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ABSTRACT: This study investigates the impact of the business cycle on the Environmental Kuznets Curve (EKC) for the Eswatini Kingdom over the period 1970 – 2014. To this end, we employ the nonlinear autoregressive distributive lag (NARDL) model to capture the long-run and short-run cointegration effects between economic activity and greenhouse gas (GHG) emissions over different phases of the business cycle. Our findings reveal that economic activity only degrades the environment during upswing of the economic cycle whilst this relationship is insignificant during downswing of the cycle. We specifically compute a value of $3.57 worth of output been gained at the cost of a metric unit of emissions during economic expansionary phases. Altogether, these results insinuate much needed government intervention in the market for emissions via environmental tax reforms (ETR) which should be designed with countercyclical bias towards upswing the business cycle.

Keywords: Economic growth; Greenhouse gas (GHG) emissions; Environmental Kuznets Curve; Business cycles; Nonlinear autoregressive distributive lag (NARDL) model; Eswatini; Sub-Saharan Africa (SSA).

1 INTRODUCTION

The co-recipient of the most recent Nobel prize in economics (2018) was awarded to William Nordhaus for his dynamic integration of natural science into mainstream economics. Indeed, the timing of this award is impeccable as climate change is currently hailed as the most pressing challenge facing the earth's environment. Greenhouse gas (GHG) emissions, which are inherent to the creation of cheap energy via fossil fuel combustion, have been religiously cited as the main driver of global warming and it is feared that climate change is approaching irreversible levels. According to the International Energy Agency, sea levels are rising, oceans are becoming warmer and more acidic and the rate of ice sheet loss is increasing. Inevitably, this has led to serious environment defects such as increased number and frequency of heat waves, hurricanes, droughts, wild fires and environmental-related diseases. Given that a majority of the GHG emission can be traced to some form of economic activity, empirically quantifying these effects remains a central focus in the academic paradigm (Auffhammer, 2018).

Since the 1990's several empirical economists have advocated for a nonlinear, inverse U-shaped relationship between economic activity and economic degradation (Beckerman (1992), Grossman and Krueger (1995), Stern et al. (1996), Roberts and Grimes (1997), Xepapadeas and Amri (1998), Rothman (1998), de Bruyn et al. (1998), Jean and Duane (1999), List and Gallet (1999), Sun (1999)). The so-called "Environmental Kuznets curve" hypothesizes on a two-stage development process between economic activity and environmental degradation. In the first stage increased economic activity causes harm to the environment due to societies heavy reliance on unclean sources of energy in pursuing income and jobs. However, as a country progresses, becomes more environmentally conscious and begins to adopt more environmentally friendly technologies, the economy enters the second stage where increased economic activity infused in low emitting technologies eventually lowers economic degradation. Estimates of the point of inflexion between the two stages of development has been the focal point of many recent studies for different classes of GHG emissions (see Galeotti et al. (2006), Azomahou et al. (2006), Ang (2007), Coondoo and

Soumyananda (2008), Lee and Lee (2009), Lean and Smyth (2010), He and Richard (2010), Iwata et al. (2011), Piaggio and Padilla (2012), Kaika and Zervas (2013), Bella et. al. (2014) and Apergis et al. (2017) for examples).

Against this flurry of studies on the EKC, we pick up two shortcomings with the previous literature. Firstly, much of this literature is focused on high-emitting, industrialized economies and nevertheless remains inconclusive (see Carson (2010), Hervieux and Mahieu (2014), Sofien and Anis (2017), Mardani et al. (2019) and Sarkodie and Strezov (2019) for in-depth reviews). Corresponding literature for Sub Saharan African (SSA) countries as low emitting nations is scarce and is limited to high-emitting SSA countries like South Africa and Nigeria (Menyah and Wolde-Rufael (2010), Kohler (2013), Shahbaz et al. (2013), Rafindadi (2016) and Khobai and Le Roux (2016)). This is worth noting since the EKC in conventional low emitting SSA countries may evolve differently in comparison to high-emitting counterparts. For instance, it is possible that due to historically low levels of investment in environmentally friendly energy sources, African societies are highly dependent on unclean, cheaper technologies to the extent of excluding any possibility of a feasible inflexion point in the EKC. The second shortcoming in the literature is the failure of previous researchers to consider the dynamics of the EKC over the business cycle, which may be viewed as an alternative form of nonlinearity. For instance, economic activity could affect environmental degradation differently during the upswing of the business cycle in comparison to the periods of economic contraction. Also considering the relative openness and vulnerability of SSA countries to global economic shocks, the assumption of the EKC being linked with the business cycle maybe a more plausible theoretical underpinning for these countries.

