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Tomiwa Sunday Adebayo (twaikline@gmail.com)
Cyprus International University: Uluslararasi Kibris Universitesi https://orcid.org/0000-0003-0094-1778
Edmund Ntom Udemba
Istanbul Gelisim Universitesi
Zahoor Ahmed
Beijing Institute of Technology School of Management and Economics
Dervis Kirikkaleli
Lefke Avrupa Universitesi

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DETERMINANTS OF CONSUMPTION-BASED CARBON EMISSIONS IN CHILE: APPLICATION OF NON-LINEAR ARDL

Tomiwa Sunday Adebayo*
Cyprus International University, Faculty of Economic and Administrative Science,
Department of Business Administration, Nicosia, Northern Cyprus, TR-10 Mersin Turkey
Email: twaikline@gmail.com*
ORCID: 0000-0003-0094-1778

Edmund Ntom Udemba
Faculty of Economics Administrative and Social sciences, Istanbul Gelisim University, Istanbul, Turkey
Orchid: https://orcid.org/0000-0003-4191-0767
Email: eudemba@gelisim.edu.tr

Zahoor Ahmed
School of Management and Economics, Beijing Institute of Technology, Beijing 100081, China
zahoorahmed83@yahoo.com
Orchid: https://orcid.org/0000-0001-9366-0582

Dervis Kirikkaleli
The European University of Lefke, Faculty of Economic and Administrative Sciences,
Department of Banking and Finance, Lefke, Northern Cyprus TR-10 Mersin, Turkey
E-mail: dkirikkaleli@eul.edu.tr

Abstract

In recent years, a growing number of scholars have employed various proxies of environmental degradation to understand the reasons behind rising environmental degradation. However, very few studies consider consumption-based carbon emissions even though a clear understanding of the impact of consumption patterns is essential to redirecting the pattern to more sustainable consumption. Thus, this study takes a step forward by using consumption-based carbon emissions (CCO_2) as a proxy of environmental degradation using the novel non-linear ARDL. To the understanding of the investigators, no prior studies have investigated the drivers of consumption-based carbon emissions utilizing non-linear ARDL. The study employed ADF and KSS (non-linear) tests to check the stationary level of the data series. Additionally, the symmetric and asymmetric ARDL approaches are utilized to explore cointegration and long-run linkages. The results could not find symmetric cointegration among variables; however, the empirical estimates divulge the long-run asymmetric connection of indicators with the CCO_2 emissions. The novel results from the asymmetric ARDL unfold that negative and positive changes in economic growth deteriorate the quality of the environment. Interestingly, a reduction in economic growth has a more dominant contribution to environmental degradation. Moreover, positive changes in renewable energy usage improve the quality of the environment in Chile inferring that Chile can achieve a reduction in environmental degradation by boosting renewable energy consumption. Surprisingly, the study found the ineffectiveness of technological innovation in reducing consumption-based carbon emissions which implies that technological innovation in Chile is not directed towards manufacturing green technology. Finally, the policy implications are discussed to reduce consumption-based carbon emissions.

Keywords: Consumption-based carbon emissions; Economic growth; Renewable energy Usage; Technological Innovation; NARDL

1. Introduction

Climate change is a worldwide concern that needs serious attention even more than the case of Covid-19. This impacts the entire earth negatively with multifaceted problems such as warming, defrosting of Antarctica and sea rising level, reducing the availability of water and upsurge in storage disease, extinction of wild and aquatic lives. In a bid to curtail the surging of climate change and global warming, United Nations Framework Convention on Climate Change (UNFCCC) in its 21st conference which was held in Paris in 2015, adopts the governing of climate action by the Paris Agreement from 2020 onwards. This is enshrined in the Paris Agreement which advocates for the commitment of both developed and developing countries in maintaining a temperature level within or a bit above the preindustrial level. Following the ratification of the Paris Agreement by many countries Chile inclusive which is premised on maintaining the temperature level of 2^0 C above preindustrial level and 1.5^0 C, the individual countries (developed and developing) need to work towards the stipulated target.

Among the targets of the Paris Agreement as it is specified under Article 2 and 7 is to encourage the capacity to adapt to the negative impacts of climate change, boost climate resilience, and low greenhouse gas (GHG) emissions development. With effect to this, Chile is one of the identified countries as compliers to the Paris Agreement who has moved from the state of highly insufficient to insufficient even exiting the region of insufficient with its current status recognizes the importance of adaptation in strengthening national stand against the impacts of climate change. The country has adopted some policies in compliance with this target such as articulated actions towards the protection of people and their rights, livelihood, and ecosystems. The steps include the urgent and immediate needs to identify in each sector, at national and subnational scale the inducers of emission.

Consumption patterns on emissions are part of the stimulating forces on emission increase. This is classified as consumption-based emission. Sustainable consumption with sustainable production styles is part of the roadmap towards the achievements of 2030 global goals for sustainable development as shrined in the Sustainable Development Goal (SDG) 12. A clear understanding of the impact of consumption patterns on emission will aid in redirecting the pattern to more sustainable consumption. Mitigating climate change involves identifying the causes and ways of alleviating them, and among the causes of climate change is the injection of carbon emissions from different sources. Economic activities targeting growth and development such as manufacturing as it involves production and consumption of the products are part of the causes of climate change. The transition from the agricultural age to the industrialization age has paved the way for excessive utilization of fossil fuels which promote pollution of earth bodies (air, land, and water bodies) that constitute the environment.

The economic activities that give rise to emission can be viewed from angles of consumption and production. Production-based emissions include all carbon footprint from the production of goods and services domestically and overseas, while the consumption-based emission is the country's final demand for goods and services majorly produced abroad. While the production-based carbon emissions have been intensively researched, it has been much criticized due to lack of insight in carbon leakage issues in trade liberalization (Peters and Hertwich, 2008; Munksgaard et al., 2005; Su and Ang, 2014). Direct emission levels and emissions patterns from production activities have been the center of research with effect on climate policy and mitigation initiatives. However, more scholars have risen with a divergent view from this perspective to a more direct and reasonable means of measuring emissions from the end users which is consumption-based carbon emissions (Barrett et al., 2013; Ferng, 2003; Feng et al., 2013; Brizga et al., 2016) General rise in income most times trigger an increase in consumption, and this is considered as among the greatest drivers of resource–use and environmental degradation globally.

Global economic activities are majorly driving towards consumption and this will insight into the role of consumption in driving global emissions. Consumer behavior and lifestyle majorly impact energy use and triggers emissions. An increasing proportion of world greenhouse gas (GHG) emissions emanating from production can be linked to consumer behavior and patterns. Many kinds of literature have been based on different indices such as economic growth, agriculture, non-renewables, trade, foreign direct investment, etc with regards to their capacity in inducing climate change via carbon emission with little attention to consumption-based carbon emission. Trade openness with regards to the flow of goods and services and increased economic activities have been identified as among the important factors that explain carbon emission (Liu et al., 2018).

International trade degraded the environment through carbon leakage through shifting of carbon emission-intensive industries to other economies. In the pursuit of reducing the impact of emission to climate change, countries of the world have embarked on different measures to mitigate carbon emission such as technological innovation and adoption of renewable measures. Technological innovation can be achieved in various ways but research and development (R&D) has been identified as among the efficient ways of reducing emission (Zhang et al., 2017). The effectiveness of technological innovation towards curbing emission has been researched by some scholars (Lee and Min, 2015; Zhao et al., 2015; Cai and Zhou, 2014). Part of technological innovation is storage technology and carbon capture which can control CO_2 emissions (Huaman and Tian, 2014). Among the initiatives that have gained global acceptance in pollution control is the adoption of renewable sources of energy (Chiu and Chang, 2009; Gessinger, 1997) in the execution of economic and productive activities.

Literature has shown and proved that fossil fuel energy contributes to carbon emission (Udemba, 2019; Apergies and Ozturk, 2015; Stern, 2016). In a bit to curb the carbon emission from fossil fuels, renewables such as wind, solar, hydro, and geothermal have been identified as likely ways of substituting the fossil fuels which will reduce the excessive emission (Chiu and Chang, 2009). These variables have been considered both at country level, regional or cross-sectional levels to see their involvement in climate change (Zhang and Da, 2015; Liu et al., 2015; Yu et al., 2012; Mi et al., 2015). Changing focus to the investigation of the role of increasing consumption in inducing carbon emissions (consumption-based carbon emissions (CCO_2) accounting) is a new idea capable of providing the research world with new insights into mitigating climate change. Investigating the climate change with consumption-based is aided with CCO_2 accounting perspective. From the consumption-based carbon emissions perspective, products and services purchased by people are measured, also, emissions are distributed to consumers of goods and services (Dawkins et al., 2010; Afionis et al., 2017).

The benefit of this accounting perspective is the accurateness of measuring emissions without double counting. This is possible by making sure that emissions from goods and services produce for exports are excluded and counted at the point of end-users. Among the benefits of consumption, carbon accounting includes sustainable consumption together with sustainable production which is in line with SDG 12, and aid a country towards national commitment in curtailing emission at the national level thereby conforming to the requirements of UNFCC Paris Agreement.

Some literature has dealt with the factors mentioned with mixed findings. CCO_2 emission has been researched by (Hasanov et al., 2018) with trade liberalization, the energy cost for the case of oil-exporting countries and found import and export increase and decrease emission respectively. Six regions were investigated on the impact of imports and consumption on CO_2 emission by Sheau-Ting & Al-Mulali, 2014, the study found import increasing emission. Renewable and non-renewable were considered in carbon emission study of Sub-Sahara African countries by Inglesi-Lotz and Dogan, 2018, and the found renewable energy controlling carbon emission. Likewise Mensah et al., 2018 and Bhattacharya et al., 2016 studied 28 countries from an organization for economic cooperation and development (OECD) and 38 countries, they found technological innovation and renewable energy controlling carbon emissions respectively. Shahbaz et al., 2018 studied France with financial development and energy innovation. The study found carbon emission is reduced by both energy innovation and financial development. Alvarez-Herranz et al., 2017 researched OECD countries with energy innovation and found energy innovation controlling emission.

