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Article

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Asymmetric Effect of Shadow Economy on Environmental Pollution in Egypt: Evidence from Bootstrap NARDL Technique

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ABSTRACT

This study examines the asymmetric effect of shadow economy on environmental pollution in Egypt during the 1970 and 2022 period. Using the bootstrap nonlinear autoregressive distributed lag (NARDL) bounds-testing approach, the study presents evidence of nonlinear cointegrating relationship between environmental degradation (carbon emission) and shadow economic activities (alongside globalisation, urbanisation, GDP per capita, and industrial growth). In addition, the results demonstrate that the impact of shadow economy (SE) on environmental pollution (ENV) is nonlinear, with the positive shock in shadow economy promoting environmental degradation and negative shocks promoting environmental quality, both in the short- and long-run. However, the study discovered that the magnitude of the impact of the SE on ENV is larger in the short-run. This is further validated by the dynamic ARDL simulation technique which demonstrates that the immediate effect of the SE on ENV is large. Additionally, the results suggest that income growth, urbanisation, and industrial growth are important drivers of environmental pollution. Therefore, the study recommends the adoption, and most importantly implementation, of policies and strategies geared towards reducing the shadow economy, and consequently environmental pollution.

Keywords: Shadow Economy, Environmental Pollution, Globalisation, Egypt, Bootstrap NARDL and Dynamic NARDL Simulations
JEL Classifications: C22, C15, O17, Q5

1. INTRODUCTION

The general consensus among scientists is that environmental pollution, an ecological-economic phenomenon, is a consequence of the excessive misuse of economic resources, and the negative anthropogenic practices of individuals and firms in the society (Erdogan and Okumus, 2021; Haseeb and Azam, 2021). While environmental pollution stems from different source, sufficient evidence have pointed to its direct and indirect harmful impact on the health and socioeconomic wellbeing of individuals (Pata and Caglar, 2021).

In the literature associated with environmental degradation, the continuous degradation of the quality of the environment has been attributed to a number activities and factors. For instance, the effect of the energy consumption, industrial productivity, and technology use in reducing the quality of the environmental is well recognised in the academic and policy circle (Adams et al., 2016). More so, researchers have equally recognised the role of certain economic, social and political factors such as economic growth and development, income inequality, urbanisation and population density, globalisation, international trade, political instability, institutional quality, democracy, and human capital development, are influencing environmental pollution (Abidin et al., 2015; Adams et al., 2016; Dada et al., 2021; Goel et al., 2013; Haseeb and Azam, 2021; Pata and Caglar, 2021; Abela et al., 2022).

In the recent decades, the realisation of the consequences of the evolution of the shadow economy[1], especially in developing countries, has invoked a renewed interest among researchers and policy makers to understand the implications of its development on social, economic, and political status. Indeed, with shadow economy accounting for more than one-third of the GDP in developing countries and constituting over 70% of total employment (Alm and Embaye, 2013; Elgin et al., 2021; Medina and Schneider, 2019), the shadow economy has remained an important obstacle to the development in developing countries. Until recently, researchers and policymakers have mostly focused on the role of shadow economic activities in fiscal policy, while ignoring its capacity in affecting the environment. Interestingly, emerging evidence have shown that the shadow economy is one of the important sources of environmental degradation, especially in developing countries (Dada et al., 2023; Dada et al., 2021; Dada and Ajide, 2021).

Unlike most developing countries, Egypt is both faced with a twin problem of sizable shadow economic activities and significant environmental challenges such as air pollution, climate change, land degradation (Ali, 2021). In Egypt, while the degradation of the environment is significantly tied to the growth of the economy, and most importantly, emissions of greenhouse gasses associated with industrial activities and urbanisation, the continuous increase in the emissions of large volume of pollutants into the environment have created serious environmental and health challenges for the country (World Bank, 2022). The vastness of these emissions does not only affect public health and the whole social-economic life but also influence the environment itself. Besides being the largest emitter of greenhouse gases, only second to South Africa, Egypt also has one of the largest shadow economies in the world. For instance, Medina and Schneider (2019) revealed that shadow economy in Egypt accounts for about 33.8% of the GDP between 1991 and 2017. Besides influencing fiscal policy and economic outcomes, such sizable shadow economy may influence the quality of the environment.

In the literature associated with the shadow economy-pollution relationship, it is argued that shadow economy may contribute to environmental degradation due to the fact that most of the firms within the shadow economy do not obey environmental laws, engage in pollutant-intensive activities such as artisanal mining, brick and tile making, bleaching and dyeing, metal working, and use inefficient and outdated technology and polluting intermediate goods in the production of final goods in the sector (Dada et al., 2021; Dada et al., 2023). Unequivocally, the continuous existence of these activities and thus expansion of the shadow economy poses significant danger for environmental sustainability.

1 Shadow economy is also known as black economy, underground economy, illegal economy, and informal economy. It comprises both illegal activities and unreported or undeclared income from the production of legal goods and services.

At the empirical front, it has been well established that environmental quality may be influence by the size of shadow economy. For instance, Elgin and Oztunali (2014a, 2014b) demonstrated that the shadow economy is associated with environmental pollution. In addition, Imamoglu (2018) illustrated that and expansion in the size of the shadow economy is an important driver of environmental pollution in Turkey. The presence of a positive relationship between shadow economy and environmental quality has also been validated in a number of studies (Chen et al., 2018; Dada et al., 2023; Dada et al., 2021). On the contrary, some other studies established a negative relationship between shadow economy and (recorded) environmental pollution level (Camara, 2022; Dada et al., 2023; Goel et al., 2013; Nkengfack et al., 2021; Yu et al., 2022). Notwithstanding the conflicting outcome, and the paucity of research into the relationship between shadow economy and environmental quality at the empirical front, an assessment of the extant literature suggests that emphasis has been on the symmetric relationship between shadow economy and environmental quality. Most of the existing literature neglects the possibility of an asymmetric relationship between shadow economy and environmental quality in the discourse.