We present an empirical case study integrating business cycles into the EKC for the Kingdom of Eswatini as a very small, low emitting-low growth SSA economy with no previous EKC literature attached to the country. Geographically Eswatini (formerly known as Swaziland) is situated in the most southern parts of Africa being mainly engulfed by South Africa to the North, West and South whilst sharing borders with Mozambique on approximately a third of her Eastern parts. The World Bank (2016) has recently reported on

Eswatini being one of the slowest growing SSA country, averaging lower than a 2 percent growth over the last decade. Conversely, the World Resources Institute (WRI) classifies Eswatini in the bottom 15 percent of global GHG emitters (i.e. ranking 169 out of 195) contributing to only 0.01% of global emissions. The most comprehensive time series data on both economic growth and GHG emissions for Eswatini is best sourced from the World Bank statistical database and this spans annually from 1970 to 2014. From the available data a profile of economic cycles and GHG emissions is extracted and summarized in Table 1. As can be observed from Table 1, emissions during recessions have lower averages in comparison to those emitted during expansionary cycles. Our aim is to econometrically validate this phenomenon for the Eswatini Kingdom using the nonlinear autoregressive distributive (N-ARDL) framework of Shin et al. (2014) which is structured to model both long-run and short-run asymmetric cycles in time series.

The rest of the study is presented as follows. The proposed methodology of the paper is outlined in the next section of the paper. The data is then described and examined for unit roots in section 3. Our empirical analysis is carried out in section 4. The concluding remarks and policy implications of the study is provided in section 5.

Table 1: Profile of business cycles, gdp and emissions in Eswatini (1970-2014)

Business cycles	periods	Average GDP (US$)	Average Emissions (metric equivalent of CO_2 emissions)
Expansion years	[1970-1975], [1977-1981], [1983], [1986-1995], [1997], [2000], [2003-2007], [2009-2012].	1,799,996,693	2,631,740,160
Recession years	[1976], [1982], [1984-1985], [1996], [1998-1999], [2001-2002], [2008], [2013-2014].	1,526,474,973	2,375,400,620

2 METHODOLOGY

The traditional EKC is represented as the following quadratic model specified between GHG emissions (E_t) and economic output (Y_t):

$$E_t = \alpha_t Y_t + \beta_t Y^2{}_t + e_t, \qquad \alpha_t > 0, \beta_t < 0, e_t \sim N(0, \sigma^2) \qquad (1)$$

From equation (1) the inflexion or turning point in the EKC is computed as the derivative of E wrt Y equated to zero and solved for optimal Y i.e. $\partial E/\partial Y = \alpha + 2\beta Y = 0$; $Y = -\alpha/2\beta$. In our study, we propose an alternative EKC function designed to capture the varying impacts of economic activity on emissions during expansions and recessions phases in the business cycles. Our baseline asymmetric cointegration model is given as:

$$E_t = \alpha_t + \beta_1 Y(+) + \beta_2 Y(-) + e_t, \qquad (2)$$

Where the coefficients β_1 and β_2 enter the long-run model asymmetrically and are designed to capture the impact of economic activity on growth on emissions during expansions and recessions, respectively. Since expansionary (recessionary) periods are defined as positive (negative) changes in economic output, we can partition the GDP output variable into its partial sum processes of positive and negative changes i.e.