On this note, this study is framed to investigate the determinants and possible ways of mitigating consumption-based-carbon emission for the case of Chile. This method permit insight into the domestic use of fossil fuels and the exemplified emissions from the economic activities. CCO_2 emission plays a direct and relevant role in climate policies. As noted before, Chile has been among the devoted countries in controlling their national emission to reduce the impact of climate change, and this has placed the country as a good specimen for understanding the best ways of mitigating the impact of Climate change. To do justice to this topic, we incorporate factors (renewable energy, technological innovation) capable of controlling and mitigating emissions in our empirical estimation and analysis. Probably, this is not the first work in assessing climate change with the identified variables but the novel and uniqueness of our study are anchored on deviation from a popular method of production based carbon emission to the adoption of consumption based-carbon emission accounting. Also, the adoption of recent approaches of both symmetric (linear) and asymmetric (non-linear) ARDL incorporating structural breaks in the analysis is an attempt by the authors to distinguish this current study from others.

The remaining part of the research is as follows; methodology is illustrated in section 3. Section 4 entails findings and discussion. Section 5 presents the study conclusion and policy path.

2. Methodology

2.1. Descriptions of Data and Theoretical Foundation

The present research explores the impact of economic growth (GDP), renewable energy consumption (REN), technological innovation (TI) on consumption-based carbon emissions (CCO_2) in Chile. The variables utilized are transformed into their natural logarithm. This was conducted to ensure that data is normally distributed (Kirikkaleli et al. 2020; Balsalobre-Lorente & Leitão, 2020). Table 1 exemplifies the data source, measurement, and unit of measurement. Also, the flow of analysis is depicted in Figure 1. The study economic function is depicted in Equation 1:

$$CCO_{2t} = f(GDP_t, REN_t, TI_t) \quad [1]$$

In Equation 1, GDP, REN, TI, and CCO_2 represent economic growth, renewable energy, technological innovation, and consumption-based carbon emissions. Therefore, the economic model of the current research is presented in Equation 2;

$$CCO_{2t} = \vartheta_0 + \vartheta_1 GDP_t + \vartheta_2 REN_t + \vartheta_3 TI_t + \varepsilon_t \quad [2]$$

The reasons why the aforementioned parameters are incorporated are discussed here. In the past 2 decades, numerous scholars (Kirikkaleli et al. 2020; Adebayo, 2020b; Alola et al. 2020; Shahbaz et al. 2020) have explored these interconnections. Nevertheless, prior studies did not incorporate CCO_2 emissions as a proxy of environmental degradation. Instead, they use CO_2 emissions and ecological footprint etc. as proxies of environmental degradation. The uniqueness of the CCO_2 carbon emissions is that it takes into account the global supply chain that contributes to the creation of emissions and distinguishes between emissions created in one nation and used in another (Safi et al. 2020; Khan et al. 2020; Knight & Schor, 2014; Shahbaz et al. 2020).

Following the studies of Balsalobre-Lorente et al. (2020), Odugbesan & Adebayo, (2020), Magazzino et al. (2020), Ayobaiji & Demet (2020), Kirikkaleli & Adebayo, (2020) the present research incorporate GDP into the model. The interrelationship between environmental pollutions and GDP is projected to be positive. This illustrates that an increase in GDP would increase environmental degradation i.e. ($\beta_1 = \frac{\partial CCO_2}{\partial GDP} > 0$). Also, following the studies of Alola (2019), Shahbaz et al. (2020), and Kirikkaleli & Adebayo, (2020) the current study introduced renewable energy usage into the framework.. The association between renewable energy usage and environmental pollutions is expected to be negative. This infers that an increase in renewable energy usage would enhance environmental quality i.e. $\left(\beta_2 = \frac{\partial CCO_2}{\partial REN} < 0\right)$. The study also investigates the linkage between innovation and environmental pollution. In line with prior studies (Khan et al. 2020; Kirikkaleli & Adebayo, 2020; Shahbaz et al. 2020) technological innovation was incorporated into the model. Thus, the association between technological innovation and environmental degradation is expected to be negative if the technology is eco-friendly i.e. $\left(\beta_3 = \frac{\partial CCO_2}{\partial TI} < 0\right)$ otherwise $\left(\beta_3 = \frac{\partial CCO_2}{\partial TI} > 0\right)$ if not eco-friendly.

To ascertain asymmetric effects, renewable energy usage, economic growth, and technological innovation are disintegrated into positive and negative changes (GDP^{+}, GDP^{-}, REN^{+}, REN^{-}, TI^{+}, TI^{-}). Ahmed et al. (2021) suggest that fiscal and monetary policies, international trade, phases of business cycles, etc., can influence macroeconomic variables leading to asymmetric properties; hence, we divide regressors into positive and negative changes since their effect may vary in direction and magnitude. Equation 2 (econometric model I) is transformed into Equation 3 as follows;

$$CCO_{2t} = \vartheta_0 + \vartheta_1 GDP_t^{+} + \vartheta_2 GDP_t^{-} + \vartheta_3 REN_t^{+} + \vartheta_4 REN_t^{-} + \vartheta_5 TI_t^{+} + \vartheta_6 TI_t^{-} + \varepsilon_t \qquad [3]$$

Table 1: Variables Units and Sources

Variable	Description	Units	Sources
Environmental Degradation	Consumption-Based Carbon Emissions	Million tons of CO_2 emissions	GCA by Peters et al. (2011) and Gilfillan et al. (2019)
GDP	Economic Growth	GDP Per Capita Constant $US, 2010	WDI, (2020)
TI	Technological Innovation	Measured as the addition of Patent applications, residents and Patent applications, non-residents	
REN	Renewable Energy	Renewables per capita (kWh)	BP (2020)

Source: Authors Compilation

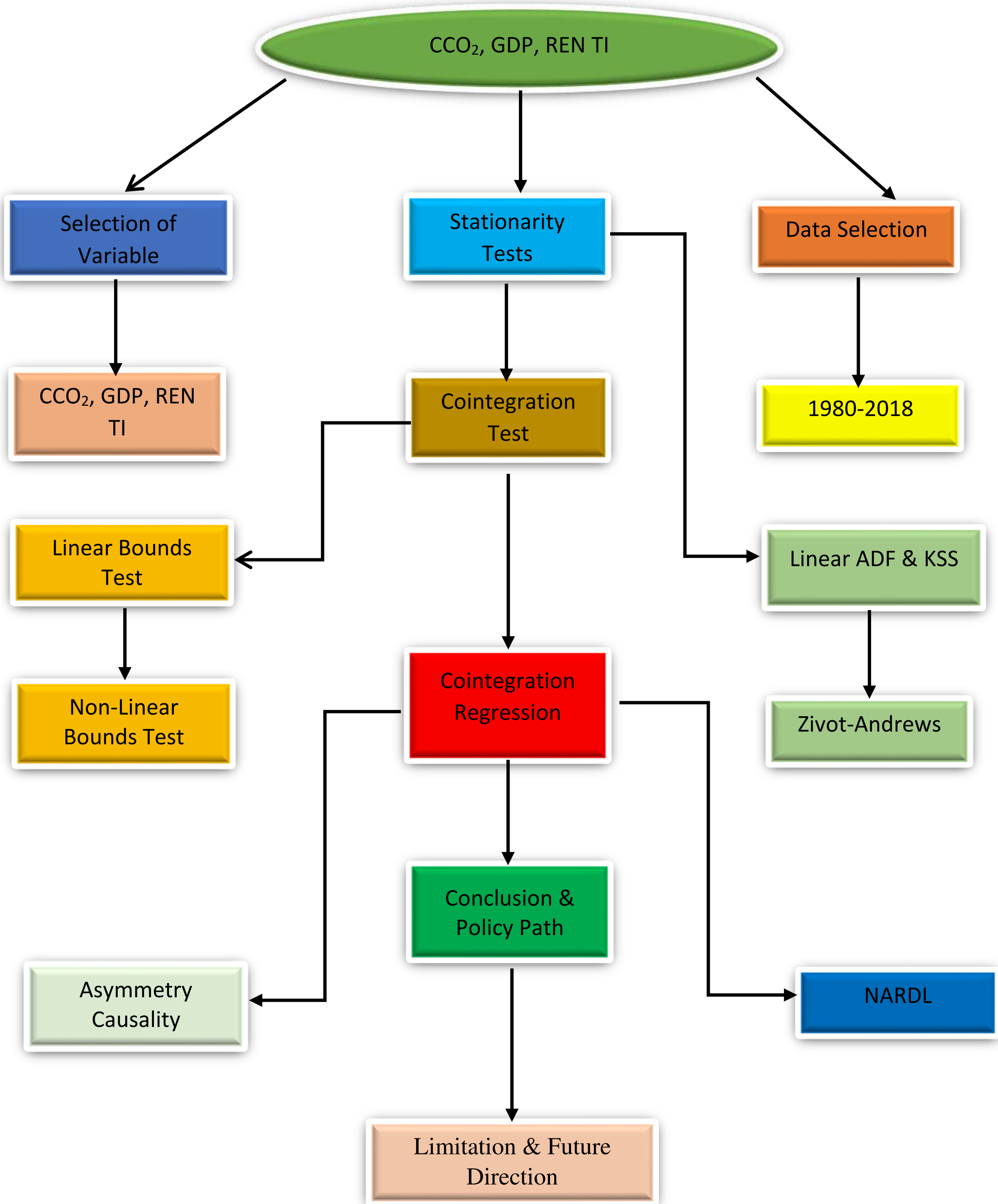

Figure 1: Flow Chart

2.2. Econometric Method

2.2.1. Unit Root Test

The econometric approach of this study comprised the usage of non-linear approaches to investigate long-term impacts and causal relations. Before implementing non-linear ARDL (NARDL), it is essential to investigate non-linear parameters. Therefore, the research utilized the renowned BDS test. After the pre-requisite is satisfied, the current study chooses a unit-root test utilizing the ADF and KSS (non-linear) tests. It should be remembered that the use of this test is merely to capture stationarity features of series, as the prior tests may yield results that are misleading if there is evidence of break(s) in the series. Although NARDL can house fractional integration, the non-linear or linear ARDL may not be reliable if there is no evidence of unit root in the dependent variable; therefore, it is reasonable to utilize a unit root test that can catch both structural break(s) and stationarity features of series. Based on this, the current study employed Zivot and Andrews (ZA) test initiated by Zivot & Andrews (2002).