Whereas it is generally argued that the expansion in the size of shadow economy may intensify the degradation of the environment due to the engagement in energy-intensive activities and application of inefficient pollutant technology. Typically, based on this, it is expected that the shrinking in the size of shadow economy will lead to an improvement in the quality of the environment. However, this may not be tenable. It is possible for the reduction in the size of shadow economy, likely due to the efforts of the government, to either have an insignificant impact on the improvement of environmental quality or even further encourage the degradation of the environment. On the one hand, the reduction in shadow economy may be insignificant in influencing the quality of the environment if the activities and/or firms constituting the decline are not pollution-intensive. Similarly, a reduction in the size of the shadow economy could further increase in degradation of the environment on account of the need for existing firms in the sector to match and balance deficit in the demand for goods and services of the sector. Interestingly, in exploring the relationship between shadow economy and environmental pollution in South Asian countries, Sohail et al. (2021) demonstrates that the effect of negative and positive shocks in shadow economy on environmental pollution is significantly different across countries.

Against this background, and occasioned by the coexistence of large volume of environmental pollution and sizable shadow economy in Egypt, it is beneficial to explore the asymmetric relationship between shadow economy and environmental pollution in Egypt. The present study is relevant and contribute to the literature in a number of ways. First, the study is a pioneering attempt at exploring the relationship between shadow economy and environmental pollution, both from a country-specific perspective. Second, and following Sohail et al. (2021), the study contributes to the growing literature by explicitly determining whether the relationship between shadow economy and environmental pollution is asymmetric. Third, to determine the robustness and consistency of outcomes, the study uses two measures of environmental pollution (total CO_2 emission (in metric tons), and CO_2 emission (in metric tons) per capita). Fourth, the current one makes methodological contributions by adopting novel and robust estimation techniques, including the bootstrap nonlinear autoregressive distributed lag (ARDL) technique and the dynamic ARDL simulation procedure. Lastly, by evaluating the asymmetric relationship between shadow economy and environmental pollution in Egypt, outcomes from the study are expected to rekindle discourse on the subject matter and expand the frontiers of knowledge among policymaker, researchers, and relevant stakeholders.

The rest of this paper is organized as follows. Section two contains the review of literature. Issues relating to methodology and data are dealt with in the third section, and the presentation and discussion of the findings are taken up in the fourth section. The study is concluded in the last section.

2. LITERATURE REVIEW

In the literature, the well-known environmental Kuznets curve (EKC) framework (Grossman and Krueger, 1991) provides an important theoretical foundation for the relationship between socioeconomic factors and environmental quality (and variables). Indeed, the framework has provided important basis for exploring the empirical connection between environmental quality and socioeconomic factors such as income, urbanisation, population density, globalisation, international trade, political instability, financial development, and institutional quality, amongst others (Dada et al., 2023). Although the empirical literature associated with the shadow economy-environmental pollution nexus is just emerging, a number of studies has been conducted from different perspective to examine the relationship between shadow economy-environmental pollution. For instance, using a panel of 152 countries, Elgin and Oztunali (2014a) examined the relationship between shadow economy and environmental pollution between 1999 and 2009. The empirical results demonstrate the presence of an inverse-U relationship between shadow economy and environmental pollution, with higher levels of shadow economy associated with larger environmental pollution. Similarly, Huynh (2020), using system generalised method of moments (SYS-GMM), demonstrates that shadow economy is positively related with air pollution in 22 Asian countries between 2002 and 2015.

Furthermore, Chu and Hoang (2022) employed the panel quantile regression estimator to evaluate the relationship between shadow economy and environmental pollution in 32 OECD countries from 1990 to 2015, and established the presence of an inverted U-shaped relationship between the shadow economy and environmental degradation. Also, using a sample of West African countries between 1992 and 2015, a dataset of 35 African countries between 1991 and 2015, and a sample of 30 African countries during the 1991-2017 period, Dada et al. (2021), Dada et al. (2022) and Dada et al. (2023) indicate a significant positive relationship between shadow economy and environmental pollution. In addition, Chen et al. (2018) examined the effect of environmental regulation, shadow economy, and corruption on environmental quality in Chinese 30 provinces between 1998 and 2012. Using the generalised method of moments (GMM) technique, the study concluded that shadow economy, stringent environmental regulation, and corruption, are positively related to environmental pollution in China.

Additionally, Elgin and Oztunali (2014b) confirms that the relationship between shadow economy and environmental pollution in Turkey between 1950 and 2009 follows an inverse U-shaped pattern. In a similar vein, a number of studies on shadow economy-environmental quality conducted at country-specific level established that shadow economy promotes environmental pollution in countries such as China, Nigeria, Pakistan, and Turkey (Baloch et al., 2022; Dada and Ajide, 2021; Imamoglu, 2018; Köksal et al., 2020; Pang et al., 2021). In contrast, some authors discovered that shadow economy and environmental pollution are negatively related (Camara, 2022; Dada et al., 2023; Goel et al., 2013; Nkengfack et al., 2021; Yu et al., 2022). In other words, the studies suggest that countries with large shadow economic activities are associated with lower (recorded) environmental pollution levels. However, Tran (2022) reported an insignificant relationship between shadow economy and environmental pollution in Veitnam.

