

where η_i is the income elasticity of commodity i. It is then observed, as expected, that the lower the income elasticity, the greater the share of the inelastic component in the consumption of commodity i. Therefore, using the set of equations (5), it is possible to regard different income elasticities for different goods and services in a tractable way.

Since the assumed economic system allows foreign consumption in addition to domestic consumption, it becomes necessary to characterize foreign consumption demand as well. This can be done in two ways: by assuming a different utility function (characterizing rest-of-the-world preferences) or by assuming that preferences are the same in all countries. Since the latter assumption is clearly far from reality, given the non-negligible 'home bias' in consumption, the first option seems the most reasonable. However, this implies that demand equations cannot be assumed to derive from one aggregated consumer, so there is no guarantee that solution prices will be unique (Arrow & Hahn, 1971). To avoid such confusion, it can be further assumed that the consumption demand from the rest of the world is the same as the demand for intermediate inputs. Therefore, the rest-of-the-world consumption demand of commodity i is included in the demand for intermediate inputs from the rest of the world $X_{N+1,i}$. This is equivalent to assuming that a country exports only intermediate goods to the rest of the world, although it also imports both final and intermediate goods from the rest of the world.[3]

Then, from this simplified characterization of the market behavior of producers and consumers, it is possible to characterize the market equilibrium of the whole economic system. For this, it is necessary to introduce additional restrictions that allow a determined system of equations to be obtained. One of these restrictions is the input-output balance of the economic system (or material balance), which resumes the supply-demand balance:

$$X_i = \sum_{j=1}^{N+1} X_{ij} + C_i + \bar{Z}_i \quad (6)$$

where $\overline{Z_\iota}$ is investment demand and government purchases of commodity i, which are assumed to be exogenously given. Additionally, the total number of employed laborers is in any case required to be equal to the number of currently employed labourers within the country, that is:

$$\sum_{j=1}^{N} L_j = \bar{L} \quad (7)$$

where $\bar{L}$ is the actual amount of labor employed in the country.[4] This restriction is a necessary requirement for the present estimation since we are interested in estimating the effects of distributing the same amount of labor alternatively to the actual case.

In addition to conditions (6) and (7), it is necessary to introduce a condition of price normalization:

$$\sum_{j=1}^{N+1} P_j^{*1} X_j^0 = \sum_{j=1}^{N+1} P_j^{*0} X_j^0 \quad (8)$$

with P_j^* representing the net price of commodity j, which is equal to:

$$P_j^* = (\beta_{K,j} + \beta_{Lj}) P_j \quad (9)$$

In summary, equations (1) to (9) make up a system of equations comprising $7(N+1) + (N+1)^2 + 2$ equations, $7(N+1) + (N+1)^2 + 2$ dependent variables (i.e., X_i, X_{ij}, P_i, P_i^*, W_i, C_i, E, D), $2(N+1) + 1$ independent variables (i.e., $\overline{K_\iota}$, $\overline{Z_\iota}$, $\bar{L}$), and $5(N+1) - 1 + (N+1)^2$ parameters (i.e., β_{Kj}, β_{Lj}, α_{ij}, π_j, μ_i, θ_i). The result is a nonlinear system of equations, the solution of which requires some algorithm. In the present case, the following strategy was followed. First, it should be noted that according to the stated model, the farm wage W_1 can be taken as numeraire so that its value is arbitrary (e.g., $W_1 = 1$). Subsequently, instead of D, it is convenient to introduce an instrumental parameter λ by which consumption demand can be represented as:

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[3] This assumption is consistent with the facts since, for all countries in the sample, exports of intermediate goods represented over half of all their total exports in the period analyzed.

[4] This equilibrium condition is equivalent to assuming that labor employment in the rest of the world can vary to accommodate small increases in output (i.e., that L_{N+1} can vary to a small extent).

$$C_i = \theta_i + \frac{\lambda\mu_i\left(Y - \sum_{k=1}^{N+1} P_k\theta_K\right)}{P_i}$$

where:

$$Y = \sum_{j=1}^{N} P_j^* X_j$$

That is, instrumentally, it can be assumed that consumption represents an arbitrary constant fraction of a country's income, Y. This way, λ can be understood as the 'marginal propensity to consume.' Then, the system of equations can be rewritten so that a set of equations is obtained depending only on prices, on the 'exchange rate' E, and on the 'marginal propensity to consume' λ. That is:

$$F_j(P_j, \lambda, E) = 0$$

Now, assuming arbitrary starting values of λ and E, the system of equations can be solved by Newton's method once the respective Jacobian matrices have been calculated. The results obtained must then be compared with conditions (7) and (8), and both parameters λ and E must be alternately changed until both conditions are met with an acceptable relative error (0.5% in the present study). In this sense, solving the system of equations F_j consists of finding the values of the marginal propensity to consume λ and the exchange rate E, for which equilibrium conditions (7) and (8) hold.

Once the algorithm to solve the general equilibrium model has been found, it is possible to estimate the effects of removing wage differentials by means of the standard method found in the literature (Hsieh & Klenow, 2009). First, the model is calibrated so that if actual wage differentials π_j^0 are assumed, then actual prices P_i^0 and output X_i^0 are obtained. Next, another set of wage differentials π_j^1 is considered, and these are assumed to be representative of a labor market free of imperfections. These differentials are usually taken from the available data of some developed country, typically the U.S. Then, once the set of parameters π_j^1 has been considered, the model is solved again, generally obtaining different prices P_i^1 and output X_i^1. Finally, the actual values are compared with these hypothetical values, and the effects on efficiency and economic structure are obtained.

The method was applied to the data available in the World Input-Output Database (Release 2016) for seven emerging-market economies (Brazil, China, Indonesia, India, Mexico, Russia, and Turkey) from 2000-2014. The data have been considered for the 56 industries of each country, also adding all others into a rest-of-the-world sector so that virtually all the information contained in the World Input-Output Tables has been taken into account. Furthermore, the relative wages of the United States appearing in this same database for 2000 have been taken as a 'benchmark.'[5] Thus, it has been assumed that wage premia over the farm wage found in the U.S. represents the case of a labor market without imperfections. Then, for each country in the sample, an evaluation was made of how that country's efficiency and structure would change were its wages altered to resemble those reported for the U.S.

In terms of the income elasticities characterizing consumer demand, it was decided to use a stylized fact. Indeed, empirical studies on developing countries agree that the income elasticity of consumer demand for food products is less than 1, whereas the income elasticity of consumer demand for foreign goods is usually found to be greater than 1 (Emran & Shilpi, 2010; Faini et al., 1988; Hong, 2001; Muhammad et al., 2011). Therefore, a value of $\eta = 0.5$ was assumed for the income elasticity of the consumer demand for the sectors of agricultural, forestry, and fishing products, as well as food and beverages. Moreover, a value of $\eta = 1.5$ was assumed for the income elasticity of consumer demand for foreign goods. Then, the income elasticity of consumer demand

[5] The year has little relevance since the wage structure in the U.S. varies little over time.

for the remaining goods was assumed to be the same, and this was obtained from the Engel aggregation condition:

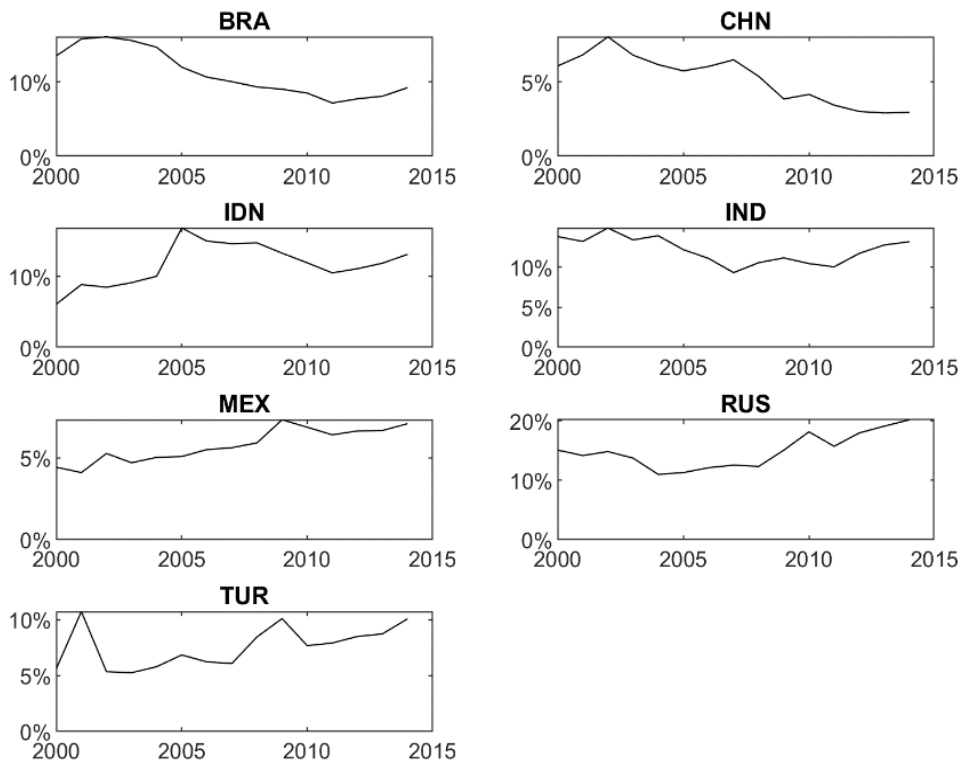
$$\sum_{i=1}^{N+1} \phi_i \eta_i = 1$$

Details of the results of this experiment are discussed in the next section.

Results and Discussion

The computable general equilibrium model presented was calibrated for each country and year of the sample, considering 56 industries plus a composite sector comprising the rest of the world (i.e., $N + 1 = 56 + 1$). The model was calibrated and then solved under the alternative assumption that relative wages are equal to actual wages or those of the U.S. The effects on major indicators of removing wage differentials are presented in Figures 1 to 6.

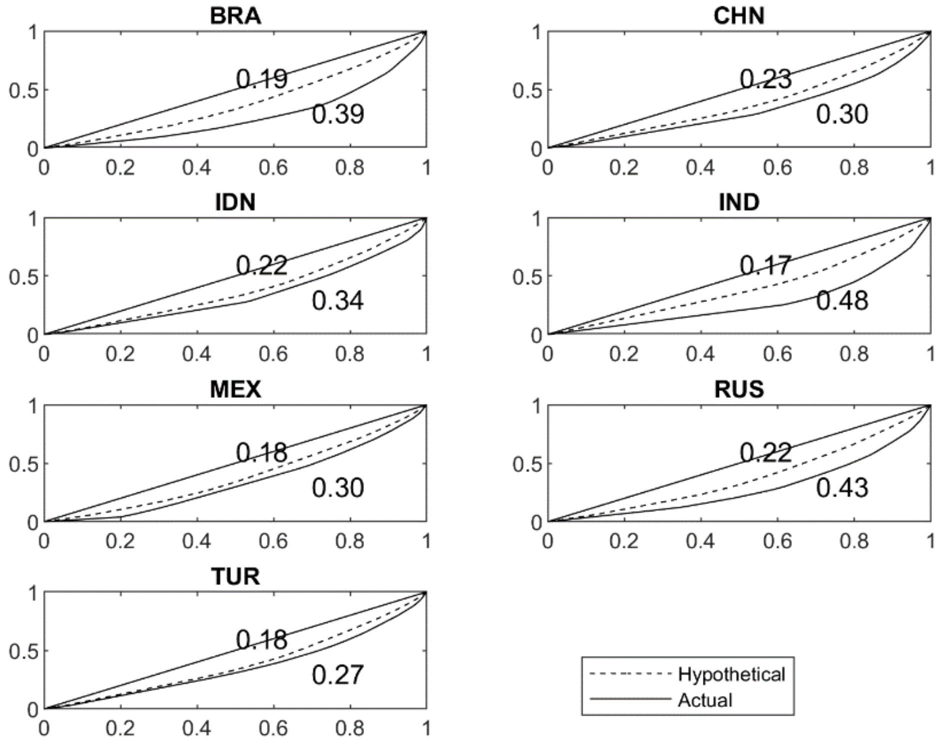
Figure 1 represents the effects on efficiency of removing wage differentials, estimated as the effects on GDP measured at constant net prices. In the results presented in Figure 1, differences can be observed in the effects on the efficiency of removing wage differentials depending on the country considered. Specifically, it is observed that for four countries in the sample (Brazil, Indonesia, India, and Russia), the efficiency gains of removing wage differentials are between 8% and 20% for all the years considered. In addition, for three countries in the sample (China, Mexico, and Turkey), the efficiency gains do not exceed 8% for any year. So, from these results, two issues can be observed. On the one hand, for no country in the sample does it appear that the removal of wage differentials would negatively affect efficiency; thus, their effect seems to be distortionary in all cases. On the other hand, these results seem more pessimistic than those offered by certain recent studies (Bartelsman et al., 2013; Bento & Restuccia, 2017; Hsieh & Klenow, 2009; Zhang et al., 2023) and yet more optimistic than those of the first studies on this matter (de Melo, 1977; Kwon & Paik, 1995).



Notes: The effects on the efficiency of removing wage differentials were calculated as the difference between hypothetical and actual GDP to actual GDP at constant net prices.

Figure 1. Effects on the efficiency of removing wage differentials

In addition to the effects on efficiency, the removal of wage differentials in emerging-market countries has an obvious impact on income distribution, as shown in Figure 2, which presents the effects on wage-income distribution of removing wage differentials as measured from the Gini index resulting from the Lorentz curves. Figure 2 shows that the effects on wage income distribution by removing wage differentials are greater in those countries where the distribution of wage income is more unequal (not surprisingly). This is the case in some countries (Brazil, India, Russia), for which it is estimated that removing wage differentials would have a drastic impact on the distribution of wage income. In other countries (China, Mexico, Turkey), this effect would be smaller but significant.



Notes: Lorentz curves for wage income were calculated for the case of the central year of the sample (2007).

Figure 2. Effects on wage-income distribution of removing wage differentials

Relating the results of Figures 2 and 1, a certain relationship emerges according to which the greater the wage inequality, the greater the efficiency gains of removing wage differentials. If the efficiency effects of removing wage differentials are plotted as a function of the Gini coefficient of the wage-income distribution, this relationship seems fairly evident. This is precisely what Figure 3 shows, which can be seen as an estimate of the 'trade-off' between wage inequality and efficiency gains. Thus, for every 0.1 point that wage dispersion decreases in the sample countries, efficiency increases by 5%. This is not an easy 'trade-off' since a change of 0.1 points in the Gini dispersion coefficient implies a drastic change in the income distribution, while efficiency gains of 5% do not seem a great reward.

Taking the analysis further, toward the details of the economic structure, some features can be discerned in the sample countries as regards the effects on output of removing wage differentials. This can be seen in Figure 4, which depicts the changes in output of four aggregate sectors, measured at constant prices, as a percentage of actual output. In all the countries in the sample, the removal of wage differentials implies an increase in the output of urban-based industries related to trade and services. In addition, the mining and manufacturing and the public utilities and transportation sectors seem to increase in many cases – sometimes more than the trade and services sectors (e.g., China and Turkey). On the contrary, rural-based activities devoted to agriculture, forestry, and fishing seem to decrease in many cases (e.g., Indonesia, India, Mexico, and Russia). Thus, it can be claimed that wage differentials influence relative prices so that the output of many urban-based industries (trade, services, public utilities) is lower than it would be without labor market distortions. In comparison, the agricultural (and sometimes manufacturing) output is higher when compared with a hypothetical non-distortionary case.

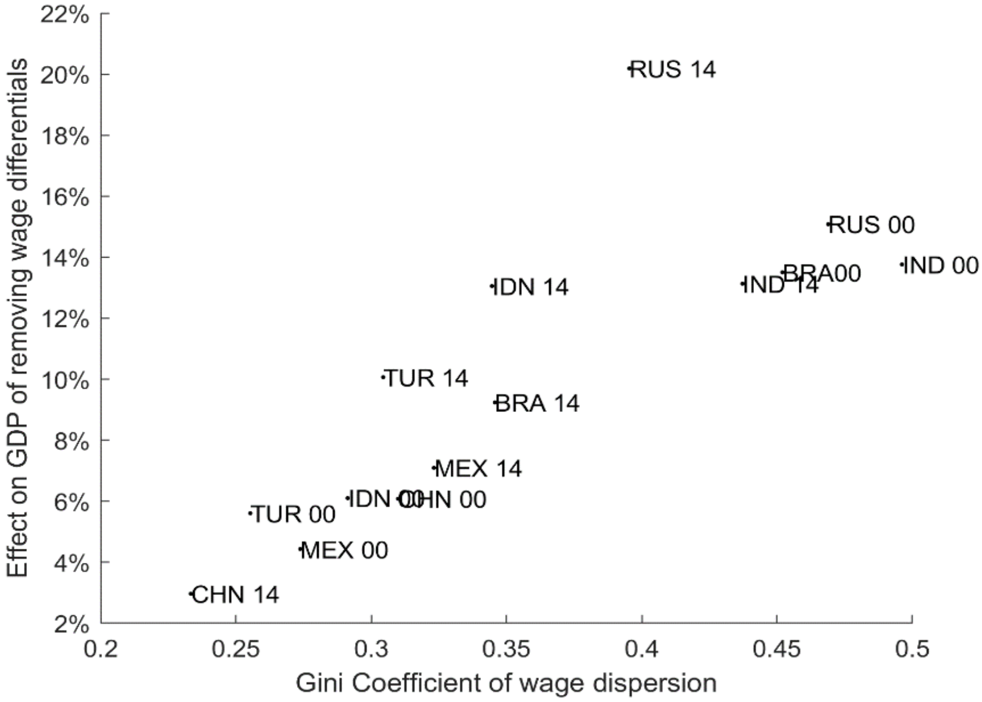
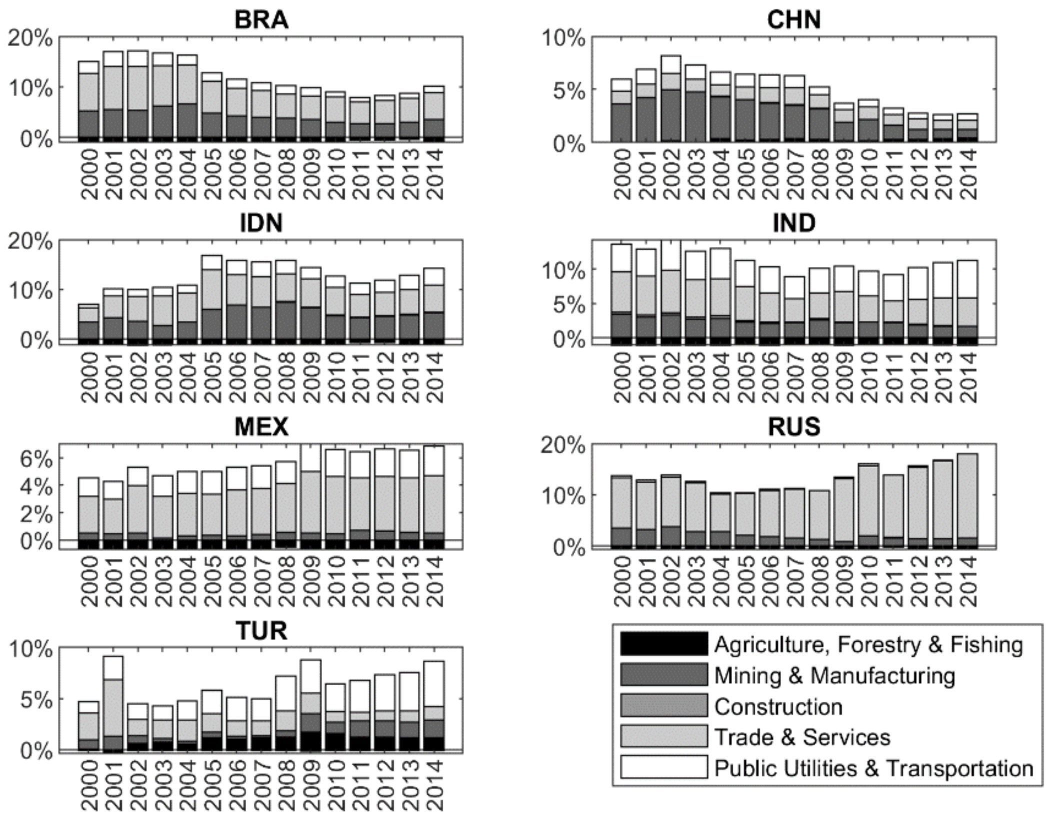


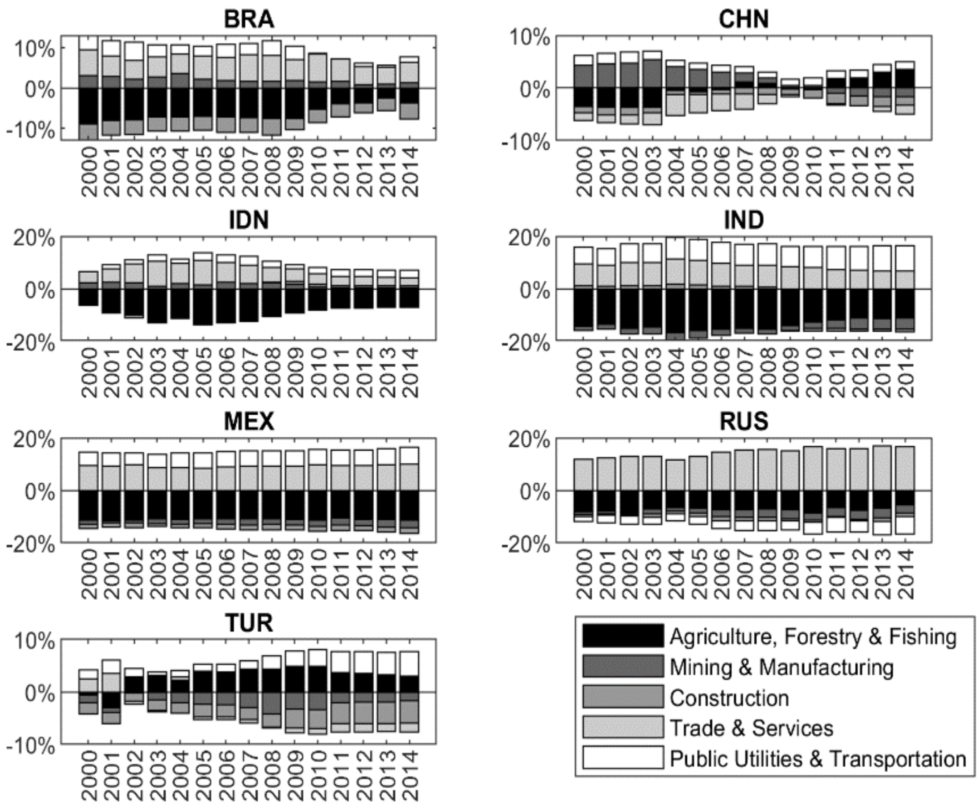
Figure 3. Effects on the efficiency of removing wage differentials as a function of the Gini coefficient of wage dispersion.



Notes: The effects on output of removing wage differentials were calculated as the difference between hypothetical and actual output, by sector, to actual output, after aggregating the 56 industries in 4 sectors.

Figure 4. Effects on the output of removing wage differentials.

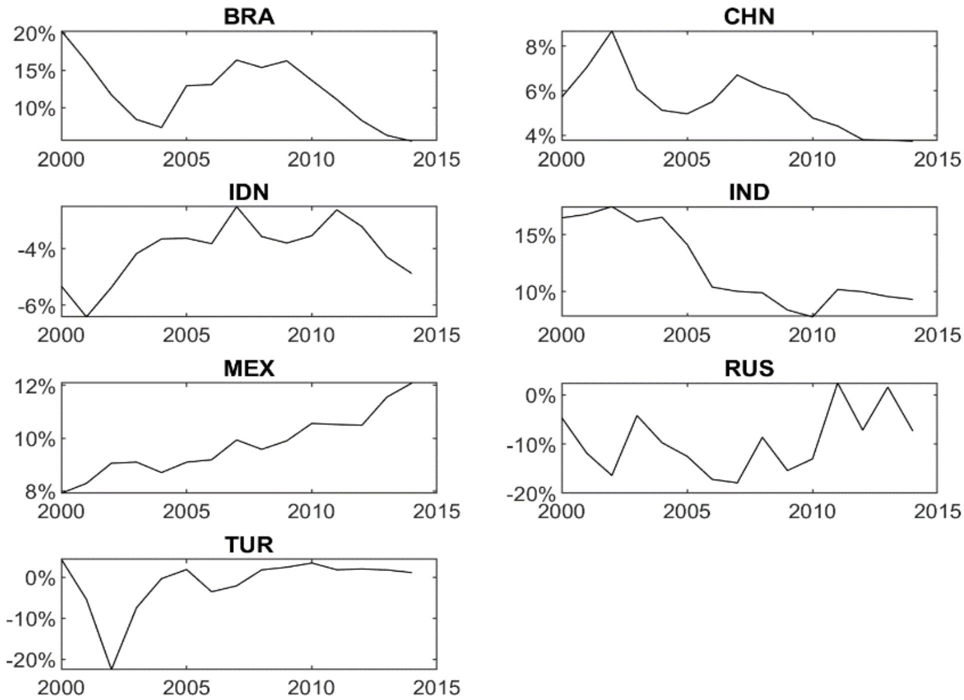
Both the efficiency (Figure 1) and output (Figure 2) effects of removing labor market distortions are ultimately due to the transfer of labor between industries that would occur in a hypothetical non-distortionary scenario. Such changes in labor employment are represented in Figure 5, which shows the change in employment by sector as a percentage of total employment. According to Figure 5, it can be observed that if wage differentials were removed, a significant amount of laborers would change their occupations. This amount ranges from around 5% (e.g., China, Turkey) to 20% (e.g., India). In many cases (Brazil, Indonesia, India, Mexico), such a change in employment structure implies a large transfer of laborers from agriculture, forestry, and fishing to urban-based sectors devoted to trade, services, or public utilities. This indicates that, in such cases, the main distortion of the labor market is the urban-rural dichotomy. However, in other cases (China, Russia, Turkey), the removal of wage differentials implies labor transfers between urban sectors (e.g., from construction to public utilities and services) so that labor market distortions seem to derive less from the urban-rural dichotomy than from imperfections in urban labor markets.



Notes: The effects on employment of removing wage differentials were calculated as the difference between hypothetical and actual employment, by sector, to total employment after aggregating the 56 industries in 4 sectors.

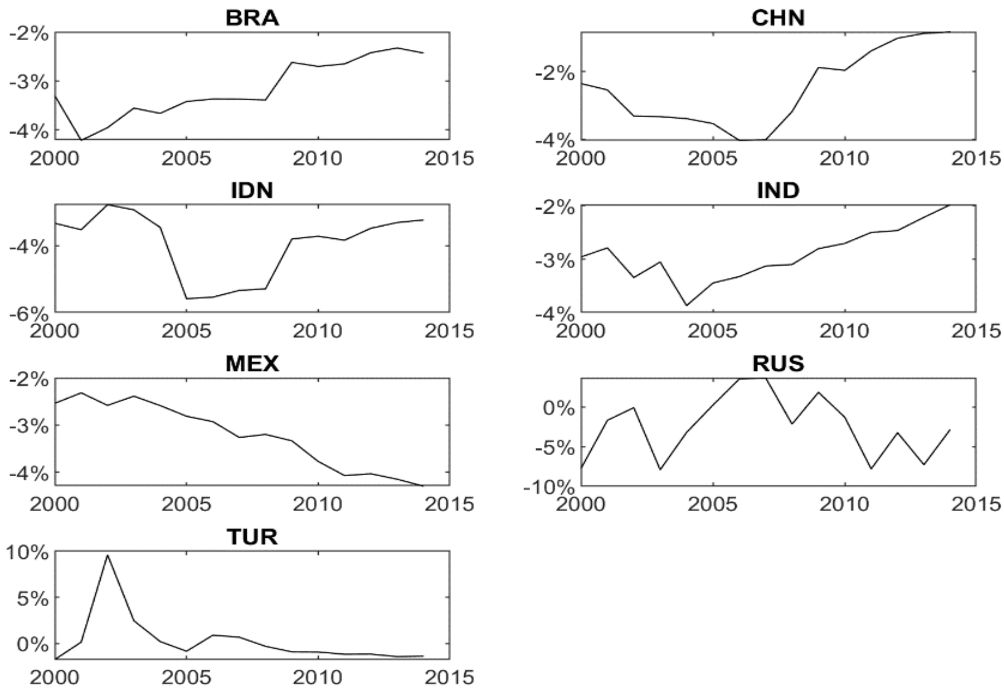
Figure 5. Effects on employment of removing wage differentials

As wage differentials affect relative prices, thus influencing the structure of output and employment, they also affect the terms of trade. In this sense, Figure 6 shows that the effects on the terms of trade of removing wage differentials vary, both in magnitude and direction, depending on the country considered. Thus, in four of the seven sample countries (Brazil, China, India, and Mexico), removing wage differentials improves the terms of trade, regardless of the technologies used. On the contrary, the case is exactly the opposite in two countries of the sample (Indonesia and Russia), while in Turkey, the results are ambiguous. These results have important implications for understanding the role that labor market distortions play in an open economy. Indeed, for many countries, labor market distortions imply an income transfer to the rest of the world. While this transfer is not negligible in some cases (e.g., Brazil, India, Mexico), in other countries, such labor market distortions prevent income transfer, in some cases to a significant degree (e.g., Indonesia, Russia). Thus, for the latter group of countries, removing wage differentials could imply 'immiserizing growth' in some way, with efficiency increasing at the cost of an income transfer to the rest of the world. This is a perverse effect that was predicted theoretically (Bhagwati, 1968) but which had yet to appear in the estimates made.



Notes: The effects on the terms of trade of removing wage differentials were calculated as the difference between hypothetical and actual terms of trade to actual terms of trade.

Figure 6. Effects on the terms of trade of removing wage differentials



Notes: The effects on net exports (as a % of GDP) of removing wage differentials were calculated as the difference between hypothetical and actual next exports, as a percentage of hypothetical and actual GDP, respectively.

Figure 7. Effects on net exports on removing wage differentials

In addition to this hypothetical phenomenon of income transfers, the effects on the terms of trade of removing wage differentials have implications for the trade balance. In this sense, Figure 7 shows the effects on net exports (as % of GDP) of removing wage differences, and it can be seen that for countries where the terms-of-trade effects of removing labor market distortions are positive (i.e., Brazil, China, India, Mexico), net exports would decrease. On the other hand, the countries in which the effects on the terms of trade were estimated to be negative (Indonesia and Russia) show that a very large deterioration in the terms of trade may not be enough to avoid a lower trade balance in a context where import demand increases due to efficiency gains and the elasticity of substitution for intermediate inputs is not greater than 1.

Conclusion

Using the data available in the World Input-Output Database (Release 2016) for seven emerging-market economies (Brazil, China, Indonesia, India, Mexico, Russia, and Turkey) and the rest of the world, it is possible to estimate the effects on efficiency and economic structure of removing wage differentials in an open economy by means of a computable general equilibrium model. The model consists of a set of nonlinear equations that comprise 56 industries of each country plus a composite sector in which the links of each economy with the rest of the world are lumped, thus endogenizing the relations of the economic system with the rest of the world.