2.2.2. ARDL Approach (Linear and Non-Linear)

The current study utilized linear (symmetric) and non-linear (asymmetric) ARDL techniques. The symmetric and Asymmetric ARDL methods are very versatile and can be extended to parameters integrated at 1(0) or 1 (1). Applying the ARDL involves the selection of adequate lag, and the conceivable issue of endogeneity can be solved by appropriate lag length. As stated by Shin et al., (2014) sufficient lag length is also effective in tackling the problem of potential multicollinearity in the NARDL. The ARDL method produces both the long-run and short-run outcomes. Equation 1 is transmuted into the following symmetric ARDL framework. As stated by Shin et al. (2014), the optimal lag period is also useful in resolving potential multicollinearity problems in the asymmetrical ARDL. The ARDL method produces short-term and long-term results as a whole, and the lagged ECT reveals details on convergence. The symmetrical ARDL model is depicted in Equation 1 as follows.

$$\Delta CCO_{2t} = \vartheta_0 + \sum_{i=1}^{t} \vartheta_1 \Delta CCO_{2t-i} + \sum_{i=1}^{t} \vartheta_2 \Delta GDP_{t-i} + \sum_{i=1}^{t} \vartheta_3 \Delta \mathrm{REN} + \sum_{i=1}^{t} \vartheta_4 \Delta TI_{t-i} + \sum_{i=1}^{t} \vartheta_5 \Delta DUM_{t-i} + \beta_1 CCO_{2t-1} + \beta_2 GDP_{t-1} + \beta_3 REN_{t-1} + \beta_4 TI_{t-1} + \beta_5 DUM_{t-1} + \varepsilon_t \quad [4]$$

Where short-run coefficients are depicted by $\vartheta_{1,2,3,4,5}$ and long-run coefficients by $\beta_{1,2,3,4,5}$. Also, the first difference operator is signified by Δ and ε_t is the error term. The null (H_0) and the alternative (H_a) hypothesis for the ARDL bound test is presented in Equations 5 and 6.

$$H_0 = \beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 \quad [5]$$

$$H_a \neq \beta_1 \neq \beta_2 \neq \beta_3 \neq \beta_4 \neq \beta_5 \quad [6]$$

To reject the null hypothesis, the F-stat must be greater than both the lower and upper bound critical values.

After confirming that the series is not stationary at I(2), the present study utilized the NARDL. This approach is beneficial for checking the existence of non-linear co-integration between parameters. It also estimates the short-run and long-run association between the explanatory variables and the dependent variable. As Ahmed et al. (2021) stated, the versatility of this approach to utilize an ideal lag length will resolve the multicollinearity probable issue. Besides, it can also accommodate fractional integration and possible endogenous and autocorrelation problems (Odugbesan & Adebayo, 2020; Onyibor et al. 2020; Adedoyin et al. 2020). In addition to all these advantages, the ability of linear ARDL to produce reliable findings for small sample sizes renders it one of the favored options for the analysis of time-series. The NARDL decomposes parameters with their corresponding positive and negative shifts. Thus, renewable energy usage, economic growth, and technological innovation will be decomposed into negative and constructive shifts in our key model. As previously mentioned in Equation 3, we have already conveyed parameters into corresponding shocks ($GDP^{+}, GDP^{-}, REN^{+}, REN^{-}, TI^{+}, TI^{-}$). Furthermore, the partial sum of shifts, in renewable energy usage, economic growth, and technological innovation are as follows.

$$GDP^{+} = \sum_{i=1}^{t} \Delta GDP^{+} + \sum_{i=1}^{t} max\left(GDP_{i,} O\right) \qquad [7]$$

$$GDP^{-} = \sum_{i=1}^{t} \Delta GDP^{-} + \sum_{i=1}^{t} min\left(GDP_{i,} O\right) \qquad [8]$$

$$REN^{+} = \sum_{i=1}^{t} \Delta REN^{+} + \sum_{i=1}^{t} max\left(REN_{i,} O\right) \qquad [9]$$

$$REN^{-} = \sum_{i=1}^{t} \Delta REN^{-} + \sum_{i=1}^{t} min\left(REN_{i,} O\right) \qquad [10]$$

$$TI^{+} = \sum_{i=1}^{t} \Delta TI^{+} + \sum_{i=1}^{t} max\left(TI_{i,} O\right) \qquad [11]$$

$$TI^{-} = \sum_{i=1}^{t} \Delta TI\text{-} + \sum_{i=1}^{t} min\left(TI_{i,} O\right) \qquad [12]$$

Nonetheless, Equation 4 mentioned earlier can be revamped into the following NARDL model, correspondingly.

$$\begin{aligned} \Delta CCO_{2t} = {} & \vartheta_0 + \sum_{i=1}^{t} \vartheta_1 \, \Delta CCO_{2t-i} + \sum_{i=1}^{t} \vartheta_2 \, \Delta \mathrm{GDP}_{t-1}^{+} + \sum_{i=1}^{t} \vartheta_3 \, \Delta \mathrm{GDP}_{t-1}^{-} + \sum_{i=1}^{t} \vartheta_4 \, \Delta \mathrm{REN}_{t-1}^{+} + \sum_{i=1}^{t} \vartheta_5 \, \Delta \mathrm{REN}_{t-1}^{-} \\ & + \sum_{i=1}^{t} \vartheta_6 \, \Delta \mathrm{TI}_{t-1}^{+} + \sum_{i=1}^{t} \vartheta_7 \, \Delta \mathrm{TI}_{t-1}^{-} + \sum_{i=1}^{t} \vartheta_8 \, \Delta DUM_{t-1} + \beta_1 CCO_{2t-1} + \beta_2 \mathrm{GDP}_{t-1}^{+} + \beta_3 \mathrm{GDP}_{t-1}^{-} \\ & + \beta_4 \mathrm{REN}_{t-1}^{+} + \beta_5 \mathrm{REN}_{t-1}^{-} + \beta_6 \mathrm{TI}_{t-1}^{+} + \beta_7 \mathrm{TI}_{t-1}^{-} + \beta_8 DUM_{t-1} \\ & + \varepsilon_t \qquad [13] \end{aligned}$$

In the NARDL, non-linear co-integration is examined using the Bounds test. To reject the null hypothesis in NARDL, the F-stat must be greater than both the lower and upper bound critical values. Further, the study used various diagnostic measures to examine the stability of asymmetrical models. In the asymmetrical ARDL method, we have utilized a WALD test to validate the long-term asymmetrical impact.

2.2.3. Asymmetric Causality

There is always a distinction in the reaction between a negative and a positive shocks which render it reasonable to comply with the present study asymmetries causality. Consequently, in the last stage of the present research, the Hatemi-j (2012) causality was deployed. This approach utilizes the theoretical foundation of the Toda & Yamamoto approach; moreover, it has the potential to separate parameters into negative and positive shocks by introducing non-linear effects. This method separates the parameters into the corresponding shocks, then tests their causality from negative shocks to negative shocks and positive shocks to positive shocks underneath the framework of VAR.

3. Discussion of Findings

This study investigates the symmetric and asymmetric impact of technological innovation, renewable energy usage, and economic growth on consumption-based carbon emissions between 1980 and 2018 in Chile. Table 2 portrays the statistical summary and different normality tests utilized. Moreover, the parameters mode, maximum, mean, standard deviation, minimum and median are illustrated by the descriptive statistics. Table 2 shows that technological innovation (TI) has the highest mean (0.620) which is followed by consumption-based carbon emissions (CCO_2), economic growth (GDP), and renewable energy usage (REN) with a mean of 0.489, 0.408, and 0.282 respectively. The research used Kurtosis to verify whether the series is light-tailed or heavy-tailed relative to normal distribution. The empirical outcomes illustrate that all the series are Platykurtic since their values are less than 3. Additionally, the parameters skewness is less than 1 which illustrates that the parameters are moderately skewed. Additionally, the outcome from the Jarque-Bera (JB) p-value shown that all the parameters conform to normality with the exemption of TI which does not conform to normal distribution.

Table 2: Descriptive Statistic

	CCO_2	GDP	REN	LNTI
Mean	3.831202	9.069771	8.143261	7.457250
Median	4.005226	9.126872	8.238431	7.785305
Maximum	4.452911	9.623224	8.607290	8.281977
Minimum	3.018824	8.404165	7.570566	6.510258
SD	0.489054	0.408138	0.282777	0.620154
Skewness	-0.383352	-0.214088	-0.609242	-0.356850
Kurtosis	1.685022	1.657846	2.197901	1.451432

Jarque-Bera	3.765129	3.225156	3.458104	4.724573
Probability	0.152199	0.199373	0.177453	0.094205
Observations	39	39	39	39

To ascertain the linearity of the parameters, the current study utilized the BDS test. The outcomes of the BDS test are depicted in **Table 3**. The findings revealed the non-linearity of the parameters. Based on the non-linearity outcomes, it is essential to utilize the non-linear techniques to investigate the interconnection between CCO_2 and its regressors. Based on this the current research utilized non-linear ADF and KSS tests. The outcomes of the ADF and KSS tests are depicted in Table 4. The results of the non-linear ADF and KSS revealed that at level i.e I(0) we fail to reject the null hypothesis. However, after the first difference i.e I(1) is taken, the series are found to be stationary i.e. there is no unit root. As stated by Olanrewaju et al. (2021), Adebayo (2020a), Alola et al. (2019), and Kirikalleli et al. (2020), if there is proof of a structural break in series, these tests may yield misleading outcomes. Therefore, the present research utilized the ZA unit root test to catch stationarity features and a single break in the series. The outcomes of the ZA is depicted in Table 5. The findings revealed that at level there is a unit root in the series. However, after the first difference was taken, the series is stationary with CCO_2, GDP REN, and TI having a structural break of 1989, 1991, 1996, and 2001 respectively. The break of 1989 in consumption-based carbon emissions is incorporated while checking cointegration and long-run results. This break coincides with the famous regime change in Chile when at the end of 1989 an authoritarian regime was replaced by the democratic government as a result of continuous political turmoil after the economic collapse in the early years (Angell and Pollack, 2014). Hence, political uncertainty and related issues can exploit macroeconomic indicators and CCO_2 resulting in a break in CCO_2.