Unequivocally, a survey of the extant literature has demonstrated the growing body of empirical research on the relationship between shadow economy and environmental quality. However, research have paid little interest in evaluating the asymmetric relationship between shadow economy and environmental pollution. Perhaps the only exception the recent study conducted by Sohail et al. (2021) on the asymmetric relationship between shadow economy and environmental pollution in selected South Asian countries (Pakistan, India, Bangladesh, Sri Lanka, and Nepal) between 1991 and 2019. The empiric al outcome of the study demonstrate that the effect of negative and positive shocks in shadow economy on environmental pollution are significantly different in the countries, with positive shocks in shadow economy leading to degradation of the environment in Pakistan but improving the quality of the environment in Bangladesh and Sri Lanka; while negative shocks in shadow economy is positively related with environmental pollution in India, and negatively associated with environmental quality in Bangladesh and Nepal. Therefore, the present study contributes to the literature by the growing body of literature by exploring the asymmetric effect of shadow economy on environmental pollution in Egypt during the 1970-2022 period.

3. METHODOLOGY AND DATA

3.1. Model Specification

Following Dada et al. (2021), a simple econometric model indicating a linear relationship between environmental pollution and shadow economic activities is specified as follows:

$$env_t = \sigma_0 + \sigma_1 se_t + \sigma_2 gl_t + \varphi^{'} Z_t + \mu_t \tag{1}$$

Where t=1, 2,…,T denotes time. *env* is environmental pollution (proxied by carbon dioxide (CO_2) emissions stemming from the burning of fossil fuels and producing cement, and the consumption of solid, liquid, and gas fuels and gas flaring, in metric tons per capita. For robustness, total CO_2 emissions in metric tons is also used). *Se* represents the magnitude of shadow economy (measured as a percentage of the nominal GDP). *gl* denotes globalization (measured by KOF globalization index), and *Z* is a set of control variables (such as GDP per capita, urbanisation, and industrialisation) considered. σ_0 is the intercept, and σ_1, σ_2, and φ are slope coefficients. μ_t is the error term, with zero mean and constant variance. To reduce skewness, per capital income and CO2 emission are transformed to natural logarithm.

3.2. Estimation Techniques

3.2.1. Bootstrap NARDL bounds-testing approach

To explore whether the effect of shadow economy on environmental pollution is asymmetric, we adopt the nonlinear autoregressive distributed lag (ARDL) bounds testing approach proposed by Shin et al. (2014). The approach is an asymmetric alternative of the traditional ARDL bounds testing technique developed by Pesaran et al. (2001). One of the main advantages of the technique over the traditional approach is its ability to capture the potential nonlinearity or asymmetry that lies within a relationship (David et al., 2020). Besides incorporating all the benefits associated with the use of the traditional ARDL bounds testing, the seemingly simple approach is comprehensive enough to accommodate asymmetric switching between short and long-runs (Abu et al., 2022).

Generally, a bivariate NARDL (p,q) model can be expressed as follows:

$$y_t = c + \beta^+ x_t^+ + \beta^- x_t^- + \chi^{'} Z + \upsilon_t \tag{2}$$

Where β^+ and β^- are the parameters of the partial sums of x_t, that is the asymmetric variable of shadow economy. Z is the vector of regressors entering the model symmetrically, and υ_t is the stochastic error term which is independently and identically distributed as a normal distribution with zero mean and finite variance. x_t is a $k \times 1$ vector of regressors decomposed as:

$$x = x_0 + x_t^+ + x_t^- \tag{3}$$

and x_t^+ and x_t^- are the partial sum process of positive and negative changes in x_t. The partial sums are generated by computing:

$$x_t^+ = \sum\nolimits_{i=1}^{t} \Delta x_i^+ = \sum\nolimits_{i=1}^{t} \max(\Delta x_i, 0) \tag{4}$$

$$x_t^- = \sum\nolimits_{i=1}^{t} \Delta x_i^- = \sum\nolimits_{i=1}^{t} \min(\Delta x_i, 0) \tag{5}$$

Following Shin et al. (2014), Equation (2) can be associated with a linear $ARD(p,q)$ model to generate an unrestricted $NARDL(p,q)$ model expressing an asymmetric relationship between variables x_i and y_i can be expressed as follows:

$$y_t = c + \rho y_{t-1} + \theta^+ x_{t-1}^+ + \theta^- x_{t-1}^- + \gamma^{'} Z + \sum_{i=1}^{p-1} \delta_i \Delta y_{t-i}$$

$$+ \sum_{i=0}^{q} (\pi_i^+ \Delta x_{t-i}^+ + \pi_i^- \Delta x_{t-i}^- + \vartheta^{'} \Delta Z_{t-1}) + \upsilon_t \tag{6}$$

Where Δ is the first difference operator, and $\theta^+ = -\rho\beta^+$, and $\theta^- = -\rho\beta^-$. ρ represents the parameter of the lagged level of the dependent variable, π_i^+ and π_i^- are the associated short-run parameters, Z is the vector parameter of the lagged level of covariates entering the model symmetrically, and ϑ is the vector parameter of differenced symmetric variables. The optimal lag lengths (p, q) are suggested by AIC.

Following Shin et al. (2014), the asymmetric cointegrating relationship variables is established based on the traditional bounds testing procedure of Pesaran et al. (2001). However, evidence have shown that the traditional bounds testing approach is associated with a number of limitations, including weak size and power properties, and the issue of inconclusive or indeterminate inferences (Abu et al., 2022; McNown et al., 2018). Therefore, to determine the asymmetric cointegrating relationship between the variables we adopt the bootstrap cointegrating procedure proposed by McNown et al. (2018). Besides dealing with the issues of weak size and power properties, and eliminating the problem of inconclusive inferences associated with the traditional ARDL bounds testing approach, the inclusion of additional test on the lagged level(s) of the independent variable(s) in the procedure to complement the existing tests in the traditional bounds-testing framework further increase the power of the F-test. By extension, this suggest that the bootstrapping approach provides a more robust insight on the cointegration status of the system (Abu et al., 2022).