$$Y_t^+ = \sum_{j=1}^{i} \Delta Y_j^+ = \sum_{j=1}^{i} \max(\Delta Y_j, 0) \text{ and } Y_t^- = \sum_{j=1}^{i} \Delta Y_j^- = \sum_{j=1}^{i} \min(\Delta Y_j, 0) \qquad (3)$$

Using the partial sums processes defined in equation (3), we estimate the long-run and short asymmetric cointegration effects for regression equation (2) using the NARDL model introduced recently by Shin et al. (2014). We begin by specifying the following NARDL (p, q) estimation regression:

$$E_t = \sum_{j=1}^{p-1} a_i E_{t-j} + \sum_{j=0}^{q-1}(b_j^+ Y_{t-j}^+ + b_j^- Y_{t-j}^-) + v_t \quad (4)$$

Which can be re-specified as the following NARDL-ECM (p, q) estimation regression:

$$\Delta E_t = \sum_{j=1}^{p} \rho_i E_{t-j} + \Phi_j^+ Y_{t-j}^+ + \Phi_j^- Y_{t-j}^- + \sum_{j=1}^{p-1} \psi_i \Delta E_{t-j} + \sum_{j=0}^{q-1}(\alpha_j^+ \Delta Y_{t-j}^+ + \alpha_j^- \Delta Y_{t-j}^-) + v_t$$

$$= \sum_{j=1}^{p} \rho_i ect_{t-1} + \sum_{j=1}^{p-1} \psi_i \Delta E_{t-j} + \sum_{j=0}^{q-1}(\alpha_j^+ \Delta Y_{t-j}^+ + \alpha_j^- \Delta Y_{t-j}^-) + v_t \quad (5)$$

Where ect_t is the nonlinear error correction term and asymmetric long run coefficients are computed as $L_Y(+) = -(\Phi^+/\rho)$ and $L_Y(-) = -(\Phi^-/\rho)$. There are four operational testing procedures for asymmetric cointegration based on the NARDL-ECM's. The first is an adaptation Banerjee et al. (1998) cointegration which is a t-test on the coefficient of the error correction term (i.e. $\rho = 0$). The second test is an extension of the joint F-test of Pesaran et al. (2001) which tests the null hypothesis of no asymmetric cointegration effects as $\rho = \Phi^+ = \Phi^- = 0$ against the alternative $\rho \neq \Phi^+ \neq \Phi^- \neq 0$. Since the asymptotic distributions of the tests are non-standard, the 'bounds testing' approach of Pesaran et al. (2001) is used to accommodate for two extreme cases amongst the regressors, that is, when all regressors are I(0) and when they are all I(1). The last two tests, as proposed by Shin et al. (2014) separately test for long-run asymmetric effects (i.e. $L_Y(+) = L_Y(-)$) and for short-run cumulative asymmetries (i.e. $\alpha_i^+ = \alpha_i^-$ for all i=0,…,q-1. The statistics testing the aforementioned asymmetric hypotheses are denoted as t_{BDM}, F_{PSS}, W_{LR} and W_{SR}, respectively.

3 DATA AND INTEGRATION TESTS

The data is sourced from the World Bank online statistical database and consists of the total greenhouse emissions expressed in metric equivalent of CO_2 emissions (E) and the gross domestic product expressed in US dollars (Y). Table 2 presents the findings from the conventional ADF and modified DF-GLS integration tests performed on the levels and the first differences of the time series variables. Note that both tests define their null hypothesis as the series containing a unit root and in our case, we consider rejecting this null hypothesis in favour of the stationary alternative if the test statistic exceeds at least the associated 5 percent critical level. The obtained tests statistics from both tests for the GDP variable in levels do not exceed their 5 percent critical values, regardless of whether the test is performed with a drift or with a drift or intercept, whilst those for emissions-in-levels can only reject the unit root hypothesis when a drift is included in the test. However, in their first differences the statistics produced from both ADF and DF-GLS tests unanimously reject the unit root null hypothesis for both variables at all critical values. Against this evidence of the series possibly containing both I(0) and I(1) variables, we conclude on the (N)ARDL model being the most suitable framework for the evaluating cointegration effects amongst the data as opposed to other frameworks (e.g. OLS, Engle-Granger, VECM) which require the data to be mutually integrated of similar order.