Table 3: BDS Test to inspect non-linearity

	M=2	M=3	M=4	M=5	M=6
T-Stat	BDS stat				
CCO_2	0.1844*	0.3106*	0.4017*	0.4661	0.5107*
GDP	0.1918*	0.3197*	0.4119*	0.4795*	0.5293*
REN	0.1400*	0.2303*	0.2891*	0.3141*	0.3306*
TI	0.1753*	0.2908*	0.3732*	0.4234*	0.4522*

Note: * refers 1% level of significance. Residual values computed from the BDS test with m dimensions show the presence of nonlinearities in variables.

Table 4: ADF and KSS tests

Variables	ADF				KSS			
	Level		Difference		Level		Difference	
	T-Stat	P-value	T-Stat	P-value	KSS stat	P-values	KSS stat	p-values
CCO_2	-0.4154	0.8963	-4.3225*	0.0015	-1.230	0.735	-4.169*	0.002

GDP	-0.0958	0.9247	-4.1227*	0.0027	-0.806	0.858	-2.960**	0.052
REN	-1.6674	0.4392	-5.9644*	0.0000	-2.199	0.244	-2.697***	0.093
TI	-1.3173	0.6116	-6.1135*	0.0000	-1.210	0.752	-3.904*	0.005
Note: * , ** & *** refers 1%, 5% and 10% level of significance.								

Table 5: ZA Unit Root Test

	Level		Difference	
Variables	t-stat	Break-Year	t-stat	Break-Year
CCO_2	-4.0701	1994	-5.2708**	1989
GDP	-3.7351	1992	-5.3692*	1991
REN	-5.3734*	1991	-6.1692*	1996
TI	-4.4360	2009	-6.5736	2001
Note: Critical values: 5% and 1% level of significance is depicted by * * and * respectively				

After the series stationarity property is confirmed, the current study investigates the long-run interaction among the parameters. To do this, the study utilized linear and non-linear Bounds test. The results of the ARDL and NARDL bound tests are depicted in Table 6. The result of the ARDL bounds test shows no evidence of cointegration in the long-run while the NARDL bounds test revealed evidence of cointegration amongst the variables in the long-run. Since there is no cointegration among the series as revealed by the ARDL bounds test, the ARDL long run estimations can not be carried out. On the other hand, the result of the NARDL bound test supports that we can estimate long-run results using the NARDL.

Table 6: **ARDL and NARDL Cointegration**

Models Estimated		F-statistics	Break-Year	AIC Lags
(CCO_2/GDP, REN, TI)		1.6416	1989	[1,1,1,0]
(CCO_2/$GDP^+, GDP^-, REN^+, REN^-, TI^+, TI^-$)		6.2017*	1989	[1,0,0,0, 1,1, 0]
	CV (Model 1)		**CV Model2**	
	1(0)	**1(1)**	**1(0)**	**1(1)**
1%	4.31	5.544	3.505	5.121
5%	3.1	4.088	2.618	3.863
10%	2.592	3.454	2.218	3.314
Note: * refers to a significance level of 1%. Optimum lag length 1 under AIC is used.				

The current study utilized the NARDL after the pre-requisite conditions are met. The outcomes of the long-run NARDL are depicted in Table 7. The empirical findings from the NARDL revealed that a positive increase in GDP harms the quality of the environment. This implies that keeping other indicators constant 1% increase in GDP increase environmental degradation by 2.103%. Also, a reduction in economic growth deteriorates the quality of the environment. Thus, a 1% decrease in economic growth would increase environmental degradation by 3.283% when other parameters are held constant.

The long-run outcome advocates that increases and reductions of economic increase environmental degradation in Chile. The estimated findings of the study differ from the prior studies on the asymmetric effects of shifts in economic growth on environmental degradation. For instance, using the US, the study of Eng and Wong (2015) revealed that there is an increase in CO2 emissions from 3 to 4% between June 1980 and April 1981 due to economic expansions. They further estimated a reduction of 1.37 to 11.37% in CO_2 emissions from the contractionary cycles accompanying these economic expansions. Though our findings of asymmetries largely support Doda (2013) but still differs from the recent asymmetric evidence of business cycles and CO_2 emissions as proposed by the recent studies. While our observations of asymmetry broadly endorse the studies of Doda (2014) and Baloch et al. (2020), it contradicts the findings of prior studies (Burke et al. 2015; Sheldon, 2017; York, 2012). As revealed by York (2012), economic expansions increase environmental degradation while the economic slowdown is accompanied by a reduction in environmental degradation.

Nevertheless, York (2012) advocated the symmetric reaction of CO_2 emissions to economic change. Therefore, distinct from this research, the current study adds to the growing studies that the current proof of economic growth and pollution decoupling institutions does not hold for emerging economies such as Chile. Conversely, the present research challenges conventional assertions by investigating that economic contractions are never subject to pollution over time. While the present study findings contradict York (2012), we still comply with him in the discussion that CO_2 emissions are largely dependent on the nation's economic infrastructure and structure. Therefore, the developed infrastructure (roads, cars, and factories) will be still in operation even when there is a dip in the economy. Additionally when economic activities reduce the investment in environmentally friendly activities can reduce. During bad economic situation government may find it difficult to concentrate on environmental sustainability and businesses may also shift to using cheap pollutant fossil fuels rather than renewables. This can lead to more pollution since environmental friendly effects of economic growth subsidize; hence, reduction in GDP has a more severe effect on environmental quality than the rise in income.

Furthermore, only an increase in renewable energy reduces environmental degradation. Thus 0.41% decrease in environmental degradation is due to a 1% positive increase in renewable energy usage. The outcome does not comply with the research of Apergis et al. (2010) for 19 advanced and emerging nations and Menyah and Wolde-Rufael (2010) for the US who established positive interconnection between renewable energy usage and environmental degradation. The outcome from the present study complies with prior studies (Kirikaleli & Adebayo, 2020; Shafiei & Salim, 2014; Wang, et al. 2021; Khan et al. 2020) who established that increase in renewable energy helps in mitigating environmental degradation. The probable cause for the negative association is because renewable technology utilizes pure and cleaner energy sources that are safe and gratify current and future necessities, whereas it is also a source of mitigation pollutions.

Moreover, positive change in technological innovation exerts a positive and insignificant influence on quality of the environment. Surprisingly, technological innovation reduction by 1% decrease environmental degradation by

0.160%. The probable reason for this association is that Chile is not investing in green technology. Thus the reduction in such technology will enhance the quality of the environment. This is a worrying sign for Chile and its policymakers should focus on green technology in its innovation strategies. The current innovation is ineffective in reducing CCO_2 indicating that innovation is mostly directed to other areas than the environmentally friendly technology.

As anticipated, the ECT (-0.33), which validates cointegration and defines the speed of adjustment. Table 6 also illustrate the outcomes of the post-estimation tests. The findings show no presence of heteroscedasticity, serial correlation in the model with the Ramsey test depicting no misspecification in the model. Furthermore, the J-B revealed normal distribution. Moreover, the model is stable as revealed by the CUSUM and CUSUMSQ in Figures 2 and 3 respectively. The focus of the paper is on the long-run estimation but short-run outcomes are also given in Table 6. Most variables are not significant in the short-run except GDP negative which has similar results to the long-run. Technological innovation increases CCO_2 in the short-run implying that innovation in Chile is not focused on environmental sustainability as discussed in the long-run results. However, convergence to the long-run equilibrium takes about three years, so differences associated with short-run shocks are corrected in almost three years.

Table 7: Non-Linear ARDL Long and Short-run Results

	Long-Run Estimation			**Short-Run Estimation**			
Variables	Coefficients	t-stat	P-value	Variables	Coefficients	t-stat	P-value
GDP^+	2.103*	3.9705	0.000	GDP^+	0.1564	0.898	0.377
GDP^-	-3.283**	-2.0995	0.045	GDP^-	-0.2378**	-2.250	0.033
REN^+	-0.419**	-2.4286	0.022	REN^+	-0.1051	-1.062	0.297
REN^-	0.354	1.1977	0.241	REN^-	-0.2114	-1.215	0.235
TI^+	0.061	0.7357	0.468	TI^+	0.1269**	2.584	0.015
TI^-	0.160*	3.3137	0.002	TI^-	0.0165	0.819	0.420
DY[a]	0.005	0.0847	0.933	DY	0.0683	1.256	0.220
C	2.377*	7.7934	0.000	ECT(-)	-0.3323*	-5.485	0.000
Diagnostic Tests							
R^2	0.99						
AdjR^2	0.99						
DW Statistics	2.28						
F-Statistics	625.7 [0.000]						
J-B Normality	0.009 [0.995]						
χ^2 LM	0.807 [0.457]						
$\chi2$ ARCH	0.112 [0.739]						
χ^2 RESET	2.683 [0.113]						

Note: *, & ** mirror 1% and 5% level of significance. [a]DY is a dummy variable included for a break in CCO_2