Adapting the bootstrapping procedure outlined in McNown et al. (2018), the presence or otherwise of an asymmetric (nonlinear) cointegrating relationship between variables y_t and x_t is established by testing the following three hypotheses: H_0: $\rho = \theta^+ = \theta^- = \gamma = 0$, based on the overall F-test on all lagged-level variables (F_1); H_0: $\rho = 0$, based on the t-test on the lagged level of the dependent variable (t); and H_0: $\theta^+ = \theta^- = \gamma = 0$, based on the F-test on the lagged levels of the independent variable(s) (F_2). The null hypotheses are rejected on the grounds that the test statistic(s) exceed the corresponding bootstrap-generated critical values at a specific significance level. All three null hypotheses must be rejected for a valid conclusion on asymmetric cointegration between variables to be reached. The associated critical values for the three tests are generated through the bootstrap procedure outlined in McNown et al. (2018). If cointegration is confirmed, the usual long-run and short-run model can be estimated. In addition, the long-run and short-run symmetry relationship can equally be tested by employing the standard Wald test. For long-run asymmetry, the relevant joint null hypothesis to be tested is: $-\theta^+/\rho = -\theta^-/\rho$, while for short-run asymmetry, the joint null hypothesis to be tested is $\sum\nolimits_{i=0}^{q} \pi_i^+ = \sum\nolimits_{i=0}^{q} \pi_i^-$

3.2.2. Dynamic ARDL simulation

In addition to the bootstrap NARDL technique, we also employ the dynamic ARDL simulations proposed by Jordan and Philips (2018) to observed the response of environmental pollution to changes in the level of shadow economic activities in Egypt. One of the key advantages of the dynamic ARDL simulation procedure over the traditional ARDL framework lies in its capacity to provide simple yet robust interpretation of short-and long-run impacts which is often difficult in the face of complex lag structures. The procedure is particularly unique in the sense that it simulates and automatically visualise the impact of a "counterfactual change in one weakly exogenous variable at only one-point in time using stochastic simulation techniques, while holding all else equal (Abu et al., 2022; Jordan and Philips, 2018). In the present study, we conduct 5,000 unique simulations using the error correction algorithm of the dynamic ARDL procedure based on the shadow economy parameter in the unrestricted ARDL equation detailed in Equation (6).

3.3. Data

The study used timeseries data covering the period between 1970 and 2022. The data for CO_2 emission is collected from Global Carbon Project. Moreover, shadow economy data is sourced from Elgin and Oztunali (2012) and Medina and Schneider (2019). Globalisation data is collected from KOF Swiss Economic Institute. The remaining variables - GDP per capita, urbanization (proxied by annual growth of the urban population), and industrialization (measured by the ratio of industrial output to the GDP) are sourced from the World Bank's World Development Indicators (WDI).

4. RESULTS AND DISCUSSION

4.1. Descriptive Statistics and Correlation Analysis

The descriptive statistics and correlation analysis of the variables are computed and summarised in panel A and panel B of Table 1, respectively. The results indicate that the average size of total CO_2 emission in metric tons and CO_2 emission per capita, as a measurement of environmental pollution is 123.37 metric tons and 1.631, respectively, ranging from 21.654 metric tons and 0.623 to 263.429 metric tons and 2.555, respectively between 1970 and 2022. In addition, the results demonstrate that the average size of shadow economy (as a share of the official GDP) in Egypt during the period is 37.487%, and the mean KOF globalisation index, GDP per capita, urban population growth rate, and industrial output growth rate between 1970 and 2022 is 55.480, US$1,398.175, 2.316%, and 5.952%, respectively.

The results of the correlations analysis suggest that environmental pollution (CO_2 emission) have a strong, positive and significant correlation with globalisation (0.913 and 0.964) and GDP per capita (0.939 and 0.867). However, the results demonstrate that the correlation between urban population growth rate (−0.784 and −0.820) is strong but negative, while environmental population while industrial growth and environmental pollution have a moderate and strong significant negative correlation.

4.2. Unit Root Test Results

Sequel to the empirical estimation of the nonlinear effect of shadow economy on environmental pollution in Egypt, we conduct unit root tests to determine the stationarity properties of the series. The results of the conventional Augmented Dickey-Fuller (ADF) and Philips-Perron (PP) tests, alongside the Kwiatkowski-Phillips-

Table 1: Descriptive statistics and correlation matrix

Panel A	env^{MT}	env^{PC}	*se*	*gl*	*pcy*	*urb*	*ind*
Mean	123.371	1.631	37.487	55.480	1398.175	2.316	5.952
SD	78.376	0.594	6.7427	10.079	1119.622	0.401	4.388
Min.	21.654	0.623	29.9	33.935	231.217	1.814	-0.963
Max.	263.429	2.555	54.22	68.456	4295.407	3.158	16.614
Panel B							
env^{PC}	0.971***	1.000					
se	−0.798***	−0.890***	1.000				
gl	0.913***	0.964***	−0.915***	1.000			
pcy	0.939***	0.867***	−0.697***	0.782***	1.000		
urb	−0.784***	−0.820***	0.829***	−0.901***	−0.670***	1.000	
ind	−0.515***	−0.491***	0.445***	−0.505***	−0.499***	0.505***	1.000

Asterisks (***), (**) and (*) denotes statistical significance at 1%, 5% and 10% levels, respectively. env^{MT}: Total CO_2 emission (in metric tons): env^{PC}: CO_2 emission per capita; *se*: Shadow economy (% of GDP); *gl*: KOF gloabalisation index; *pcy*: GDP per capita; *urb*: Urban population growth rate; *ind:* Industrial output annual growth rate