The conclusions of the present study are four in number. First, it is observed that wage differentials appear to be distortionary, although they seem less distortionary than certain recent studies conclude (Aoki, 2012; Hsieh & Klenow, 2009). Second, a relationship emerges according to which the greater the wage-income inequality of the countries, the greater the efficiency gains that would be obtained by removing labor market distortions. Third, it is observed that in many emerging-market countries, the main distortion in the labor market remains the urban-rural dichotomy. However, in others, the main labor market distortion involves imperfections in urban labor markets. Fourth, the present estimate indicates that labor market distortions have effects on the terms of trade. Specifically, in most cases, labor market distortions imply a transfer of income from the rest of the world. However, cases appear to exist in which removing labor market distortions can lead to 'immiserizing growth.

The present study has policy implications. Indeed, it can be seen that in countries with large wage inequality, greater labor mobility can be an important source of efficiency (Figure 3). Thus, it seems that in countries such as Brazil or India, the enhancement of greater labor mobility can have a significant impact on efficiency, even in a context of rigid production technologies. Furthermore, it seems that in many of these countries (e.g., Brazil, Indonesia, India), one of the most significant causes of labor market distortions is the urban-rural dichotomy (Figure 4 and Figure 5). For these countries, increases in urbanization can be a stimulus to efficiency insofar as it encourages the transfer of laborers from rural-based industries such as agriculture or fishing to urban-based industries such as public utilities and services. However, this is not always the case, since in quite a few countries (e.g., China, Russia), labor market distortions derived from imperfections in the urban labor market, so increasing urbanization does not promise a further stimulus to efficiency. Only reforming urban labor markets could favor labor transfer between industries needed to increase efficiency and welfare.

The conclusions of the present study are far from the conclusions of some of the most recent studies on these matters (Aoki, 2012; Hsieh & Klenow, 2009; Zhang et al., 2023). This discrepancy is due to the different sets of assumptions and data considered. Specifically, most recent studies start from firm-level data for a single industry – usually manufacturing – and assume that this industry is comprised of a set of firms that use only primary inputs and that compete monopolistically with each other in the face of relatively elastic demand. On the contrary, the present study starts from input-output data for a set of industries and assumes that each industry uses both primary and intermediate inputs in a relatively rigid manner. In this sense, it seems that further research is needed in which, perhaps, both data from input-output tables and data at the firm level can be taken into account simultaneously. This would seem a formidable task, especially if the intention is to solve such a system of equations using a fixed-point method. In any case, there will be two versions of the same story: one told by the followers of the 'love-of-variety models' and another by input-output practitioners.

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Economic Journal of Emerging Markets, 15(2) 2023, 143-159

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Available at https://journal.uii.ac.id/jep

Measuring fintech-driven financial inclusion for developing countries: Comprehensive Digital Financial Inclusion Index (CDFII)

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Article Info

Article history:
Received 30 June 2023
Accepted 09 October 2023
Published 31 October 2023

JEL Classification Code:
C43, G21, O33.

Author's email:
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DOI: 10.20885/ejem.vol15.iss2.art3

Abstract

Purpose — The main objective of this study is to develop a comprehensive digital financial inclusion index (CDFII) that accounts for technology-driven financial inclusion and to compare it with a traditional financial inclusion index (TFII) to enhance the measurement of fintech-driven financial inclusion across countries.

Methods — The study employs a three-stage principal component analysis (PCA) to construct the CDFII and TFII using the latest available data from 31 developing countries during the period 2015-2021. The CDFII incorporates a new sub-index measuring individual literacy levels for using financial services, along with existing sub-indices capturing the penetration, availability, and usage of DFS. By integrating digital financial inclusion (DFII) and TFII, the overall CDFII is estimated.

Findings — The findings reveal that the levels of DFII and CDFII are higher than TFII for most of the economies examined. This indicates the significant impact of technology-driven financial inclusion in expanding access to formal banking and non-banking financial services for previously unbanked populations.

Implication — The study implies that policymakers and researchers should prioritize the integration of technology-driven financial inclusion indicators, such as the comprehensive digital financial inclusion index (CDFII), into their assessments and interventions to ensure a more accurate and effective approach to promoting inclusive and sustainable economic development.

Originality — This study introduces the CDFII as a novel comprehensive index that addresses the shortcomings of traditional financial inclusion indices. By incorporating individual skill levels and considering dimensions specific to DFS, the CDFII provides a more accurate representation of fintech-driven financial inclusion levels. This contributes to the existing literature on financial inclusion measurement and provides a valuable analytical tool for researchers and policymakers.

Keywords — Financial inclusion, fintech, digital financial services, comprehensive digital financial inclusion index

Introduction

Financial technology has revolutionized the provision of financial services, enabling financial institutions to reach a wider population more efficiently and cost-effectively. Fintech solutions, delivered through digital platforms, offer fast and user-friendly access to financial services, making them a transformative force for financial inclusion (FI). Recognizing the significance of FI, the

P ISSN 2086-3128 | E ISSN 2502-180X

United Nations has included it as a target in the Sustainable Development Goals (SDGs) (UN, 2015), considering it as a catalyst for poverty alleviation, economic growth, gender equality, and innovation. Fintech has the potential to enhance access to financial services, particularly for the unbanked and underserved populations, with a significant focus on women (Blancher et al., 2019; Lukonga, 2018; Tarazi & Breloff, 2010). These technological advancements enable individuals to overcome barriers such as geographical distance, limited physical infrastructure, and high transaction costs, fostering greater financial inclusion. Furthermore, fintech solutions expand the availability and efficiency of financial services, reaching previously excluded segments like small and medium-sized enterprises (SMEs) and individuals with limited credit history. Digital lending, crowdfunding, and peer-to-peer lending platforms enable access to capital and financial resources, stimulating entrepreneurship and economic growth. Additionally, fintech empowers individuals through digital financial education and literacy initiatives, equipping them with the necessary tools to make informed financial choices, manage their finances, and plan for the future. This knowledge enables individuals to navigate the complexities of the financial system, improve their financial well-being, and contribute to their overall economic empowerment.

While existing studies predominantly measure FI using conventional indicators, limited attention has been given to quantifying the impact of technology-enabled financial inclusion. Existing studies such as Beck et al. (2007), Cámara and Tuesta (2014), Honohan (2008), Sarma (2012), and World Bank (2013) measure FI using conventional indicators such as access to financial services and usage of financial products. Some studies have examined digital financial inclusion by considering indicators related to mobile financial services (Davidovic et al., 2019; Sy et al., 2019). Yet, it is crucial to recognize that information and communication technology (ICT) and digital literacy play essential roles in facilitating digital financial inclusion. Access to mobile and internet services directly influences the usage of financial services, as it reduces transaction costs (Blancher et al., 2019). Moreover, the level of digital and financial literacy significantly affects individuals' ability to effectively engage with digital financial services. However, these dimensions have been largely overlooked in previous FI measurement frameworks.

Constructing a digital financial inclusion index (DFII) is crucial for accurately assessing and monitoring financial inclusion initiatives. Such indices enable policymakers, researchers, and development practitioners to measure the extent of digital financial inclusion in a comprehensive and standardized manner, facilitating cross-country comparisons and the identification of best practices. This information, in turn, informs evidence-based policymaking and the design of targeted interventions to address gaps and barriers that hinder digital financial inclusion. Additionally, a digital financial inclusion index sheds light on the impact of fintech in expanding access, availability, and usage of financial services. It provides valuable insights into the effectiveness of technology-driven initiatives and guides the allocation of resources and investments to maximize positive outcomes. Furthermore, constructing such an index enables the identification of specific dimensions and indicators of digital financial inclusion that require attention and improvement. This knowledge fosters innovation and collaboration among stakeholders, including financial institutions, fintech companies, regulators, and policymakers, all working towards advancing inclusive financial systems. Thus, the underlying research question of the study is: how do traditional financial inclusion indices fail to capture the impact of technology-driven financial inclusion, and how can a comprehensive digital financial inclusion index (CDFII) address these limitations to provide a more accurate measurement of fintech-driven financial inclusion across countries?

To address these gaps, this study aims to develop a comprehensive digital financial inclusion index (CDFII) by integrating dimensions of access, availability, and usage of both digital financial services (DFS) and traditional financial services (TFS), along with measures of digital and financial literacy. The primary contribution of this research is the creation of a digital financial inclusion index (DFII) that incorporates ICT indicators and skill levels alongside existing DFS dimensions. Additionally, a traditional financial inclusion index (TFII) is constructed using established TFS dimensions. By integrating DFII and TFII, the CDFII is calculated for a panel dataset of 31 developing countries from 2015 to 2021. The index is estimated using a three-stage principal component analysis (PCA), utilizing data from the Financial Access Survey (FAS) of the

International Monetary Fund (IMF), World Telecommunication/ICT Indicators, and the Human Development Index (HDI) Database.

Exiting literature defines financial inclusion as a multifaceted concept that lacks a universally agreed-upon definition. However, it generally encompasses actions aimed at facilitating individuals' access to and usage of affordable financial products and services offered by banks and non-bank financial institutions (NBFIs), with a particular emphasis on reaching the unbanked and underserved populations (de Koker & Jentzsch, 2013; Sahay et al., 2015; Sarma & Pais, 2008; World Bank, 2018). In a similar vein, digital financial inclusion (DFI), enabled by fintech, refers to the swift and convenient access to financial services (e.g., savings, loans, money transfers, insurance, e-payments) through digital channels such as mobile phones (both application-based and non-application based) and computers or laptops connected to the internet. In the context of DFI, both fintech companies and traditional financial institutions bear the responsibility of providing financial services to existing and potential business and individual customers. DFI is widely recognized as a vital driver of sustainable development by policymakers and researchers alike (Tay et al., 2022).

Numerous studies have attempted to measure financial inclusion using various indicators and methodologies. Many of these measures focus on a single aspect of financial services, such as the number of bank branches, ATMs, or accounts per person (Beck et al., 2007; Honohan, 2008). Recognizing the limitations of relying on a single indicator, Sarma (2012) and Sarma and Pais (2008) proposed a comprehensive framework that considers three dimensions: penetration (measured by deposit accounts per 1000 adults), availability (number of branches, sub-branches, or offices of financial institutions and ATMs per adult), and usage (total deposit and credit as a percentage of GDP). This framework weighted each dimension using subjective values assigned based on the Human Development Index (HDI) approach. Building on Sarma's work, Gupte et al. (2012) developed an index that combined four components: outreach, usage, value of financial transactions, and transaction cost. Similarly, Park and Mercado (2015, 2018) constructed an index by combining components such as ATMs, branches, creditors, depositors, and the ratio of domestic credit to GDP.

Although these studies have made significant contributions, criticisms arose regarding the equal weighting of components and dimensions of financial services. To address this, Amidžić et al. (2014) and Cámara and Tuesta (2014) employed Factor Analysis (FA) and Principal Component Analysis (PCA) methods to determine appropriate weights for each dimension of financial inclusion. However, due to data availability, proxies were used for quality and barrier measurements, which were later criticized by researchers. Consequently, recent studies, including Amidžić et al. (2014) and Mialou et al. (2017), have largely neglected these dimensions when constructing financial inclusion indices.

Over the past decade, mobile money and internet usage have witnessed rapid growth globally, surpassing traditional banking in some countries and capturing a significant portion of the unbanked population, including the poor, students, youth, refugees, and women. However, existing studies have largely overlooked the dimensions of access, availability, and usage of mobile money and internet technology in measuring financial inclusion. Some recent studies, such as Cámara et al. (2017), Manyika et al. (2016), and Sy et al. (2019), have considered mobile money transactions and the number of mobile money accounts as indicators of digital financial inclusion. However, these indicators provide only a limited perspective on the development of digital financial inclusion.

Overall, efforts have been made to develop comprehensive indices for measuring financial inclusion, primarily focusing on traditional financial services. However, there is no consensus on the selection of indicators, dimensions, and measurement approaches, and the inclusion of fintech factors, such as accessibility, availability, and usage of mobile financial services, ICT services, internet usage, e-commerce transactions, and digital literacy, remains lacking (Mialou et al., 2017). A recent study on the developing financial inclusion index by Sahay et al. (2020) only covers the years 2014 and 2017 for 52 emerging developing countries. Our study aims to address these gaps by considering traditional financial inclusion and digital financial inclusion, as well as the level of skill and knowledge in using these services. By incorporating these factors, our approach provides a comprehensive measure of digital financial inclusion from 2015 to 2023. Table 1 presents a summary of the literature, including the measurement variables and methodologies used to assess traditional and digital financial inclusion indexes.

Table 1. Review of existing literature: studies, approaches, indicators used to construct FI index

Study	Country, year coverage, data source, Methods/Weight allocation	Dimensions/variables considered for each study
Sarma (2012)	94 countries; 2004 – 2010, FAS; UNDP Approach; Penetration 1, Availability: 0.5 and Usage: 0.5	Banking penetration: Bank accounts per thousand population Availability: Bank branches per 0.1 million population, ATMs per million population. Usage: Credit and Deposits as a % of GDP.
World Bank (2013)	2011; Findex and others; Equal Weights	Bank branches/100,000 adults; Bank accounts/ 1000 population; Market capitalization; Value traded; Yields of public bond; Ratio of private and total debt securities; Enterprises with bank credit (% of all enterprises and small firms); accounts at a formal financial institution (% age 15+)
Cámara and Tuesta (2014)	82 countries; 2011, Findex and FAS; Two-stage PCA	Bank branches/ 100,000 population; ATMs/1000,000 population; ATMs/ 1000 sq km; Bank offices or branches/1000 sq km; Persons who hold at least a minimum financial product (%); Adults Saved at a banks and NBFIs (% age 15+); Loan from a banks and NBFIs (% age 15+); Barriers to FI.
Sahay et al. (2015)	176 countries; 1980 – 2013, FAS and Others; PCA	Bank branches/100,000 adults; Market capitalization; Value traded outside; Total number of debt issuers.
Dabla-Norris et al. (2015)	104 countries; 2011 & 2014; Findex, Enterprise Survey and FAS; Equal weights	Household dimension: Accounts at a bank or NBFI (% age 15+); Saved at a bank or NBFI in the earlier period (% age 15+); Loan from a bank or NBFI in the earlier period (% age 15+); Person credit card taken (% age 15+); Person a debit card taken (% age 15+); ATM as a main channel of withdrawal (% age 15+). SMEs dimension: Companies with a bank loan; Companies with a current or deposit account; Companies using banks to funding & investment; Collateral required for a credit % of the loan amount; Companies not required a credit; Companies identifying cost of investment as a major limitation. Access dimension: Bank branches/100,000 population; ATMs/ 1000,000 population; ATMs/1000 sq km; Bank branches/1000 sq km.
Park and Mercado (2015)	188 economies; FAS; UNDP approach	ATMs per thousand adults; Branches and offices of banks per 0.1 million adults; Creditors per thousand adults, number, from banks; Depositors per thousand adults, number, with banks; Ratio of domestic credit GDP.
Mialou et al. (2017)	31 Nations; 2009 – 2012, FAS; WGM, Factor analysis	Access Dimensions: ATMs per thousand sq km; Bank branches per thousand sq km. Usage dimensions: Resident household depositors, number, with ODCs per thousand adults; Resident household borrowers, number, with ODCs per thousand adults.
Loukoianova et al. (2018)	163 countries, FAS; WGM, Factor analysis	Bank branches, number, per 0.1 million population; ATMs, number, per 1 million population; ATMs, number, per thousand sq km; Bank, number, branches per thousand sq km.

Study	Country, year coverage, data source, Methods/Weight allocation	Dimensions/variables considered for each study
Blancher et al. (2019)	88 Economies, FAS; WGM, Factor analysis	Bank branches, number, per 0.1 million population; ATMs, number, per 1 million population; ATMs, number, per thousand sq km; Bank branches, number, per thousand sq km; Bank depositors, number, per thousand adults; Bank borrowers, number, per thousand adults.
	87 countries, FAS; WGM, Factor analysis	ATMs, number, per thousand sq km; Bank branches, number, per thousand sq km; Bank depositors, number, per thousand adults; Bank borrowers, number, per thousand adults.
	Household Findex; FAS, Enterprise Survey: PCA	Bank branches per 0.1 million population; ATMs per 0.1 million population; Accounts, number, at a bank (% age 15+); Saving accounts, number, at a bank in the earlier period (% age 15+); Loan accounts, number, from a Bank and NBFI in the earlier period (% age 15+); Any money saved last year (% age 15+); Credit card holder (% age 15+); Debit card holder (% age 15+
	SME Findex; FAS, Enterprise Survey	Enterprises with a bank credit (%); Enterprises with a current or deposit account (%); Enterprises using banks for investment (%); Enterprises using banks for working capital (%); Investments disbursed by banks (%); Working capital financed by banks (%).
Ahamed and Mallick (2019)	86 countries over the period 2004–12; FAS; PCA	Outreach: Bank sub-branches or branches and ATMs per 0.1 million people; Bank branches and ATMs per thousand sq km) Usage: Bank accounts per thousand populations.

Methods

This analysis utilizes annual secondary data from the Financial Access Survey (FAS), ITU World Telecommunication/ICT Indicators, and the Human Development Index (HDI) Database of UNDP for the period of 2015 to 2021 in 31 developing countries (Appendix A). However, it is important to note that not all developing economies are included in the analysis due to incomplete or missing data on mobile financial services throughout the years. The selected study period of 2015-2021 was chosen because it provided complete data for the variables considered in each selected country. Additionally, the period was significant as it marked the visible growth of mobile money and internet payment in financial services, particularly in developing countries, as noted by Demirguc-Kunt and Klapper (2012), making it a relevant timeframe for this study.

In constructing composite financial inclusion (FI) indexes, existing studies employ both parametric and non-parametric approaches. Non-parametric approaches rely on subjective judgment to allocate weights to indicators, which introduces bias and makes the index sensitive to small adjustments in weights. To address this, we adopt a parametric approach, specifically Principal Component Analysis (PCA), to determine the appropriate weights for each indicator and develop a comprehensive digital financial inclusion index (CDFII). Through PCA, CDFII is derived as a linear combination of various indices, including the Digital Financial Inclusion Index (DFII) and Traditional Financial Inclusion Index (TFII). This approach ensures a more objective and robust measure of digital financial inclusion. We can express the relationship as:

$$CDFII_{jt} = \omega_{DFII} DFII_{jt} + \omega_{TFII} TFII_{jt} + u_{jt} \quad (1)$$

Where *CDFIIjt* is the comprehensive DFII of country *j* at year *t*; ω_{DFII} and ω_{TFII} are the weights obtained from PCA of the corresponding index *DFII* and *TFII*, respectively; and u_{jt} is the model residuals.

The DFII is defined as the linear combination of four different dimensions (sub-index) such as penetration (D^p), access (D^a) to, usage of (D^u), and level of skill and ICT knowledge of people (SL) of using digital financial services (DFS).

$$DFII_{jt} = \varphi_1 D_{jt}^{p} + \varphi_2 D_{jt}^{a} + \varphi_3 D_{jt}^{u} + \varphi_4 SL_{jt} + \varepsilon_{jt} \quad (2)$$

The TFII could be obtained from the following linear equation where TFII is the function of penetration (T^p), access (T^a) and usage (T^u) dimension (sub-index) of conventional financial services.

$$TFII_{jt} = \mu_1 T_{jt}^{p} + \mu_2 T_{jt}^{a} + \mu_3 T_{jt}^{u} + \vartheta_{jt} \quad (3)$$

Each sub-index is defined as the linear function or combination of the two or more explanatory variables. Therefore, each sub-index of the DFII can be obtained from the following linear equations:

$$D_{jt}^{p} = \alpha_1 MMAC_{jt} + \alpha_2 FBIS_{jt} + \alpha_3 MMT_{jt} + \varepsilon_{1,jt} \quad (4)$$

$$D_{jt}^{a} = \beta_1 MMAG_{jt} + \beta_2 MBS_{jt} + \beta_3 MCTS_{jt} + \beta_4 FTS_{jt} + \varepsilon_{2,jt} \quad (5)$$

$$D_{jt}^{u} = \gamma_1 VMMT_{jt} + \gamma_2 OBMFS_{jt} + \gamma_3 IUI_{jt} + \varepsilon_{3,jt} \quad (6)$$

$$SL_{jt} = \mathfrak{z}_1 EYS_{jt} + \mathfrak{z}_2 MYS_{jt} + \vartheta_{4,jt} \quad (7)$$

Each sub-index of TFII can be estimated through the following system of equations:

$$T_{jt}^{p} = \delta_1 DAC_{jt} + \delta_2 LAC_{jt} + \vartheta_{1,jt} \quad (8)$$

$$T_{jt}^{a} = \zeta_1 BR_{jt} + +\zeta_2 ATM_{jt} + \zeta_3 ATMPSQF_{jt} + \vartheta_{2,jt} \quad (9)$$

$$T_{jt}^{u} = \Omega_1 OD_{jt} + \Omega_2 OL_{jt} + \vartheta_{3,jt} \quad (10)$$

The composition of each dimension and variables considered in this study is described in Table 2.

Table 2. Components/dimensions of CDFII and their notations

Comprehensive Digital Financial Inclusion Index (CDFII)	
Components of DFII	Components of TFII
a) Penetration of DFS (D_{jt}^{p}) - Mobile money accounts, Registered, per thousand adults (MMAC) - Fixed-broadband Internet subscriptions, per thousand inhabitants (FBIS) - Mobile money transactions per thousand adults (MMT)	a) Penetration of TFS (T_{jt}^{p}) - Deposit or savings accounts with FI per thousand adults (DAC) - Loan or Credit accounts with FI per thousand adults (LAC)
b) Availability of DFS (D_{jt}^{a}) - Mobile money agent outlets, registered, per 0.1 million adults (MMAG) - Active mobile-broadband subscriptions, per 100 residents (MBS) - Mobile-cellular telephone subscriptions, Number per hundred inhabitants (MCTS) - Fixed telephone subscriptions per hundred inhabitants (FTS)	b) Availability of TFS (T_{jt}^{a}) - Branches and offices of FI, number, per 0.1 million adults (BR) - Automated teller machines, number, per 0.1 million adults (ATM) - Automated teller machines, per square kilometer (ATMPSQF)
c) Usage of DFS (D_{jt}^{u}) - Transactions of mobile money, value, % of GDP (VMMT) - Outstanding balances with mobile financial services, % of GDP (OBMFS) Individuals using the internet, in % (IUI)	c) Usage of TFS (T_{jt}^{u}) - Deposit (outstanding) with banks, % of GDP (OD) - Loans (outstanding) % of GDP from banks (OL)
d) Level of skill and ICT knowledge for using DFS (SK_{jt}) - Years of schooling, Mean (MYS) - Years of schooling, Expected (EYS)	

Our study aims to develop a comprehensive Fintech-enabled or digital Financial Inclusion Index (CDFII) for selected developing countries using the Principal Component Analysis (PCA) method recommended by Camara and Tuesta (2014). The estimation of CDFII involves a three-stage PCA approach. In the first stage, we intend to find out the value of weights α, β, γ, ʓ,,, δ, ζ and Ω using PCA to calculate the dimensions D_j^p, D_j^a, D_j^u, SL_{jt}, T_j^p, T_j^a and T_j^u, respectively. Each dimension contains linear combinations of several explanatory variables or indicators related to entry into, availability, and usage of DFS and TFS ,and the final value of evalution are also called indices. In the second stage, we once again apply the PCA methods to estimate the weights φ_1, $\varphi_2, \varphi_3, \varphi_4, \mu_1, \mu_2$ and μ_3 of corresponding dimensions D_j^p, D_j^a, D_j^u, SL_{jt}, T_j^p, T_j^a ad T_j^u in order to calculate value of DFII and TFII. In the final stage, we apply PCA over again, to obtain the parameters ω_{DFII} and ω_{TFII} of the respective index of DFII and TFII from the Equation (1) and we obtain our ultimate index CDFII. However, before conducting PCA, each indicator is normalized to ensure that all indicators contribute evenly to a scale (0 to 1) when they are added collectively. The final comprehensive index of DFI value lies between 0 to 1, where 0 refers to no tech-enabled FI and 1 indicates high inclusion.

Results and Discussion

Table 3 presents the summary statistics of the individual indicators used in estimating the comprehensive index of Digital Financial Inclusion (DFI). The indicators are categorized into three dimensions for Digital Financial Services (DFS) and Traditional Financial Services (TFS): access, availability, and usage. Additionally, two dimensions are considered for ICT services: access and usage. Furthermore, a single dimension is utilized to measure the skill-level of access to financial/ICT services. The values for each dimension are calculated from the corresponding indicators using Principal Component Analysis (PCA).

Table 3. Summary Statistics

Dimensions	Variable	Obs.	Mean	Std. Dev.	Min	Max
Penetration of DFS (D_{jt}^p)	MMAC	217	537.887	520.946	0.009	2308.780
	FBIS	217	4.034	6.561	0.007	38.772
	MMT	217	20601.130	35001.460	0.145	228876.000
Availability of DFS (D_{jt}^a)	MMAG	217	298.132	353.521	0.826	1583.040
	MBS	217	46.158	29.321	1.330	154.920
	MCTS	217	93.189	35.068	31.541	198.150
	FTS	217	5.347	7.595	0.031	36.885
Usages of DFS (D_{jt}^u)	VMMT	217	17.808	29.182	0.000	177.578
	OBMFS	217	0.297	0.753	0.000	6.158
	IUI	217	35.647	21.816	0.204	87.660
Penetration of TFS (T_{jt}^p)	LAC	217	138.735	153.477	2.905	810.066
	DAC	217	828.102	703.036	32.745	2946.410
Availability of TFS (T_{jt}^a)	BB	217	10.376	10.606	0.837	55.071
	ATM	217	25.872	27.590	0.856	117.792
	ATMPSQF	217	0.126	0.218	0.000	1.000
Usages of TFS (T_{jt}^u)	OD	217	46.463	35.168	5.080	192.782
	OL	217	32.535	25.656	2.798	140.595
Skill Level for using ICT, DFS (SL_{jt})	EYS	217	11.914	2.011	7.349	16.049
	MYS	217	6.990	2.816	1.936	11.572

In this first-stage PCA stage, we measure the sub-indices for the penetration (p), availability (a), and usage (u) dimensions of Digital Financial Services (DFS) and Traditional Financial Services (TFS), as well as the sub-index for the level of skill (SL), using the selected variables mentioned in Equation 4 to 10 in the second column of the summary statistics. Table 4 provides information on the minimum number of principal components that account for the majority variation, along with their respective highest Eigenvalue (EV), within each dimension. Following Kaiser (1960) criterion, components with an EV greater than one are considered for further analysis.

Table 4. Principal components for different indicators of DFS and TFS

Dimensions	Variables	Component	EV	Difference	Proportion	Cumulative
(1) Digital Financial Services (DFS)						
D_{jt}^{p}	MMAC, FBIS, MMT	C1	1.7	0.8783	0.565	0.565
		C2	0.8	0.3298	0.272	0.837
		C3	0.5		0.162	1
D_{jt}^{a}	MMAG, MBS, MCTS, FTS	C1	2.144	1.150	0.536	0.536
		C2	0.994	0.381	0.248	0.784
		C3	0.613	0.363	0.153	0.938
		C4	0.249		0.062	1.000
D_{jt}^{u}	VMMT, OBMFS, IUI	C1	1.263	0.333	0.421	0.421
		C2	0.930	0.122	0.310	0.731
		C3	0.808		0.269	1.000
(2) Traditional Financial Services (TFS)						
T_{jt}^{p}	LAC, DAC	C1	1.778	1.556	0.889	0.889
		C2	0.222		0.111	1.000
T_{jt}^{a}	BB, ATM, ATMPSQF	C1	2.165	1.662	0.722	0.722
		C2	0.502	0.169	0.167	0.889
		C3	0.333		0.111	1.000
T_{jt}^{u}	OL, OD	C1	1.799	1.598	0.899	0.899
		C2	0.201		0.101	1.000
(3) Level of Skill of ICT and DFS (SL)						
SK_{jt}	EYS, MYS	C1	1.724	1.448	0.862	0.862
		C2	0.276		0.138	1.000

The results indicate that the first principal component (C1) has the highest eigenvalue in all three combinations, which suggests that it explains the maximum amount of variation within each group. Specifically, for the DFS dimensions, C1 explains 42% to 56% of the total variation in the explanatory variables. In the case of Traditional Financial Services (TFS), the first component (C1) accounts for more than 72% of the overall variation in the independent variables. Furthermore, for the skill dimension (SL), C1 explains 86% of the total data variation. Based on these findings, we focus our analysis on the first principal component (C1) for each dimension, as it captures the most significant proportion of variation. We estimate the sub-indices by utilizing the parameters assigned to C1. To further refine the results, we employ orthogonal varimax rotation, which helps determine the weights associated with each C1 and their respective eigenvalues (Table 5).

Our analysis revealed that the first principal component (C1) in the penetration dimension of DFS (D_j^p) is strongly influenced by the variables mobile money account (MMAC) and mobile money transactions (MMT). An increase in the number of mobile money accounts held by unbanked individuals and the volume of transactions conducted through mobile or tech-enabled channels positively contributes to the value of C1. On the other hand, fixed broadband subscription (FBIS) negatively affects C1 which suggests that an increase in fixed broadband subscription (FBIS) is associated with a decrease in the value of C1. Regarding the availability dimension of DFS (D_j^a), mobile-cellular telephone subscriptions play a significant role in C1 (0.608), followed by mobile broadband subscriptions (MBS) and financial transactions through mobile apps (FTS). The presence of mobile phones enables individuals to access mobile financial services via USSD codes and mobile applications provided by financial service providers. Therefore, an increase in mobile phone users strongly influences the value of the first principal component. In the usage dimension of DFS(D_j^u), the value of mobile money transactions as a percentage of GDP, along with the outstanding balance with mobile financial services (OBMFS), exhibit a strong positive correlation with C1. This is primarily due to the widespread use of mobile or digital platforms for domestic and international remittances, as well as for various financial transactions such as receiving wages, paying for goods and services, and utility bill payments. Conversely, there is a negative correlation between C1 and the number of individuals using the Internet (IUI) for financial transactions, indicating that not all Internet users utilize digital channels for such purposes. in sum, IUI has a negative relationship with C1, indicating a contrasting impact compared to VMMT and OBMFS.

Table 5. Scoring estimates for orthogonal varimax rotation (weights)

Estimate	Variable	C1	Unexplained	KMO	KMO overall
D_{jt}^p	MMAC	0.6417	0.3018	0.557	0.583
	FBIS	-0.4656	0.6325	0.704	
	MMT	0.6095	0.3702	0.568	
D_{jt}^a	MMAG	-0.289	0.820	0.633	0.570
	MBS	0.529	0.400	0.565	
	MCTS	0.608	0.208	0.547	
	FTS	0.517	0.428	0.598	
D_{jt}^u	VMMT	0.607	0.535	0.536	0.542
	OBMFS	0.470	0.721	0.585	
	IUI	-0.641	0.481	0.531	
SL_{jt}	EYS	0.707	0.138	0.500	0.500
	MYS	0.707	0.138	0.500	
T_{jt}^p	LAC	0.707	0.110	0.500	0.500
	DAC	0.707	0.110	0.500	
T_{jt}^a	BB	0.579	0.274	0.690	0.694
	ATM	0.600	0.220	0.653	
	ATMPSQF	0.552	0.342	0.761	
T_{jt}^u	OL	0.707	0.104	0.500	0.500
	OD	0.707	0.104	0.500	

The analysis also reveals that all the explanatory variables in the Level of Knowledge and Skills on Formal Financial Services (SL) dimension, as well as the Penetration (T_j^p) and usage (T_j^p) dimensions of traditional financial services, show positive and equal correlations with the first principal component. Among these variables, the presence of bank branches (BB) and automatic teller machines (ATMs) play a crucial role in determining the availability of traditional financial services. These variables make significant positive contributions to the first component of the Principal Component Analysis (PCA). Specifically, ATMs and CDM (Cash Deposit Machine) devices have a higher impact on the first component compared to bank branches. This is likely because the number of available ATMs and CDM devices surpasses that of traditional bank branches, indicating their greater accessibility in providing financial services.