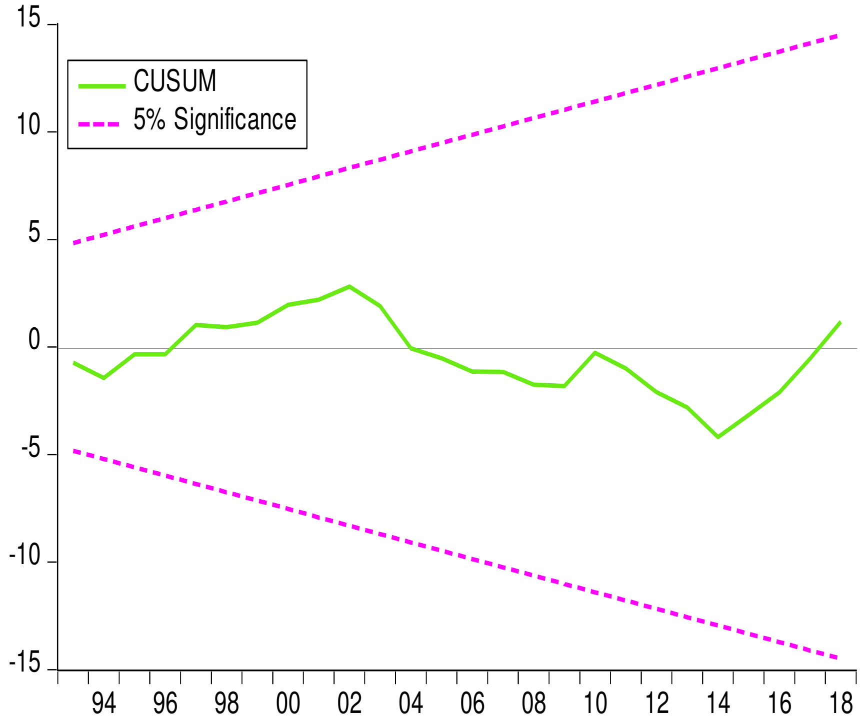

Figure 2: CUSUM

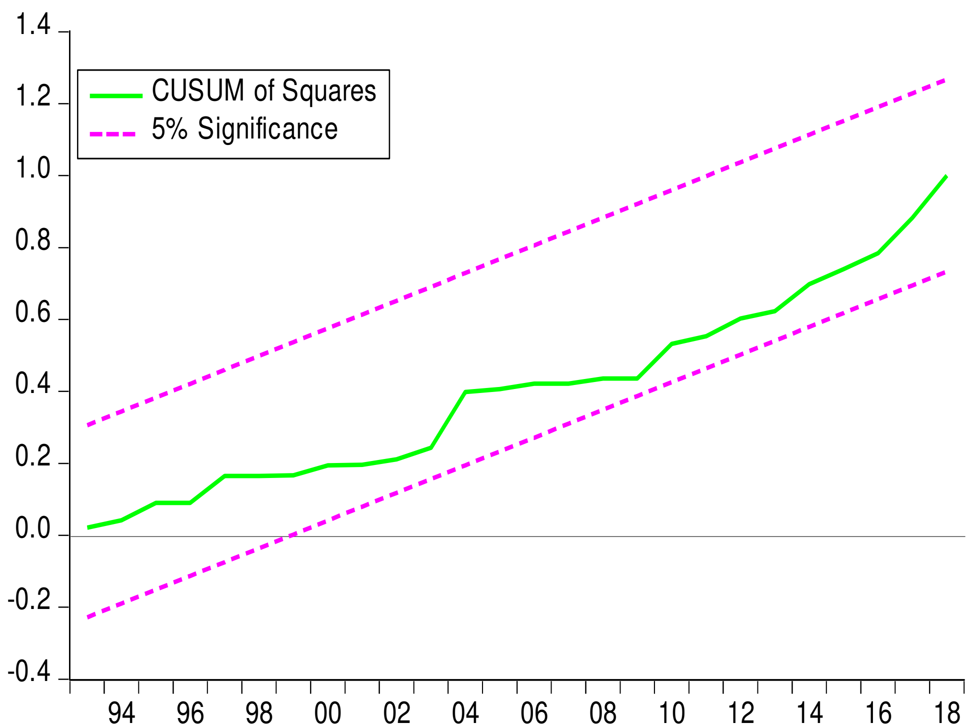

Figure 3: CUSUMSQ

The present paper utilized the Wald test to ascertain the long-run asymmetries' significance. The outcomes of the WALD test is depicted in Table 8. The findings show that both economic growth and renewable energy usage has long-run asymmetries while Technological innovation does not have long-run asymmetries

Table 8: Long-run asymmetries (WALD test)

Variables	F-stat [P-value]
GDP	19.5374* [0.0002]
REN	11.9595*[0.0019]
TI	1.8399 [0.1866]

Note: * indicates 1% significance level.

In other to capture the causal linkage among the variables, the current study utilized an asymmetric causality test. The outcomes of the causality test are portrayed in Table 9. The empirical findings show that positive renewable energy usage Granger cause positive consumption-based carbon emissions. This illustrates that positive renewable energy usage can predict significant variation in positive consumption-based carbon emissions. Also, negative shock in technological innovation Granger causes a negative change in consumption-based carbon emissions. This outcome implies that negative shock in technological innovation can predict negative shock in consumption-based carbon emissions. Last, there is asymmetric causality from negative economic growth to negative technological innovation.

Table 9: Asymmetric Causality Test

Path of Causality	W.stat	CV (1%)	CV (5%)	CV (10%)
$GDP^{+} \rightarrow CCO_2^{+}$	1.858	12.031	7.317	4.902
$GDP^{-} \rightarrow CCO_2^{-}$	0.703	7.431	4.580	2.965
$CCO_2^{+} \rightarrow GDP^{+}$	0.385	11.244	5.083	3.296
$CCO_2^{-} \rightarrow GDP^{-}$	0.003	20.467	4.443	2.387
$REN^{+} \rightarrow CCO_2^{+}$	3.718***	14.150	5.582	3.453
$REN^{-} \rightarrow CCO_2^{-}$	0.682	12.724	5.034	3.220
$CCO_2^{+} \rightarrow REN^{+}$	0.273	10.859	5.068	3.275
$CCO_2^{-} \rightarrow REN^{-}$	0.002	8.716	4.071	2.850
$TI^{+} \rightarrow CCO_2^{+}$	0.250	10.337	5.308	3.246
$TI^{-} \rightarrow CCO_2^{-}$	11.292*	9.238	4.922	3.360
$CCO_2^{+} \rightarrow TI^{+}$	0.068	13.827	5.559	3.979
$CCO_2^{-} \rightarrow TI^{-}$	1.114	9.420	4.535	3.051
$GDP^{+} \rightarrow REN^{+}$	0.985	9.371	4.772	3.270
$GDP^{-} \rightarrow REN^{-}$	0.079	13.856	4.873	2.198
$REN^{+} \rightarrow GDP^{+}$	0.652	10.854	5.046	3.233
$REN^{-} \rightarrow GDP^{-}$	0.862	10.637	4.461	2.485

$GDP^{+} \rightarrow TI^{+}$	0.216	10.890	5.112	3.400
$GDP^{-} \rightarrow TI^{-}$	6.065**	44.598	5.436	3.251
$TI^{+} \rightarrow GDP^{+}$	0.422	9.022	4.893	3.132
$TI^{-} \rightarrow GDP^{-}$	0.007	103.345	3.792	1.888
$TI^{+} \rightarrow REN^{+}$	0.003	11.711	5.309	3.509
$TI^{-} \rightarrow REN^{-}$	0.157	9.016	5.192	2.963
$REN^{+} \rightarrow TI^{+}$	2.233	11.746	4.876	3.091
$REN^{-} \rightarrow TI^{-}$	0.002	14.649	5.361	3.252
Note: Significance level of 1%, 5% and 10% is depicted *, **, and ***				

Lastly, Figures 4, 5, and 6 illustrate the Multipliers for the three independent parameters which illustrate a modification to a new balance after early positive and negative shocks. The non-linear modification of CCO_2 to negative shocks is depicted by the black dotted line, whereas the adjustment of CCO_2 to a positive shock is depicted by a solid black line. The red dotted line which is the asymmetric pattern is the alteration between positive and negative shocks. The outcome in Figure 1 illustrates that an increase in GDP has a positive effect on CCO_2 as revealed by the black line, whereas a decrease in GDP has a positive impact on CCO_2 as revealed by the blue line. Moreover, the outcomes reveal that the effect of a negative change leads the positive change. Figure 2 reveals that an upsurge in REN has a positive effect on CCO_2 as revealed by the black line, whereas a decrease in REN has a positive effect on CCO_2 as revealed by the blue line. Moreover, the outcomes reveal that the effect of a positive change is more than the negative change. Figure 3 shows that an upsurge in TI exerts a positive impact on CCO_2 as revealed by the black line, whereas a decrease in TI has a negative effect on CCO_2 as revealed by the blue line.