Source: Author's computation using EViews 12

Table 2: Results of unit root tests

	Env^{PC}	$lenv^{MT}$	*se*	*gl*	*lpcy*	*urb*	*ind*
ADF							
Level	−1.268	−2.672*	−4.578***	−2.796*	−0.6459	−1.7628	−4.038***
1st Diff.	−9.799***	−8.863***	–	−5.251***	−5.336***	−4.7445***	–
PP							
Level	−1.174	−2.965**	−3.313**	−2.669*	−0.583	−1.773	−4.069*
1st Diff.	−9.783***	–	–	−5.304***	−5.349***	−4.491***	−22.735***
KPSS							
Level	0.839***	0.971***	0.787***	0.945***	0.962***	0.831***	0.717**
1st Diff.	0.100	0.453	0.084	0.070	0.045	0.103	0.4601

l is natural logarithm. ADF represents the Augmented Dickey and Fuller (1979) test, KPSS denotes Kwiatkowski et al. (1992) test, and PP is Philips-Perron test. MacKinnon's (1996) critical values (CV) for ADF and PP tests (intercept only) are given as: −3.58, −2.92, and−2.59, and−3.56, −2.92, −2.59, at 1%, 5% and 10% levels, respectively. KPSS asymptotic CV are: 0.739 (1%), 0.463 (5%), and 0.347 (10%). ADF and PP tests the null hypothesis of unit root against the alternative hypothesis of a (trend-) stationary process. On the other hand, KPSS test the null of stationarity against the alternative hypothesis of a unit root. The optimal lag length selection in ADF and PP is based on the Schwarz Information Criteria (SIC) of Schwarz (1978). The bandwidth for the KPSS test is automatically determined based on the Newey-West method using the Bartlett kernel. Asterisks (***), (**) and (*) indicate significance at 1%, 5% and 10% level, respectively

Source: Authors' computation using EViews 12

Schmidt-Shin (KPSS) unit root test are summarised in Table 2. The results of the tests present some mixed outcomes. For instance, while the ADF tests indicate that environmental pollution variables (env^{MT} and env^{PC}), *gl*, *lSea*, and *urb* are stationary after taking their first difference, while and are stationary at level at 1% level of significance. On the other hand, the PP tests suggest that Env^{MT} and *se* are integrated of I(0) process, while env^{PC}, *gl*, *lpcy*, *urb*, and *ind* are integrated of I(1) process. In addition, the KPSS tests conclude that the variables are stationary after taking their first difference, thus they are integrated of I(1) process. Apparently, the results indicate that the variables are a mixture of I(0) and I(1). However, since none of the variables are integrated of order greater than I(1), we have sufficient justification to adopt the bootstrap NARDL bounds testing approach.

4.3. Bootstrap NARDL Bounds-testing Cointegration Results

To determine the cointegrating relationship between the series, the bootstrap NARDL bounds testing procedure is adopted. The results of the bounds testing, based on an NARDL model with lag-length (2,3,1,0,3,1,1) suggested by AIC, are summarised in Table 3. The results demonstrate that the values of the overall F-statistic on the lagged level variables (3.733), t-test on the lagged level dependent variable (−5.585), and the F-statistic on lagged level independent variables (4.336) are all greater than the bootstrap-generated critical values at 5% level. Therefore, there is sufficient evidence to reject the null hypothesis of no cointegration between the series in the system.

4.4. Estimation Results of the NARDL Model

Following the confirmation of the presence of a cointegrating relationship between environmental pollution and shadow economy (alongside globalisation, GDP per capita, urban population growth, and industrial growth), the results of the corresponding short-and long-run estimates of the selected ARDL model are presented in Table 4. In particular, the long-and short-run estimates (alongside long-run and short-run asymmetry test results) are summarised in panel A and panel B of Table 4, respectively. The results of the long-run and short-run asymmetry tests (using the Wald restriction test) suggest that the long-and short-run relationship between shadow economy and environmental pollution is asymmetric.

Moreover, the short-and long-run results (panel A) indicate that positive shocks in shadow economy have a significant positive effect on environmental pollution (CO_2 emission per capita), while the negative changes in shadow economy reduce environmental pollution, both in the long-and short-run, and the relationships are significant at 5% level. This indicates that the relationship between

Table 3: Bootstrap NARDL bounds-testing result

Model	Lag length	Statistics	Values	Bootstrap-generated CVs		
				1%	5%	10%
$enc^{PC}\|se^+, se^-, gl, lpcy, urb, ind$	2,3,1,0,3,1,1	F_1	3.733**	4.43	3.61	3.23
		t	−5.585***	−4.99	−4.38	−4.04
		F_2	4.336**	4.69	3.72	3.25

Asterisk (**) denotes significance at a 5% level based on critical values generated from the bootstrap procedure (with 1,000 replications) of McNown *et al*. (2018). F_1 represents the F-statistic for the lagged level variables F_2 denotes the F-statistic for the lagged level of the independent variables, and t is the t-statistic for the lagged level of the dependent variable. The optimal lag-length is suggested by AIC

Source: Authors' computation using EViews 12

Table 4: Results of NARDL model

Panel A: ARDL (2,3,1,0,3,1,1) Long-run coefficient estimates-Dependent variable: env^{PC}

cons	se^+	se^-	*gl*	*lpcy*	*urb*	*ind*
−3.242***	0.089**	−0.031**	0.034***	0.236*	0.319**	−0.006
(0.581)	(0.044)	(0.015)	(0.009)	(0.154)	(0.135)	(0.007)

Panel B: ARDL (2,3,1,0,3,1,1) Short-run coefficient estimates–Dependent variable: Δenv^{PC}

Regressors	Lag order		
	0	1	2
Δenc^{PC}		−0.251 (0.108)**	
Δse^+	0.035 (0.054)	−0.365 (0.071)***	−0.269 (0.069)***
Δse^-	−0.127 (0.022)***		
$\Delta lpcy$	0.270 (0.119)**	0.018 (0.126)	−0.295 (0.112)**
Δurb	−0.162 (0.118)*		
Δind	0.002 (0.003)		
W_{LR}	7.525 [0.010]**		
W_{SR}	6.565 [0.010]**		