In the second stage of PCA, we focus on determining the weights (φ and μ) for the sub-indices $D_{jt}^p, D_{jt}^a\ D_{jt}^u,\ SL_{jt},\ T_{jt}^p, T_{jt}^a,$ and T_{jt}^u, which are essential in calculating the DFII and TFII using Equations 2 and 3. Accessing and utilizing digital financial services (DFS) requires individuals to possess certain technological skills, such as using mobile USSD menus, applications, smartphones, the internet, and other computerized channels. The level of technological skills (SL) is a crucial factor in determining individuals' access to the formal financial system (Lenka & Barik, 2018). In our analysis, we approximate technological skills using the education index, which is derived from the PCA. The results presented in Table 6 show the outputs of the PCA. In both cases, the first principal component (C1) has the highest eigenvalue, exceeding 2, and it accounts for 52.5% and 80.5% of the total data variation in the DFII and TFII analysis respectively.

Table 6. Estimation of PC and eigenvalue of sub-indices of DFII and TFII

Indices	Sub-indices	Component	EV	Difference	Proportion	Cumulative
Digital Financial Services (DFS)						
$DFII$	$D_{jt}^p, D_{jt}^a, Dt_j^u$, SL_{jt}	C1	2.100	1.067	0.525	0.525
		C2	1.033	0.519	0.258	0.783
		C3	0.514	0.162	0.129	0.912
		C4	0.353		0.088	1.000
Traditional Financial Services (TFS)						
$TFII$	$T_{jt}^p, T_{jt}^a, T_{jt}^u$	C1	2.414	1.991	0.805	0.805
		C2	0.423	0.261	0.141	0.946
		C3	0.163		0.054	1.000

The scoring coefficients (weights) for each sub-index of the DFII and TFII are presented in Table 7. When measuring DFII, the first principal component (C1) shows a strong positive correlation with two sub-indices. Specifically, C1 increases with the availability of Digital Financial Services (DFS) and the level of skills required for using digital devices. On the other hand, the access and usage dimensions of DFS exhibit a negative correlation with C1. This aligns with expectations as these dimensions heavily rely on the availability of DFS and individuals' proficiency in using mobile USSD, apps, and the internet for cashless transactions. Furthermore, the availability of fintech and technological innovation in financial services plays a crucial role in promoting financial inclusion by ensuring easier and cost-effective access to financial services. This, in turn, can stimulate the growth of non-financial technologies and foster innovation. Collaboration between financial institutions and mobile network operators has resulted in hybrid systems that provide access to formal savings, deposits, credit, and insurance services to both banked and unbanked individuals. Based on the PCA, the index of digital financial inclusion (DFII) has been illustrated in Appendix B.

Table 7. Scoring coefficients (weights) and overall KMO

Estimate	Variable	C1	Unexplained	Overall KMO
DFII	D_j^p	0.556	0.317	0.657
	D_j^a	-0.568	0.296	
	D_j^u	0.602	0.218	
	SL_j	0.077	0.036	
$TFII$	T_j^p	0.595	0.146	0.7005
	T_j^a	0.597	0.140	
	T_j^u	0.538	0.301	

Similarly, when measuring TFII, the sub-indices related to the penetration, attainability, and usage of Traditional Financial Services (TFS) are positively associated with the first principal component (C1). The scores of T_j^p, T_j^a and T_j^u contribute to an increase in C1. The penetration index of TFS receives the highest score, followed by the availability and usage index, suggesting that financial services through more traditional channels such as ATMs, bank branches, loans, and savings accounts tend to exhibit better financial inclusion. The index of traditional financial inclusion (TFII) is illustrated in Appendix C. Both appendixes also include the ranking of different countries based on the five-year average of the access, availability, and usage sub-indices of Traditional Financial Inclusion (TFI).

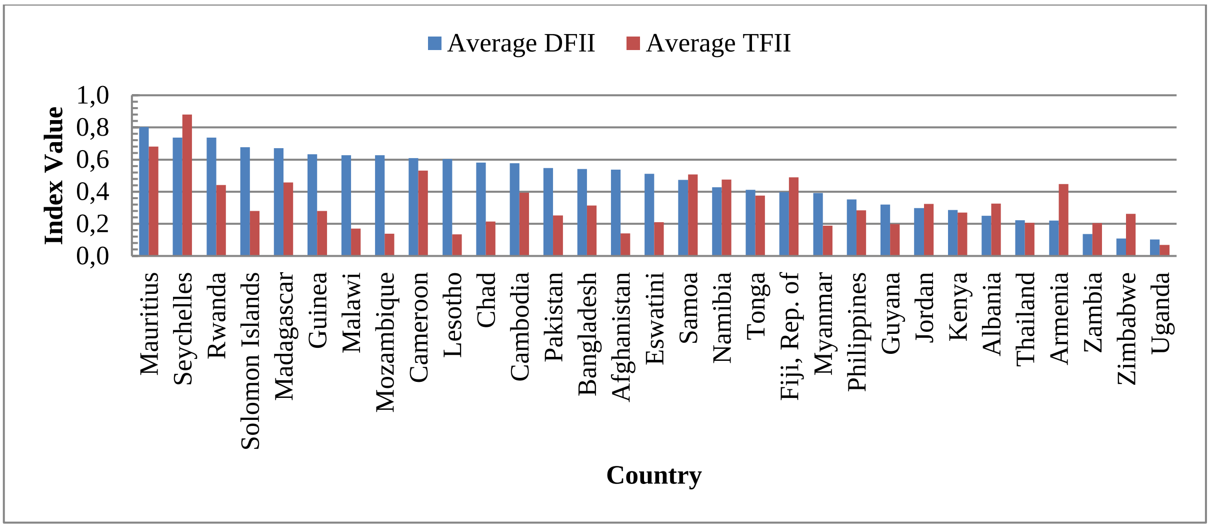

Figure 1. Comparative portrait of DFII and TFII

Additionally, Figure 1 displays a plot diagram illustrating the digital and traditional financial services indices from 2015 to 2021. In most countries, the DFII surpasses the TFII. Mauritius and Seychelles demonstrate equal improvements in both traditional and digital financial services, securing the first and second positions, respectively, in both categories. Notably, there have been changes in the ranking of countries from the third position.

Several factors contribute to the higher values of DFS indices compared to TFS indices. Firstly, the collaboration between mobile money service providers, mobile financial apps, and debit and credit cards has played a significant role. This collaboration has facilitated increased money transfers, withdrawals, and access to financial services through mobile phones and the Internet. The substantial growth in the number of active mobile money users during the study period supports this trend. Mobile money operators have also witnessed significant expansion, contributing to the accessibility and availability of DFS (Shaikh et al., 2023). Secondly, the adoption of technology in providing financial services has seen remarkable progress, mainly due to improved access to technology. Developing countries have experienced a surge in Smartphone users, with mobile phones becoming the primary device for internet access. This shift has led to a substantial increase in the usage of app-based financial services through mobile devices. Moreover, there has been a doubling of domestic and international remittances, utility bill payments, and website-based money transfers across all countries (Pazarbasioglu et al., 2020).

Another contributing factor is the increase in the number of mobile money agents in developing economies. These agents provide services such as bill payments, cash top-ups, cash-outs, and peer-to-peer transactions, which further facilitate the usage of DFS. The number of ATMs and mobile financial services accounts has also shown similar growth globally, indicating the widespread availability of financial services. Furthermore, the rapid diffusion of information and communication technology (ICT) and the growth of mobile phones, personal computers, and internet users in developing countries have played a crucial role. Mobile phone penetration has exceeded fixed-line subscriptions in the past two decades. This shift has allowed previously underserved groups to access and benefit from DFS, reducing transaction costs, particularly associated with managing physical branches. ICT and financial services through mobile phones improve access to deposits, credit, and remittance facilities, leading to the emergence of branchless financial services and promoting digital financial inclusion. Lastly, the improvement in secondary and higher education levels in developing countries has contributed to the higher adoption of mobile financial services. Higher levels of education spread awareness and enhance people's confidence in using mobile banking. A stronger understanding of the different uses and benefits of mobile financial services, particularly among the younger generation, promotes digital financial inclusion through cashless payments (Urhie et al., 2021). These factors collectively contribute to the higher values of DFS indices compared to TFS indices, showcasing the growing importance and impact of digital financial inclusion in various economies

In the third stage of PCA, we measure the Comprehensive Digital Financial Inclusion Index (CDFII) by integrating the values of the Digital Financial Inclusion Index (DFII) and the Traditional Financial Inclusion Index (TFII) obtained in the previous stage. We define the equation as follows:

$$CDFII_{jt} = f(DFII_{jt}, TFII_{jt}) \quad (11)$$

$$CDFII_{jt} = \omega_{DFII} DFII_{jt} + \omega_{TFII} TFII_{jt} + u_{jt} \quad (12)$$

According to the findings of the PCA presented in Table 8, the first component (C1) has an Eigenvalue of 1.75 and explains 87.7% of the variance. In this stage, we consider two components, DFII and TFII, which were obtained from the second-stage PCA. The overall Kaiser-Meyer-Olkin (KMO) statistic is 0.50, and both components have equal loading scores of 0.7071, with the squared summation of the scores equal to one.

Table 8. Third-stage PCA for measuring comprehensive DFII

Index	Indicators	Component	Eigenvalue	Difference	Proportion	Cumulative	Overall KMO
CDFII	DFII	C1	1.75447	1.50894	0.8772	0.8772	0.50
	TFII	C2	0.24553		0.1228	1	

Table 9. Ranking of countries based on CDFII

Economy	2015	2016	2017	2018	2019	2020	2021	Average	Ranking
Mauritius	0.899	0.896	0.920	0.897	0.918	0.955	0.955	0.920	1
Seychelles	0.765	0.786	0.852	0.890	0.976	1.000	0.984	0.893	2
Thailand	0.756	0.781	0.790	0.783	0.803	0.833	0.847	0.799	3
Armenia	0.652	0.675	0.687	0.711	0.731	0.778	0.769	0.715	4
Zambia	0.554	0.537	0.555	0.637	0.693	0.691	0.746	0.630	5
Albania	0.560	0.631	0.627	0.600	0.597	0.625	0.631	0.610	6
Jordan	0.613	0.597	0.612	0.612	0.596	0.620	0.603	0.607	7
Namibia	0.503	0.650	0.597	0.580	0.655	0.620	0.619	0.603	8
Fiji	0.505	0.522	0.559	0.536	0.542	0.542	0.545	0.536	9
Tonga	0.491	0.505	0.553	0.528	0.495	0.547	0.545	0.524	10
Samoa	0.437	0.487	0.489	0.500	0.505	0.529	0.531	0.497	11
Philippines	0.416	0.457	0.481	0.477	0.477	0.506	0.489	0.472	12
Guyana	0.424	0.422	0.427	0.432	0.449	0.510	0.504	0.453	13
Cambodia	0.325	0.327	0.374	0.394	0.382	0.415	0.450	0.381	14
Bangladesh	0.338	0.350	0.346	0.353	0.355	0.427	0.407	0.368	15
Myanmar	0.288	0.323	0.340	0.364	0.376	0.413	0.418	0.360	16
Eswatini	0.340	0.343	0.333	0.324	0.267	0.350	0.418	0.339	17
Pakistan	0.274	0.278	0.282	0.286	0.293	0.303	0.293	0.287	18
Kenya	0.243	0.244	0.253	0.257	0.254	0.292	0.262	0.258	19
Lesotho	0.285	0.276	0.264	0.234	0.209	0.254	0.217	0.249	20
Mozambique	0.312	0.283	0.247	0.250	0.211	0.185	0.164	0.236	21
Afghanista	0.221	0.230	0.234	0.234	0.235	0.240	0.241	0.234	22
Cameroon	0.257	0.258	0.221	0.186	0.154	0.196	0.183	0.208	23
Chad	0.194	0.197	0.202	0.192	0.196	0.215	0.231	0.204	24
Solomon Islands	0.254	0.249	0.273	0.137	0.128	0.200	0.176	0.202	25
Malawi	0.210	0.209	0.198	0.182	0.175	0.184	0.173	0.190	26
Guinea	0.246	0.234	0.209	0.184	0.155	0.137	0.105	0.181	27
Madagascar	0.195	0.174	0.166	0.211	0.136	0.157	0.129	0.167	28
Rwanda	0.190	0.174	0.170	0.158	0.149	0.126	0.085	0.150	29
Zimbabwe	0.073	0.075	0.118	0.131	0.116	0.095	0.120	0.104	30
Uganda	0.135	0.128	0.121	0.107	0.089	0.062	0.027	0.096	31

The first principal component (C1) shows a significant correlation with both the original DFII and TFII indices. An increase in C1 indicates an improvement in both DFII and TFII, suggesting that these two criteria change together. In other words, when one index increases, the other index tends to increase as well. Thus, C1 serves as a measure of the penetration, access, usage, and skill of both Digital Financial Services (DFS) and Traditional Financial Services (TFS). On the other hand, the second principal component (C2) increases with digital financial inclusion initiatives but decreases with traditional financial services. The Eigenvalue of C2 is negative (-0.7071) indicating a negative impact of conventional and formal financial services, such as services provided through bank branches or requiring physical presence at financial service providers' outlets to access real economic opportunities.

Based on the findings of the PCA in the third stage, we construct the CDFII for the years 2015 to 2021. Table 9 presents the ranking of 31 developing countries based on the average CDFII scores. Mauritius and Seychelles hold the first and second ranks, respectively, while Uganda ranks last.

Conclusion

This study sheds light on the shortcomings of traditional financial inclusion indices in capturing the true extent of technology-driven financial inclusion. It highlights how current indices overlook the contribution of modern technologies like mobile money, internet connectivity, and mobile cellular services. Additionally, the arbitrary assignment of weights to different dimensions of financial inclusion in these indices raises questions and invites debate. The study emphasizes the significant role of mobile phones and other digital devices in improving payment systems and granting easier access to formal banking and non-banking financial services for the unbanked and economically disadvantaged populations. However, traditional financial inclusion indices fail to adequately consider these technological advancements, leading to an inaccurate portrayal of a country's actual level of financial inclusion. Furthermore, previous studies have neglected the influence of people's knowledge and education when calculating financial inclusion indices, despite these factors being essential determinants of financial inclusion.

To address these limitations, this study introduces a novel comprehensive digital financial inclusion index (CDFII) that incorporates individual skill levels and dimensions related to the penetration, availability, and usage of digital financial services (DFS). The study also constructs a traditional financial inclusion index (TFII) that focuses solely on traditional financial services (TFS) without considering the skill dimension. By integrating DFII and TFII, the overall CDFII is calculated, revealing significantly higher levels of digital financial inclusion compared to traditional financial inclusion for each economy examined. However, it is important to note that this study has its limitations, including the limited coverage of only 31 countries due to data availability on DFS indicators. Moreover, the study's dataset includes a wide range of countries, encompassing both developing and emerging economies, which may introduce disparities and outliers that could potentially impact the generalizability and robustness of the findings.

The proposed CDFII serves as a valuable analytical tool for researchers and policymakers, enabling them to measure and compare fintech-driven financial inclusion levels across countries. This comprehensive index provides a more nuanced understanding of the impact of technology on financial inclusion and can inform targeted interventions aimed at enhancing access, availability, and usage of digital financial services. Ultimately, the adoption of such interventions can contribute to inclusive and sustainable economic development. Future research should aim to expand the sample size and incorporate a wider range of countries to enhance the generalizability of the findings. Additionally, ongoing updates to the CDFII are necessary to reflect the evolving landscape of financial technology and digital financial services.

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Appendix A

Table 10. List of developing countries

Afghanistan	Fiji	Mauritius	Seychelles
Albania	Guinea	Mozambique	Solomon Islands
Armenia	Guyana	Myanmar	Thailand
Bangladesh	Jordan	Namibia	Tonga
Cambodia	Kenya	Pakistan	Uganda
Cameroon	Lesotho	Philippines	Zambia
Chad	Madagascar	Rwanda	Zimbabwe
Eswatini	Malawi	Samoa	

Appendix B

Table 11. Ranking of countries based on DFII

Economy	2015	2016	2017	2018	2019	2020	2021	Average	Ranking
Mauritius	0.724	0.736	0.751	0.788	0.821	0.867	0.923	0.801	1
Seychelles	0.731	0.746	0.727	0.735	0.743	0.713	0.760	0.737	2
Rwanda	0.662	0.688	0.692	0.723	0.741	0.789	0.856	0.736	3
Solomon Islands	0.574	0.585	0.549	0.782	0.812	0.696	0.735	0.676	4
Madagascar	0.610	0.644	0.664	0.597	0.725	0.700	0.748	0.670	5
Guinea	0.526	0.544	0.592	0.633	0.681	0.705	0.756	0.634	6
Malawi	0.616	0.610	0.605	0.633	0.643	0.629	0.650	0.626	7
Mozambique	0.507	0.554	0.601	0.595	0.661	0.719	0.746	0.626	8
Cameroon	0.523	0.523	0.583	0.645	0.698	0.634	0.660	0.609	9
Lesotho	0.531	0.546	0.579	0.632	0.671	0.599	0.663	0.603	10
Chad	0.593	0.592	0.582	0.598	0.591	0.565	0.542	0.580	11
Cambodia	0.559	0.585	0.530	0.531	0.581	0.613	0.639	0.577	12
Pakistan	0.555	0.555	0.553	0.555	0.549	0.525	0.541	0.548	13
Bangladesh	0.568	0.558	0.572	0.567	0.571	0.453	0.495	0.541	14
Afghanistan	0.558	0.546	0.537	0.538	0.532	0.527	0.527	0.538	15
Eswatini	0.526	0.533	0.545	0.553	0.577	0.448	0.396	0.511	16
Samoa	0.513	0.480	0.489	0.492	0.481	0.427	0.434	0.474	17
Namibia	0.444	0.414	0.429	0.450	0.453	0.389	0.420	0.428	18
Tonga	0.426	0.409	0.372	0.397	0.462	0.387	0.422	0.411	19
Fiji	0.422	0.417	0.361	0.393	0.381	0.403	0.407	0.398	20
Myanmar	0.478	0.434	0.414	0.387	0.391	0.321	0.324	0.393	21
Philippines	0.412	0.356	0.328	0.338	0.349	0.323	0.352	0.351	22
Guyana	0.371	0.371	0.360	0.351	0.334	0.228	0.229	0.321	23
Jordan	0.266	0.303	0.286	0.291	0.309	0.302	0.329	0.298	24
Kenya	0.217	0.233	0.240	0.261	0.335	0.350	0.375	0.287	25
Albania	0.280	0.260	0.225	0.250	0.262	0.240	0.228	0.249	26
Thailand	0.279	0.237	0.220	0.241	0.212	0.189	0.171	0.221	27
Armenia	0.248	0.229	0.224	0.216	0.228	0.191	0.204	0.220	28
Zambia	0.089	0.107	0.121	0.131	0.161	0.173	0.174	0.137	29
Zimbabwe	0.210	0.196	0.109	0.000	0.023	0.087	0.135	0.108	30
Uganda	0.184	0.160	0.114	0.084	0.058	0.061	0.064	0.104	31

Appendix C

Table 12. Ranking of countries based on TFII

Economy	2015	2016	2017	2018	2019	2020	2021	Average	Ranking
Seychelles	0.749	0.785	0.834	0.869	0.986	0.971	0.973	0.881	1
Mauritius	0.650	0.660	0.698	0.678	0.687	0.695	0.696	0.681	2
Cameroon	0.437	0.459	0.462	0.534	0.544	0.608	0.674	0.531	3
Samoa	0.429	0.493	0.510	0.541	0.537	0.514	0.528	0.507	4
Fiji	0.454	0.486	0.490	0.484	0.481	0.509	0.522	0.489	5
Namibia	0.479	0.464	0.469	0.466	0.483	0.467	0.497	0.475	6
Madagascar	0.253	0.265	0.364	0.445	0.533	0.646	0.694	0.457	7
Armenia	0.405	0.457	0.458	0.463	0.469	0.474	0.406	0.447	8
Rwanda	0.385	0.386	0.398	0.460	0.464	0.471	0.520	0.441	9
Cambodia	0.242	0.283	0.314	0.358	0.400	0.519	0.633	0.393	10
Tonga	0.329	0.337	0.392	0.371	0.349	0.410	0.443	0.376	11
Albania	0.259	0.270	0.304	0.327	0.339	0.370	0.407	0.325	12
Jordan	0.277	0.294	0.304	0.351	0.350	0.343	0.354	0.325	13
Bangladesh	0.285	0.297	0.308	0.316	0.326	0.324	0.338	0.314	14
Philippines	0.244	0.257	0.272	0.276	0.292	0.320	0.321	0.283	15
Guinea	0.233	0.205	0.311	0.313	0.343	0.290	0.271	0.281	16
Solomon Islands	0.208	0.212	0.239	0.235	0.555	0.254	0.256	0.280	17
Kenya	0.207	0.214	0.258	0.252	0.280	0.304	0.380	0.271	18
Zimbabwe	0.221	0.247	0.274	0.250	0.299	0.263	0.277	0.262	19
Pakistan	0.214	0.235	0.240	0.251	0.258	0.284	0.285	0.252	20
Chad	0.152	0.185	0.165	0.234	0.228	0.264	0.273	0.214	21
Eswatini	0.232	0.248	0.242	0.234	0.140	0.147	0.225	0.210	22
Thailand	0.141	0.114	0.185	0.210	0.258	0.261	0.278	0.207	23
Zambia	0.259	0.262	0.251	0.198	0.160	0.166	0.128	0.203	24
Guyana	0.203	0.200	0.194	0.193	0.210	0.197	0.186	0.198	25
Myanmar	0.150	0.166	0.178	0.194	0.177	0.191	0.265	0.189	26
Malawi	0.147	0.156	0.162	0.167	0.189	0.175	0.193	0.170	27
Afghanistan	0.116	0.133	0.125	0.124	0.179	0.138	0.168	0.140	28
Mozambique	0.144	0.144	0.128	0.127	0.131	0.153	0.144	0.139	29
Lesotho	0.117	0.118	0.136	0.143	0.140	0.142	0.146	0.135	30
Uganda	0.049	0.049	0.056	0.076	0.082	0.085	0.086	0.069	31

Economic Journal of Emerging Markets, 15(2) 2023, 160-172

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Available at https://journal.uii.ac.id/jep

The role of the Foreign Direct Investment inflows on export in Azerbaijan: An ARDL approach

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Article Info

Article history:
Received 17 April 2023
Accepted 21 September 2023
Published 31 October 2023

JEL Classification Code:
B22, B27, C01.

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DOI: 10.20885/ejem.vol15.iss2.art4

Abstract

Purpose — This study aims to investigate the impact of FDI inflows on Trade in Azerbaijan from 1993 to 2021.

Method — This study uses the datasets from the World Bank Database. It employs the Augmented Dickey and Fuller (ADF), Phillips and Perron (PP), Zivot and Andrews (ZA), ARDL bounds testing approach, and the Granger Causality tests for the empirical part of the study.

Findings — The bound test shows the presence of cointegration between FDI and Export. The estimated long-run equation suggests a positive and significant relationship, whereas the estimated short-run equation indicates a positive but insignificant relationship between FDI and export. Additionally, the results of Granger causality test show a unidirectional causality running from FDI to export.

Implications — Since the FDI inflows show a positive effect on the export of Azerbaijan, most foreign investments come into the oil and gas sector. Accordingly, oil and gas products and services account for a significant share of exports in Azerbaijan. Policymakers might need new regulations to attract more attention from foreign investors to non-oil sectors.

Originality/value — There were vast studies about FDI and trade relationships in different countries with different techniques. This study is unique because it employs a new methodology and the latest dataset in which Azerbaijan was a focused area for the first time.

Keywords — FDI, export, Azerbaijan, unit root tests, ARDL bounds testing approach, and Granger causality test

Introduction

After the II World War, with the globalization processes, the developed countries started to search for alternative spots for investments to increase their profit due to the potential advantages of those hosting countries in transportation costs, cheap labor, abundant raw materials, and weak state control over regulations. In general, foreign investments are considered an essential source of advanced management, new technologies, and cash flow for a hosting country (Karimov & Belkania, 2018). Besides those positive sides, there are undeniably also negative sides of foreign investments in developing countries. Statistics and written documents show that developed countries often transfer polluted industries to less developed countries due to the strict environmental regulations and harsh taxation policies in their home countries (Karimov, 2020).

P ISSN 2086-3128 | E ISSN 2502-180X

Additionally, technological, cash, and management dependence occurs during FDI investments. In this case, if the government does not consider these issues and will not implement regulations towards this kind of problem, then monopolistic actions will occur in an economy. From our point of view, fruitful conditions for foreign investors should be organized by policymakers. However, after the foreign investment inflows, the state should take this process under control to not harm the competitive market in the economy.

As a developing country, Azerbaijan is also eager to attract foreign investments into its economy. The Investment Law issued on 22 June 2022 is proof of attempts to attract foreign investments into Azerbaijan's economy[1]. Additionally, there are several reasons why foreign investors are interested in Azerbaijan. One of the main advantages of Azerbaijan is its geographical location. Azerbaijan is in the hub of Europe and Asia and bridges those subcontinents. Another advantage of Azerbaijan is the richness of natural resources, including oil and non-oil resources, which makes Azerbaijan more attractive in comparison with neighboring countries. Moreover, the well-organized infrastructure in comparison with neighboring countries and cheap transportation costs are also crucial factors in the attraction of foreign investors to the country. From previous studies and real-life experience, the educated young cheap labor is one of the most important issues for foreign investors. As for the demography, 44 % of the active labor force of Azerbaijan[2] is between 15-24 ages, the literacy level of youth is 100% (between 15-24 ages)[3] and minimum wage is 345 AZN (approx. 203 USD)[4] which in turn makes this country even more attractive for foreign investments.

Additionally, the creation of political and economic stability, a favorable business and investment environment, and liberalization processes by giving equal rights to the investors started to attract the attention of foreign investors to Azerbaijan. The huge reserves of oil and gas made Azerbaijan very attractive to foreign investors who seek to invest in the energy sector. The East-West and North-South transportation pathways, the Baku-Tbilisi-Ceyhan oil pipeline, the Baku-Tbilisi-Erzurum gas pipeline, one of the European Union's important energy initiatives (Shah Deniz-2, the expansion of the South Caucasus pipeline), and the Southern Gas Corridor are the results of Azerbaijan's diligence in attracting and establishing foreign partnerships. According to the trade statistics of Azerbaijan, the biggest share of exports, 93.6%, belongs to the oil and gas industry. [5] The relationship between FDI, EXP, and GDP will be illustrated in Figure 1.

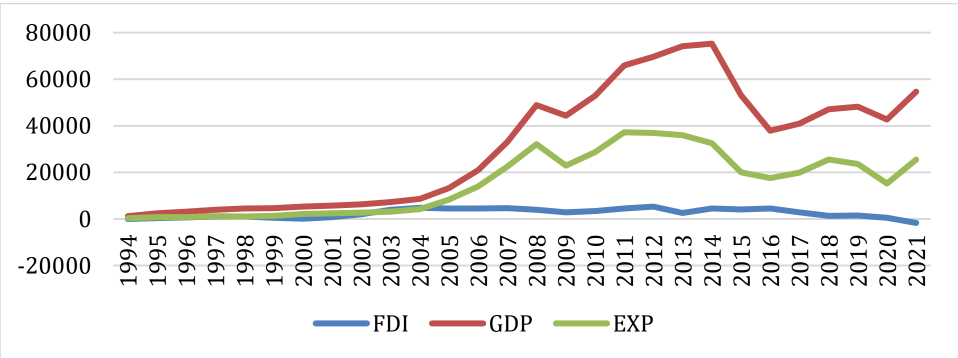

Figure 1. The relationship between FDI, EXP, and GDP (million USD)
Source: World Bank Database (https://data.worldbank.org/)

Figure 1 displays a similar trend between GDP and EXP for almost all the period except 2019-2020 due to the COVID-19 pandemic issue (exports decreased, and afterward, the GDP followed the export and it decreased until the end of the pandemic). When we look at the relationship between FDI and EXP, GDP, it can be seen that, mostly, there is no similar trend line between FDI and those series. Based on the practice, the relationship between analyzed series cannot be confirmed through graphical illustration; the exact results will be gained after further empirical estimations.

Based on the (UNCTAD 2022) report, the total stock of FDI was 31.6 billion AZN (approx. 18.5 billion USD), which was 57.9 % of the country`s GDP in 2021. This report also states that most of the investment was in the oil and gas industry. However, the new strategy of the policymakers of Azerbaijan is to drive the attention of foreign investors from the oil sector to the non-oil sectors such as transportation, agriculture, and tourism. According to this report from the CIS Union, Russia was a leader in foreign investment in Azerbaijan. In addition, Russia assumes its leadership in the Azerbaijan economy due to the customs union between Russia, Belarus, Armenia, and Kazakhstan. Based on the statistics from the Central Bank of Azerbaijan, the total FDI inflows from foreign countries were 4.57 billion AZN (approx. 2.76 billion USD) in the first nine months of 2022. Additionally, the main partners of Azerbaijan with the share of FDI inflows are demonstrated below in Figure 2.

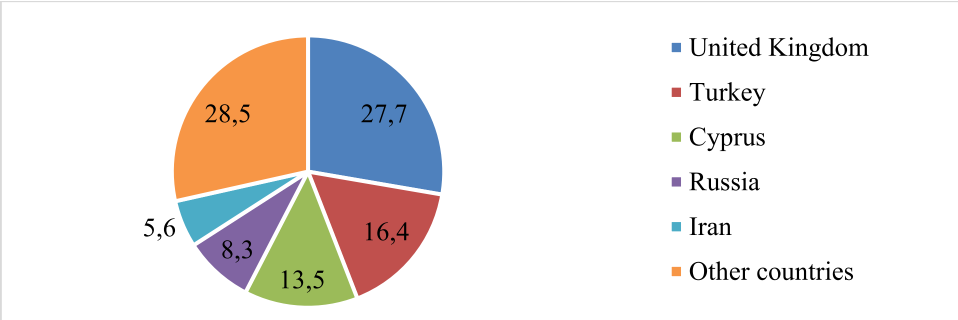

Figure 2. The total share of FDI inflows into Azerbaijan in the first 9 months of 2022
Source: (UNCTAD, 2022)

Furthermore, Figures 3 and 4 demonstrate the partner countries of Azerbaijan in Trade (Export, Import). Figure 3 shows the top 5 countries which export goods and services to Azerbaijan. The top 5 countries which import goods and services from Azerbaijan are demonstrated in Figure 4.