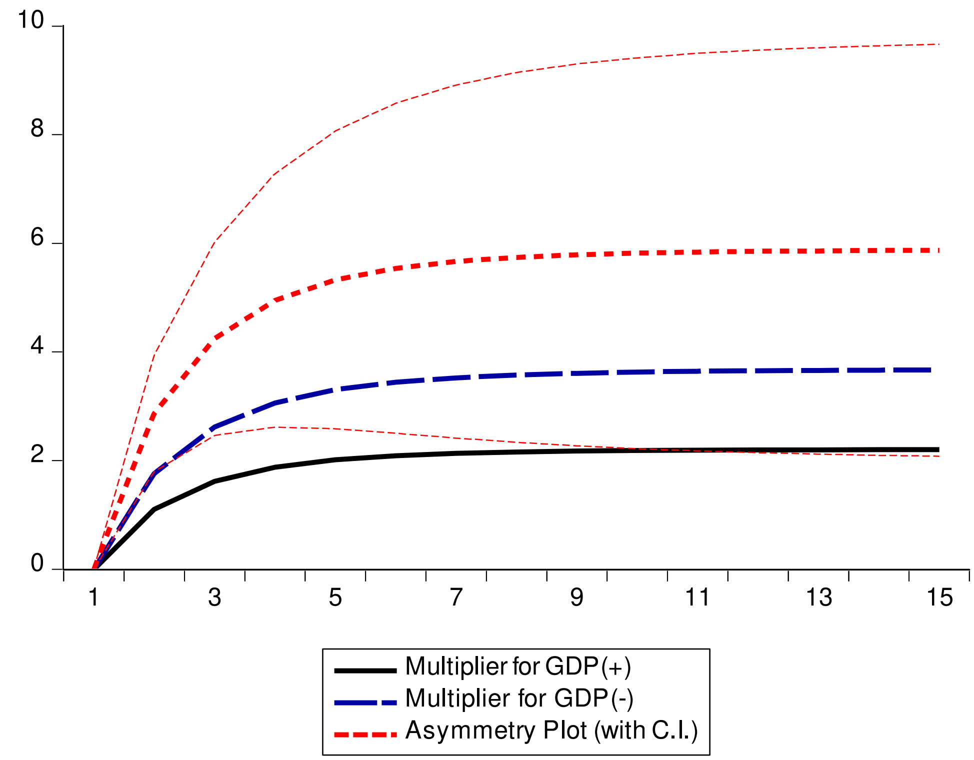

Figure 4: Multiplier for GDP

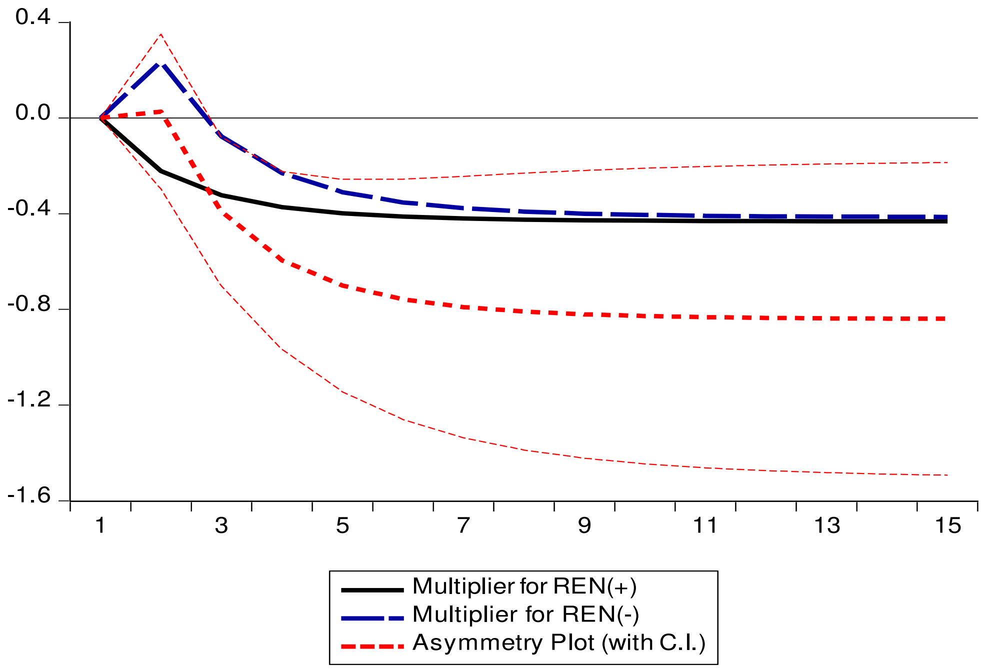

Figure 5: Multiplier for REN

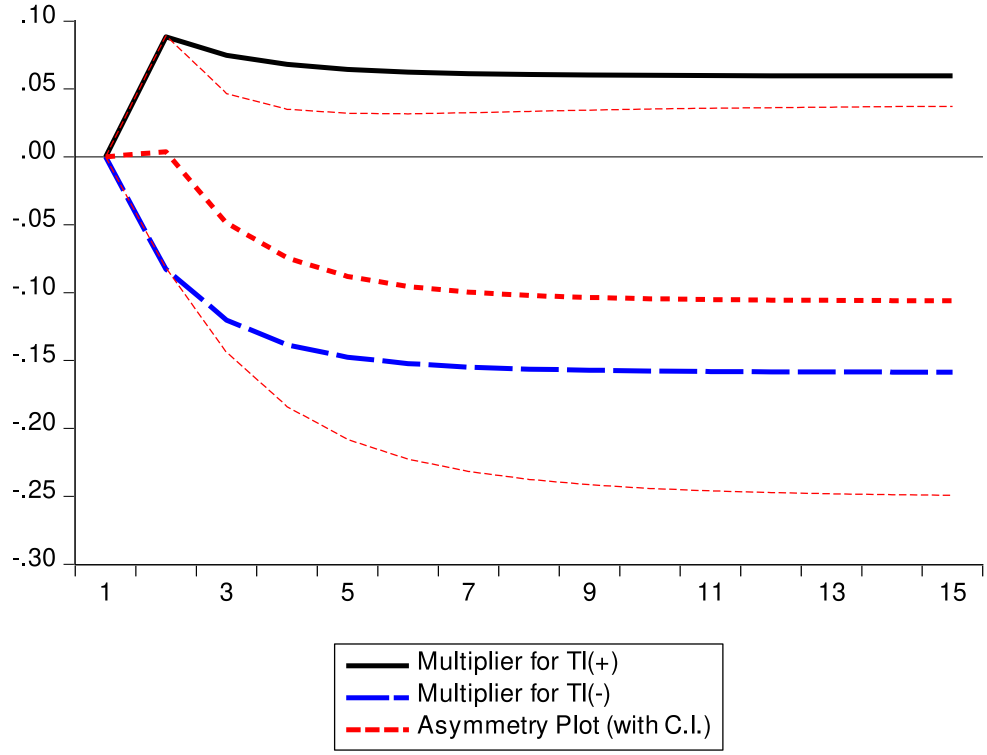

Figure 6: Multiplier for TI

4. Conclusion and Policy Direction

Utilizing Chile, the 5th biggest economy in Latin America as a case study, the current study examines whether consumption-based carbon emissions (CCO2) are nonlinearly influenced by renewable energy usage (REN), technological innovation (TI), and economic growth (GDP) from 1985 to 2018. The study employed both linear and nonlinear ARDL approaches to investigate these dynamics. Furthermore, the asymmetric causality test was utilized to examine the causal association amongst the economic variables. The outcome of the ARDL bounds test revealed evidence of no linear cointegration while the NARDL bounds test show evidence of cointegration among the indicators. The novelty of the NARDL technique is that It can capture the positive and negative impact of the regressors on CCO2 emissions. Furthermore, the current study includes a dummy variable for discontinuity of series to compute the CCO_2 function. The outcomes of the unit root test implemented reveal that series are integrated at first difference. Moreover, the outcomes of the Wald test propose that the NARDL is suitable for this empirical analysis. The current study outcome can be utilized for suggesting a policy framework towards the attainment of SDGs objectives.

The outcomes of the NARDL model revealed long-run interconnection between GDP and CCO_2, TI and CCO_2, REN and CCO_2 in Chile. In the long-run, increase and decrease in GDP exert a positive impact on CCO_2 while the impact of negative change is dominant. Furthermore, an increase in REN is escorted by a reduction in CCO_2.

Moreover, an upsurge in TI exerts an insignificant effect on CCO_2 while a decrease in TI decreases CCO_2. In the short-run, a decrease in GDP exerts a positive impact on CCO_2 and an increase in TI harms the quality of the environment in Chile. The outcomes of the asymmetric causality reveal that; (a) positive REN Granger positive CCO_2; (b) negative shock in TI Granger cause a negative change in CCO_2; (c) negative shock in TI Granger cause CCO_2, and (d) negative GDP Granger cause TI.

Since a surge in economic growth is accompanied by an upsurge in environmental degradation, policymakers in Chile can take steps to organize more public awareness drives in favor of renewable goods, while the government should place lower tax rates on businesses that use sustainable technologies in their production. The negative change in economic growth has a more severe impact on environmental quality, so the government should assure continuing growth in the economy using clean energy sources. Also, we advocate the subsidization of investment in the development of renewable energy and the adoption of carbon taxes on the use of fossil fuels to prevent their use and to promote a transition of energy usage from renewable energy sources. Furthermore, green technology should be encouraged by the policymakers since currently, innovation is not directed towards clean technology and innovation does not reduce consumption-based emissions. In planning policies that include economic growth, technological innovation, environmental degradation, and renewable energy usage, Chile needs to be more vigilant in taking into consideration the existence of asymmetries in the interaction between these variables. This research has a limitation in that it incorporated only a few factors to explore the drivers of CCO_2 due to a limited period of data. As such, additional research is required to examine the asymmetric interconnection among these economic indicators in developing and advanced economies for a more extended period adding more variables to the model.

Ethical Approval: This study follows all ethical practices during writing.
Consent to participate: Not Applicable
Consent to publish: Not Applicable

Authors Contribution: Zahoor Ahmed and Tomiwa Sunday Adebayo designed the experiment and collect the dataset. The introduction and literature review sections are written by Tomiwa Sunday Adebayo and Edmund Ntom Udemba. Dervis Kirikkaleli and Edmund Ntom Udemba constructed the methodology section and empirical outcomes in the study. Tomiwa Sunday Adebayo and Zahoor Ahmed contributed to the interpretation of the outcomes. All the authors read and approved the final manuscript.

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Availability of Data: Data is readily available at https://data.worldbank.org/country/chile
Transparency: The authors confirms that the manuscript is an honest, accurate, and transparent account of the study was reported; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained.