Table 2: Unit root test results

Series	ADF		DF-GLS	
	Intercept	Intercept+trend	Intercept	Intercept.+trend
Y	-0.09 (0)	-2.51 (1)	-0.18 (1)	-2.45 (1)
ΔY	-4.67*** (0)	-4.62*** (0)	-4.68*** (0)	-4.71*** (0)
E	-1.87 (0)	-4.66*** (0)	-1.39 (0)	-4.77*** (0)
ΔE	-7.07*** (1)	-6.99*** (1)	-7.15*** (1)	-7.18*** (1)

Notes: "***", "**" denote the 1% and 5%significance levels, respectively. The optimal lag lengths of the unit root tests as determined by the SC is reported in parentheses.

4 RESULTS

Prior to presenting our main NARDL empirical results, we provide baseline ARDL estimates for the quadratic EKC function (equation 1) for comparative purposes. From the findings reported in Table 3, both the t_{BDM} and F_{PSS} statistics produce estimates of 7.71 and -4.36, respectively, which both exceed their corresponding 1 percent critical levels. This evidence supports significant ARDL-ECM cointegration effects amongst the series. However, note that whilst our computed long-run coefficient on the output variable (L_Y) produces an expected positive and statistically significant estimate of 0.73, the long-run coefficients on the output-squared terms (L_{YSQ}) produces a statistically insignificant estimate of -5.64E-11. Similar insignificant estimates are also observed for the estimated short-run coefficients i.e. ΔY and ΔYSQ. Altogether, the insignificance of the YSQ variable over both the long-run and short-run implies the absence of an inflexion point in the EKC for Swazi data and hence our proposition of modelling the EKC over the business cycle is well justified.

Table 3: Baseline ARDL (1,0,0) estimates

	Estimate	p-value
F_{PSS}	7.71	0.00***
t_{BDM}	-4.36	0.00***
E_{t-1}	-0.679053	0.00***
Y_{t-1}	0.497031	0.00***
Ysq_{t-1}	-5.64E-11	0.07*
ΔY	-0.399691	0.44
ΔYsq	6.77E-11	0.47
L_Y	0.731055	0.00***
L_{YSQ}	-8.31E-11	0.18
R^2	0.76	
Adj. R^2	0.74	
χ^2_{SC}	1.729450	0.19
χ^2_{HET}	0.007106	0.93
χ^2_{FF}	1.401993	0.17

Notes: "***", "**" denote the 1%, 5% and 10% significance levels, respectively. The optimal lag length of the ARDL model is determined by the SC information criterion. χ^2_{SC}, χ^2_{HET} and χ^2_{FF} denote the tests statistics for serial correlation, heteroscedasticity and function form.

Our main NARDL modelling results presented in Table 4 provide sufficient and necessary evidence of a business cycle induced EKC for Eswatini. Our first point of reference are the t_{BDM} and F_{PSS} statistics which both reject the null hypotheses of no nonlinear ECM effects and no asymmetric ARDL cointegration relations, respectively, at all critical levels. Similarly, the reported Wald test statistics for long-run asymmetries (i.e. $W_{LR} = 18.21$) exceeds the associated 1 percent upper bound critical level reported in Pesaran et al. (2001). Note that the long-run coefficients $L_{Y(+)}$ and $L_{Y(-)}$ produce estimates of 0.28 and -0.05, respectively, albeit only statistically significant for the former and insignificant for the latter. Hence, for the Swazi case, a dollar increase in GDP output during the upswing of the business cycle results in a 0.28 metric increase in CO_2 equivalent GHG emissions. Equivalently, this implies that during expansionary periods an increase of $3.57 worth of GDP is gained from every unit increase in GHG emissions. Note that during the downswing of the cycle, reduced economic activity as measured by the $L_{Y(+)}$ variable, does not significantly influence emissions over the long-run. Furthermore, we fail to find evidence of short-run asymmetries as the W_{SR} statistic produces and estimate of 3.08 which falls in between the 10 percent I(1) and I(0) critical values reported in Pesaran et al. (2001). In such a case, we render the outcome of the test as being inconclusive (Shin et al., 2001).