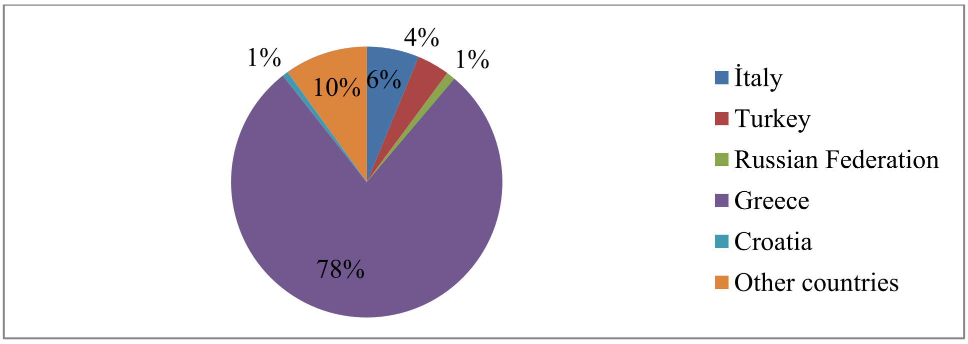

Figure 3. Top 5 export partners of Azerbaijan in 2021
Source: World Integrated Trade Solution (https://wits.worldbank.org/CountrySnapshot/en/AZE)

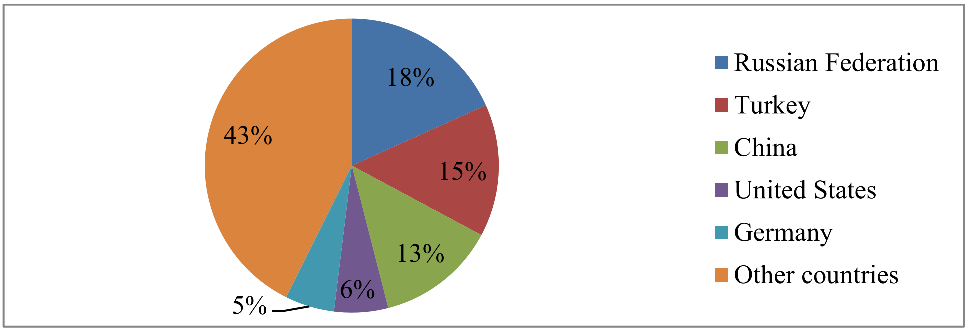

Figure 4. Top 5 import partners of Azerbaijan in 2021
Source: World Integrated Trade Solution (https://wits.worldbank.org/CountrySnapshot/en/AZE)

The authorities of Azerbaijan have emphasized the need to strengthen the business environment and impose minimal filtering on inward foreign investment. Azerbaijan launched a single virtual platform to provide company permits to boost FDI inflows into the economy despite delayed systemic and curbing corruption adjustments. Despite this, the UNCTAD named the government one of the top 20 reformist states for its achievements in recording belongings, securing finance, safeguarding minority investors, and implementing agreements. Based on the (UNCTAD 2022) report, Russian companies invest in Azerbaijan`s construction, trade, services, banking, insurance, information technologies, transportation, and agriculture sectors. On the other hand, to secure the energy safety of European countries, the EU is interested in the safe transportation of gas and oil through a new corridor, which will be delivered in the following route: Azerbaijan – Georgia - Turkey – Europe. Moreover, after the Nagorno-Karabakh conflict between Azerbaijan and Armenia, the state allocated 2.2 billion AZN (approximately 1.3 billion USD) in 2021 and 2.7 billion AZN (approximately 1.6 billion USD) in 2022 for the restoration and reconstruction of Nagorno-Karabagh region and now actively seeks for the foreign investors who interest in investing those regions.[6]. Additionally, the state plans to increase the investment amount from 2.7 billion AZN to 3 billion AZN (approximately 1.8 billion USD) in 2023. Despite the strong sides of Azerbaijan, there are also the weak sides of this state. The policymakers should strengthen the liberalization processes without discriminating against local investors and must strict the anti-trust regulations to create a competitive market. It was mentioned that Azerbaijan has a well-organized infrastructure compared to neighboring countries, which are not considered a competitor for developed countries of the rest of the World. That is why the state should increase the quality of infrastructure in Azerbaijan to create a fruitful climate for foreign investors. Additionally, the level of CIT (corporate income tax) in Azerbaijan is adjusted to 20%[7]. Compared to other countries Azerbaijan's corporate income tax rate is not the highest and lowest but comparable with foreign investment-oriented countries, for instance, Hungary (9%), Qatar (10), Ireland (12,5), Georgia (15), Singapore (17), and Ukraine (18), the CIT of Azerbaijan is not competitive. From the previously mentioned information, the policymakers put some effort into attracting the attention of foreign investors towards non-oil sectors. However, from the export of products and services (93,6%), it should be confirmed that they failed with this mission. Furthermore, the Nagorno-Karabakh war, which occurred during the pandemic, harmed Azerbaijan`s economy very hard. After this occasion, the state started to focus on the liberated regions in Karabakh, which cost a lot of Azerbaijan. Moreover, Azerbaijan needs to use the potential in R & D development. There are plenty of universities and scientific centers in Azerbaijan that should be financed by state or foreign investors to discover and develop new high-tech. Unfortunately, the amount of finance invested in science is meager in Azerbaijan. That is why there is a technological dependence of Azerbaijan on other countries and companies.

Studies on the effect of FDI on the export of hosting countries are abundant. These studies provide different results due to different utilized data, methodologies, and considered countries. Basilgan and Akman (2019) analyzed the effect of foreign direct investment inflows on exports in Turkey from 2005 to 2018. The Autoregressive Distributed Lag Bounds Testing approach has been employed to analyze the impact of FDI on exports regarding Turkey. The results of the ARDL approach indicated a statistically significant and positive impact of foreign direct investment on exports in Turkey.

Moreover, Enimola (2011) investigated the relationship between FDI and exports in Nigeria from 1970 to 2008. The ADF and PP unit root tests, Johansen cointegration test, and Granger causality test were employed for the empirical part of the research. The findings of the Johansen cointegration test indicated at least 1 cointegration among the analyzed series. The results of the Granger causality test demonstrated a unidirectional causality from FDI to export. Karimov (2019) examined the effect of FDI on Trade in Turkey from 1974 to 2017. The Augmented Dickey-Fuller, Granger causality and Johansen cointegration tests were applied for the statistical part of the research. The findings indicated a unidirectional causality running from export to foreign direct investment and an existence of cointegration between examined variables. Gebremariam and Ying (2022) investigated the impact of FDI on exports in Ethiopia from 1992 to 2018. The ARDL approach was utilized to examine the effect of FDI on exports. The results of the ARDL test indicated an insignificant relationship between the analyzed series.

Selimi (2016) examined the relationship between FDI and exports in Western Balkan countries from 1996 to 2013. The panel and Least Square Dummy Variable regression tests were employed for the statistical part of the paper. The findings of statistical tests confirmed that the foreign direct investment consequences are positive on exports regarding Western Balkan countries. Sultanuzzaman et al. (2018) analyzed the long-run and short-run linkage among FDI, economic growth, and exports in Sri Lanka from 1980 to 2016. The ARDL approach was utilized to accomplish an empirical part of the paper. The results which were gained from statistical tests presented a significant and positive relationship between FDI and economic growth. Thus, an increase in FDI inflows will lead to economic growth. Moreover, according to the findings of empirical analyses, the relationship between exports and economic growth was significant and negative. This means an increase in FDI inflows will back economic growth. The ARDL cointegration test confirmed a negative and significant relationship between FDI and exports. Hence an increase of FDI inflows will reduce the export of Sri Lanka. Sultan (2013) investigated the relationship between foreign direct investment and exports in India from 1980 to 2010. The Johansen cointegration and Granger causality tests were employed to fulfill the empirical part of the study. According to the findings of Johansen's cointegration test, there was a cointegration between the analyzed series. Moreover, according to the findings of the Granger causality test based on VECM, there was a unidirectional causality running from export to foreign direct investment. In contrary to previous results, there was no causality running between variables in the short run.

By reviewing the current literature, it can be observed that there is a shortage of empirical research in the case of FDI and export relationship. Additionally, when we take a look at previous literature, it can be observed that there is no implemented research regarding Azerbaijan. Hence, this study will fill that gap in the current literature. This study aims to examine the relationship between foreign direct investment and trade (export) in Azerbaijan. This study expects to provide recommendations for Azerbaijani policymakers to tackle prevailing difficulties in the Azerbaijan economy and boost the volume of FDI inflows into the economy. The remainder of this paper is organized as follows. The next section outlines the methodology and data. The section that follows presents empirical results and discussion. The final section concludes and provides policy suggestions.

Data and Methods

Data Source

An annual time-series dataset from 1993 to 2021 taken from the World Bank Database was utilized for the statistical part of the paper.[8] Table 1 presents the data set.

Table 1. Description of utilized series

Variables	Abbreviation	Measurement unit	Source
Export of goods and services (% of GDP) (dependent)	EXP	Percentage change	World Bank
Foreign Direct Investment inflow (% of GDP) (Independent)	FDI	Percentage change	World Bank
Gross Fixed Capital Formation (% of GDP) (explanatory)	GFCF	Percentage change	World Bank

Unit Root Tests

This study employs the Augmented Dickey and Fuller (ADF) (Dickey & Fuller, 1981), Phillips and Perron (PP) (Phillips & Perron, 1988), and Zivot and Andrews (ZA) (Zivot & Andrews, 1992) unit root tests to check the stationarity of series. Unlike the ADF and PP tests, the ZA test considers structural breaks. The use of the ZA test in this study serves as an improvement from the previous studies.

ARDL Bound Testing Approach

In time-series investigations, several cointegration analyses are employed to investigate long-term correlations between variables. As an example, the most widely employed cointegration analyses are the Johansen cointegration (Johansen, 1988), Engle and Granger cointegration (Engle & Granger, 1987), and the Johansen and Juselius cointegration (Johansen & Juselius, 1990) tests. The disadvantage of these tests is that all series should be stationary at level (I(1)). Moreover, this complication has been figured out by (Pesaran et al., 2001; Pesaran & Shin, 1995; Pesaran & Smith, 1998) by developing the Autoregressive Distributed Lag Bounds Testing (ARDL) approach. The great advantage of the ARDL cointegration test over the other cointegration tests is that all series might be integrated of order 1 (I(1)), order 0 (I(0)), or might be of mixed order. The ARDL econometrical model is as follows.

$$(1){:}\Delta EXP_t = \alpha_0 + \sum_{i=1}^{m} \alpha_{1i}\Delta EXP_{t-i} + \sum_{i=0}^{m} \alpha_{2i}\Delta FDI_{t-i} + \sum_{i=0}^{m} \alpha_{3i}\Delta GFCF_{t-i} + \alpha_4 EXP_{t-1} + \alpha_5 FDI_{t-1} + \alpha_6 GFCF_{t-1} + \mu_t \quad (1)$$

where Δ is first difference operator; μ_t is the error term; m is the optimal lag length.

The long-run and short-run relationships can be investigated through the ARDL approach. The null hypothesis implies no cointegration between the analyzed series and the alternative hypothesis shows that there is a cointegration between examined variables. The value of *F* statistics should be taken into consideration in bound testing. To confirm the presence of cointegration between analyzed series the value of *F* statistics should be more than critical values of upper bounds to reject the null hypothesis. When the *F* statistic is less than the critical values of the upper bound, there is no cointegration between the analyzed series.

Granger Causality Test

The causality test was used to identify the causality link once the cointegration between the series in the research was confirmed. The Granger causality explores the causality between two variables in a time series to determine whether one series will be relevant in predicting another series (Granger, 1969). Null hypothesizes of the Granger causality are the following (2):

X does not granger cause Y; Y does not granger cause X (2)

To accept or reject the null hypotheses (there is no Granger causality between analyzed series) probability value should be taken into consideration. If the p-value is more than 0.05 then the null hypothesis should be accepted (there is no Granger causality between analyzed series) and if the p-value is less than 0.05 then the null hypothesis should be rejected and the alternative hypothesis (there is a Granger causality between analyzed series) should be accepted. The causality between the analyzed series might be in two forms (unidirectional and bidirectional). As the name indicates if there is causality running from X to Y and vice versa then it is called bidirectional and if there is just one-way causality between analyzed series then it is named unidirectional causality.

Results and Discussion

This section presents the findings. Table 2 displays the descriptive statistics and correlation estimates for the series utilized in the research.

Table 2. The descriptive statistics and correlation matrix of the series

	EXP	FDI	GFCF
Mean	45.624	13.823	27.077
Median	46.661	7.626	23.817
Maximum	68.128	55.070	57.710
Minimum	22.699	-3.126	15.643
Std. Dev.	12.771	14.771	9.971
Skewness	-0.094	1.540	1.636
Kurtosis	2.249	4.792	5.374
Jarque-Bera	0.722	15.356	19.756
Correlation			
EXP	1		
FDI	-0.055	1	
GFCF	-0.169	0.911	1

The correlation matrix output indicates a negative and insignificant relationship between FDI, GFCF, and EXP and a positive and significant relationship between GFCF and FDI. The correlation matrix and descriptive statistics convey specific early details of the link among series. On the other hand, empirical techniques will be employed to acquire a more accurate understanding of the interactions between series.

The Results of ADF, PP, and ZA Unit Root Tests

Before continuing with the cointegration testing, the stationary property of the data must be examined. Misleading regression issues emerge in research with non-stationary time series. The ARDL approach requires the variables to be maximum of first-order stationary.

Table 3. The outputs of ADF and PP unit root tests

Variables	ADF (Intercept and trend)		PP (Intercept and trend)	
	At level	At 1st difference	At level	At 1st difference
EXP	[-2.597] (0.283)	[-7.195] *** (0.000)	[-2.804] (0.207)	[-7.212] *** (0.000)
FDI	[-4.384] *** (0.009)	-	[-1.936] (0.609)	[-4.375] *** (0.009)
GFCF	[-3.428] (0.068)	[-4.218]** (0.013)	-1.722 (0.714)	[-3.650]** (0.044)

Note: In the ADF and PP unit root tests, the parentheses indicate p-values, brackets indicate t-statistics, and asterisks (***, **) denote statistical significance at a 1%, and 5% level respectively. The critical values for this test at 1%, and 5% significance levels are -4.33, and -3.58, respectively

The ADF and PP unit root tests presume that series have a unit root at levels. To reject the null hypothesis t-statistics must be higher than critical values at levels and the probability value needs to be less than 0.05. According to the outputs of the ADF unit root test, FDI is stationary at level and EXP, and GFCF is stationary at the first difference. Outputs of the PP unit root test indicate that all series (FDI, EXP, and GFCF) are stationary at the first difference (See Table 3).

The Results of the Zivot-Andrews Unit Root Test (Structural Break)

Table 4. The findings of the ZA test

Variables	ZA unit root test					
	Model A (Intercept)		Model B (Trend)		Model C (Intercept and trend)	
	t-statistic	Break year	t-statistic	Break year	t-statistic	Break year
EXP	-4.869*	2016	-6.256***	2007	-6.482***	2009
FDI	-4.745*	2001	-5.875***	2004	-5.259**	2008
GFCF	-5.104**	2002	-4.359*	2004	-5.628***	2007

Note: The critical values for Model A at 1%, 5%, and 10% significance levels are -5.34, -4.93, and -4.58 respectively. The critical values for Model B at 1%, 5%, and 10% significance levels are -4.80, -4.42, and -4.11 respectively. The critical values for Model C at 1%, 5%, and 10% significance levels are -5.57, -5.08, and -4.82 respectively. The asterisks (***, **, *) denote statistical significance at a 1%, 5%, and 10% level respectively.

The disadvantage of the ADF and PP unit root tests is that these tests do not consider structural breaks. Accordingly, the ZA unit root test was developed to solve this weakness. The ZA unit root test considers the structural breaks in the time series dataset and analyzes the presence of unit root in the dataset. The ZA unit root test looks for structural breaks in a sequence of 3 distinct models. Model A shows solely a break in the intercept; Model B represents just a break in the trend; and Model C demonstrates both a break in the intercept and a break in the trend. The

ZA test`s H_0 is that the variables are nonstationary (include a unit root), whereas the H_A is that the variables are stationary (do not include a unit root). To reject the null hypothesis and accept the alternative hypothesis the value of t-statistics should be higher than critical values at significance levels. According to the findings of the ZA test, all variables are stationary with one structural break (t-statistics are higher than critical values 1%, 5%, and 10% respectively) (See Table 4).

The Results of the ARDL Approach

According to the findings of ARDL bounds testing the F statistic (5.156265) is higher than the upper bounds at 5% significance, which indicates that there is a cointegration between analyzed series (See Table 5).

Table 5. The findings of ARDL cointegration test

Estimated equation			EXP_t= f(FDI_t, $GFCF_t$)	
Autoselected lag structure			(1,1,1)	
Cointegration	*F* statistic	Significance	Critical values	
			lower bounds I(0)	upper bounds I(1)
Yes	5.156265	10%	3.17	4.14
		5%	3.79	4.85
		1%	5.15	6.36
R-squared			0.751	
Adjusted R-squared			0.695	
F-statistic			13.310	
Prob(F-statistic)			0.000	
Durbin-Watson stat			1.177	

The Results of Long-Run and Short Analysis

After confirming the presence of cointegration between the analyzed series, the long-run and short-run analysis will be run to check whether there is a long-run, short-run, or both relationship between the analyzed series. The findings of the long-run test indicated that there is a positive long-run relationship between FDI and EXP and a negative long-run relationship between GFCF and EXP. Thus, a 1 % increase in FDI will increase the EXP by 2.15 %, and a 1% increase in GFCF will decrease EXP by 2.3%. Based on the Error Correction Form test, there is no short-term relationship between FDI and EXP, but there is a negative short-term relationship between GFCF and EXP. Hence, a 1 % increase in GFCF will decrease EXP by 1.18 %. Also, the coefficient of the ECM, CointEq(-1), is negative and statistically significant, which demonstrates that the export of goods and services (EXP) adjusts towards its long-run equilibrium at the rate of 31% (Table 6).

Table 6. The long-run and short-run analysis

Long-run analysis			Short-run analysis		
Variable	Coefficient	T statistic and Prob.	Variable	Coefficient	T statistic and Prob.
FDI	2.152	[3.083]** (0.00)	D(FDI)	0.441478	[2.055] (0.05)
GFCF	-2.303	[-2.563]** (0.01)	D(GFCF)	-1.186711	[-4.361]** (0.00)
Constant	24.249	[2.159] (0.04)	CointEq(-1)	-0.318507	[-4.107]** (0.00)

Source: Author`s calculations

The Results of Diagnostic Tests

The next step would be to run a diagnostic test to test the functionality of the built model. Based on the outputs of the diagnostic test, there is no serial correlation and heteroscedasticity, and the residuals are normally distributed. We can conclude that the model is correctly specified (Table 7).

Table 7. The findings of diagnostic tests

Diagnostic test	χ^2	P-value	Conclusion
The Breusch-Godfrey Serial Correlation LM Test	4.796	0.09	Absence of serial correlation
The Breusch-Pagan-Godfrey`s heteroskedasticity test	4.244	0.51	Absence of heteroskedasticity
The Jarque-Bera Normality Test	5.646	0.05	Residual is normally distributed
The Ramsey RESET test	0.878	0.38	The model is stable (correctly specified)

Source: Author`s calculations

For the further step to check the structural stability in the model, the CUSUM and CUSUMSQ tests will be employed. The results of the CUSUM and CUSUMSQ stability tests indicated that the predicted model is steady during the relevant period (See Figure 5).

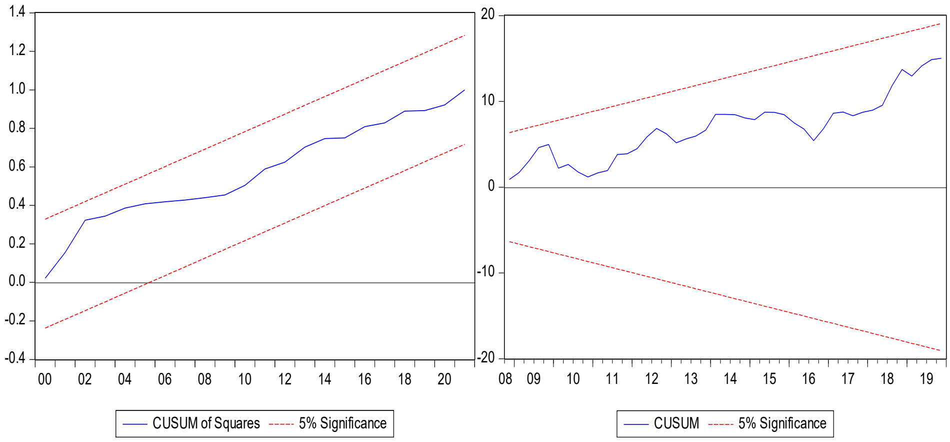

Figure 5. The findings of CUSUM and CUSUMQ tests

The Results of Granger Causality Test

The cointegration between analyzed series can be detected with the help of the ARDL bound testing approach, however, the direction of the relationship between analyzed series cannot be done through this test. Hence, the Granger Causality test needed to be performed to determine the direction of the relationship between the analyzed series.

Table 8. The findings of the Granger Causality test for FDI and EXP

Pairwise Granger causality test, Lags 2, Sample 1993-2021, Observations 27		
Null Hypothesis	F-statistic	Prob.
FDI does not Granger Cause EXP	5.152	0.014
EXP does not Granger Cause FDI	0.045	0.955

The Granger causality test results indicated that there is Granger causality running from FDI to EXP (the null hypothesis that FDI does not Granger cause EXP is rejected due to the probability value, which is below 0.05, and the alternative hypothesis that FDI Granger causes EXP is accepted). Moreover, when we take a look at the direction of the relationship from EXP to FDI, it can be observed that there is no Granger causality between the analyzed series (the null hypothesis that EXP does not Granger cause FDI is accepted due to the probability value which is higher than 0.05). In summary, the unidirectional relationship running from FDI to EXP was confirmed via the Granger Causality test (See Table 8).

Conclusion

This research aimed to investigate the effect of foreign direct investment inflows on trade (export) in Azerbaijan. Taking into consideration the theories about FDI and trade relationships and implemented empirical studies on this topic, it can be said that, foreign direct investment has a positive effect on trade (export) in recipient countries. Therefore, to verify our claims, further statistical tests were required to be done. The results of the ARDL cointegration test revealed a positive and significant relationship between the analyzed series (EXP and FDI). Moreover, the results of the long-run test indicated a positive and significant relationship between FDI and EXP; however, the results of the short-run test demonstrated an insignificant relationship between analyzed series. Thus, based on the long-run and short-run analyses, the foreign direct investment inflows boost exports of Azerbaijan only in the long term. The findings of the Granger Causality test indicated a unidirectional causality from FDI to EXP in Azerbaijan. Overall, it is proved that the foreign direct investment inflows will positively contribute to the export of Azerbaijan. The thing is, when we take a look at the trade statistics.[9] it can be seen that 93.6 % of the export of Azerbaijan consists of crude oil, natural gas, and oil products, which means that the country's economy strongly depends on the oil and gas industry. However, Azerbaijan Republic has great potential in other sectors as well. To sum up, the Azerbaijan Republic has great potential not just in the oil and gas sector but also in manufacturing, agriculture, mining, transportation, tourism, and energy (renewable) sectors. Hence, the recommendation for the policymakers would be the following:

1. To liberalize the economy of Azerbaijan and make it more suitable for foreign investors but without taking the rights of domestic investors
2. To develop the infrastructure not just in the oil and gas sector but also in other sectors such as manufacturing, agriculture, mining, transportation, tourism, and energy (renewable)
3. To support the domestic and foreign investors in non-oil sectors by giving them incentives and subsidies
4. To decrease the corporate income tax (CIT) from 20%[10] up to 18% in order to attract more foreign investors to Azerbaijan
5. To strengthen the anti-trust activities against monopolistic actions of local and foreign companies in the Azerbaijan Republic with the help of new strict regulations
6. To stabilize the economic and political situation of the country after the COVID-19 pandemic, oil crisis, and Nagorno-Karabakh War with Armenia, which occurred during the pandemic.
7. To put scientific investments in R&D development at universities to develop high technologies. Thus, developing the new high-tech will decrease technological dependence on other countries and MNCs and, afterward, will profit by exporting them to other countries.

The research results indicated a positive and significant relationship between FDI and exports. Additionally, this research will fill the gap in scarce literature and serve as a guide for policymakers of Azerbaijan.

Acknowledgments

Not applicable

Disclosure Statement

The authors do not have any competing financial, professional, or personal interests from other parties.

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Examining entry and exit rates of poverty in Turkey: A dynamic probit regression analysis

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Article Info

Article history:
Received 09 June 2023
Accepted 26 October 2023
Published 31 October 2023

JEL Classification Code:
I32, H31, F63.

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DOI: 10.20885/ejem.vol15.iss2.art5

Abstract

Purpose — The purpose of this study is to add to the current poverty dynamics literature by investigating the underlying causes of poverty persistence in Turkey, with an emphasis on both entry and exit rates.

Methods — The study analyzes data from the Turkish Statistical Institute's "Survey on Income and Living Conditions" from 2018 to 2021 using dynamic probit models. This large dataset, which gives a detailed picture of socioeconomic situations, helps in properly understanding the complex aspects influencing poverty rates.

Findings — The analysis reveals significant poverty persistence in Turkey, influenced by factors such as gender, marital status, employment, and health conditions. According to the research, these variables frequently interact, forming a complex structure that maintains poverty throughout the country.

Implications — The findings necessitate targeted interventions to address persistent poverty, considering the diverse influencing factors. This could lead to a reduction in poverty rates and improved socioeconomic conditions for individuals.

Originality/Value — This study offers a unique perspective on poverty dynamics in Turkey, focusing on both entry and exit rates. It provides valuable insights for those formulating policies or strategies aimed at poverty reduction, emphasizing the need for a comprehensive approach to poverty alleviation.

Keywords — Poverty dynamics; state dependence; poverty durations; poverty persistence; probit model.

Introduction

The study of poverty and its causes has long been an important area of research in the field of social sciences. One aspect that has gained attention in recent years is the phenomenon of "state dependence" in poverty. This refers to the extent to which experiencing poverty in the present increases the likelihood of experiencing poverty in the future. The other aspect is unobserved heterogeneity, where unmeasured characteristics or circumstances influence an individual's poverty status (Justino & Litchfield, 2003; Wooldridge, 2002). The concept of "poverty persistence" is a complex issue that can be brought about by a variety of issues, such as a lack of education and experience, restricted access to employment opportunities, social exclusion, and insufficient welfare systems. It has an immense adverse effect since it can lead to a cycle of poverty that lasts from one generation to the next.

According to literature on poverty persistence and state dependency, poverty is a dynamic phenomenon that is influenced by prior experiences and choices as well as current social and

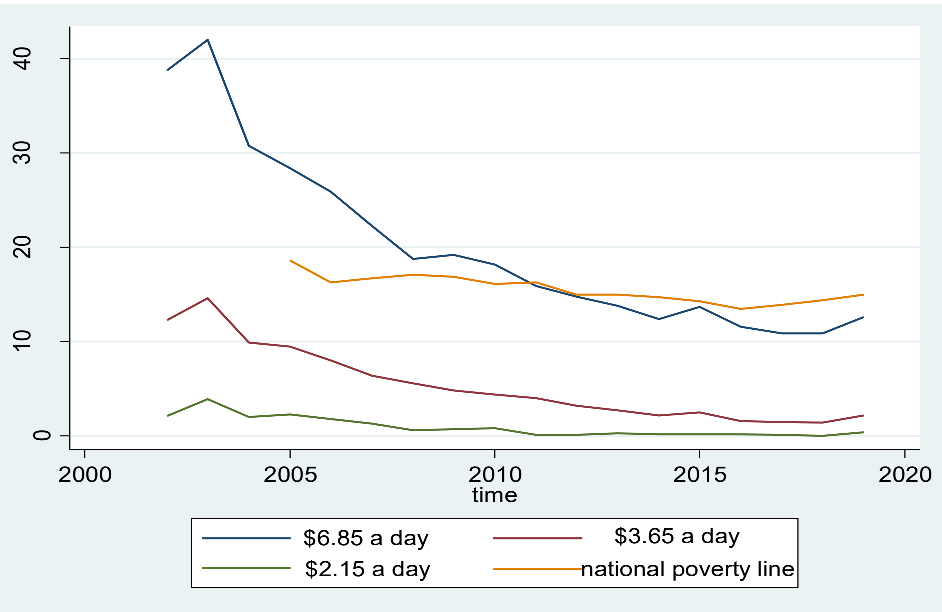
P ISSN 2086-3128 | E ISSN 2502-180X

economic circumstances. Stevens' (1999) work on poverty measurement has led to a growing recognition of the significance of assessing poverty persistence, which involves considering an individual's likelihood of both exiting and returning to poverty throughout their lifetime.

Entry and exit rates of poverty play a crucial role in understanding the transient nature of poverty versus its chronic or persistent state. Studies such as (Bane & Ellwood, 1986; and Stevens, 1999) have emphasized the importance of understanding these rates to shed light on the dynamics of poverty spells and their durations. Buddelmeyer and Verick (2008), examine the factors affecting poverty dynamics in Australian households, highlighting the roles of education, employment, disability, geographic location, and significant life events like separation. Bigsten and Shimeles (2008), delves into Ethiopia's poverty dynamics from 1994 to 2004, emphasizing the recurrent transitions households experience in and out of poverty. The study underscores that prolonged spells in poverty intensify the challenges of escaping it, with notable disparities between male- and female-headed households.

Several recent studies have focused on Turkey's ongoing poverty. Even though substantial progress has been made in reducing poverty over the past 20 years, the issue persists, especially in rural areas and among certain demographic groups. The persistence of poverty in Turkey has been studied using a variety of econometric methods, including static and dynamic models (Şahin & Kılıç, 2021; Şeker & Dayioğlu, 2015; Yildirim et al., 2018).

In the past two decades, the Turkish government has made significant efforts to alleviate poverty and enhance economic well-being. The Conditional Cash Transfer Program has been a key initiative that provides financial assistance to families with children, the elderly, and disabled people. The government has also invested in education and infrastructure development, such as expanding access to preschool education and improving transportation systems. Additionally, policies like special economic zones and tax incentives have created job opportunities and improved the overall economic status of the population. These efforts have yielded positive results, but more work is needed to ensure equal access to necessities and opportunities for all citizens.



Source: World Development Indicators (World Bank)

Figure 1. Poverty headcount ratio (2017 PPP) (% of the population).

According to the World Bank, Turkey has made significant progress in reducing poverty over the past 15 years, thanks in part to robust economic growth, which has averaged over 5% annually during this period. In addition, monetary assistance programs implemented after the 2001 economic crisis may have contributed to this positive trend.

Despite these improvements, however, Turkey's poverty rate is still higher than the average for OECD countries. This suggests that some poverty may have become chronic and that more permanent policies are needed. Hence, there is a need to ensure the long-term stability of key macroeconomic indicators such as economic growth, unemployment, and inflation, to combat poverty persistence and state dependence.