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Figures

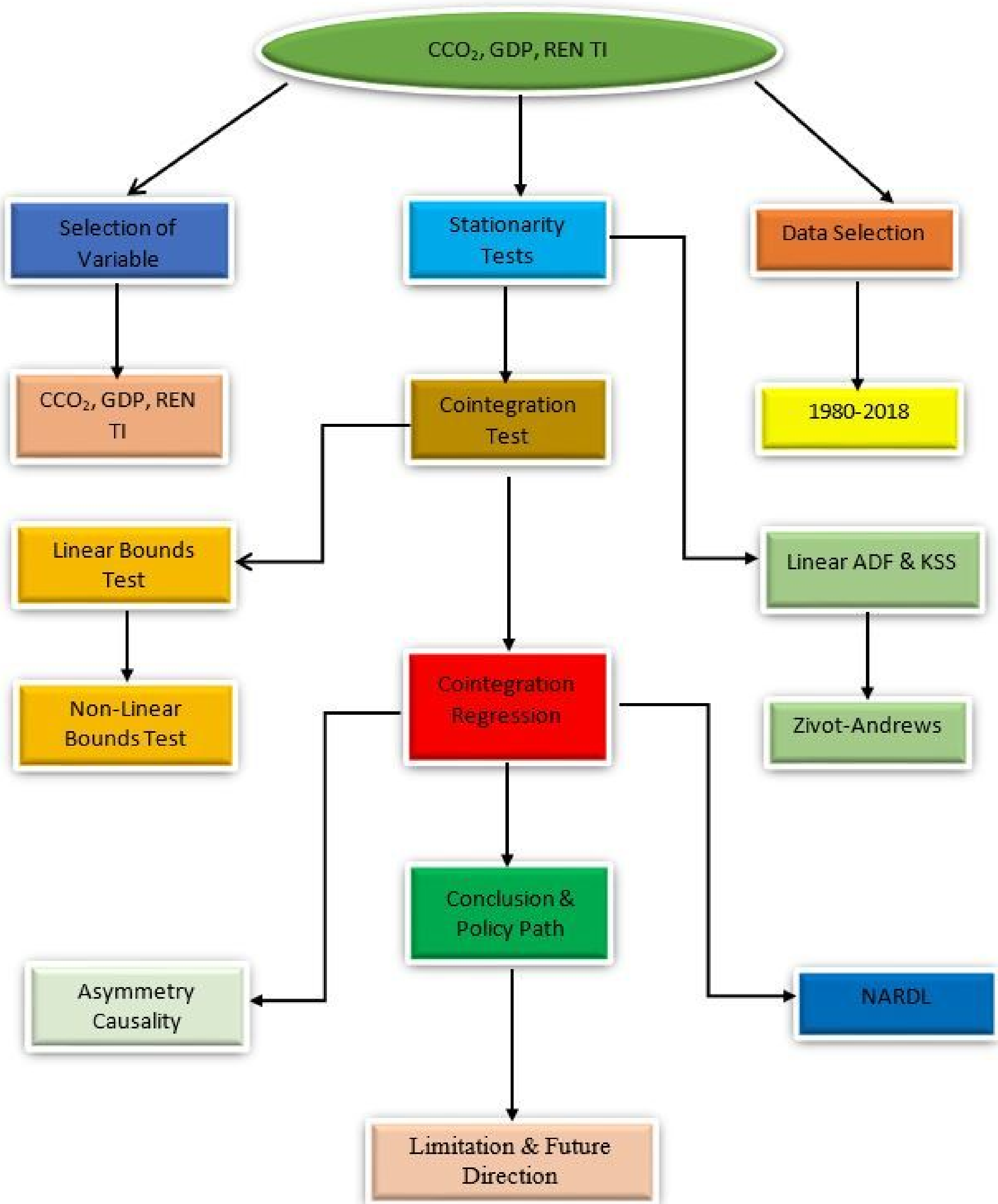

Figure 1

Flow Chart

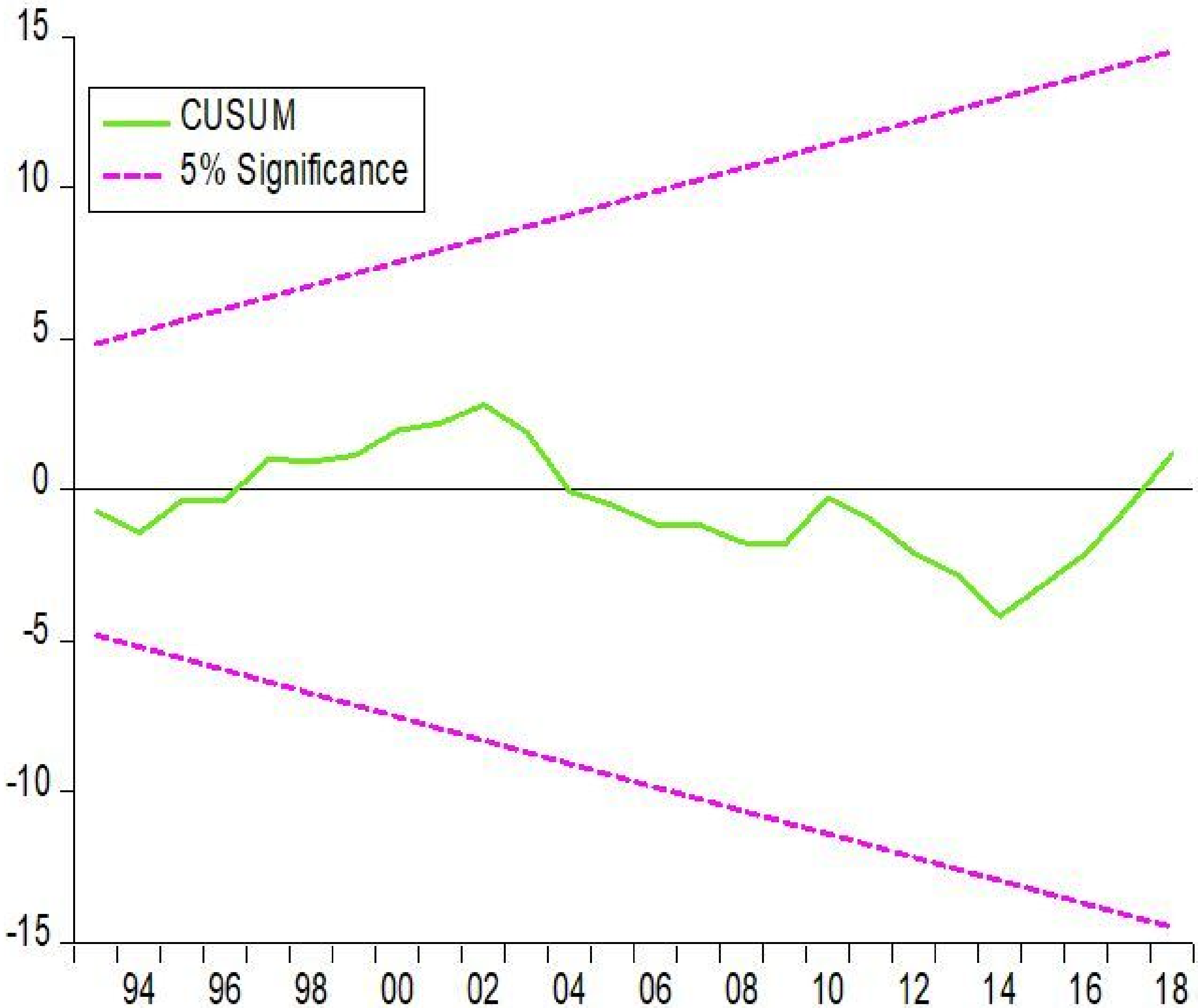

Figure 2

CUSUM

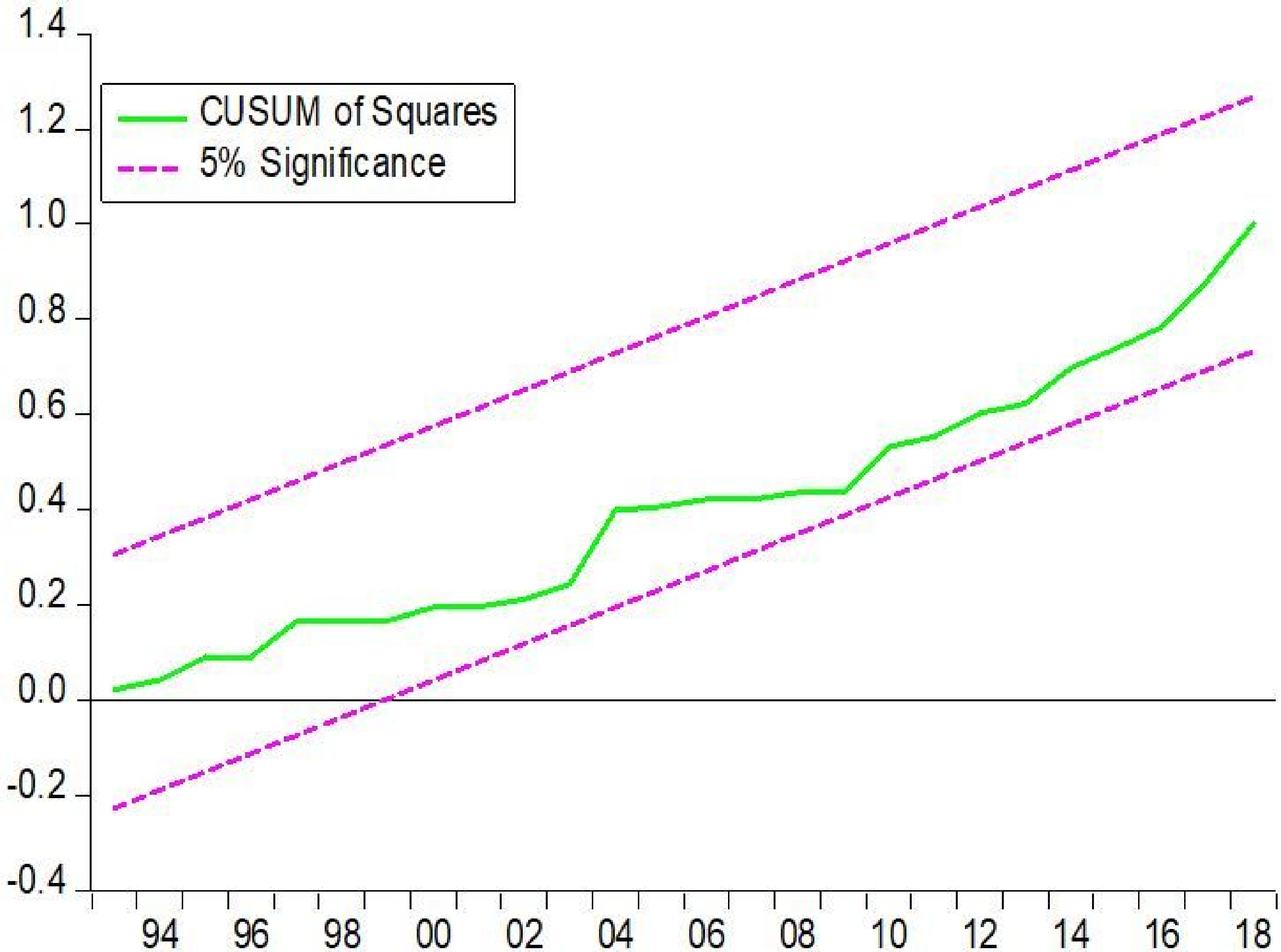