Panel C: Diagnostic test statistics

ECT_{t-1}	χ^2_{sc}	χ^2_{HET}	χ^2_{FF}	χ^2_{JB}	$Adj.R^2$
−0.807 (0.124)***	3.947 [0.139]	22.542 [0.165]	3.579 [0.068]	1.892 [0.388]	0.541

The optimal lag-length is suggested by AIC. Δ represents the first difference operator. Asterisk (***), (**) and (*) denote significance at 1%, 5%, and 10% level, respectively. In panels A and B, in parenthesis (.) are the standard errors, and values in square parenthesis [.] in panel C are the probability values of the LM test statistics. Superscripts "+" and "–" denote positive and negative partial sums, respectively. ECT_{t-1} is the parameter of one period lagged error term, representing the speed of adjustment back to equilibrium in the long run following a deviation from the equilibrium in the short-term. W_{LR} represents the Wald test statistics of long-run symmetry defined by . $-\hat{\theta}^+ / \hat{\rho} = -\hat{\theta}^- / \hat{\rho}$. W_{SR} is the short-run symmetry defined by $\sum_{i=0}^{q} \pi_i^+ = \sum_{i=0}^{q} \pi_i^-$. χ^2_{SC} , χ^2_{HET} , χ^2_{JB} and χ^2_{FF} denote the Breusch-Godfrey serial correlation, Breusch-Pagan-Godfrey heteroscedasticity, Jarque-Bera normality, and Ramsey RESET's functional form test statistics, respectively shadow economy and environmental pollution is asymmetric, with increase in the activities in the shadow economy worsening environmental quality in Egypt, and negative shocks in the activities leading to improvement in environmental quality. However, the results suggest that the magnitude of the impacts of the shocks in activities in the shadow economy on environmental pollution differs significantly. For instance, in the short-run, the magnitude of the impact of negative shocks in shadow economic activities is larger compared to the resulting short-run effect of positive shocks, but the magnitude of the long-run effect of positive shocks in shadow economy outweighs the impact of negative shocks in the long-run.

With shadow economic activities accounting for more than one-third of the Egyptian GDP, it clearly implies that the country will have to contend with poor environmental quality as shadow economic activities continue to thrive. Indeed, the shadow economic activities are major sources of environmental pollution due in part to the wide application of low technology and use of polluting intermediate goods to produce the final goods in the sector, and most importantly, the fact that they operate outside the monitoring and regulations of the government. Therefore, any positive shock or expansion in the activities in the shadow economy in the midst of lax environmental standards are recipe for the degradation in the quality of the environment. Apparently, any attempt to ensure a decline (negative shock) in activities in the sector will typically lead to the improvement in environmental quality. In a way, this outcome is partly consistent with the findings of previous studies which concluded that expansion in the size of shadow economic activities worsen the environmental quality (Dada et al., 2021; Elgin and Oztunali, 2014; Huynh, 2020; Swain et al., 2020; Yu and Gao, 2015).

Regarding the control variables, the results indicate that globalisation, GDP per capita, and urban population growth have positive and significant impact on CO_2 emission. This suggests that the integration of the global economy, an increase in the income of individuals from higher activity, and expansion in the urban population are key drivers of environmental degradation in Egypt. These outcomes support the findings of existing studies (Adams et al., 2016; Dada et al., 2021; Data et al., 2023; Pata and Caglar, 2021). Theoretically, it is argued that movement to a higher level of income would encourage the demand for cleaner and efficient energy-intensive goods, thus improvement in the quality of the environment. However, with the disparity in income level, especially in developing countries, it is apparent that such increase in income may not necessarily lead to reduction in environmental pollution. In fact, it is suggestive that an increase in income level would spur the demand goods and services. Consequently, this increased demand would drive production, leading to an increase in the degradation of the environment. In addition, the capacity of globalisation in reducing the quality of the environment is rather non-controversial. Specifically, given that globalisation directly contributes to trade and production activities, an increase in the integration of the world economy will spur and facilitate the consumption of energy-intensive, thus contributing to the pollution of the environment. Indeed, due to globalisation, the increase in international transportation has significantly contributed to environmental pollution. Furthermore, the increase in the population of urban areas could contribute to environmental degradation through the increase in energy use and emission, both from households and the industry, associated with urbanisation. In addition, the convergence coefficient (coefficient of error correction term lagged by one period), which is interestingly correctly signed, less than one, and statistically significant, suggest that about 81% of disequilibrium in environmental pollution through Co2 in the short-run will be corrected within a year.

4.5. Post-estimation diagnostics and model stability test results

To determine the adequacy of the estimated model for policy making, we conducted some post-estimation diagnostics. The results of the diagnostics summarised in panel C of Table 4 demonstrate that the estimated model is free from the problem of serial-correlation, heteroscedasticity, misspecification error, and the error terms in the model is normally distributed. Moreover, plots of the cumulative sum of recursive residuals (CUSUM) and the cumulative sum of squares of recursive residuals (CUSUMSQ) plots presented in Figure 1a and b, respectively, suggest that the parameters of the estimated model are stable over time.

4.6. Robustness and Consistency Checks

To ascertain the robustness and consistency of the results obtained, we used total CO_2 emission (in metric tons) as alternative measure of environmental pollution. The results of the estimation using the measure summarized in Table 5 show that the coefficient of interest variables (positive and negative shocks in size of shadow economy) is similar in terms of signs and significance. (Although the sizes of the coefficient are somewhat different). In the estimated model, the positive shocks in the size of shadow economy enter with a significant positive coefficient, and the coefficient of negative shocks is negative and significant at 5% level of significant, further confirming that the effect of shadow economy on environmental pollution is asymmetric. In addition, the results of the long-run asymmetry tests (using the Wald restriction test) show that the long-run relationship between shadow economy and environmental pollution is asymmetric. Furthermore, the signs and coefficient of the control variables are also consistent with the results summarised in Table 4. The coefficients of globalization, GDP per capita, and urban population growth are positive and significant, while industrial output growth enters with a positive but statistically insignificant coefficient. Interestingly, the results of the post-estimation diagnostics and model stability tests confirm the appropriateness and stability of the estimated model.