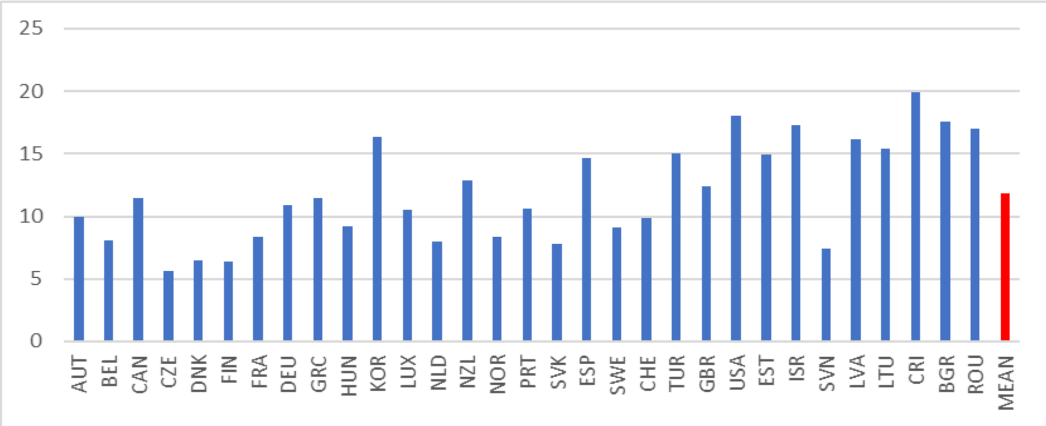


Figure 2. Poverty Rate (OECD Members). Source: OECD (2020).

Regarding the factors that contribute to the country's persistent poverty, there is still much to understand. By employing a dynamic probit regression model to analyze the dynamics of income poverty and considering a variety of aspects, including demographic factors, this study aims to contribute to the literature on the persistence of poverty in Turkey. The dynamic probit regression model is preferred in the study for a variety of reasons. First, it effectively captures state dependency by allowing the inclusion of lagged dependent variables. This is significant in demonstrating how earlier experiences with poverty may affect the current situation. Second, unobserved heterogeneity, a prevalent issue in studies of poverty, may be successfully addressed by the model. It enables this by accounting for individual fixed effects that account for individual-specific influences on poverty. The inherent flexibility of the dynamic probit model, which enables it to precisely represent the probability of the natural transitions that households go through into and out of poverty based on both observed and unobserved factors, is another important advantage of the model. In this study, I analyze entry and exit rates of poverty among households based on their characteristics.

The roots of persistent poverty often lie in income inequality, educational limitations, poor health, and restricted access to resources (Klasen, 2008; Ravallion, 2011). As shown in the existing literature, these drivers manifest differently across developing and developed countries, and understanding these dynamics is vital for effective policy interventions.

Research in developed countries has identified key mechanisms underlying poverty persistence, such as state dependence, initial conditions, and household characteristics (Ayllón, 2013; Ayllón & Gábos, 2017; Biewen, 2009; Bosco & Poggi, 2019; Cappellari & Jenkins, 2002; Devicienti & Poggi, 2011; Fusco & Islam, 2020; Giarda & Moroni, 2018). For instance, Fusco and Islam (2020) underscored the relationship between household size, poverty, and its persistence over time, highlighting the complexity of poverty dynamics.

Parallelly, studies in developing countries have highlighted various contributors to poverty such as educational levels, employment instability, asset ownership, and household demographics (Alia et al., 2016; Garza-Rodriguez et al., 2021; Kedir & Mckay, 2005; Kudebayeva, 2018; Ribas & Machado, 2007; Roberts, 2000; You, 2017). Notably, You (2017) emphasized the role of asset-based poverty traps in rural China, which is a critical factor to consider in other developing economies like Turkey.

Literature on poverty dynamics within Turkey is abundant (BaşakDalgıç AytekinGüven, 2015; Şahin & Kılıç, 2021; Şeker & Dayioğlu, 2015; Şeker & Jenkins, 2015; Yildirim et al., 2018). It outlines the significance of labor market characteristics, socio-economic factors, and demographic factors in determining poverty entries and exits.

To conclude, although there exists a wide array of research exploring poverty dynamics, there remains a gap in the thorough analysis of poverty's entry and exit rates, especially within the specific context of Turkey. This study seeks to address this issue by employing a dynamic probit regression model to explore the root causes and persistent nature of poverty in Turkey.

The remainder of this paper is organized as follows: Section II provides a review of the literature. In Section III, I outline the methodology for analyzing poverty persistence. Section V reveals our empirical findings and contains a discussion of their importance. Finally, Section VI concludes.

Method

This study, which deals with the dynamic poverty process, uses the "Income and Living Conditions Survey" provided by the Turkish Statistical Institute (TUIK). Since 2006, the "Survey on Income and Living Conditions (SILC)" has been conducted as part of the European Union (EU) studies to determine the distribution of income between households and individuals, to measure the living conditions of individuals, and to reveal social exclusion and poverty in Turkey.

Table 1. Descriptive Statistics

Dependent variable (Y)	*=1 if household poor*	*0,26*	*0,438*	*0*	*1*
Number of persons living in the same house		2,55	1,18	1	13
Household Head Characteristics					
Age	Age (in years)	50,7	15.9	15	109
Female	=1 if female	0,275	0,446	0	1
No Education		0,156	0,363		
Primary-Secondary School	=1 if primary and secondary education	0,497	0,5	0	1
High school	=1 if high school	0,094	0,292	0	1
Vocational High school	=1 if vocational high school	0,076	0,265	0	1
University and above	=1 if university and higher degree	0,175	0,38	0	1
Single	=1 if single	0,22	0,414	0	1
Married	=1 if married	0,78	0,414	0	1
Skilled worker	=1 if skilled	0,94	0,228	0	1
Unskilled worker	=0 if unskilled	0,6	0,228	0	1
Wage Earner	=1 if earns wage	0,73	0,443	0	1
Bad health	=1 if the health problem	0,376	0,484	0	1
N=80527					

Source: Author's calculation based on the data.

According to TUIK, households below the threshold determined by median income are defined as poor. This limit can be determined according to 50% or 60% of the median income. Based on Şeker and Dayioğlu (2015) and Yildirim et al. (2018), the poverty line in this study is calculated at 60% of the median income and the unit of analysis in this paper is "household". The study uses a panel data set covering the years 2018-2021.

Table 1 presents descriptive statistics. Accordingly, households classified as "poor" in the period under review, constitute 26% of total households. The average household size is 2,55 and the average age is 50,7. Descriptive statistics show that 27.5% of household heads are women. Moreover, 15.6% of household heads have no schooling, while 49.7% have primary or secondary education. In terms of schooling, about 9% of the household heads have a regular high school diploma, and 7.5% have completed vocational school. The remaining 17.5% have a university degree or higher education.

It can be seen that 22% of the population is single, while the majority (78%) is married. Moreover, a large part (94%) of the population is skilled workers and only a small part (6%) is unskilled. In terms of occupation, 73% of the population are wage earners, while 26% are employers. The data also show that 37.6% of the population reported poo health.

Table 2. Poverty Transition Matrix

Previous Year	Current Year	
	Not Poor	Poor
Not Poor	90,97	9,03
Poor	28,56	71,44
Total	74,6	25,4

Source: Author's calculation based on the data.

Table 2 provides an overview of the poverty status of Turkish households at time t based on their status at time t-1. The data show that 38.56% of those who were poor at time t-1 can escape poverty in the following year, leaving 71.44% of those who were poor at time t-1 still living in poverty at time t. The data also show that the poverty status of those who were poor at time t-1 is higher than that of those who were poor at time t-1. in contrast, 90.97% of those who were not poor at time t-1 remain non-poor at time t. The data also show that 9.03% of those who were not poor at time t-1 newly enter poverty.

Previous sections have put forth the idea that poverty is a dynamic occurrence rather than a static one, a notion backed by existing research. Utilizing a dynamic perspective in poverty analysis offers decision-makers a deeper understanding of poverty's enduring nature, thereby addressing the shortcomings of a static approach. This strategy enables decision-makers to concentrate on the causes of poverty rather than only treating its symptoms, which can help in the development and application of more efficient strategies for eradicating poverty (Baulch & Masset, 2003; Cappellari & Jenkins, 2002; Tran et al., 2015).

To examine the dynamic structure and persistence of poverty, this study utilizes dynamic probit regression. We can express the dynamic regression model as follows:

$$y_{it}^{*} = \gamma Z_{it} + \rho y_{it-1} + c_i + u_{it} \quad (1)$$

where y_{it}^{*} represents the poverty status of household i (i=1...N) at time t. Additionally, y_{it-1} denotes the poverty status in the previous year. The poverty status is determined by a set of time-varying explanatory variables, Zit, which are considered exogenous, given the unit-specific time-constant unobserved effect, c_i. The idiosyncratic error term is denoted by u_{it}.

The initial conditions issue arises in the equation due to the potential for individuals' poverty status observations to begin before the first wave of observation. This could cause a correlation between the starting value of the dependent variable and unobserved individual differences, leading to biased estimates of heterogeneity and genuine state dependence if not properly addressed. To tackle this issue, various approaches have been proposed in the literature, including those by (Biewen, 2009; Heckman, 1981; Rabe-Hesketh & Skrondal, 2013; Wooldridge, 2005). In this research, I used the methods developed by Heckman (1981) and Rabe-Hesketh and Skrondal (2013). By applying both models and comparing their coefficients, we assess the robustness of the estimators obtained in this study.

To model the unit-specific unobserved effect, c_i, we adopt the framework proposed by Rabe-Hesketh & Skrondal (2013).

$$c_i = \alpha_0 + \alpha_1 y_{i0} + \overline{Z}_\iota \alpha_2 + Z_{i0}\alpha_3 + \alpha_i \quad (2)$$

Accordingly, c_i can be expressed using the initial values of the outcome (y_0), the time-varying explanatory variables (Z_{i0}) and unit-specific time-constant error term (α_i), as shown in equation 1.

Results and Discussion

To examine the dynamic process and persistence of poverty, I have constructed the following model. Here, household-head-specific demographic variables are included.

$$Poverty = Poverty_{t-1} + \beta_0 + \beta_1 household\ size + \beta_2 age + \beta_3 sex + \beta_4 martialstatus + \beta_5 education + \beta_6 skilledworker + \beta_7 wageearner + \beta_8 health \quad (3)$$

Table 3. Results of Dynamic probit models

VARIABLES	R-S (2013) Model	Heckman (1981b) Model
poverty	0.634***	0.462***
	(0.050)	(0.086)
age	-0.012	-0.016***
	(0.016)	(0.003)
hhsize	-0.486***	-0.443***
	(0.044)	(0.042)
sex	-0.297***	-0.284**
	(0.0373)	(0.137)
martialstatus	-0.277	-0.552***
	(0.170)	(0.141)
education	-0.387***	-0.476***
	(0.017)	(0.043)
skilledworker	-0.287***	-0.425***
	(0.044)	(0.124)
employer	-0.164**	-0.549***
	(0.069)	(0.087)
badhealth	0.260***	0.199*
	(0.035)	(0.094)
Initial Conditions		
1.povertyz__0	1.594***	
	(0.082)	
age__0	-0.018	-0.000
	(0.034)	(0.003)
hhsize__0	0.095**	-0.344***
	(0.044)	(0.048)
wageearner__0	0.164**	-0.412***
	(0.079)	(0.100)
martialstatus__0	0.283*	-0.535***
	(0.167)	(0.119)
Within-unit averages		
m__age	0.014	
	(0.038)	
m__hhsize	0.079	
	(0.075)	
m__wageearner	-0.598***	
	(0.132)	
m__martialstatus	-0.127	
	(0.286)	
Constant	1.287***	2.664***
	(0.135)	(0.385)
Observations	36,961	58,292
Number of groups	18,987	
LR test of rho = 0:		$\chi2$= 20024.98
prob		0.000

Robust standard errors are in parentheses. *** and ** indicated statistically significant at 1%, and 5%, respectively.

The results of the two estimated models are shown in Table 3. The first model yields robust standard errors. The second model is statistically significant overall according to the chi-square test. Both models have similar coefficients. Accordingly, the coefficient of poverty in the table represents the lagged value of the dependent variable and is an indicator of state dependence. A positive value for this coefficient indicates the existence of significant dynamics associated with genuine state dependence in both models.

The output table presents the coefficients for the control variables that are used in the analysis. Accordingly, the analysis shows that households with a female head of household have a lower risk of poverty, and households with a married head of household also have a lower risk of poverty. On the other hand, poor health is associated with a higher risk of poverty. In addition, households with a head of household who is an employer (as opposed to an employee) have a lower poverty risk, while households with an employee as head of household have a higher poverty risk.

Table 4. Entry and Exit Probabilities of Poverty

		Entry probability (%)	Exit probability (%)	Steady-state probability (%)	Mean Duration
Education Level	No Education	27.1	57.1	32.1	1.749
	Primary-Secondary Education	19.3	67.3	22.3	1.484
	General High School	13.1	76	14.7	1.314
	Vocational School	8.4	83.2	9.2	1.201
	University and above	5	88.8	5.3	1.126
Sex	Male	15.3	74.9	17	1.334
	Female	19.4	69.4	21.8	1.440
Marital status	Single	20	68.2	22.7	1.466
	Married	17.3	71.7	19.4	1.393
Occupational Skill	Skilled	17.5	71.5	29.7	1.398
	Unskilled	22.2	65.4	25.3	1.528
Employer	Wage Earner	18.7	70	21	1.427
	Employer	16.3	73.1	18.3	1.367
Health Condition	Good	17.4	71.6	19.5	1.394
	Bad	21.4	66.4	24.3	1.504

The probabilities of entering and exiting poverty for demographic factors are shown in table 4. Accordingly, individuals with higher levels of education have a lower probability of entering poverty and a higher probability of exiting poverty than those with lower levels of education, according to the statistics. Individuals with a university degree or higher have the lowest chance (5%) of falling into poverty and the greatest chance (88.8%) of escaping out of it. Individuals with no educational attainment, on the other hand, have the greatest probability (27.1%) of entering poverty and the lowest probability (57.1%) of exiting poverty. These results highlight the significance of education in poverty reduction and imply that policies to improve educational opportunities and attainment may be effective.

The entry and exit probabilities of men and women into and out of poverty indicate that poverty rates differ between the sexes. Women have a greater probability of falling into poverty than men. At the same time, women, are less likely than males to move out of poverty, implying that once in poverty, they are less likely to move out. A variety of factors may contribute to these disparities, including unequal access to education, job opportunities, and social support. Addressing these factors through tailored policies and programs could help reduce male and female poverty rates. Both single and married people are at risk of falling into poverty, but the likelihood is greater for single people. However, married people have a greater likelihood of escaping poverty. Our findings reveal a pronounced and positive coefficient of state dependence, aligning with prior research such as those by Şahin and Kılıç (2021), Şeker and Dayioğlu (2015), and Yildirim et al. (2018). This indicates a consistent trend of persistent poverty in Turkey.

Individuals with occupational skill have a lower poverty entry probability and a higher poverty exit probability compared to those with unskilled workers. The probability of falling into poverty is a little greater for wage earners. Yet, they have a higher probability of escaping poverty. Finally, households with a head in poor health are more likely to experience poverty entry and less likely to exit poverty than households with a head in good health, indicating that the health condition of the household head plays a significant role in poverty dynamics.

Conclusion

This paper investigates the persistence of poverty in Turkey based on SILC data for 2018-2021. To achieve this objective, we used the random effects dynamic probit model as proposed by Heckman (1981) and Rabe-Hesketh and Skrondal (2013). Our results show a highly significant and positive coefficient of state dependence, which is consistent with the previous studies by Şahin and Kılıç (2021), Şeker and Dayioğlu (2015), and Yildirim et al. (2018). These findings suggest that poverty has a persistent nature in Turkey.

According to the estimation results, poverty dynamics in Turkey are significantly influenced by a complex interplay of key factors, such as gender, marital status, employment, and health status. Findings reveal that individuals with higher levels of education and occupational skills have a significantly lower probability of falling into poverty and a greater likelihood of escaping it, when compared to their counterparts with low levels of education and unskilled workers.

Moreover, our analysis has revealed that women are persistently at a disadvantage, with a lower probability of escaping poverty when compared to men. This highlights the urgent need for targeted policies that are specifically designed to tackle gender-based disparities in the incidence of poverty. Additionally, research has shown that the health status of the family head plays a significant role in poverty dynamics, with households headed by individuals with poor health more likely to experience poverty and less likely to exit it.

According to the findings of this research, policies aimed at reducing poverty in Turkey need to focus on specific groups, particularly those at risk of persistent poverty. Gender inequalities in poverty dynamics are necessary to addressed, particularly for women. Access to affordable health care, education and training programs, and social protection programs could benefit women.

Furthermore, the findings suggest that education and professional abilities are critical to reducing poverty in Turkey. Prioritizing policies that improve access to education and training, especially for vulnerable groups, is essential. Furthermore, policies that promote economic growth and job creation can have a significant impact on reducing poverty in Turkey.

The existing literature on poverty dynamics in Turkey focuses on the role of socio-economic factors, labor market characteristics, and household attributes in determining poverty persistence. In accordance with these studies, findings indicate that gender, marital status, employment, and health status all play a role in poverty dynamics.

This study provides an analysis of poverty dynamics in Turkey by calculating entry rates and exit chances using two benchmark models. The application of two models not only ensures the robustness and accuracy of our analysis but also enhances the validity of our findings by accounting for variations in model specifications. By focusing on entry and exit dynamics, we offer a comprehensive understanding of poverty transitions in Turkey and shed light on the complex processes underlying poverty persistence.

In summary, persistent poverty is a major challenge for Turkey. The findings of this study suggest that targeted policies to reduce poverty, especially for vulnerable groups such as women, those with low levels of education and unskilled workers, and those with poor health, are essential. Investment in education and vocational skills, economic growth and job creation, and access to health services and social protection programs are necessary to reduce poverty and promote sustainable development in Turkey.

Disclosure Statement

No potential conflict of interest was reported by the author(s).

Data Availability Statement

The data that support the findings of this study are available from the "Turkish Statistical Institute" Restrictions apply to the availability of these data, which were used under license for this study.

Data are available (https://www.tuik.gov.tr/Kurumsal/PDF_Detay) with the permission of Turkish Statistical Institute.

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Economic Journal of Emerging Markets, 15(2) 2023, 183-198

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Impact of industrialization and renewable energy on carbon dioxide emission in 9 ASEAN countries

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Article Info

Article history:
Received 12 January 2023
Accepted 29 October 2023
Published 31 October 2023

JEL Classification Code:
Q42, Q43, O53.

Author's email:
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DOI: 10.20885/ejem.vol15.iss2.art6

Abstract

Purpose — This research investigates the relationship between ASEAN's industrialization, renewable energy, and CO2 emissions. The primary objectives are to assess the existence of the Environmental Kuznets Curve (EKC) in ASEAN and to explore the potential mediating effect of renewable energy in the relationship between industrialization and CO2 emissions.

Methods — The study utilizes the PMG-ARDL estimation method in nine ASEAN countries from 1990 to 2019, providing short- and long-term analyses of the variables involved.

Findings — The finding reveals the presence of the EKC in ASEAN in the short term for most member states. It also finds that renewable energy mediates the relationship between industrial value-added and CO2 emissions, with renewable energy adoption altering the turning point of per capita CO2 emissions during industrialization in several ASEAN nations.

Implication — The findings suggest that transitioning to renewable energy can help mitigate the environmental impact of ASEAN's industrial development. Thus, member states committed to energy targets should prioritize deploying renewable energy in their industrial sectors to achieve environmental benefits.

Originality — This research contributes to the existing literature by specifically examining the interplay between industrialization, renewable energy, and CO2 emissions in ASEAN. The use of the PMG-ARDL estimation method and the focus on the mediating role of renewable energy add originality to the study.

Keywords — Industrialization, renewable energy, carbon emissions, Environmental Kuznets Curve (EKC), ASEAN

Introduction

Over the past few years, addressing climate change and reducing greenhouse gas (GHG) emissions has been a critical action that should be taken. In 2018, the Intergovernmental Panel on Climate Change (IPCC) put forth a crucial proposal, advocating for achieving net-zero emissions by 2050 as a key strategy to restrict global warming to 1.5° Celsius. This recommendation underscores the pressing need for decisive action in addressing the climate crisis. However, the current trajectory suggests that GHG emissions will continue to rise until 2030, leading to a global temperature increase of 2.1° to 3.9° Celsius (UNEP, 2020). The ASEAN Centre for Energy (ACE, 2020) predicts a significant increase of 34% to 147% in energy-related GHG emissions by 2040. The

P ISSN 2086-3128 | E ISSN 2502-180X

ASEAN region must lead a decarbonizing revolution (Lewis & Maslin, 2015) to achieve the net-zero emissions target by the end of the century.

ASEAN has taken some action to mitigate GHG emissions and proactively address climate change risks by implementing the ASEAN Plan of Action for Energy Cooperation (APAEC) 2016-2025. The primary objective of APAEC is to bolster energy connectivity and market integration within ASEAN, aiming to achieve comprehensive energy security, accessibility, affordability, and sustainability for all member nations. Some of the key APAEC set an ambitious target of incorporating 23% renewable energy in the ASEAN energy mix and achieving 35% installed power capacity from renewable sources by 2025.

Over recent years, the ASEAN region has experienced rapid economic growth, which is expected to continue in the long term (Lu, 2017). While the industrial sector drives economic development in many ASEAN countries, it also contributes to environmental issues such as deforestation and reliance on non-renewable energy sources (Hoad, 2015). Forecasts indicate that long-term carbon and GHG emissions from fossil fuel combustion will significantly impact climate change trends (Ahmed et al., 2021). Consequently, ASEAN faces the unique challenge of achieving a balance between economic growth and environmental preservation, necessitating a comprehensive study of the role of renewable energy within the framework of the Environmental Kuznets Curve (EKC) hypothesis for CO2 emissions.

This research makes several notable contributions by studying industrialization's environmental impact. Firstly, the study explores the impact of industrialization on emissions in the EKC hypothesis, considering the influence of renewable energy utilization. While most EKC hypotheses traditionally use GDP or income to measure a country's development, we recognize the significant role of industrialization in driving ASEAN's GDP growth. Therefore, industrialization is a better proxy for economic progress (Rahman & Alam, 2022). Secondly, this study employs the PMG-ARDL estimator, which imposes homogeneity in the long-run coefficient while incorporating country-specific effects. This approach enables a more precise analysis of the linkage between renewable energy, industrialization, and CO2 emissions.

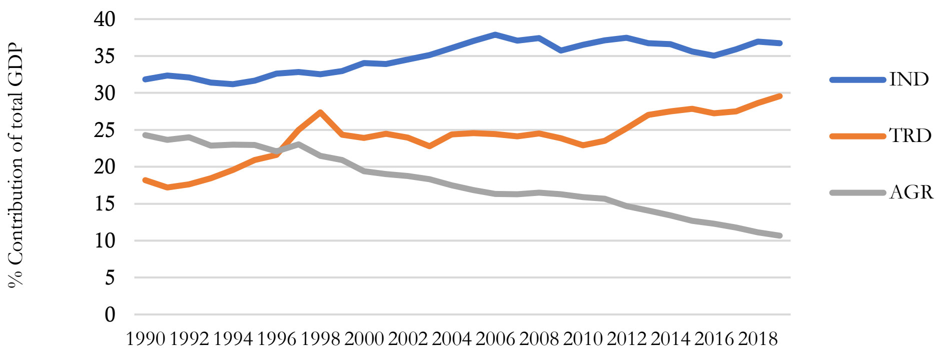


Figure 1. Change in ASEAN’s Share of GDP from Agriculture, Industry, and Trade

The EKC hypothesis offers a structured framework for examining the dynamic correlation between environmental impacts and economic growth across temporal dimensions. Early economic growth, dominated by agricultural production and heavy industry, often increases environmental pollution (Dasgupta et al., 2002). However, pollution levels decrease as the service and industrial sectors expand (Figure 1). The EKC hypothesis typically measures environmental proxies, such as carbon dioxide emissions, with economic development indicators, such as GDP or income. In the case of ASEAN, industrialization has been used to examine the EKC theory (Apergis & Ozturk, 2015; Aquilas et al., 2022; Bulut, 2019; Rahman & Alam, 2022). According to Rahman and Alam (2022), industrialization, which increases CO2 emissions, is a more suitable proxy for economic progress. Moreover, the transformation driven by industrialization contributes significantly to ASEAN's GDP.

Figure 2 shows the dynamic shifts of the EKC under varying conditions. As more countries embrace renewable energy to mitigate carbon emissions, the curve's turning point moves from point

A to point B, leading to an accelerated process (from EKC1 to EKC0). Conversely, neglecting renewable energy adoption can hold the turning point, resulting in a shift from EKC0 to EKC2, with the turning point shift from point A to point C. A slower progression towards the inflection point implies that during the early stages of economic expansion, the costs of environmental degradation and trade-offs between economic growth and environmental sustainability are higher.

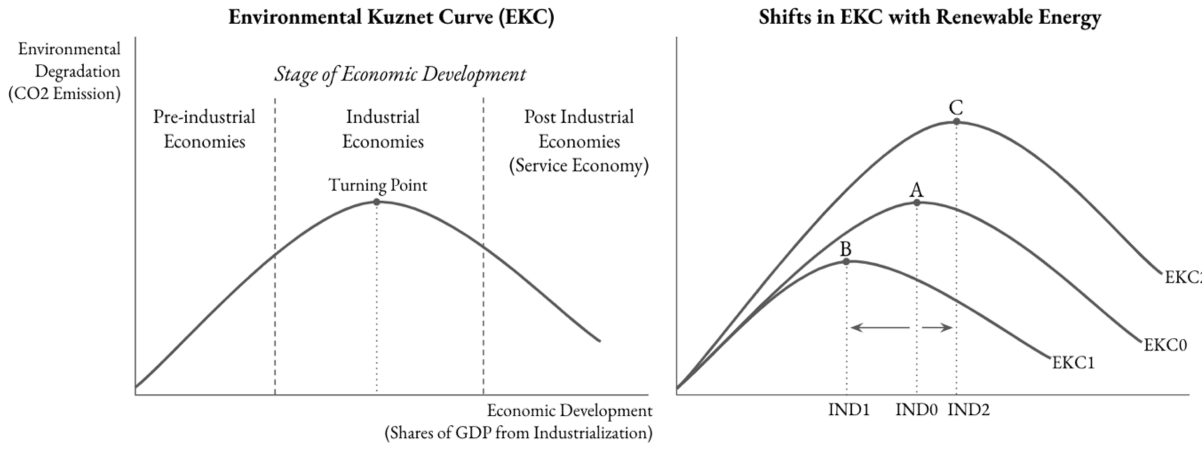


Figure 2. Shifts in Environmental Kuznets Curve

Despite extensive research on the relationship between economic development and the environment using the EKC theory, limited attention has been devoted to studying this phenomenon within the context of ASEAN, mainly focusing on industrialization and renewable energy as primary factors. Furthermore, prior studies have yet to validate the presence of the EKC hypothesis in ASEAN. Chandran and Tang (2013) studied the EKC in five ASEAN countries. Liu et al. (2017) examined Indonesia, Malaysia, the Philippines, and Thailand from 1970 to 2013 and found no evidence of a long-term inverted U-shaped EKC. However, Gillani and Sultana (2020) investigated the EKC framework for selected ASEAN states from 1970 to 2019 and strengthened the the result through increased energy efficiency and the greater adoption of renewable energy sources.

The results of ASEAN-specific research on the EKC varied among researchers. Saboori and Sulaiman (2013) found a U-shaped curve in Singapore and Thailand, but the relationship was statistically insignificant in Malaysia. Indonesia and the Philippines exhibited a U-shaped curve at a 10% significance level, indicating that they are still in the growth phase of the curve. These varied outcomes can be related to the five ASEAN states' different economic development stages.

The correlation between industrialization and CO2 emissions has been a growing scholarly study. China has witnessed notable environmental degradation despite the economic advantages of rapid industrialization. Empirical investigations have demonstrated that a 1% increase in industrialization in China results in a 0.3% rise in CO2 emissions (Liu & Bae, 2018). Similarly, Li and Lin (2015), utilizing the STIRPAT model, found a positive association between industrialization and CO2 emissions in low- and middle-income countries but no significant impact in high-income countries. These findings indicate that industrialization plays a role in CO2 emissions, particularly during the early stages of economic development, when it influences energy demand and consumption patterns. However, industrialization can also facilitate climate change adaptation and mitigation by improving energy efficiency and utilizing infrastructure and agglomeration (Zhou et al., 2013).

Within ASEAN countries, industrialization has been pinpointed as a primary driver of environmental sustainability challenges, evident in the substantial levels of CO2 emissions stemming from the transportation sector across nations like Malaysia, Indonesia, Thailand, the Philippines, Singapore, and Laos during the period from 1995 to 2015 (Jermsittiparsert, 2021). Tarasawatpipat and Mekhum (2020) also found a valid link between industrialization and greenhouse gas emissions in ASEAN countries, with varying degrees of significance in different nations.

The importance of environmentally friendly energy, particularly renewable energy, in reducing CO2 emissions cannot be overstated (Bölük & Mert, 2014; Shafiei & Salim, 2014). Replacing fossil fuels with renewable energy sources has the potential to reduce CO2 emissions significantly. Multiple studies have investigated the impact of renewable energy on CO2 emissions in ASEAN countries. For instance, Abbasi et al. (2020) examined the association between renewable energy and carbon dioxide emissions in Thailand from 1980 to 2018, utilizing the ARDL regression approach to assess both short- and long-term effects. Their findings supported the notion that transitioning to renewable energy consumption can assist Thailand in achieving its long-term CO2 emission reduction objectives. Similarly, Vo et al. (2019) studied Malaysia, the Philippines, and Thailand and identified a one-way causal relationship between economic growth, renewable energy usage, and CO2 emissions. However, they observed that the current level of renewable energy adoption is insufficient to mitigate CO2 emissions effectively.

While there is a consensus that renewable energy can help mitigate emissions, the indirect impact of renewable energy on pollution has yet to be extensively explored. Some studies have employed interaction models to investigate how energy usage influences the relationship between carbon emissions and variables related to economic growth. For example, Shah et al. (2022) argued that adopting renewable energy can reduce the positive contribution of agriculture to CO2 emissions, thereby offsetting agricultural contributions to climate change. Tang et al. (2020) evaluated the role of renewable energy in the industrial sector of OECD nations, while Dargahi and Khameneh (2019)observed the effects of renewable energy on structural shifts in OECD countries. However, the effects of renewable energy on carbon dioxide emissions can vary depending on the specific economic factors characterizing each country (Jimenez & Mercado, 2014).

Although the amount of renewable energy required to address environmental degradation remains inconclusive, it is widely acknowledged that increasing renewable energy usage in ASEAN countries will lead to lower CO2 emissions (Shafiq et al., 2020). Adopting renewable energy can contribute to reducing environmental damage. Liu et al. (2017), Nathaniel and Khan (2020), Zeraibi et al. (2021) have all demonstrated that renewable energy can effectively reduce CO2 emissions in ASEAN countries. Expanding renewable energy use fosters technological innovation and helps decrease ecological footprints. However, it is important to recognize that the extent of this impact may vary.

This current study aims to shed light on the moderating effect of renewable energy on the relationship between industrialization and CO2 emissions in ASEAN countries. By exploring this relationship within the framework of the EKC hypothesis, the research seeks to contribute to a deeper understanding of the dynamic relation between economic development, renewable energy adoption, and environmental sustainability. The findings of this study can offer valuable insights for policymakers and stakeholders in the ASEAN region as they strive to achieve their climate goals and promote sustainable economic growth.

Methods

This research uses data from the World Bank Development Indicator. ASEAN member states included in this study are Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, the Philippines, Singapore, and Thailand from 1990 to 2019, using the Pooled Mean Group-Autoregressive Distributed Lag (PMG-ARDL) estimator. Table 1 shows all variables and their descriptive statistics.