Figure 3

CUSUMSQ

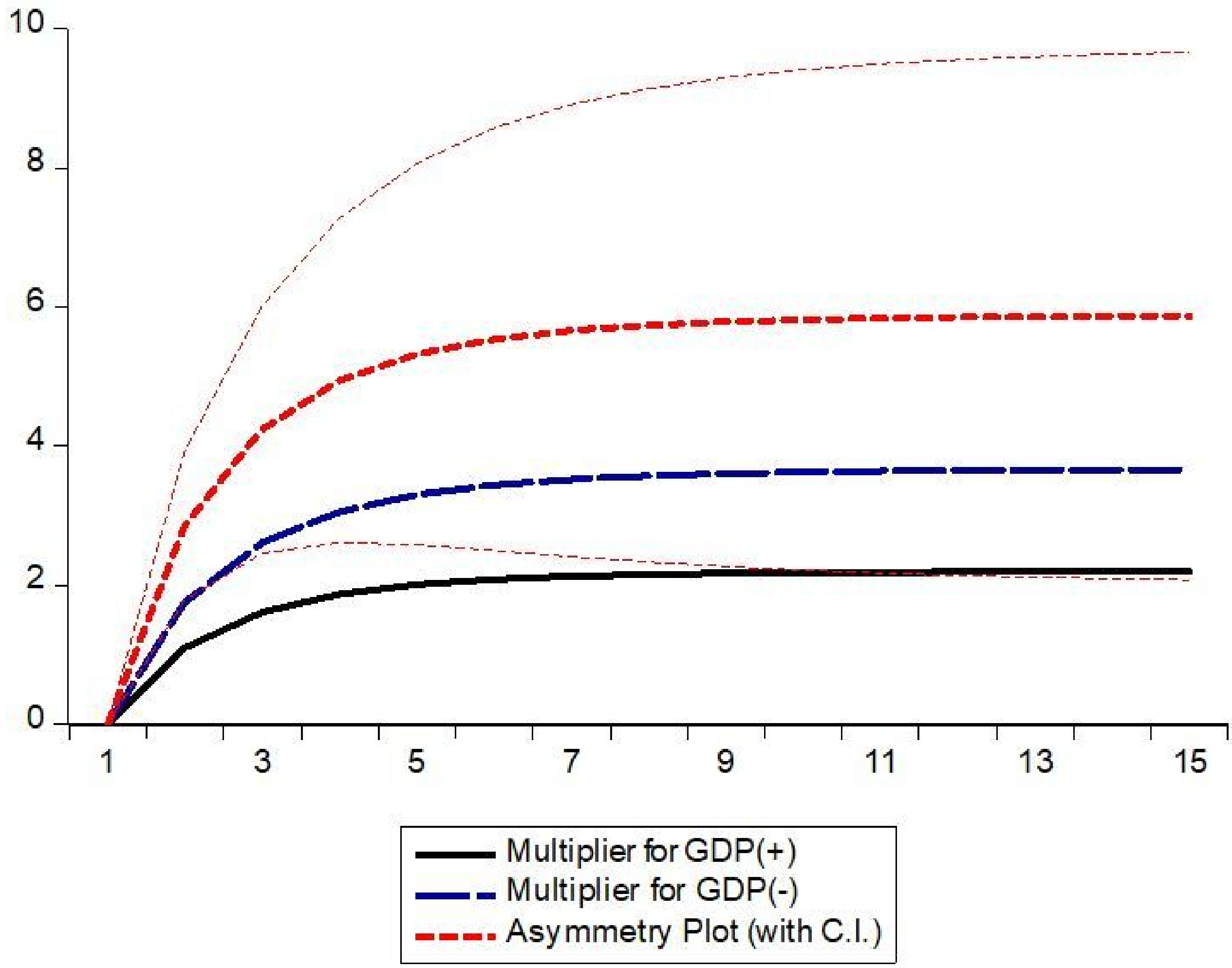

Figure 4

Multiplier for GDP

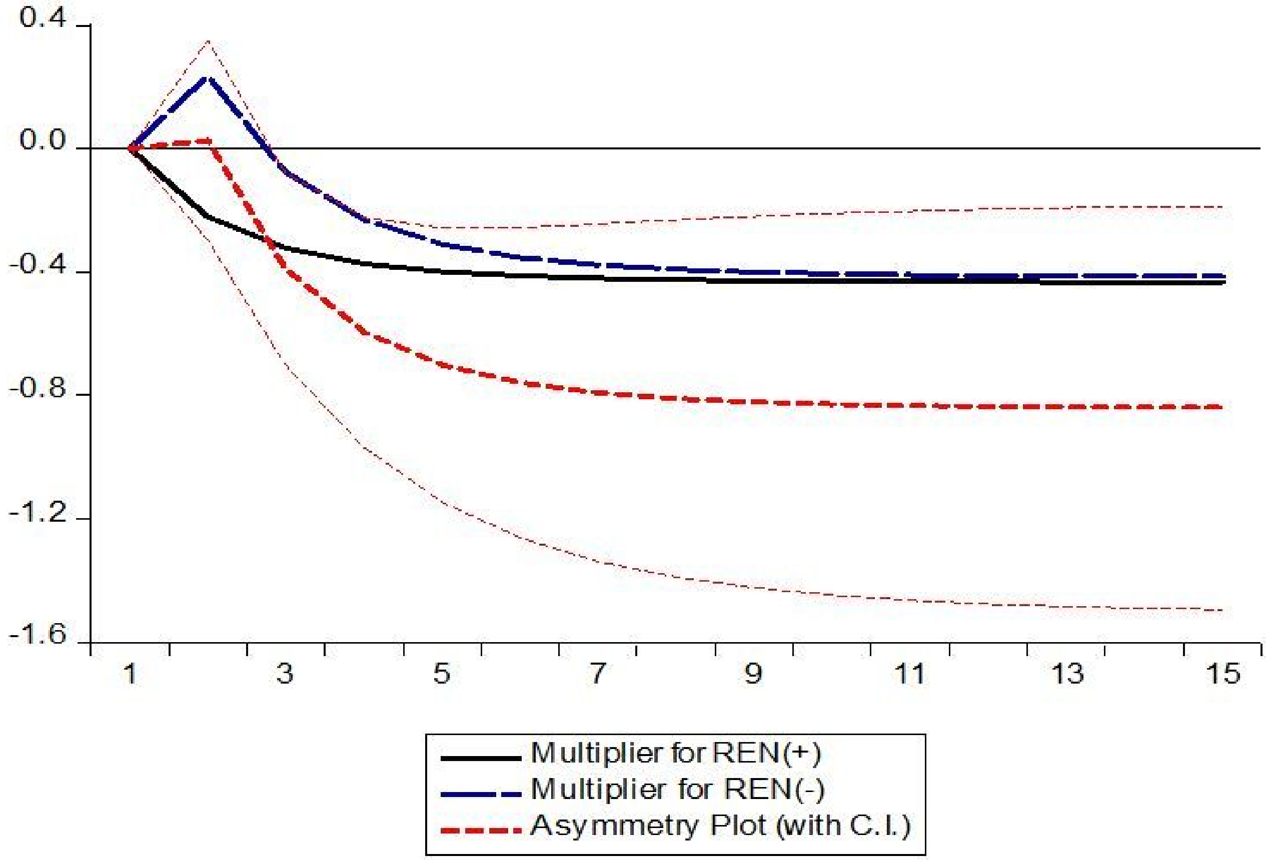

Figure 5

Multiplier for REN

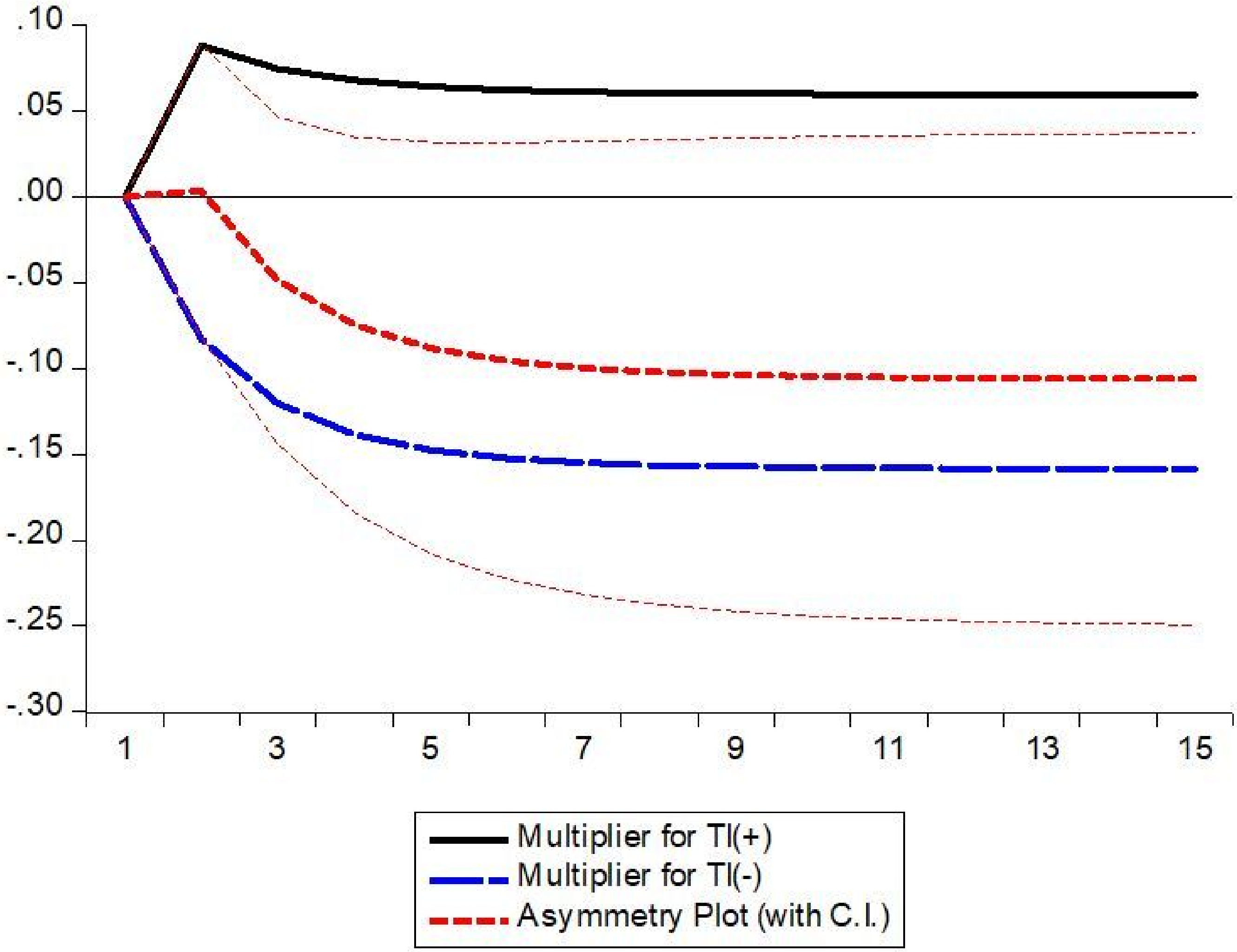

Figure 6

Multiplier for TI