Table 4: N-ARDL (1,1,0) estimates

	Estimate	p-value
F_{PSS}	7.895407	0.00***
t_{BDM}	-4.697587	0.00***
W_{LR}	18.20807	0.00***
W_{SR}	3.075617	0.08*
E_{t-1}	-0.718854	0.00***
$Y_{t-1}(+)$	0.203845	0.00***
$Y_{t-1}(-)$	-0.027428	0.06*
$\Delta Y(+)$	0.203542	0.06*
$\Delta Y(-)$	-1.915623	0.05*
$L_{Y(+)}$	0.282657	0.07*
$L_{Y(-)}$	-0.046783	0.95
R^2	0.77	
Adj. R^2	0.75	
χ^2_{SC}	0.383890	0.68
χ^2_{FF}	0.024287	0.88

χ^2_{HET}	1.712683	0.11

Notes: "***", "**" denote the 1%, 5% and 10% significance levels, respectively. The optimal lag length of the NARDL model is determined by the SC information criterion. χ^2_{SC}, χ^2_{HET} and χ^2_{FF} denote the tests statistics for serial correlation, heteroscedasticity and function form.

5 CONCLUDING REMARKS AND POLICY IMPLICATIONS

This paper examines the possibility of integrating the business cycle into the EKC for the Eswatini Kingdom as a small, landlocked SSA country. The current availability of time series data confines our empirical analysis over a uniform period of 1970-2014 for the GDP and GHG emissions. Notably, over this time span both conventional (ADF) and modified (DF-GLS) unit root tests find the series to be combinations of I(0) and I(1) variables. Against these integration properties, we find it best to base our time series analysis on the (N)ARDL econometric framework which is accommodative of series integrated of orders lower than I(2). Moreover, considering the relative short span of time series available for empirical use, the ARDL model stands out as a more favourable model attributing to its superior asymptotic properties in small sample sizes.

In estimating the traditional EKC specification using the linear ARDL, as a control model, we fail to capture the quadratic form since the 'nonlinear' term intended to capture the inflexion point in the EKC is insignificant. However, employing the NARDL regressions to capture the EKC over the business cycle model circumvents this problem in terms of modelling nonlinear cointegration behaviour amongst the series. The NARDL model estimates that during the upswing of the business cycle, a dollar increase in Swazi GDP over the steady-state produces 0.28 metrics of total GHG emissions which amounts to approximately $3.57 per unit metric of emissions). On the other hand, we observe that lower economic activity experienced during recessionary periods does not significantly influences environmental degradation in the Eswatini Kingdom.

In drawing policy implications from our study, we find it inadvisable for the Swazi government to rely on the mechanics of the traditional EKC which implies that Eswatini should seek to reach some ‘threshold’ level of income before the Kingdom can safely transition into an economy characterized by large-scale reductions in environmental degradation. So, what is the way forward for Eswatini policymakers? Firstly, fiscal authorities need to intervene in the market for GHG emissions and this can be feasibly achieved through environmental tax reforms (ETR). These extra tax revenues can relieve pressure of the currently strained fiscal budget of the Kingdom and can be used to protect lower income groups from the increased tax burden. Secondly, the design of these carbon-pricing policies should be countercyclical in nature, that is, emissions should be priced with a strong bias towards upswing of the business cycle. Thirdly, considering that we estimate a \$3.57 value of output associated with a metric unit of emissions, this value can serve as the ceiling price of a unit of emissions. Any price of carbon above this level risks the economy of entering into market failure.

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