Table 1. Variable description and descriptive statistics

Variable	Description	Unit	Mean	Standard Deviation	Min	Max
CO	Carbon dioxide emission per capita	metric tons per capita	4.20	5.19	0.09	20.84
IND	Value added of Industry sectors to GDP	current USD	34.83	13.95	10.20	74.11
REN	Share of renewable energy consumption.	%	36.75	31.49	0.010	91.11
GDP	Gross domestic product per capita	current USD	8625.78	14008.19	49.26	66859.34
OPN	Share of value added of trade sectors to GDP.	% Ratio	117.63	94.87	11.85	437.32
AGR	Share of value added of agriculture sectors to GDP.	% Ratio	17.85	15.92	0.03	57.14

We expand the EKC framework by integrating the industrialization and renewable energy sectors and a set of empirically suggested controls. The comprehensive empirical model can be represented as follows:

$$CO_{it} = f(IND, RE, GDP, OPN, AGR)_{it} \quad (1)$$

The formulated econometric model is presented in equation (2):

$$lnCO_{it} = \beta_0 + \beta_1 lnIND_{it} + \beta_2 lnIND^2{}_{it} + \beta_3 RE_{it} + \beta_4 lnIND \cdot RE_{it} + \beta_5 lnGDP_{it} + \beta_6 OPN_{it} + \beta_7 AGR_{it} + \varepsilon_{it} \quad (2)$$

Where $\ln CO$ is the log natural of emissions per capita, $\ln IND$ is the value added of industry, $\ln IND^2$ is log natural square of value added of the industry. RE denotes renewable energy consumption as % total energy use; $\ln IND \cdot RE$ is the interaction terms of renewable energy and industrialization; i represents country, t represents time, and ε is the regression error term. For variable control, $\ln GDP$ denotes a natural logarithm of GDP per capita that represents the welfare of a country; OPN is trade openness calculated from the share of value added of trade (%); AGR is the share of value added of agriculture (%).

The EKC framework is a commonly used theoretical model for evaluating the relationship between development and CO2 emissions. The model initially proposes a quadratic relationship between GDP and environmental degradation. We augmented the EKC hypothesis by using IND and IND^2, which are also used as a proxy for economic development. Using the value of industrialization of each ASEAN country helps to explore the moderating impact of how renewable energy use mediates the relationship between industry value adds and CO2 emissions. The study also uses the moderating effect by multiplying industrialization and renewable energy $(IND \cdot RE)$ into the equation.

Based on *a priori* theory, the coefficient of $\ln IND$ should be positive ($\beta_1 > 0$) while the coeffithe cient of $\ln IND^2$ should be negative ($\beta_2 < 0$) to support the EKC hypothesis. The hypothesis expects that industrialization has an inverted U-shaped non-linear impact on emissions. Otherwise, the EKC theory is not supported. A positive interaction is expected between RE and CO ($\beta_3 > 0$). Likewise, for interaction variables of $\ln IND \cdot RE$ and CO, both positive and negative can be obtained according to the magnitude of industrialization in the coefficient ($\beta_4 > 0$). A positive connection is expected between $\ln GDP$ and CO ($\beta_5 > 0$). A positive interaction is anticipated between OPN and CO ($\beta_6 > 0$). A positive association is also expected between AGR and CO ($\beta_7 > 0$).

Moreover, calculating the elasticity will tell us how carbon dioxide emission changes when industrialization changes, when other covariates are assumed to be held constant:

$$e_{CO,IND} = \frac{d(\ln CO)}{d(\ln IND)} = \frac{dCO}{dIND} \cdot \frac{IND}{CO} = (\beta_1 + 2\beta_2 \ln IND + \beta_4 RE) \quad (3)$$

Equation (3) illustrates the elasticity effect of industrialization on carbon dioxide emissions, considering the integration of renewable energy in industrial activities. Industrialization is expected to impact the change in the carbon dioxide emissions rate. Consequently, the impact of renewable energy on mitigating the adverse effects of industrialization depends on the signs of the coefficients; if the coefficient of the industrial sector is positive ($\beta 1 > 0$) and the coefficient of the interaction term is negative ($\beta 4 < 0$), renewable energy will have a favorable influence in reducing the adverse impact of industrialization on emissions. Conversely, if $\beta 1 < 0$ and $\beta 4 > 0$, industrialization will hinder the positive effects of renewable energy on emissions. The statistical significance of the interaction term in these models will confirm the existence of moderating roles. Thus, this study postulates that the share of renewable energy may mitigate the effect of industrialization on carbon dioxide emissions. The turning point or maximum point slope is reached when the value equals 0, allowing us to calculate the turning point of the EKC when renewable energy scores are at zero, as follows:

$$\widehat{IND} = e^{-\frac{\beta_1}{2\beta_2}} \quad (4)$$

Moreover, to assess the influence of renewable energy, the turning point of the EKC is computed by incorporating the supplementary interaction variable, as demonstrated in the following equation:

$$\widehat{IND} = e^{-\frac{\beta_1+\beta_4 RE}{2\beta_2}} \quad (5)$$

We use several approaches to assess the impact of renewable energy on the relationship between industrialization and emissions. Initially, we conducted a cross-sectional dependence (CSD) test to identify any potential issues of cross-sectional dependency in the panel data series. Specifically, the Breusch and Pagan Lagrange Multiplier (LM) test is utilized as the primary method to detect such dependencies within the dataset. The Pesaran (2004) cross-sectional dependency test is also employed, particularly suitable for handling datasets with limited cross-sectional observations and short-time dimensions. The Pesaran CSD statistic tests the null hypothesis of no cross-sectional dependence. This test statistic is distributed as a two-tailed standard normal distribution, $N(0,1)$, when N tends to infinity (∞) and T is sufficiently large.

Mandala and Wu's estimation method involved using four-panel unit root tests to assess variable stationarity. Stationary tests used are Levin-Lin-Chao, Im, Pesaran, and Shin, Augmented Dickey-Fuller (ADF), and Phillips–Perron tests. These tests are used to determine the integration orders of the variables. A cointegration test investigates potential long-term relationships between two or more non-stationary time series variables. This technique is utilized to ascertain whether the non-stationary time series variables are in long-term equilibrium. The panel cointegration test proposed by Kao (1999) is utilized to determine the long-term integration of the panel series.

After conducting a cointegration test, we employ the PMG-ARDL estimator to strengthen the analysis of short-term cross-sectional units in the sample panel, which is better than other estimators. It estimates homogenous long-run effects while allowing for heterogeneous short-run impacts. Our analysis focuses on the seven largest emerging economies with identical long-term dynamics. However, due to country-specific macroeconomic factors, short-term dynamics may vary. Therefore, equation (6) provides a re-parametrization of equation (2) that characterizes the long-run and short-run cointegration equation of a dynamic panel.

$$\Delta \ln CO_{it} = \phi_i EC_{it} + \sum_{j=1}^{p-1} \lambda_{1j} \Delta \ln CO_{t-j} + \sum_{j=1}^{q-1} \theta \Delta X'_{i,t-j} + \varepsilon_{it} \Delta X = \begin{bmatrix} \Delta \ln IND \\ \Delta \ln IND^2 \\ \Delta RE \\ \Delta \ln IND \cdot RE \\ \Delta \ln GDP \\ \Delta OPN \\ \Delta AGR \end{bmatrix} \quad (6)$$

Error correction equation is expressed in: $\mathrm{EC}_{it} = \sum_{j=1}^{p} \delta_{1j} \ln CO_{t-j} + \sum_{j=1}^{q} \beta_{ij} X'_{i,t-j} + \varepsilon_{it}$

Where ϕ_i is the coefficient of error correction term that measures the speed of adjustment towards equilibrium; Δ is the first difference operator; j is the time lag; EC_{it} is the error correction term. The lag selection for this study is determined using the Akaike information criterion (AIC) test.

Subsequently, the Wald test is conducted to examine the significance of the interaction term parameter in the model. The t-statistics, F-statistic, and Chi-square statistics test the null hypothesis (H0) that the interaction term does not impact the equation. On the other hand, if the alternative hypothesis (H1) is supported, it indicates that the interaction term plays a significant role in the model. Thus, the Wald test of coefficient evaluates if the EKC model should include the interaction term.

Results and Discussion

Table 2 shows a cross-sectional dependency analysis. The Breusch-Pagan LM test, Pesaran scaled test, and Pesaran CD test reject the null hypothesis of cross-sectional independence at the significance levels of 1% and 10%, respectively, suggesting the presence of cross-sectional dependence.

Table 2. Cross-sectional Dependency Test

Test	Statistic	d.f.	Prob.
Breusch-Pagan LM	400.7957***	36	(0.000)
Pesaran scaled LM	42.991***		(0.000)
Pesaran CD	-1.678*		(0.093)

Notes: Standard errors in parentheses, *** and ** indicated statistically significant at 1%, and 5%, respectively.

Table 3 presents the results of four-panel unit root tests (LLC, IPS, PP-Fisher, and ADF-Fisher). The test statistics for all variables are not statistically significant, indicating that the null hypothesis of non-stationarity is accepted for all variables. However, after performing the first difference, the test statistics for all variables become statistically significant at the 1% level, suggesting that most series are integrated of first order (1).

Table 3. Results from Panel Unit Root Test

Test	Variables	Level	First Difference
Levin, Lin, and Chu	Carbon Dioxide	1.537	-6.395***
	Industrialization	-0.171	-8.410***
	Renewable energy	-3.612***	-9.544***
	Gross Domestic Product	0.216	-9.195***
	Trade Openness	-0.399	-7.850***
	Agriculture	-1.303*	-2.711***
Im, Pesaran and Shin W-Stat	Carbon Dioxide	3.718	-6.997***
	Industrialization	2.457	-8.088***
	Renewable energy	-3.264***	-10.63***
	Gross Domestic Product	2.921	-8.017***
	Trade Openness	-4.009***	-12.406***
	Agriculture	-0.966	-7.335***
ADF Fisher Chi-square	Carbon Dioxide	15.47	105.08***
	Industrialization	7.908	98.493***
	Renewable energy	56.841***	127.628***
	Gross Domestic Product	4.756	96.206***
	Trade Openness	55.045***	152.239***
	Agriculture	28.223*	95.462***
PP Fisher Chi-square	Carbon Dioxide	33.106**	122.761***
	Industrialization	7.439	114.346***
	Renewable energy	41.526***	154.524***
	Gross Domestic Product	4.358	101.389***
	Trade Openness	18.299	139.774***
	Agriculture	43.816***	160.006***

Notes: Standard errors in parentheses, *** and ** indicated statistically significant at 1%, and 5%, respectively.

Table 4 presents the outcomes of the Kao panel cointegration analysis. The test statistic estimate from the Kao test is statistically significant at the 1% level. These findings demonstrate that panel cointegration tests reject the null hypothesis, indicating that the estimated model exhibits cointegration for all three specifications.

Table 4. Results of the Kao Residual Cointegration

Test Statistic	t-Statistic	Prob.
ADF	-3.435***	(0.000)

Notes: Standard errors in parentheses, *** and ** indicated statistically significant at 1%, and 5%, respectively.

Long-run and short-run estimation in ASEAN

In this section, we present the long-term elasticity estimates of CO2 emissions concerning industrialization, renewable energy, moderating variables of industrialization and renewable energy, and GDP per capita. The PMG-ARDL model estimation in Table 5 is the basis for these computations, with all variables estimated in their natural logarithm form.

The results in Table 5 indicate that, in ASEAN, all coefficient signs have results aligned with the hypothesis. Most variables present statistical significance at the 1% level, except for GDP, which is statistically significant at the 10% level. The negative significant coefficient of $\ln IND$ and the positive sign of $\ln IND^2$ provide evidence ofprovide Environmental Kuznets Curve (EKC) of industrialization in ASEAN. This result suggests that carbon emissions per capita increase with industrialization, but beyond a certain level of industrialization (the turning point), they begin to decrease.

In the long run, the share of renewable energy reduces the percentage of carbon emissions per capita, as indicated by the negative coefficient on both RE and $ln(IND) \cdot RE$. Additionally, GDP per capita contributes to increase in emissions where a 1% increase in GDP per capita leads to a 0.2% increase in carbon emissions per capita.

Table 5. ARDL Estimation

Variable	Coefficient	Std. Error
Long Run Equation		
$\ln IND$	1.325***	0.153
$\ln IND^2$	-0.031***	0.003
RE	-0.010*	0.006
$\ln IND \cdot RE$	-0.002***	0.000
$\ln GDP$	0.203***	0.018
AGR	-0.019***	0.002
OPN	-0.004***	0.000
Short Run Equation		
$COINT$	-0.341	0.264
$\Delta \ln CO$ (-1)	-0.008	0.214
$\Delta \ln CO$ (-2)	-0.019	0.144
$\Delta \ln CO$ (-3)	-0.038	0.150
$\Delta\, lnIND$	-5.613**	2.706
$\Delta\, lnIND$(-1)	-2.088	2.838
$\Delta\, lnIND^2$	-0.114**	0.054
$\Delta\, lnIND^2$ (-1)	-0.045	0.068
$\Delta\, RE$	-11.400	15.214
$\Delta\, RE$(-1)	-39.449	37.387
$\Delta \ln IND \cdot RE$	-0.363**	0.521
$\Delta \ln IND \cdot RE$(-1)	-1.811**	1.725
$\Delta \ln GDP$	-0.095	0.191
$\Delta \ln GDP$ (-1)	-0.149	0.206
$\Delta\, AGR$	-0.101	0.070
$\Delta\, AGR$ (-1)	-0.042	0.091
$\Delta\, TRD$	-0.001	0.000
$\Delta\, TRD$ (-1)	-0.001	0.000
C	-4.096	3.154

Notes: Standard errors in parentheses, *** and ** indicated statistically significant at 1%, and 5%, respectively. Model selection method: Akaike info criterion (AIC).

Notably, a 1% increase in OPN and the share of AGR corresponds to a 0.4% and 1.9% rise in carbon emissions per capita, respectively. Based on previous research, Nathaniel (2021) demonstrates that the effect of trade on ecological footprint differs in the long and short term. International trade worsens environmental degradation in the short run but not in the long run. This effect suggests that trade provides emerging economies access to environmentally friendly technologies over time. Aside from the fact that trade activities magnify the transition from a pre-industrial economy to an industrialized economy, these findings validate the Technology Spillover Effect. Trade liberalization plays a pivotal role in facilitating the transfer of advanced technology from technology-exporting countries to technology-importing countries, leading to enhanced productivity and improved CO2 emission performance on a global scale (Du & Li, 2019).

Research conducted by the Food and Agriculture Organization (FAO) suggests that the agricultural sector has significant potential to reduce global emissions by 20-60% by 2030 through reduced deforestation and increased renewable energy generation (Liu et al., 2017). Agriculture's promotion of renewable energy development and CO2 emission reduction holds promise for mitigating the impacts of global warming and climate change (Appiah et al., 2021)

In the short run, the estimated coefficient for ECT is negative and statistically significant, indicating the presence of a long-run equilibrium relationship among the series. Moreover, variables of RE, $\ln GDP$, AGR, and OPN are not statistically significant in this panel. The findings regarding industrialization in the short run align with the long-run results, demonstrating the existence of the inverted U-shaped Environmental Kuznets Curve (EKC) (Table 6). This finding confirms that in the early stage of industrialization, the increase of value added by an industry to the GDP will increase carbon emissions. After reaching the peak, the increase in the industry will reduce emissions.

The investigation into causality among the variables reveals evidence of a relationship between the value added by the industry and CO2 emissions in both the short and long run. Previous studies, such as the one conducted by Gillani and Sultana (2020) on selected ASEAN countries, have also tested the EKC framework. Their findings support the EKC theory, showing a negative effect of GDP and a positive effect of GDP square on the relationship.

Table 6. EKC Hypothesis in Long- and Short-run ASEAN Countries

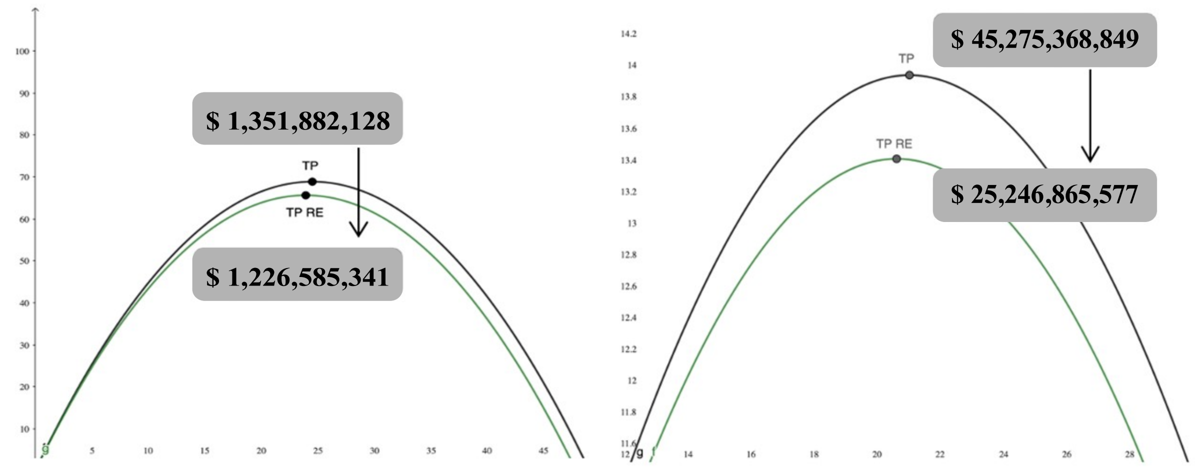
	Coefficient of $\ln IND$		Coefficient of $\ln IND^2$		Results
Long Run	1.325	$\beta_1>0$	-0.031	$\beta_2<0$	Inverted-U shaped relationship
Short Run	5.613	$\beta_1>0$	-0.114	$\beta_2<0$	Inverted-U shaped relationship

Turning point of Environment Kuznets Curve in ASEAN

Calculating the EKC's turning point at zero renewable energy scores is observed at $1,351,882,128 in the long run and $45,275,368,849 in the short run. However, considering ASEAN countries' average renewable energy consumption rate, the EKC's peak turning point reaches $1,226,585,341 in the long run and $25,246,865,577 in the short run. These findings suggest that a growth in industrialization, accompanied by a greater dependency on renewable energy, reduces emissions, resulting in a faster shift of the turning point of the Environmental Kuznets Curve (EKC) compared to the EKC without considering renewable energy.

Our findings aligned with previous studies, such as Dargahi and Khameneh (2019) and Tang et al. (2020). These findings highlight the potential for economic growth to be significantly enhanced by reducing pollution levels and adopting improved technologies, contributing to the overall environmental quality in ASEAN countries. Moreover, technological advancements also promote the adoption of alternative energy sources and renewable energy production, fostering the expansion of the secondary, tertiary, and services sectors, all of which help to mitigate carbon emissions (Kaika & Zervas, 2013).

The EKC hypothesis posits that improving the environment involves replacing outdated and polluting technologies with new and cleaner ones, representing the technique effect of economic growth. As a result, using renewable energy is considered crucial, as it is seen as an effective means of reducing CO2 emissions by advancing clean technologies. The interaction factors might mitigate industrialization's impact on CO2 emissions. Given the enormous potential for ASEAN industrialization to develop clean energy sources, which may accelerate its industry sector to improve its environmental performance, the focus is renewable energy. Numerous studies have demonstrated that renewable energy consumption may dramatically reduce carbon emissions, but few have explained how this may influence the EKC's turning point.



Long-run Estimation EKC in ASEAN Short-run Estimation EKC in ASEAN

Figure 4. Long-run and Short-run Estimation Environmental Kuznet Curve (EKC) in ASEAN

Figure 4 illustrates our results that encouraging renewable energy consumption can hasten EKC's transition to its turning point. Increasing renewable energy may accelerate the EKC's turning point, lowering carbon emissions. Therefore, a nation (or group of nations) can accelerate the EKC's tipping point by boosting renewable energy usage. It presents a possible response to the issue of whether the shift in energy consumption caused by the growth of renewable energy is a crucial element influencing the EKC tipping point.

Short-run country-specific in ASEAN member state

Varied outcomes regarding the Environmental Kuznets Curve (EKC) hypothesis among ASEAN member states have been observed. The results indicate that the EKC exists in most ASEAN countries, including Brunei, Cambodia, Laos, Myanmar, Malaysia, Singapore, and Thailand, as evidenced by the confirmation of an inverted U-shaped curve. However, the EKC hypothesis does not hold in the case of Indonesia and the Philippines. Considering the coefficient of $\beta 1 < 0$, it is possible to say that the EKC relationship of industrialization and emission has a U-shaped relationship.

Several works of literature have also validated these varied results of the EKC hypothesis in ASEAN member states. In the case of the Philippines and Indonesia, Saboori & Sulaiman (2013) indicate that Indonesia and the Philippines remain in the growing portion of the carbon Kuznets curve. Due to the varying levels of economic development among ASEAN countries and the unequal distribution of economic progress across the region, diverse outcomes are expected. From 1970 to 2013, Liu et al. (2017) discovered that the estimates do not substantiate the existence of the inverted U-shaped Environmental Kuznets Curve (EKC) in particular ASEAN countries, including Indonesia, the Philippines, and Thailand.

Similar findings were reported by Chandran and Tang (2013), who also found no evidence supporting the EKC for several ASEAN member states. Notably, some countries within ASEAN, such as Indonesia and the Philippines, are experiencing the emergence of a new consumer class driven by rising incomes. As consumer spending per capita increases, these factors have pushed demand to intensify their industry sectors to cope with the region's advancement. Moreover, there are serious efforts to increase their renewable energy consumption despite the predominantly emission-intensive industry, especially manufacturing, which demands electricity and extensive heat.

Examining the role of renewable energy in addressing environmental degradation in ASEAN countries, Table 8 computes the turning point of the Environmental Kuznets Curve (EKC) hypothesis. While the previous section provided results for ASEAN as a whole, inconsistent findings are evident when analyzing each country individually.

Table 7. EKC Hypothesis in ASEAN Countries (Short-run)

Countries	Coefficient of $\ln IND$		Coefficient of $\ln IND^2$		Results
Brunei	6.864	$\beta_1 > 0$	-0.158	$\beta_2 < 0$	Inverted-U shaped relationship
Indonesia	-3.5631	$\beta_1 < 0$	0.070	$\beta_2 > 0$	U-shaped relationship
Cambodia	14.673	$\beta_1 > 0$	-0.348	$\beta_2 < 0$	Inverted-U shaped relationship
Laos	16.214	$\beta_1 > 0$	-0.289	$\beta_2 < 0$	Inverted-U shaped relationship
Myanmar	7.3477	$\beta_1 > 0$	-0.089	$\beta_2 < 0$	Inverted-U shaped relationship
Malaysia	4.304	$\beta_1 > 0$	-0.040	$\beta_2 < 0$	Inverted-U shaped relationship
Philippines	-15.636	$\beta_1 < 0$	0.313	$\beta_2 > 0$	U-shaped relationship
Singapore	16.650	$\beta_1 > 0$	-0.321	$\beta_2 < 0$	Inverted-U shaped relationship
Thailand	4.378	$\beta_1 > 0$	-0.080	$\beta_2 < 0$	Inverted-U shaped relationship

The moderating effect of renewable energy in industrialization in Myanmar, Singapore, Cambodia, Laos, and Malaysia reduces the EKC's turning point. These findings align with the predictions made by Nathaniel and Khan (2020) and Zeraibi et al. (2021), supporting the notion that renewable energy contributes to lower ecological footprints in the Philippines, Singapore, and Malaysia. Singapore serves as an illustrative example, where Nathaniel and Khan (2020) assert that the environmental impact of economic expansion is minimized due to the country's reliance on natural gas instead of coal for energy generation. This strategic decision has resulted in reduced emissions associated with economic growth. Additionally, the nation is more aggressive than other ASEAN members in combating climate change by acquiring clean technology and constructing infrastructures.

Table 8. Turning point for EKC Hypothesis

Short-run Country Specific	EKC of Industrialization in billion US $	EKC of Industrialization with Renewable Energy in Billion US $	Results
Brunei	2,559.467	2,634.887	Increasing
Cambodia	1,411.662	1,407.920	Decreasing
Laos	4,929.951	3,130.602	Decreasing
Myanmar	1,948.935	1,931.287	Decreasing
Malaysia	82,523.523	48,894.278	Decreasing
Singapore	32,058.865	31,795.514	Decreasing
Thailand	68,637.478	78,914.608	Increasing

Brunei and Thailand's estimation shows that despite the indirect effect of renewable energy in industrialization, these countries adjusted turning point increases. Value-added industries with more renewable energy produce more carbon emissions at this region's early stages of economic development. Similar to the findings for Thailand, as indicated by Vo et al. (2019), this study also suggests that the current level of renewable energy usage in ASEAN countries might need to be revised to mitigate CO2 emissions effectively. Furthermore, renewable energy has a limited impact on reducing environmental degradation. However, Gill et al. (2018) argue that a shift towards less polluting renewable energy sources could significantly accomplish sustainable development objectives.

Impact of renewable energy on industrialization sectors towards emissions in ASEAN

The industry's value added to GDP derived from 2019 encompasses industrialization's short-term and long-term impact. Similarly, renewable energy data was obtained from the percentage of renewable energy consumption in 2019. Table 9 illustrates the relationship between industrialization and renewable energy concerning carbon emissions in ASEAN, as estimated through short and long-run elasticity analysis. Deriving from our previous results in PMG-ARDL estimation, the short-run elasticity is explained as follows:

$$\frac{\%\,CO}{\%\,IND} = 5.613 + 2 \times -0.114 \ln IND - 0.363RE$$

and the long-run elasticity is described through:

$$\frac{\%\,CO}{\%\,IND} = 1.325 + 2 \times -0.031 \ln IND - 0.002RE$$

Table 9. Elasticity of Industrialization and Renewable Energy to CO2 in ASEAN

Countries	Results (%) in Short-run	Results (%) in Long-run
Brunei	-0,75	-0,12
Indonesia	-1,67	-0,37
Cambodia	-0,78	-0,13
Laos	-0,70	-0,10
Myanmar	-1,01	-0,19
Malaysia	-1,38	-0,30
Philippines	-1,34	-0,28
Singapore	-1,31	-0,27
Thailand	-1,47	-0,31

Table 9 projects the short-run elasticity of industrialization to the share of renewable energy consumption in carbon dioxide emissions per capita for each ASEAN country in 2019. We can conclude that assuming ceteris paribus, every 1% increase in industrialization will reduce carbon dioxide per capita by 0.75% in Brunei, 1.67% in Indonesia, 0.78% in Cambodia, 0.70% in Laos, 1.01% in Myanmar, 1.38% in Malaysia, 1.34% in the Philippines, 1.31% in Singapore, 1.47% in Thailand.

The third column of Table 9 shows the long-run estimation of the elasticity of value added from the industry concerning the share of renewable energy consumption in carbon dioxide emissions per capita for each ASEAN country in 2019. Every 1% increase in industrialization will reduce carbon dioxide per capita by 0.12% in Brunei, 0.37% in Indonesia, 0.13% in Cambodia, 0.1% in Laos, 0.19% in Myanmar, 0.3% in Malaysia, 0.28% in the Philippines, 0.27% in Singapore, 0.31% in Thailand. Based on both short-run and long-run analyses, it is confirmed that the share of renewable energy mitigates the impact of industrialization on carbon dioxide emissions per capita. This observation suggests a structural shift in the industry, with technological advancements and stricter environmental regulations aligning with growing environmental consciousness. Moreover, regarding renewable energy consumption, industrialization negatively influences carbon dioxide emissions. In the early phases of industrialization, many nations pursued high GDP development and supported industrialization by using vast quantities of fossil fuels. As industrialization reaches significant levels, there is a concerted effort to phase out or incentivize industries with high pollution levels and energy consumption, encouraging their transition towards adopting renewable and clean energy sources.

Consequently, the favorable impact of industrialization on carbon dioxide emissions has diminished at this point. In addition, industrialization has always profited from technical advancements, such as the enhancement of industrial output and energy technology development. During industrialization, these have reduced reliance on fossil fuels to some extent, as shown by the elasticity from our finding in Table 9.

The effectiveness of implementing the EKC is highly dependent on the comparative resource advantages of each country. The expectation is for countries to specialize in resource-intensive production while adhering to environmentally friendly regulations. However, a concerning trend emerges where developed countries shift the impact of environmental pollution to developing nations. Strengthening international cooperation in energy and environmental sustainability is urgent regarding this issue. This action involves a commitment from each country to foster environmental sustainability through various innovations, such as technology transfer, which can promote sustainable development across the globe.

Post Estimation Wald Test for Interaction Variable

The Wald test of coefficient restriction was employed to assess the necessity of including the interaction term $(\ln IND \cdot RE)$ in this study (see Table 10). As indicated by the t-statistics, F-statistic, and Chi-square statistics, the results reject the null hypothesis (H0). This supports the inclusion of the interaction term in the EKC model for the current research.

Table 10. Wald Test Results

Test Statistic	Value	Degree of Freedom	Probability
t-statistic	-6.0696	92	0.000
F-statistic	36.841	(1, 92)	0.000
Chi-square	36.841	1	0.000

Notes: Standard errors in parentheses, *** and ** indicated statistically significant at 1%, and 5%, respectively.

Conclusion

This study examines industrialization, renewable energy, and carbon emissions in nine ASEAN nations from 1990 to 2019. PMG-ARDL provides for short-run dynamics throughout the sample panel's cross-sectional units. Incorporating industry and renewable energy departs from the EKC framework. Short-run and long-term tests show that ASEAN has industrialized EKC. Renewable energy also mediates industry-CO2 emissions. We found that switching to renewable energy can reduce ASEAN industrialization's environmental impact—Brunei, Laos, Myanmar, Malaysia, Singapore, and Thailand. EKC is absent in the Philippines and Indonesia in the short term, though not statistically significant. The studies show that Indonesia and the Philippines are still growing on the carbon Kuznets curve. This varied outcome is expected since the nine ASEAN nations analyzed are at different economic stages.

We also find that renewable energy can move the turning point of CO2 emissions per capita in Cambodia, Laos, Myanmar, the Philippines, Singapore, and Malaysia, but not Brunei and Thailand, by reducing industrialization in each ASEAN state. As most ASEAN may minimize the EKC curve's turning point, renewable energy can mitigate industrialization's environmental effect. This analysis also estimates industry and renewable energy consumption elasticity by estimating per capita carbon dioxide emissions. Industrialization will cut carbon dioxide per capita in all ASEAN nations in the short and long term. It also shows that renewable energy cuts industrialization's direct carbon dioxide emissions.

This study should have added other variables and expanded the observation period. Therefore, future research could examine the impact of factors like human capital, population dynamics, and foreign direct investment (FDI) on explaining carbon emissions, along with investigating the drivers impacting the adoption of renewable energy in another region. Also, we acknowledge that spatial autocorrelation might occur in this issue. Thus, further study might consider this matter to complete these findings and provide more appropriate and practical policy recommendations.

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Economic Journal of Emerging Markets, 15(2) 2023, 199-211

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The impact of population aging and fertility rate on economic growth in Malaysia

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Article Info

Article history:
Received 04 September 2023
Accepted 25 October 2023
Published 31 October 2023

JEL Classification Code:
C01, C22, J11, J13, O40, O47.