4.7. Simulation of the Response of Environmental Pollution to Changes in Shadow Economy Size

In addition to the bootstrap ARDL bounds-testing estimation, we also adopt the dynamic ARDL simulation technique in its nonlinear form to predict the response of environmental pollution to counterfactual changes/shocks in the size of shadow economy in Egypt over a 50-year period (that is from 2022 to 2071). The spike plots of the simulations of the response of environmental pollution to positive and negative shocks in the size of shadow economy in Egypt over a 50-year period based on 10,000 replications are presented in Figures 2 and 3, respectively.

Considering a one standard deviation counterfactual changes, the Figure 2 illustrates that CO_2 emission would increase to about 1.75

Table 5: Alternative estimation results of the nonlinear effect of shadow economy on environmental pollution

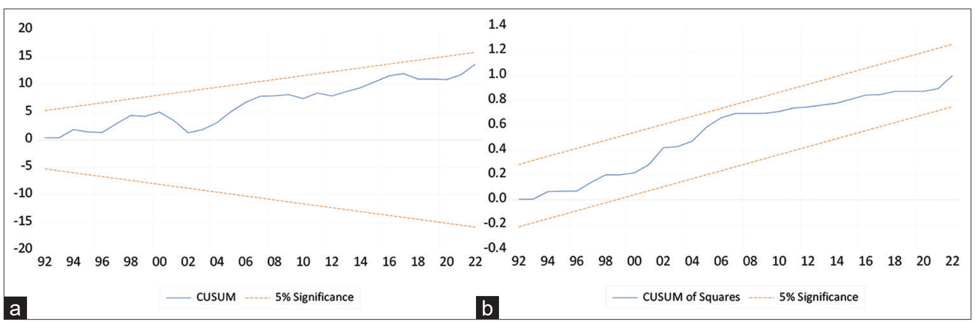
Panel A: ARDL (4,3,0,0,3,1,0) Long-run coefficient estimates-Dependent variable: $lenv^{MT}$						
cons	se^{+}	se^{-}	*gl*	*lpcy*	*urb*	*ind*
−0.292	0.139***	−0.031**	0.0362***	0.2436*	0.2925**	0.0049
(0.481)	(0.044)	(0.012)	(0.0081)	(0.146)	(0.142)	(0.0055)

Panel B: ARDL (4,3,0,0,3,1,0) Short-run coefficient estimates-Dependent variable: $\Delta lenv^{MT}$				
Regressors	Lag order			
	0	1	2	3
ΔEnv^{MT}		−0.541 (0.116)***	−0.352 (0.125)***	−0.239 (0.116)**
Δse^{+}	−0.073 (0.036)**	−0.242 (0.045)***	−0.205 (0.045)***	
$\Delta lpcy$	0.223 (0.076)***	−0.011 (0.072)	−0.195 (0.069)***	
Δurb	−0.085 (0.080)			
W_{LR}	7.067 [0.000]			

Panel C: Diagnostic test statistics					
ECT_{t-1}	χ^2_{sc}	χ^2_{HET}	χ^2_{FF}	χ^2_{JB}	$Adj.R^2$
−0.5135 (0.061)***	0.787 [0.675]	21.122 [0.221]	0.4799 [0.494]	0.3738 [0.8295]	0.632

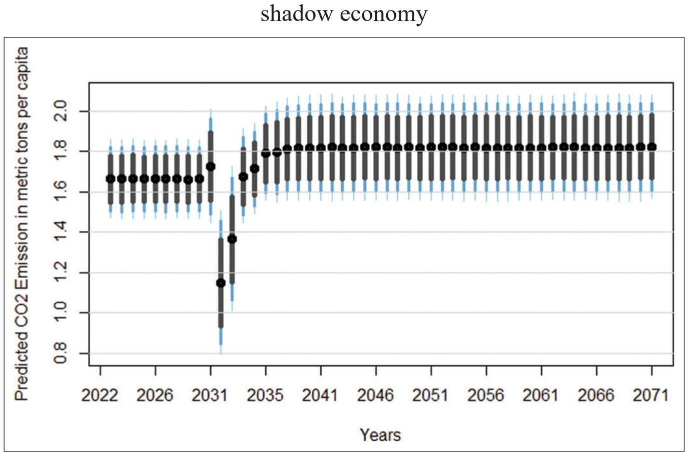
The optimal lag-length is suggested by AIC. Δ represents the first difference operator. Asterisk (***), (**) and (*) denote significance at 1%, 5%, and 10% level, respectively. In panels A and B, in parenthesis (.) are the standard errors, and values in square parenthesis [.] in panel C are the probability values of the LM test statistics. Superscripts "+" and "–" denote positive and nWegative partial sums, respectively. ECT_{t-1} is the parameter of one period lagged error term, representing the speed of adjustment back to equilibrium in the long run following a deviation from the equilibrium in the short-term. W_{LR} represents the Wald test statistics of long-run symmetry defined by $-\hat{\theta}^{+} / \hat{\rho} = -\hat{\theta}^{-} / \hat{\rho}$. χ^2_{SC}, χ^2_{HET}, χ^2_{JB}, and χ^2_{FF} denote the Breusch-Godfrey serial correlation, Breusch-Pagan-Godfrey heteroscedasticity, Jarque-Bera normality, and Ramsey RESET's functional form test statistics, respectively
Source: Authors' computation using EViews 12

Figure 1: Plots of CUSUM (a) and CUSUMSQ (b)



Source: Authors' computation

Figure 2: Plot of predicted CO_2 emission following a positive shock in shadow economy

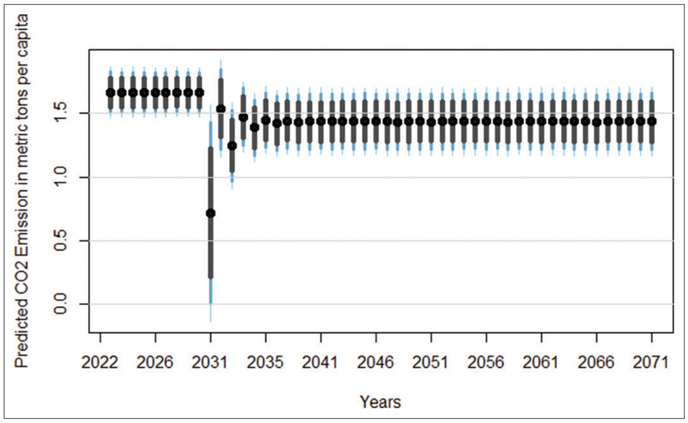


Note: The simulation is executed based on 10,000 replications. Black dots show the average predicted value, while shaded lines (from darkest to lightest) show the 75, 90, and 95 percentiles of the simulations' predictions, similar to a confidence interval
Source: Authors' computation using dynardl() and dynardl.simulation.plot() functions in dynamic R package

points following a 1 standard deviation shock in positive increase in the size of shadow economy in the 10th year (2031) from about 1.65 in the pre-shock periods (2022-2030). However, in the next year (2032) the amount of CO_2 emission (in metric tons per capita) declined significantly to about 1.15 points before rising back to about 1.25 points in 2033, 1.65 points (pre-shock level) in 2034, and then 1.7 points in 2035 before stabilising to about 1.8 points from 2034 through 2071. In essence, this suggests that, while positive shocks in the size of shadow economy would directly lead to an increase in degradation of the environment, it would be immediately followed by a short-term but significant improvement in the environmental quality, possibly due to the actions of the government. However, and perhaps due to the ineffectiveness of environmental regulations, the following years would be associated with further degradation of the environment to points higher than the pre-shocks levels.

In addition, to assess the response of CO_2 emission to negative shocks in shadow economy, the plot presented in Figure 3 demonstrates that the immediate impact of a standard deviation negative shock in the size of shadow economy after 10 years (2031) is the reduction in CO_2 emission (in metric tons per capita) from about 1.7 points in the

Figure 3: Plot of predicted CO_2 emission following a negative shock in shadow economy



Note: The simulation is executed based on 10,000 replications. Black dots show the average predicted value, while shaded lines (from darkest to lightest) show the 75, 90, and 95 percentiles of the simulations' predictions, similar to a confidence interval

Source: Authors' computation using dynardl() and dynardl.simulation.plot() functions in dynamic R package

pre-shock period (2022-2030) to about 0.7 point in 2031. However, in the next period the amount of CO_2 emitted (in tons per capita) increased to 1.5 point, and continue to fluctuate within the region of 1.3 and 1.5 before stabilising at a point a little <1.5.

Overall, the implication of these findings is that positive shocks in shadow economy leads to the degradation of the environment, and negative shocks in shadow economy reduces environmental pollution in Egypt. However, compared to the response of environmental pollution in the long-run, the magnitude of the impact of shocks in shadow economy is much larger in the short-run. Therefore, it is suggestive that the results of the simulations of the both positive and negative shocks in shadow economy confirm the results generated using the bootstrap NARDL approach.

5. CONCLUSION AND RECOMMENDATIONS

This study examines whether the impact of shadow economy on environmental pollution is asymmetric in Egypt. Using data from 1970 to 2022, and employing novel estimation techniques including the bootstrap NARDL bounds testing approach and the dynamic (N)ARDL simulation procedure, the results provides evidence of asymmetric cointegrating relationship between environmental pollution (proxied by aggregate CO_2 emission in metric tons, and CO_2 emission in metric tons per capita) and shadow economy (alongside globalization, GDP per capita, industrial growth and urbanisation. In addition, the results of the NARDL model confirms that the effect of shadow economy on environmental pollution is nonlinear, with positive shocks in shadow economy influencing the degradation of the environment while negative shocks in shadow economy improves the quality of the environment, both in the short- and long-run. However, the results illustrate that the magnitude of the impact of shocks in shadow economy is much larger in the short-run than in the long-run. Using an alternative measure of environmental pollution suggests that the outcome is robust. Additionally, the results demonstrate that GDP per capita, urbanisation, and globalisation are also important drivers of environmental pollution in Egypt. Besides, the adoption of the dynamic ARDL simulation procedure confirms that positive shocks in shadow economy leads to the degradation of the environment while negative shocks reduce environmental pollution, but the size of the effect is larger in the short-run.

The main policy implication from the study is that shadow economy has significant impact on environmental pollution in Egypt, and thus requires a well-though and pragmatic effort by the government to manage its expansion. With shadow economic activities accounting for more than one-third of Egyptian economy, the government must adopt a very efficient and effect policy action to reduce its magnitude, and thus the degradation of the environment. On the one hand, evidence suggests that the size of the shadow economy can be reduced by promoting good governance, strengthening the economic institutions, reducing regulatory and administrative burdens, enhancing tax compliance, promoting electronic payments, and automating procedures. However, to ensure that reduction in carbon emission, the government and policy makers should go beyond designing and adopting environmental policy action plans, but should actually ensure the implementation of the standards and regulations to protect the environment. This may involve the adoption of a reward and punishment system to encourage the adherence to environmental standards.

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