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DOI: 10.20885/ejem.vol15.iss2.art7

Abstract

Purpose — This study aims to examine the impact of population aging and fertility rates on economic growth in Malaysia for the sample spanning from 1961 to 2020.

Method — The study uses an Autoregressive Distributed Lagged (ARDL) model to examine the relationship between economic growth, the aging population, fertility rate, capital stock, and employment rate.

Findings — The main results provide evidence of a long-run relationship between aging, fertility rate, employment, and capital stock on Malaysian economic growth. The results also show that the aging population harms economic growth in the long run, but a decline in the fertility rate has been favorable to long-term economic growth.

Implication — These findings have significant implications for the execution and formulation of national aging and demographic policies and government efforts to achieve long-term fiscal sustainability.

Originality — This study empirically investigated the link between population aging and economic development, reflecting recent demographic trends in Malaysia. This study uses current data and an Autoregressive Distributed Lagged (ARDL) technique to analyze long-term economic growth and its association with supply-side determinants.

Keywords — Aging population, ARDL model, economic growth, employment, the fertility rate

Introduction

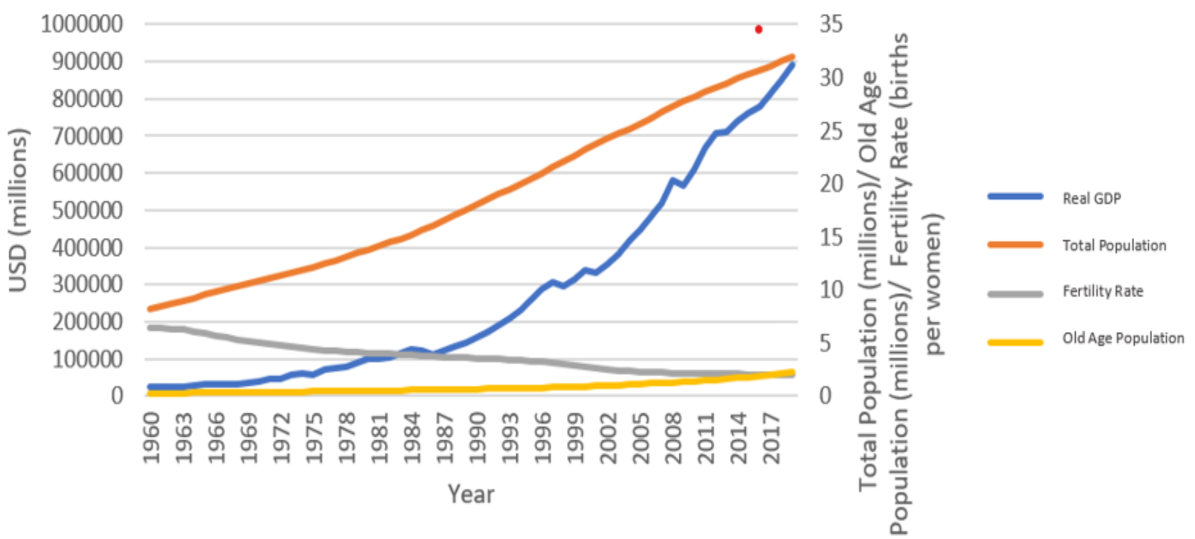
The Sustainable Development Goals (SDG) agenda for 2030 is focused on addressing population aging and community health (SDG, 2030). However, global trends in recent years have demonstrated a rapid rise in population aging. According to the United Nations (2020), in 2020, 727 million individuals over 65 are living in the world. The United Nations (2020) anticipated that the ratio of individuals 65 and above globally will climb from 9.3 percent (2020) to roughly 16 percent (2050). Over the next 30 years, the world's elderly population is expected to grow by more than half to more than 1.5 billion people by 2050 (United Nations, 2020b). Because of the exceptional phenomena of population aging, fundamental fluctuations in population demands and capabilities are occurring, with potentially significant consequences for savings, employment, consumption, and the general state of the economy (Bloom & Luca, 2016).

P ISSN 2086-3128 | E ISSN 2502-180X

A growing percentage of the population is anticipated to be over 65 due to falling fertility and increased life expectancy. According to the United Nations (2019), a 65-year-old can expect to live an additional 17 years on average worldwide from 2015 to 2020. However, the longer life expectancy of the old population will increase to 19 years between 2045 and 2050 due to improvements in the healthcare system. In contrast, the average fertility rate worldwide in 2019 was 2.458 births per woman, a decrease of 0.41 percent from 2018 (United Nations, 2019b). In addition, the United Nations (2020a)has also projected that the global fertility rate will decline, reaching 2.2 births per woman in 2050 and 1.9 in 2100. Fertility rates vary by country; in 2019, the fertility rates in more developed nations like Japan and Europe were 1.52 and 1.36, respectively, lower than the global average. A decline in birth rates will eventually result in a smaller population overall, concerns about long-term replacement in the working-age population, and a labor shortage.

With a shrinking population and increasing number of elderly citizens, governments are concerned about ensuring that the country's productive human resources are available to meet its future needs. As the older population grows, the cost of providing pensions, healthcare facilities, and care centers for the elderly will rise. Although voluminous studies have examined the impact of population aging on economic growth in developed countries, the findings still need clarification. Several economists such as Auerbach and Kotlikoff (1987), Hviding and Mérette (1998), and Miles (1999) first proposed hypotheses that a rapidly growing aging population would lead to lower national savings rates and lower real per capita production.

According to government forecasts, Malaysia's population will reach 32.7 million people in 2021, with a rise in elderly persons from 7 percent to 7.4 percent from the previous year (Department of Statistics Malaysia, 2021). Figure 1 depicts the overall relationship between Malaysia's population, elderly population, fertility rate, and accurate Gross Domestic Product (GDP). The graph shows that from 1960 to 2019, Malaysia's population grew steadily with real GDP, demonstrating a positive relationship between total population and real GDP. As this has been happening, Malaysia's fertility rate has been steadily declining, suggesting a negative correlation between fertility rates and real GDP. The overall population is growing despite a declining fertility rate because of the rise in life expectancy. The Department of Statistics Malaysia or DOSM (2021) forecasts a decline in the younger age group in 2021, from 23.3 percent in 2020 to 23.0 percent in 2021, but a significant increase in the elderly age group, as people have expected to live longer. This is due to the low fertility rate and higher life expectancy. Malaysia is expected to grow gradually to 20% by 2056, designating Malaysia as a "super-aged" nation. However, the combination of low fertility rates and an increasing elderly population raises concerns about the possibility that Malaysia will be the next super-aging country.



Source: World Bank

Figure 1: Total population, old age population, fertility rates, and real GDP in Malaysia

According to forecasts by the United Nations in 2009, Malaysia would become an old country by 2030, with 15% of the total population being 60 or older. The government of Malaysia took early action to address the issue of population aging by passing the National Policy for the Aged in 1995 and the National Policy for Older People (NPOP) in 2011. This number recognizes that Malaysia will soon face an aging population. By offering services geared towards the elderly and fostering circumstances that promote old-age well-being, these policies have strongly emphasized empowering individuals, families, and communities. The government supports projects to enhance care and infrastructure for the elderly under the 11th Malaysia Plan. The government supports active aging by providing additional opportunities for the elderly to keep studying and gaining knowledge and skills in collaboration with universities, community colleges, and the Senior Citizen Activity Center. Also, social awareness initiatives on volunteering will encourage retired professionals to contribute their knowledge, expertise, and experience to the community.

On the other hand, the government aspires to reach a population of 70 million by 2100, as stated in the Population Policy Malaysia vision. The goal of reaching 70 million people is to create a market and demand for domestic manufacturing goods. This forecast of future population increase significantly depends on the course of future fertility. When projected across decades, variations in fertility patterns might cause significant population differences. Raising two important aspects of the population is necessary to achieve this goal: the gross birth rate and the fertility rate. With the fertility rate, the United Nations estimates Malaysia's population will reach only 40 million by 2100, or under half of the original goal (United Nations, 2019a). Malaysia has 32.37 million people overall as of 2020, and its average fertility rate was 1.98 births per woman (World Bank, 2019). By increasing the number of people who are working age, lowering the dependence ratio among the elderly, and minimizing the possibility of a long-term labor shortage, among other things, higher fertility and birth rates may also help to lessen the adverse consequences of population aging.

Given this context, the study aims to investigate the impact of Malaysia's aging population and low birth rate on the country's economic development. The results of this study are relevant to both the body of knowledge and policymakers in the following ways: first, by demonstrating how the relationship between the old age population and fertility rate in national economic growth affects policymakers' ability to implement government policies, particularly the Malaysian Population Policy and the National Senior Citizens Policy (DWEN). With the most recent statistics, policymakers can update the Malaysian Population Policy and the National Senior Citizens Policy (DWEN) to reflect the most recent demographic trends. The study also adds to the corpus of knowledge in the following ways from earlier research. Second, this study uses recent data and an ARDL technique to model Malaysia's economic growth while considering the aging population and fertility rate. To further understand how the supply-side determinants reflect long-run economic growth, this study uses the supply-side model to analyze the growth empirics in Malaysia, considering the roles of capital stock and productive labor (employed).

The three most essential economic growth theories are the classical, neo-classical, and modern. Domar (1946), Harrod (1939), Solow (1956), Swan (1956) (neo-classical growth), and Adam Smith (classical growth) were the most significant proponents of economic growth theory (modern growth). According to classical economists like Adam Smith (1776) and David Ricardo, understanding how economies expand and contract helps shed light on the relevance of economic growth. Neo-classical theorists like Solow and Swan emphasize that how people interact with the economy within a framework necessary for growth is important. The modern perspective emphasizes that overcoming the fundamental economic issue of supplying unending needs with finite resources leads to growth. It is also suggested that information is essential to development throughout the conversation. Adam Smith and David Ricardo are generally regarded as having had the most significant intellectual influence on the advancement of the conventional theory of economic growth. They suggested that population growth reaches a point after which, if it continues, the economy's wealth diminishes.

Romer (1994) developed a different endogenous growth model that suggests investments in knowledge and human capital are important drivers of economic progress. According to a study by Peterson (2017), high-income countries with slow population growth are more likely to experience social and economic issues. On the other hand, it has been anticipated that rapid population growth in low-income countries will stifle progress. Although many people are against it, international migration might help to reduce these discrepancies. In addition, he argues that fewer people migrating and slower population growth will likely lead to greater economic inequality on a national and international scale in the future.

Even though the link between population aging and economic development has been widely investigated in the previous literature, the conclusions are quite equivocal, with a combination of positive and negative results reported. The neoclassical growth model developed by Solow (1956) gives a theoretical clarification for the adverse relationship between population increase and per capita production growth in the United States. The model is referred to as the exogenous growth in certain circles. According to this model, rapid population growth leads to less capital per worker and slower economic advancement (Bucci, 2015). Besides, Mankiw et al. (1992) have extended Solow's model to include human capital accumulation, and they have shown that greater population growth rates are associated with lower steady-state economic growth rates.

Between 2006 and 2030, it is anticipated that the number of elderly persons in less developed nations will grow by 140 percent, compared to a 51% increase in more developed countries over the same period (Krug et al., 2002). According to their research, Powell and Cook (2009) also specified that if the worldwide population aging patterns continue to climb, the number of elderly people worldwide will surpass the number of young people in 2050. Four-generation households may become increasingly widespread as life expectancy increases and the total of persons aged 85 and above increases. According to relatively recent research by Huang et al. (2019), an aging workforce significantly influences economic growth. On the other hand, the old-age dependency fraction has a statistically substantial negative impact on economic development. They concluded that human capital is critical for total factor productivity (TFP) advance and that population aging significantly impacts productivity via TFP. Increases in longevity positively influence per capita production growth, but reductions in fertility have a negative impact, according to Prettner's (2013) research using endogenous growth models.

In addition, according to Fougère and Mérette (1999), population aging may provide chances for future generations to engage in human capital development, encouraging economic growth and mitigating the negative effect of aging on production per capita. In Japan, the population aged 70-74 increased and connected with a drop in economic growth. However, a rise in the number of people aged 75 and older has increased economic growth (Oliver, 2015). Beaudry and Collard (2003) noted that in 18 countries, including Japan, a strong systematic relationship exists between the growth rate of the 15-64 age group and economic success. Mee (2019) made the case that population aging might raise fiscal spending by increasing social welfare spending and spending on the young and old.

On the other hand, using data from OECD nations, Lindh and Malmberg (1999) demonstrate that employees aged 50-64 significantly improve productivity, but workers aged 65 years and older negatively influence production. However, Aiyar and Ebeke (2016) discovered that an increasing share of the workforce aged 55-64 years results in a considerable decrease in overall output. On the other hand, the ratios of old-age reliance and young-age dependency do not affect the situation. Furthermore, Manabu and Hosoyama (2004) found that population aging reduces the growth rate of the workforce and capital stock and that this demographic shock leads to an increase in the financial burden in the form of taxes and pensions, a reduction in economic welfare, and a significant decrease in the growth rate of the economy. Miles (1999) further indicates that the population's aging will significantly negatively impact national saving rates and real production per capita over the next several decades.

In contrast, Feyrer (2007) discovered that the 15-39 age group is linked with poorer productivity, but the 40-49 age group is associated with better productivity after examining the share of the workforce by age group in 19 OECD nations over the years 1990-1995. Furthermore, it was shown that being above the age of 50 was connected with decreased production than being between the ages of 40 and 49. According to Lisenkova et al. (2012), through the aging population, the individual labor productivity level should be lowered since the physical capability of the workforce diminishes with time. On the other hand, Göbel and Zwick (2012) discovered no statistically significant variations in the age-productivity relationship between the manufacturing and services sectors.

Another topic that has recently gained the attention of researchers is the link between health and economic development. Positive cross-country correlations between health and economic development are widely documented. Nevertheless, the underlying processes are complicated to identify between one nation and another because determining causality and quantifying it is empirically difficult, the relationship changes as economic development progresses, and many aspects of health may have additional economic implications (Bloom et al., 2018). Barro (1996, 2013) suggests that health status is essential to economic growth and is a more significant predictor of eventual economic development than initial education. Aside from that, excellent health has been shown to contribute significantly to economic development, both short and long-term (Boachie, 2017). Adult survival rates (ASR), a measure of health status used by Bhargava et al. (2001), correlate positively with GDP growth rates in low-income countries. Furthermore, Lorentzen et al. (2008) demonstrate that declining adult mortality promotes lower risk-taking behavior, lower fertility, more significant investments in physical capital, and higher economic growth. Additionally, Weil (2007) proves that health is a crucial factor in cross-country data that affects how much income varies.

There needs to be more research looking at how population increase, population aging, and health status affect economic growth in Malaysia. Prior research only addressed the population problem. For instance, Nor (2018) discovered that Malaysia's rising aging trend is brought on by reducing fertility by women delaying marriage or getting married later in life and population growth in terms of education, health, and life expectancy. Ismail et al. (2015) examined the impact of aging on economic development using data from 1970 to 2013. Based on the findings, only the fertility rate has a statistically meaningful long-run link and is associated with stronger economic development in Malaysia. They concluded that, notwithstanding Malaysia's aging population, stabilizing economic development would be achieved by increasing investments in human capital. In a recent study, (Taasim, 2020) examined how the aging population impacted economic development between 1990 and 2017. He connected population aging, education spending, and long-term economic growth. As a result, he recommended that the government enhance spending in the education sector to develop a better human capital potential and address the aging phenomenon simultaneously.

Methods

Data Description

The study utilizes the World Bank Open Data and Penn World Table Database, which covered the years 1961 through 2019. The factors taken into account include the real Gross Domestic Product (RGDP) on the expenditure side, the capital stock (CAP), the labor force (EMP), the elderly population (AGING), and the fertility rate (FR). While other explanatory variables are expressed in percentage terms (%), RGDP and CAP are in log form. Table 1 summarises the variables employed in the investigation.

Table 1. Dependent and Independent Variables

Abbreviation	Variables	Unit of Measurement	Expected Sign
RGDP	Expenditure-side real GDP at chained PPPs	Millions 2017 USD	
CAP	Capital Stock at current PPPs	Millions 2017 USD	Positive
EMP	Labour Employed	Millions	Positive
AGING	Old Age Group Population	Percent of total population (%)	Negative
FR	Fertility Rate	Total (births per woman)	Negative

Empirical Model

An Autoregressive Distributed Lag (ARDL) model, as proposed by Pesaran et al. (1999, 2001) is employed to examine the relationship between economic growth and the aging population and fertility rate, capital stock, and employment rate. First, we investigate the cointegration among variables using the bound testing technique, which is as follows:

$$\Delta LRGDP_t = \alpha + \beta_1 LRGDP_{t-1} + \beta_2 LCAP_{t-1} + \beta_3 LEMP_{t-1} + \beta_4 AGING_{t-1} + \beta_5 FR_{t-1} + \sum_{i=1}^{p} \theta_1 \Delta LRGDP_{t-1} + \sum_{i=1}^{q} \theta_2 \Delta LCAP_{t-1} + \sum_{i=1}^{r} \theta_3 \Delta LEMP_{t-1} + \sum_{i=1}^{s} \theta_4 \Delta AGING_{t-1} + \sum_{i=1}^{t} \theta_5 \Delta FR_{t-1} + \varepsilon_t \quad (1)$$

In equation [1], LRGDP stands for the log of Gross Domestic Product, LCAP for the log of capital stock, LEMP for the log of labor employed, AGING for the percentage of the population over 65 years old, FR for fertility rates (average birth rate per woman), and (p,q,r,s,t) for the best lag length determined by the Akaike Information Criterion (AIC) or Bayesian Criterion (BIC).

Wald test (joint test or F test) is used to determine whether or not cointegration exists. Wald test calculated from equation [1] must be compared to the critical value (usually for case III) suggested by Pesaran et al. (2001). If the calculated F-statistics are more significant than the critical value's upper bound, the null hypothesis of no cointegration is rejected. Similarly, if the estimated F statistics are smaller than the lower bound, the null hypothesis cannot be rejected. The result is inclusive if the projected value falls within the critical value band. The following hypothesis is used to determine whether or not cointegration exists:

$H_0: \beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = 0$ (there is no cointegration amongst the variables)

$H_1: \beta_1 \neq \beta_2 \neq \beta_3 \neq \beta_4 \neq \beta_5 \neq 0$ (there is cointegration amongst the variables)

In the second step, when cointegration has been established, the long-run model of economic growth is estimated using the long-run ARDL (p,q,r,s,t) model as follows:

$$LRGDP_t = \alpha + \sum_{i=1}^{p} \theta_1 LRGDP_{t-1} + \sum_{i=1}^{q} \theta_2 LCAP_{t-1} + \sum_{i=1}^{r} \theta_3 LEMP_{t-1} + \sum_{i=1}^{s} \theta_4 AGING_{t-1} + \sum_{i=1}^{t} \theta_5 FR_{t-1} + \varepsilon_t \quad (2)$$

The long-run model in equations [2] is required to derive the error correction term that will be used as an explanatory variable in the short-run model as follows:

$$\Delta LRGDP_t = \alpha + \sum_{i=1}^{p} \theta_1 \Delta LRGDP_{t-1} + \sum_{i=1}^{q} \theta_2 \Delta LCAP_{t-1} + \sum_{i=1}^{r} \theta_3 \Delta LEMP_{t-1} + \sum_{i=1}^{s} \theta_4 \Delta AGING_{t-1} + \sum_{i=1}^{t} \theta_5 \Delta FR_{t-1} + \phi ECT_{t-1} + \varepsilon_t \quad (3)$$

In equation [3], ECT is an error correction term and ϕ is the speed of adjustment that measures how long the disequilibrium in the short run will be corrected until it converges to the long-run equilibrium.

In addition, the cumulative sum of recursive residuals (CUSUMQ) is used to test the model's structural stability, as Brown et al. (1975) recommended. If the CUSUMQ plot stays inside the critical limit at a 5% significance level, the coefficients and the error correction model are stable and cannot be rejected. Similarly, if the two lines intersect, the null hypothesis of coefficient constancy may be rejected at 5%.

Results and Discussions

The unit root test can be used to show that there is no second difference or I(2) series among the variables, even though the ARDL cointegration technique does not require it. Only the I(0) and I(1) series are suitable for use with the ARDL approach. For this reason, the order of integration of each variable is determined using four methods: Augmented Dickey-Fuller, Phillips-Perron (PP), Kwiatkowski-Phillips-Schmidt-Shin (KPSS), and the breakpoint unit root test. The unit root test results from the ADF, PP, KPSS, and breakpoint test methods demonstrated a mixture of I(0) and I(1) integration of underlying variables, as shown in Tables 2 and 3. Thus, with no I(2) series available, the ARDL technique advanced by Pesaran et al. (2001) may be utilized to examine the long-term connection among the variables.

Table 2. Unit Root Test using ADF (Augmented Dickey-Fuller) and Phillips-Perron (PP)

Variable	Augmented Dickey-Fuller				Phillips-Perron Test Equation			
	Level		First Difference		Level		First Difference	
	Constant	Constant with Trend	Constant	Constant with Trend	Constant	Constant with Trend	Constant	Constant with Trend
LRGDP	-0.74	-1.75	-7.43***	-7.46***	-0.76	-1.97	-7.43***	-7.46***
LCAP	-0.27	-3.30*	-3.43***	-3.38*	0.03	-2.27	-2.67	-2.61
EMP	4.13	-0.78	-5.35***	-6.73 ***	3.90	-0.81	-5.52***	-6.69***
AGING	2.95	2.17	0.74	-1.38	9.88	4.31	4.31	-1.40
FR	-3.94***	-8.71***	-6.17***	-7.73***	-3.43***	-1.23	-1.91	-3.23*

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

Table 3. Unit Root Test using KPSS and Break Test

KPSS Unit Root Test				
Variable	At Level I (0)		First Difference I (I)	
	Constant	Constant with Trend	Constant	Constant with Trend
LRGDP	0.95	0.14**	0.12***	0.08***
LCAP	0.96	0.10*	0.09***	0.09***
EMP	0.93	0.23	0.72***	0.03***
AGING	0.78	0.21	0.72***	0.21
FR	0.93	0.17***	0.47***	0.08***

Unit Root with Break Test						
Variable	At Level I (0)			First Difference I (I)		
	Constant	Constant with Trend	Trend	Constant	Constant with Trend	Trend
LRGDP	-2.00	-3.08	-3.09	-8.46***	-8.77***	-7.69***
LCAP	-1.91	-4.56	-3.87	-3.86	-4.87	-3.92
EMP	1.38	-3.43	-1.98	-7.31***	-9.63***	-6.88***
AGING	0.81	-3.16	-1.92	-3.43	-4.38	-4.55**
FR	-8.84***	-6.84***	-5.37***	-4.30*	-3.57	-3.57

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

The results of the Bound tests used to look for the long-term association (cointegration) between LRGPD, LCAP, EMP, AGING, and FR are shown in Table 4. The findings demonstrate that the regression's F-statistics were higher than those for the upper bound's I(1) critical value at a 1% significance level. These results suggest that economic growth fluctuates over the long term depending on the movement of capital stock, employment, aging, and fertility rate. These results show that Malaysian economic development and the explanatory factors have a long-term relationship (cointegration), rejecting the null hypothesis.

Table 4. Bound Tests Cointegration Results

Estimates of Cointegration Bounds Test		Null Hypothesis: No levels of relationship		
Test Statistic	Value	Significance Level.	I(0)	I(1)
			Asymptotic: n=1000	
F-statistic	6.8564	10%	2.45	3.52
k	4	5%	2.86	4.01
		2.5%	3.25	4.49
		1%	3.74	5.06

Table 5 summarizes The long-run elasticity of all explanatory factors concerning economic growth. At a 5% significance level, the long-run coefficient is statistically significant. According to conventional economic theory, the stock of capital and employment benefit economic growth (supply-side economy). For instance, over time, a 1% increase in capital stock results in an increase of 0.18% in Malaysia's economic growth. Malaysia's economic growth will be increased by 0.10% with an additional 1% of employed labor. These results suggest that both supply-side variables are essential for long-term economic growth. However, the aging population and the fertility rate significantly impact long-term economic growth in Malaysia. Economic growth is reduced by 0.07% for every percentage point rise in the population that is getting older. These results indicate that the older population will negatively impact economic growth since they are unproductive (not working) members of society. According to Manabu and Hosoyama (2004) population aging slows the expansion of the labor force and capital stock, and this demographic shock results in higher taxes and pension costs, worse economic welfare, and a sharp decline in the economy's growth rate. Moreover, Lisenkova et al. (2012) stated that as the population ages, labor output declines due to the workforce's deteriorating physical abilities.

Table 5: Long-Run Elasticity

ARDL (p,q,r,s) Dependent variable: D(LRGDP)	Coefficient
LCAP	0.176** (0.099)
EMP	0.105*** (0.028)
AGEING	-0.073** (0.036)
FR	-0.496*** (0.047)

Note: Numbers in parentheses are standard errors.
***, **, and * indicate significance at 1%, 5%, and 10% significance levels, respectively.

Table 6: Short Run Model and Diagnostic Checkings

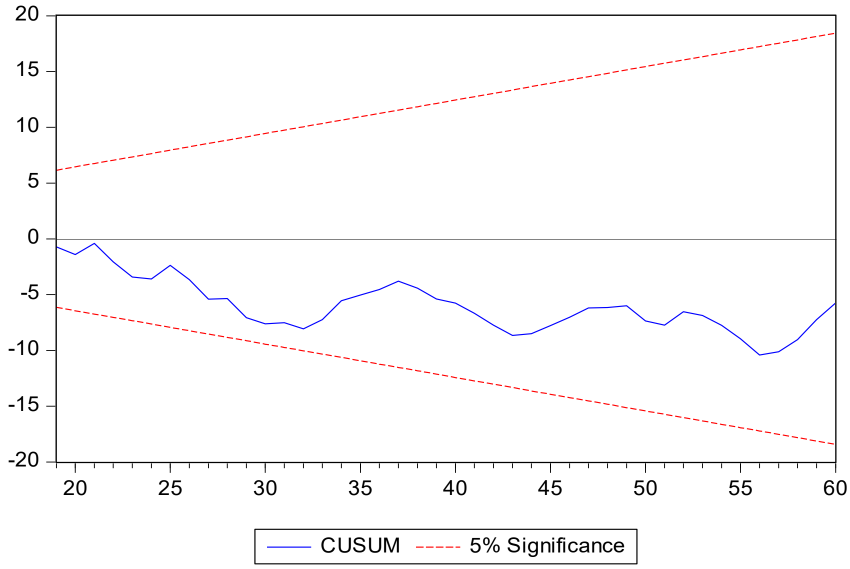
Panel A: Estimated Model						
Dependent Variable	Selected Model ARDL	Independent Variable				
		D(LCAP)	D(EMP)	D(AGING)	D(FR)	ECT
D(LRGDP)	(2,2,2,2)	1.693 (4.076) ***	-0.013 (-0.069)	-0.211 (-0.792)	0.190 (-0.049)	-1.119 (-6.128) ***
Panel B: Diagnostic Testing						
Serial Correlation					[1.775]	
Normality Test					[-0.186] 2.682	
Heteroscedasticity Test					[1.042]	

Note: Numbers in parentheses are t-statistics.
***, **, and * indicate significance at 1%, 5%, and 10% significance levels, respectively. Wald Test is utilized to test the significance of each independent variable.

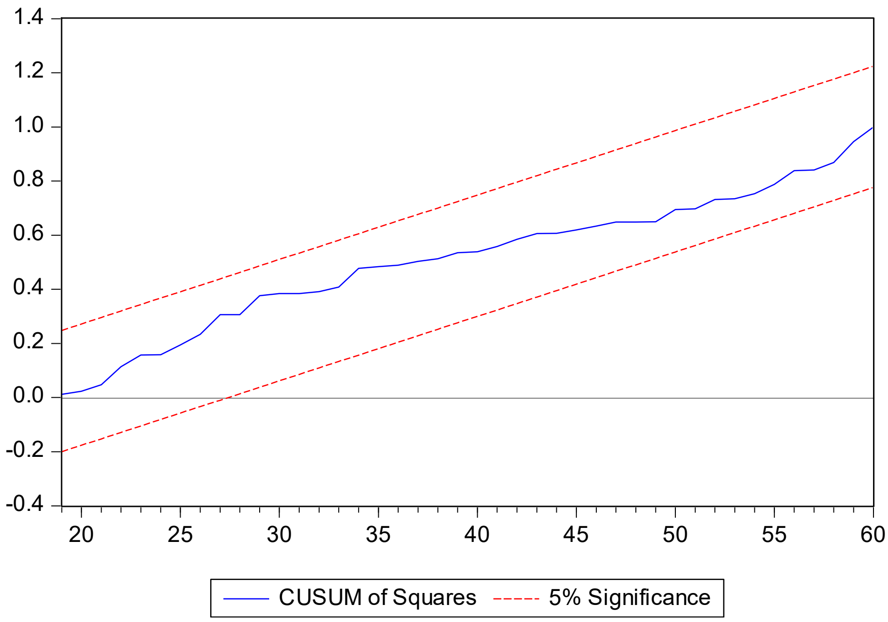
The findings also indicate that the fertility rate negatively impacts Malaysia's economic growth. Given that Malaysia's fertility rate is declining, our country's economic growth has been boosted by the decline in fertility. The findings support Prettner's (2013) findings that lower fertility rates were associated with greater economic growth. Furthermore, the low fertility rate is connected to the rise in female labor force involvement (Bloom & Finlay, 2009). Many working women marry later and may not want many children because it is assumed that they will stop working to care for their children. As the baby boomer generation increases, the senior population will soon outweigh working persons. As the baby boomer generation increases, the senior population will soon outweigh working persons, and the dependency ratio will greatly impact the country's economic development. Moreover, Huang et al. (2019)prove that the old-age dependence ratio hinders economic growth.

Table 6 (Panel A) summarises the results of the short-run study utilizing the ARDL error correcting model (ECM). The results show that capital stock significantly impacts short-term and long-term economic growth. Apart from capital stock, factors like the labor force, elderly population, and fertility rate have little impact on economic growth in the short term. At a 1% significance level, the error correction terms (ECT) coefficient is statistically significant, suggesting that all explanatory factors have a long-term causal effect on economic growth. According to the speed of adjustment (1/ECT = 0.98), it will take 0.98 years, or 10.7 months, to correct the disequilibrium brought on by the shock from the previous year and converge to long-run equilibrium growth.

Several diagnostic tests have been performed to ensure that the model is reliable. No evidence of serial correlation or heteroscedasticity influence in terms of disturbance is seen in Table 6 (Panel B). The model also passed the Jarque-Bera normality test, which shows that the errors are distributed regularly. The structural stability is subsequently evaluated using the CUSUM and CUSUM square tests. Both results exhibit structural stability in the intercept and variance of the residual, as shown in Figure 2.



CUSUM Test



CUSUM of Squares

Figure 2.CUSUM Test dan CUSUM of Squares

Conclusion

Future human capital development in Malaysia is in danger due to a considerable rise in the elderly population and declining fertility rates. Thus, policymakers need to comprehend how Malaysia's aging population and fertility rate can affect the country's economic growth to develop a suitable demographic policy. This study employs annual data from 1960 to 2019 and the ARDL model to empirically analyze this topic by analyzing the long- and short-term effects of population aging, fertility rate, capital stock, and employment on economic growth in Malaysia.

The major findings showed that while the stock of capital and employment favorably impacted economic growth in Malaysia, the old-age population (aging) and fertility rate had a negative impact. Older individuals do not immediately impact the economic development of the nation. Due to decreasing productivity brought on by an increase in the older population, which slows down labor and capital stock growth, will undoubtedly have a substantial long-term influence on Malaysia's economic growth (Manabu & Hosoyama, 2004). Moreover, the fertility rate has a negative long-term impact on the nation's economic growth. Low reproduction rates are usually linked to higher female labor force participation and later marriage, which are detrimental to economic growth. However, concerns about an excessive old-dependency ratio in the near future are raised by a dropping birth rate coupled with an aging population. In low-fertility countries like Malaysia, further fertility losses would eventually lead to a labor shortage as well.

Capital stock substantially impacts economic growth in the short and long term, indicating the importance of adopting an effective strategy to promote capital accumulation through domestic and foreign direct investment (FDI). Long-term economic growth is also significantly influenced by employment, suggesting that increasing the number of people actively employed is preferable to accelerate long-term growth by increasing aggregate expenditure, particularly aggregate consumption.

For policymakers, this study has some significant ramifications. Authorities must have a suitable succession plan in place to counteract the rise in the elderly population because it undermines economic growth in the long run (unproductive resources). This can be accomplished by strengthening the labor force participation rate of the economy and increasing the working-age population (productive resource). Policymakers should also encourage older people to participate in the economy (productive aging) as a workforce, motivators or actively engage as volunteers because the aging population has a wealth of experience and skill in many disciplines. Second, even though a decline in the fertility rate has boosted economic growth, the government should not restrict population expansion.

The inverse association between fertility and economic growth is typically associated with late marriage and higher female labor force participation. Therefore, policymakers may offer special incentives like tax breaks and childbearing incentives and upgrade the rules and legislation regarding maternity and paternity leave to encourage a quicker population increase. Finally, governments must encourage household savings and investments to promote capital stock accumulation because Malaysia's economic growth depends on the capital stock and the labor force. A high household savings rate promotes capital formation and, over time, can speed up economic growth. Lastly, since employment significantly impacts growth, policymakers should prioritize their strategy to increase job opportunities by fostering a favorable business climate and resolving the labor market mismatch in the economy by enhancing education and training standards.

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Economic Journal of Emerging Markets, 15(2) 2023, 212-225

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The externalities of solid fuel CO2 emissions on rice production: A time series analysis for Pakistan

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Article Info

Article history:
Received 25 March 2023
Accepted 23 October 2023
Published 31 October 2023

JEL Classification Code:
D62, Q53, Q56, C22.

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DOI: 10.20885/ejem.vol15.iss2.art8

Abstract

Purpose — This study examines the externalities of CO2 emissions from solid fuel consumption on rice production in Pakistan using time series data from 1984 to 2021.

Methods — The independent variables include CO2 emissions from solid fuel consumption, cultivated area, agricultural equipment, tube wells, and improved seed, whereas the dependent variable is rice production. A robust analysis was done by altering the solid fuel CO2 emissions proxy. The empirical study used the vector error correction model and Johansen's cointegration test.

Findings — Solid fuel CO2 emissions negatively and significantly impact rice production, implying that solid fuel CO2 emissions decrease rice production. Tube wells have a negative and significant influence on rice production. Conversely, cropped land, agricultural machinery, and improved seeds boosted rice production. The results remained robust even when the proxy for solid fuel CO2 emissions was changed.

Implications — The study recommends developing regulations to limit solid fuel CO2 emissions to prevent environmental degradation and increase rice production. To boost rice production, more land should be farmed, agricultural machinery should be employed, and improved seeds should be used.

Originality — This study is the first to examine the impact of CO2 emissions from solid fuel consumption on rice production in Pakistan.

Keywords — Externalities, CO2, Pakistan, rice production

Introduction

Food security has been challenged by various interconnected factors, including population growth, environmental problems, and land degradation (Chandio, Magsi, et al., 2020). To fulfill global food demand, primary crop production must be significantly expanded (Godfray et al., 2010). However, there may be several barriers to boosting the production of agriculture to fulfill this need, one of which is environmental deterioration (Adzawla et al., 2020; Arunrat & Pumijumnong, 2015; Tripathi et al., 2016).

To encounter the harmful effects of environmental degradation and lower the agriculture sector's sensitivity, adaptation approaches, and feasible cures must be created (J. Wang et al., 2018). Natural disasters are predicted to occur more frequently and with greater severity because of global warming. Other effects include erratic climate extremes, intense heat waves, decreased soil moisture, rising sea levels, surface water runoff, droughts, excursions of glaciers, and erosion of soil (Pickson

P ISSN 2086-3128 | E ISSN 2502-180X

et al., 2020; Praveen & Sharma, 2019; Tesfahunegn & Gebru, 2021). These changes will have a disastrous effect on global economies and may lead to socio-economic chaos (Chandio et al., 2021).

Although climate change affects all significant sectors, agriculture is the most vulnerable (Guntukula, 2020) because many crops are temperature-sensitive. Global warming will lower agricultural output (Appiah et al., 2018). Higher mean temperatures can potentially affect the agricultural production of both crops by modifying the time necessary for a plant to develop (Hatfield & Prueger, 2015). Climate has a wide-ranging impact on agricultural output. Many plant species are temperature sensitive, and rising global temperatures severely impact agriculture and crops (Appiah et al., 2018; Ben Zaied & Ben Cheikh, 2015; Vaghefi et al., 2016).

Rice output is predicted to be altered by unforeseeable future changes in temperature, CO2, and rainfall caused by global warming. Climate change's quick consequences may be seen as harmful consequences of harsh weather conditions on rice production systems and food security (Chandio, Jiang, et al., 2020).Previous studies have indicated that the changing climate is increasing temperatures while reducing rice crop output and quality. This detrimental impact might be attributed to land degradation (Magsi & Sheikh, 2017) and weather variations (Joyo et al., 2018).

Climate change has both positive and negative effects on grain crop output. Nonetheless, the negatives outweigh the benefits generally, and various climatic factors affect different crops and regions in different ways (Akhtar & Masud, 2022; Pickson et al., 2020). In recent years, greater heat from climate change has aided in extending grain-planted areas and generating more grain (Yang et al., 2015). Increasing CO2 concentrations and rainfall favor agricultural productivity to a certain level, although higher temperatures may negate this benefit in specific locations (Dai et al., 2018; Malhi et al., 2021). Similarly, climate change exerts a negative impact on the yield of grain by expanding disease and pest occurrence areas, decreasing crop growing seasons, and increasing the frequency of extreme events of weather (Wang et al., 2021).

Carbon emissions play a vital role in agricultural production to prevent climate change. Various studies suggest that CO2 emissions impact farmland, which evaluates the input function to agricultural productivity (e.g., Ayyildiz & Erdal, 2021; Rehman et al., 2020). Furthermore, the carbon footprint of crops in significant agricultural areas differs from the norm, and the highest crop yields are carbon emitters (She et al., 2017). The environmental impact of harmful gas emissions has become a primary concern. CO2 emissions are a significant contributor to global warming and continue to gain scholarly interest (Appiah et al., 2017; İpek Tunç et al., 2009; Sarkar et al., 2015). Carbon dioxide emissions are the most significant proportion of greenhouse gas emissions in rising economies (Khan et al., 2011). The emissions of carbon dioxide have risen with time because of rising population, rising consumption of energy, rising economic growth, and rising agricultural productivity to ensure food security (Asumadu-Sarkodie & Owusu, 2016; Kofi Adom et al., 2012; McAusland, 2010).

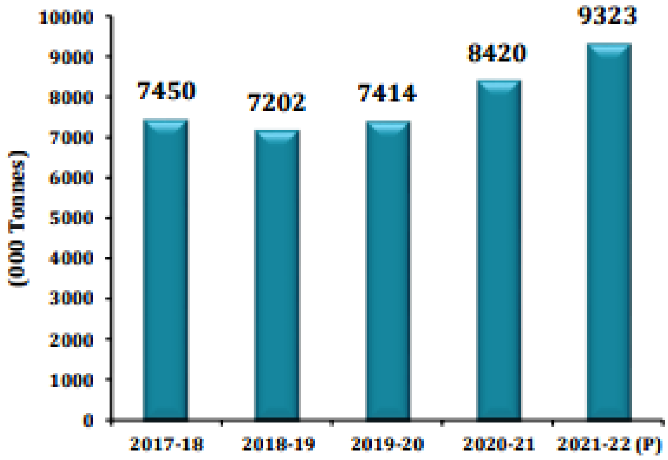
Rice is a vital cash crop and, after wheat, the country's second-most-eaten staple food. Its output comprises 34% basmati (fine) and 66% coarse varieties. The output of coarse kinds has increased recently as farmers have brought additional land under hybrid coarse types. It contributes 0.5% to GDP and 2.4% to the value-added of agriculture. In 2021-22, 3,537 thousand hectares of crop were planted, a 6.1 percent increase from the previous year's yield of 3,335 thousand hectares. In 2021-22, rice output hit a record high of 9.323 million tonnes, a 10.7 percent increase over the output for last year, which was 8.420 million tonnes. The area under rice farming has been increasing during the previous several years. Domestic rice output typically surpasses domestic yearly requirements, producing an exportable surplus (Source: Pakistan Bureau of Statistics). Table 1 displays the rice production, area, and yield during the previous five years.

Many research studies investigated this link after Auffhammer et al. (2006) published a seminal article assessing climate change's impact on agriculture productivity. Climate change may influence agricultural productivity in both direct and indirect ways. The direct way is through changes in rainfall patterns and increases in temperature. The indirect channel is through the spread of diseases, which raises costs and complicates the management of crops (Ben Zaied & Ben Cheikh, 2015; Qureshi et al., 2016).

Table 1. Production, Area, and Yield of Rice

Year	Production		Area		Yield	
	(000 Tonnes)	% Change	(000 Hectare)	% Change	(Kgs/Hec.)	% Change
2017-18	7,450	-	2,901	-	2,568	-
2018-19	7,202	-3.3	2,810	-3.1	2,563	-0.2
2019-20	7,414	2.9	3,034	8.0	2,444	-4.6
2020-21	8,420	13.6	3,335	9.9	2,52	3.3
2021-22	9,323	10.7	3,537	6.1	2,635	4.4

Source: Pakistan Bureau of Statistics



Source: Pakistan Bureau of Statistics (2022)

Figure 1: Production of rice

Even though there is research that looks at the link between environmental degradation and rice yield (Chandio, Magsi, et al., 2020; Gul et al., 2022), they fail to take into account the role of CO2 emissions from solid fuel consumption, which is a significant contributor to environmental degradation in rural areas, as suggested by increased production, the improper use of plant hormones, chemical fertilizers, pesticides and, processing of soil, irrigation and the dumping the animal waste unsuitable for soil (Önder et al., 2011; Waheed et al., 2018). The present study covers this gap. Second, to test the robustness of the estimated results, this study employs two measures of CO2 emissions from solid fuel consumption. The consumption of solid fuel in rural areas makes the country's agricultural sector sensitive to environmental degradation (Önder et al., 2011), and a significant contributor to climate change is the carbon dioxide emissions from agriculture besides the industrial sector (Ayyildiz & Erdal, 2021). This also applies to Pakistan being an agricultural economy. We analyze the influence of CO2 emissions from solid fuel use on rice production using time series data from 1984 to 2021 to offer a foundation for policy making. We use Johansen's cointegration test as suggested by the results of two tests of unit root, i.e., the Phillips-Perron (PP) test and the Augmented Dickey-Fuller (ADF) test. Considering the findings, the present study would enable the country to develop policies to achieve agricultural sustainability regarding rice production, one of the most cultivated in Pakistan, and to use strategies to reduce the harmful effects of environmental degradation on rice production.

The remaining portions of the study are structured as follows: the second section addresses the literature review; the third section includes data, methodology, empirical findings, and interpretations; and the fourth section concludes.

Although the impact of CO2 emissions on rice production has received significant attention due to its importance, empirical findings have been inconsistent and sometimes ambiguous. CO2 emissions, according to several studies, are harmful to rice production. Rice is susceptible to weather and environmental challenges. CO2 emissions, according to studies, enhance the rate of photosynthesis, loss of water, and, eventually, yield (Mahato, 2014). However, rising temperatures would reduce rice output since temperatures above 35 °C damage the viability of pollen and spikelet sterility (Tesfahunegn & Gebru, 2021). The rising temperatures and a decrease in precipitation induce a decrease in the quality and output of crops (Boonwichai et al., 2019; Shrestha et al., 2017). Özdoğan (2011), based on simulations, projected that increased CO2 emissions might affect agricultural yields by 5 to 35% in northern Turkey.

From 1986 to 2018, Javed et al. (2017) investigated the influence of CO2 emissions on cereal crop yield in Pakistan. The empirical findings indicated that CO2 emissions reduce cereal crop production. From 1968 to 2015, Hussain et al. (2018) evaluated the link between emissions of CO2 and the productivity of rice crops in Pakistan. The study established a short-run and long-run linkage between variables and indicated that an increase in CO2 by 1% results in a 1.3% drop in rice crop yield. Similarly, Vanli et al. (2019) verified, utilizing the data on the farmer field level, that environmental issues harmed agriculture.

Chandio, Magsi, et al. (2020) investigated the effect of emissions of CO2 on the yield of rice in the case of Pakistan. The significant findings revealed that a rise in emissions of CO2 by 1% affects rice crop yield by 0.21%. Pickson et al. (2020) examined how climate change would affect China's rice farming. The data suggest that rice production is negatively impacted by climate change. Ozdemir (2022) investigated the role of CO2 in the agricultural sector's productivity in Asia and discovered that CO2 has a detrimental impact on agricultural output.

Gul et al. (2022) discovered that the productivity of food-producing vital crops was negatively impacted by temperature in Pakistan from 1985 to 2016, although the impact of rainfall is positive. Similarly, Chandio et al. (2021) discovered that CO2 negatively affected grain productivity in Pakistan from 1977 to 2014, lowering cereal production. In the instance of India, Bhardwaj et al. (2022) found that climatic factors had a detrimental effect on rice production. CO2 emissions, according to Akhtar and Masud (2022), have a detrimental impact on Malaysian agricultural output.

Some studies contend that, in the medium and short term, some locations, such as the northern region of Europe, may benefit from climate change and improve food yields (Isoard, 2011). Janjua et al. (2014) discovered that CO2 emissions, yearly temperature, and annual rainfall had a beneficial short-term and long-term effect on the output of the main crops in Pakistan. Ntiamoah et al. (2022) studied the influence of CO2 emissions on agricultural output in Ghana from 1990 to 2020. According to the data, CO2 emissions favorably influence crop productivity. Similarly, Kumar et al. (2021) examined the climate change-cereal crop output relationship in selected countries with lower middle income between 1971 and 2016. The data demonstrated that CO2 emissions increased and that there was a bidirectional relationship between CO2 emissions and agricultural yields.

However, Zhai et al. (2017) found that from 1970 to 2014 in China, temperature did not affect wheat productivity per acre in both the long and short term. Pickson et al. (2020) examined how climate change affected rice growing in China from 1998 to 2017. The data revealed that the impact of climatic variables on rice output is insignificant.

A study of the existing literature reveals that the link between CO2 emissions and rice production needs to be clarified. Secondly, the lack of literature on the relationship between solid fuel consumption CO2 emissions and rice production makes the empirical inquiry necessary.

Methods

For an empirical investigation of the effects of CO2 emissions on rice production, the following models will be specified:

$$lnRICEP = a + \beta_1\, CO21 + \beta_2\, AREA + \beta_3\, lnAGM + \beta_4\, lnTUBEWELL + \beta_5\, SEED + \mu \quad (1)$$

For robustness analysis, the following model has been specified:

$$lnRICEP = a + \beta_1\, CO22 + \beta_2\, AREA + \beta_3\, lnAGM + \beta_4\, lnTUBEWELL + \beta_5\, SEED + \mu \quad (2)$$

It may be derived from the generic equation (1) as follows to establish the long-run equation:

$$lnRicep_{\,t} = a + \beta_1\, Co21_{\,t\text{-}1} + \beta_2\, Area_{\,t\text{-}1} + \beta_3\, lnAgm_{\,t\text{-}1} + \beta_4\, lnTubewell_{\,t\text{-}1} + \beta_5\, Seed_{\,t\text{-}1} + \mu_t \quad (3)$$

For robustness analysis, the following model will be specified:

$$lnRicep_t = a + \beta_1 Co22_{t-1} + \beta_2 Area_{t-1} + \beta_3 lnAgm_{t-1} + \beta_4 lnTubewell_{t-1} + \beta_5 Seed_{t-1} + \mu_t \quad (4)$$

If, at minimum, one cointegration association exists, this analysis will utilize the Vector Error Correction Method (VECM) to examine the association in the short run. The VECM equation for rice production and other variables is as follows:

$$\Delta lnRicep_t = a + \beta_1 \Delta Co21_{t-1} + \beta_2 \Delta Area_{t-1} + \beta_3 \Delta lnAgm_{t-1} + \beta_4 \Delta lnTubewell_{t-1} + \beta_5 \Delta Seed_{t-1} + \pi (lnRicep_t - a - Co21_{t-1} - Area_{t-1} - lnAgm_{t-1} - lnTubewell_{t-1} - Seed_{t-1}) + \mu_t \quad (5)$$

For robustness analysis, the following model is specified:

$$\Delta lnRicep_t = a + \beta_1 \Delta Co22_{t-1} + \beta_2 \Delta Area_{t-1} + \beta_3 \Delta lnAgm_{t-1} + \beta_4 \Delta lnTubewell_{t-1} + \beta 5 \Delta Seed_{t-1} + \pi (lnRicep_t - a - Co22_{t-1} - Area_{t-1} - lnAgm_{t-1} - lnTubewell_{t-1} - Seed_{t-1}) + \mu_t \quad (6)$$

where RICEP is rice production measured in thousands of tons (Chandio et al., 2021; Chandio, Magsi, et al., 2020), which is the dependent variable, CO21 is emissions of carbon dioxide from the use of solid fuels as a percentage of the total, CO22 is emissions of carbon dioxide from the use of solid fuels in kilotons previously used by Ahmad et al. (2020), Ahsan et al. (2020), and Pickson et al. (2020) which is the primary independent variable; however, these studies used overall CO2 emissions but not CO2 emissions from solid fuel consumption. AREA is cropped area measured in million hectares (Chandio et al., 2018; A. Hussain, 2012; Janjua et al., 2014), AGM is agricultural machinery proxied by number of tractors being used (Ozdemir, 2022), TUBEWELL is the number of tube wells public and private measured in thousands (Asumadu-Sarkodie & Owusu, 2016) and SEED is improved seed distribution measured in thousands of tonnes (Abbas, 2022; Zhai et al., 2017; Zhang et al., 2022). The data has been taken from 1984 to 2021. The data has been gathered from the Economic Survey of Pakistan and WDI. To calculate the elasticity of coefficients, we use the logarithmic values of the variables.

Table 2. Results of Augmented Dickey-Fuller (ADF) test for unit root

Variable	Intercept	Intercept and Trend
lnRicep	-0.286	2.175
	(0.917)	(0.992)
ΔlnRicep	-9.179*	-8.474*
	(0.000)	(0.000)
CO21	-0.327	-0.940
	(0.911)	(0.940)
ΔCO21	-5.649*	-5.950*
	(0.000)	(0.0001)
CO22	1.211	-0.690
	(0.998)	(0.967)
ΔCO22	-5.518*	-5.946*
	(0.0001)	(0.0001)
Area	-2.508	0.940
	(0.122)	(0.904)
ΔArea	-9.765*	-9.417*
	(0.000)	(0.000)
lnAgm	-1.607	-2.688
	(0.469)	(0.247)
ΔlnAgm	-6.426*	-6.335*
	(0.000)	(0.000)
lnTubewell	-1.888	-0.556
	(0.334)	(0.976)
ΔlnTubewell	-5.917*	-6.491*
	(0.000)	(0.000)
Seed	1.881	-0.851
	(0.999)	(0.951)
ΔSeed	-5.461	-5.445
	(0.000)	(0.000)

Before starting the empirical study, the variables must be verified for stationarity. The Augmented Dickey-Fulller and Phillips-Perron tests for the unit root were applied at the level and the first difference. These are statistical tests for checking the stationarity of variables. The null hypothesis is that a unit root exists within a given time series sample. The results are in Tables 2 and 3.

Table 3. Results of Phillips-Perron (PP) test for unit root

Variable	Intercept	Intercept and Trend
lnRicep	0.139	3.365
	(0.965)	(0.999)
ΔlnRicep	-15.933*	-8.474*
	(0.000)	(0.000)
CO21	-0.702	-1.2131
	(0.834)	(0.893)
ΔCO21	-5.692*	-5.950*
	(0.000)	(0.000)
CO22	1.034	-1.033
	(0.996)	(0.927)
ΔCO22	-5.617*	-5.976*
	(0.000)	(0.000)
Area	-2.366	2.010
	(0.158)	(0.988)
ΔArea	-9.831*	-9.417*
	(0.000)	(0.000)
lnAgm	-1.439	-2.654
	(0.553)	(0.260)
ΔlnAgm	-7.052*	-6.761*
	(0.000)	(0.000)
lnTubewell	-1.945	-0.532
	(0.309)	(0.977)
ΔlnTubewell	-5.955*	-6.492*
	(0.000)	(0.000)
Seed	8.266	0.0411
	(1.000)	(0.995)
ΔSeed	-5.335*	-8.998*
	(0.000)	(0.000)

The results of the unit root analysis's ADF test and PP test show the stationarity of all the variables at first difference. However, non-stationarity at their levels suggests the order of integration for all of these is one, namely $I(1)$. As a result, Johansen's cointegration test is an appropriate option for empirical analysis.

The optimal lag to include in the model has been chosen using the Vector Auto Regression (VAR) lag order selection criterion. One lag was chosen because it fulfilled three criteria that recommended including one lag in the model.

Table 4. Lag length criteria (VAR) for model 1

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-310.683	NA	2.912	18.096	18.363	18.188
1	-155.311	248.595*	0.003	11.275	13.141*	11.919*
2	-120.176	44.170	0.004	11.324	14.791	12.521
3	-65.482	50.006	0.003*	10.256*	15.322	12.005

Following is Johansen's test of cointegration for model 3.

Table 5. Unrestricted cointegration trace test for model 3

Hypothesized CE(s)	Trace Statistic	Eigenvalue	Critical Value (0.05)	Prob.
None *	119.420	0.763	95.753	0.001*
Maximum 1	67.531	0.568	69.818	0.075
Maximum 2	37.277	0.370	47.856	0.335
Maximum 3	20.655	0.275	29.797	0.380
Maximum 4	9.061	0.219	15.494	0.360
Maximum 5	0.157	0.004	3.841	0.692

*Indicates that the hypothesis was rejected at 0.05 level.

Table 6. Unrestricted cointegration maximum eigenvalue test for model 3

Hypothesized CE(s)	Max-Eigen Statistic	Eigenvalue	Critical Value (0.05)	Prob.
None *	51.889	0.763	40.077	0.002*
Maximum 1	30.254	0.568	33.876	0.128
Maximum 2	16.622	0.370	27.584	0.613
Maximum 3	11.594	0.275	21.131	0.588
Maximum 4	8.904	0.219	14.264	0.294
Maximum 5	0.157	0.004	3.841	0.692

* indicates that the hypothesis was rejected at 0.05 level.

The null hypothesis in Johansen's cointegration test is the absence of cointegration among the variables. The Maximum EigenValue and Trace cointegration tests both show the existence of cointegration or a long-run association and reject the null hypothesis.

Table 7. Estimation result for equation (normalized), model 3

Dependent variable: lnRiceP			
Variable	Coefficient	Standard Error	t-Statistic
CO21	-0.020	0.004	-5.314
Area	0.139	0.015	9.096
lnAgm	0.201	0.021	9.413
lnTubewell	-0.137	0.046	-2.980
Seed	0.001	0.000	12.707

Normalized cointegration coefficients have been used to demonstrate the impact of independent factors on rice production. The findings indicate that emissions of CO2 have a significantly negative impact on rice production. However, cropped areas, agricultural machinery, and improved seeds significantly impact rice production. However, tube wells have a negative and significant impact on rice production. When other parameters are held constant, the elasticity of rice production with CO2 emissions is -0.0203, which means that a 1% rise in CO2 emissions would result in a 0.02% reduction in rice output. A 1% rise in the cropped area, agricultural machinery, and improved seed leads to a rise in rice production by approximately 0.13%, 0.20%, and 0.001%, respectively. As tube wells harm rice production, a 1% rise in tube wells will reduce rice production by approximately 0.13%.

Table 8. VECM estimation results for model 3

Error Correction:	D(lnRiceP)	D(CO21)	D(Area)	D(lnAgM)	D(lnTubewell)	D(Seed)
CointEq1	-0.343	-3.233	-2.508	0.360	0.101	-19.002
Std. Error	0.141	1.893	0.633	0.374	0.058	71.630
t-Ratio	-2.434	-1.707	-3.960	0.962	1.727	-0.265

The next stage is to examine the short-run connection among variables carried out by using VECM, given that there is cointegration among variables. The value of the error correction term is -0.343 with the *t*-statistic of -2.434. This demonstrates convergence in the model since the error correction term is significant and has a negative sign, which suggests that if there is any disruption in equilibrium, there will be a 34% adjustment in the model throughout each phase from dis-equilibrium to equilibrium.

The results of the empirical study were checked for robustness in the second stage. For this, the variable CO2 emissions from the usage of solid fuel in kilotons (CO22) were used instead of the variable CO2 emissions from the usage of solid fuel as a percentage of the total (CO21). The following is the lag length criteria (VAR) for model 4.

Table 9. Lag Length Criteria (VAR) for Model 4

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-566.193	NA	6385864	32.697	32.963	32.789
1	-407.805	253.421*	6055.316	25.703	27.570*	26.348*
2	-371.928	45.103	7381.249	25.710	29.176	26.907
3	-321.841	45.793	5779.242*	24.905*	29.971	26.654

The following is Johansen's test of Cointegration for Model 2

Table 10. Unrestricted cointegration trace test for model 4

Hypothesized CE(s)	Trace Statistic	Eigenvalue	Critical Value 0.05	Prob.
None *	121.967	0.719	95.753	0.000*
Maximum 1*	76.284	0.629	69.818	0.014*
Maximum 2	40.574	0.394	47.856	0.203
Maximum 3	22.529	0.317	29.797	0.270
Maximum 4	8.814	0.213	15.494	0.383
Maximum 5	0.183	0.005	3.841	0.669

* indicates that the hypothesis was rejected at 0.05.

Table 11. Unrestricted cointegration maximum eigenvalue test for model 4

Hypothesized No. of CE(s)	Max-Eigen Statistic	Eigenvalue	Critical Value 0.05	Prob.**
None *	45.683	0.719	40.077	0.011*
Maximum 1*	35.710	0.629	33.876	0.030*
Maximum 2	18.046	0.394	27.584	0.491
Maximum 3	13.715	0.317	21.131	0.389
Maximum 4	8.630	0.213	14.264	0.318
Maximum 5	0.183	0.005	3.841	0.669

* indicates that the hypothesis was rejected at 0.05.

Table 12. Estimation result for equation (normalized), model 4

Dependent variable: lnRiceP			
Variable	Coefficient	Standard Error	t-Statistic
CO22	0.000	0.000	-4.243
Area	0.202	0.023	8.874
lnAgM	0.262	0.030	8.604
lnTubewell	-0.219	0.061	-3.588
Seed	0.002	0.000	9.239

Table 13. VECM results for Model 4

Error Correction:	D(lnRiceP)	D(CO22)	D(Area)	D(lnAgM)	D(lnTubewell)	D(Seed)
CointEq1	-0.401	-6345.800	-3.199	0.571	0.095	23.029
Std. Error	0.16633	3619.250	0.722	0.439	0.076	88.8743
t-Ratio	-2.408	-1.753	-4.432	1.299	1.254	0.259

The findings demonstrate that the optimal lag length, as recommended by three VAR lag order selection criteria, was 1. At a 5% level of significance, the trace test and the maximum eigenvalue test both rejected the null hypothesis that there was "no cointegration" between rice production and the model's independent variables, indicating the occurrence of a long-run association. According to the normalized equation's results, every variable's coefficient had the same sign as that of model 1 and was statistically significant. This suggests that the empirical findings from the model were robust. CO_2 emissions continue to have a significant and adverse impact on rice output. The VECM findings demonstrated that with a value of -0.400, the error correction term's value is still statistically significant and negative, indicating a model convergence rate of about 40% each period.

The findings of this analysis are supported by earlier studies. Climate change and environmental issues can affect rice yield. Research reveals that CO_2 emissions result in a reduction in rice production (Boansi, 2017; Boonwichai et al., 2019; Ozdemir, 2022; Özdoğan, 2011; Pickson et al., 2020; Shrestha et al., 2017). The cropped area positively affected rice production, as found by Ahsan et al. (2020), Chandio et al. (2018), Hussain (2012), and Janjua et al. (2014). Agricultural machinery significantly enhanced rice output as found by Ozdemir (2022). Similarly, improved seed positively impacts rice production, as previously found by Abbas (2022), Zhai et al. (2017), and Zhang et al. (2022).

Conclusion

Climate change is caused by a sharp rise in carbon dioxide emissions, threatening food security. The ongoing threat of climate change brought on by carbon dioxide emissions has prompted various countries to make a concerted effort to address it seriously. Researchers' interest has increased in determining the causes and effects of different variables on global emissions. The relationships between factors are crucial for establishing policy. Pakistan's fast development makes it highly vulnerable to climate change due to conventional technical production methods. The current study collects time series data from 1984 to 2021 to empirically investigate the impact of CO_2 emissions on rice production in Pakistan. Rice production is the regressed, and the regressors are CO_2 emissions, cropped area, agricultural machinery, tubewells, and improved seeds. The CO_2 emissions have been calculated in two ways: as a percentage of all CO_2 emissions and kilotons of CO_2 emissions from burning solid fuel. The ADF and PP tests have been employed to determine the integration order of the variables, and the results showed that all the variables are stationary at their first difference. The long-run connection between variables was investigated using the Johansen cointegration test, whereas VECM was used to examine the short-term relationship. There were two models designated for empirical analysis. The findings suggested that both models had long-term relationships between the variables, and short-run analysis demonstrated that both models were convergent toward equilibrium in the long run. The negative and significant effects of CO_2 emissions on rice production imply a reduction in rice output with increased CO_2 emissions from solid fuel. Like this, tube wells significantly and adversely affect rice production. However, cropped areas, agricultural machinery, and improved seeds increase rice production. Even with a different proxy for CO_2 emissions from the solid fuel, the findings remained robust with the same signs. The negative role of CO_2 emissions in reducing crop production may be due to the cause of environmental degradation, as suggested by Boonwichai et al. (2019), Ozdemir (2022), and Pickson et al. (2020).

As the results show that CO_2 emissions from solid fuel consumption reduce rice production, the government should devise a policy to reduce solid fuel combustion, especially in rural areas, to reduce environmental degradation. This may help in increasing rice production. Secondly, more area should be cropped, more agricultural machinery should be used, and more improved seeds should be used to increase rice production.

The limitation of the current study is that it only considers the impact of CO_2 emissions on rice production. The future direction of the study may be to check this impact on other major crops, such as wheat. The open-access datasets employed in the analyses can be accessed from the following links: https://databank.worldbank.org/source/world-development-indicators; www.finance.gov.pk/survey_2022.html

Conflict of Interest

The authors declare no conflict of interest.

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E ISSN 2502-180x

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