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Determinants of Circular Economy: An Empirical Approach in the Context of the United States of America

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Abstract

The USA is the world's largest economy in terms of the consumption of resources. The excessive and irresponsible consumption of resources in the developed countries has jeopardized the stock of global resources. This quantitative study highlighting the importance of the circular economy (CE), has assessed the factors that would support the circular transition in the USA. Time series analysis based on the Autoregressive Distributed Lag (ARDL) model was employed to analyze the impact of Gross Domestic Product (GDP) per capita, Research and Development expenses, and Renewable Energy consumption on circular economy in the US with annual data from 1971 to 2017. While the study indicated the existence of a long-run relationship between the GDP per capita and renewable energy consumption, no relationship was observed between research and development expenses and the circular economy. The study strongly emphasizes the need for policy interventions to enhance the level of awareness regarding circular economy, increase consumption of renewable energies and steering investments in research and development activities to support CE activities in the USA.

Keywords: Circular economy, resource productivity, the USA, determinants of circular economy, quantitative, ARDL, time series analysis

Introduction

The pace at which human civilizations are consuming resources is alarming. Already, the ramification of this *extraction economy*, which focuses more on extracting virgin minerals from the earth, is observed across the globe. Obdurate and hasty quench for production and consumption (P&C) has become unsustainable, bringing numerous implications across the social, economic, and environmental domains. A philosophy of *cowboy economy,* which advocates for infinite availability of resources (Boulding, 1966; Smith, 1972) should be taken off by the *spaceship economy,* which emphasizes the cautious use of the limited amount of the earth's resources (Brown, 2004) since we are already heading towards the *dumping economy*.

The Global Resources Outlook report published by United Nations (2019) stated that resource extraction has tripled since 1970, driving up the annual global extraction of materials from 27 billion tons in 1970 to 92 billion tons in 2017. For the first time, it was over 100 billion tons (Circular Economy, 2020). As stated in United Nations Environment report, North America and Europe has annual per capita material footprints (MF) of 25 and 30 tons, respectively, whereas it is 9 for the Asia Pacific (Mosbergen, 2016). If everybody consumes as the average person in a high-income country, we would need 3.8 Earths to sustain our survival (Hickel, 2018). This will soon create a deficit where human civilizations have to scramble for resources impacting how businesses produce, people consume, and countries trade (Circular Economy, 2020).

The circular economy, which focuses on an ethical and responsible utilization of resources is a testament to enhancing resource productivity and minimize the pressure of our hasty P&C in the limited resources left. While the circular economy CE concept has gained more traction and presence in EU countries, it is still at its infancy in the USA. Hence this study is objectified to empirically assess the impact of GDP per capita, consumption of renewable energy, and research and development expenses on the transition of the USA from the linear economy (LE) to the CE mode of P&C. The following hypotheses were setup:

Hypothesis 1: Resource productivity is positively influenced by GDP per capita.

Hypothesis 2: Resource productivity is positively influenced by renewable energy consumption.

Hypothesis 3: Resource productivity is positively influenced by research and development (R&D) expenses.

Circular Economy

Circular economy (CE) is a shift from the traditional take-make-dispose mode of production and consumption to a much more restorative and regenerative approach that emphasizes the optimum use of resources. Alhawari et al. (2021) described CE as a dual-loop regenerative system that effectively and efficiently utilizes resources. In contrast to the linear economy (LE), the CE involves incorporating holistic product life cycle analysis to fit in resource life extension strategies (RLES). But equally, it has to be known that CE is more and beyond the waste management alone, it is about managing the resources to reduce the waste (Upadhayay & Alqassimi, 2019)

Relevant Literature

Cautisanu et al. (2018) incorporated clustering and path analysis to examine the determinants of CE in OECD countries where it stressed the importance of circular strategies in the management of waste created due to the higher consumption as a virtue of economic growth; further it asserted the positive impact of education on GDP per capita and R&D which could foster innovative recycling techniques. Busu and Trica (2019) to assess the sustainability of CE indicators in the economic growth of the EU employed a multi regression model with panel data from 2010 to 2017 and concluded that circular material use rate, recycling rate of municipal waste, resource productivity, and GDP per capital growth to have significant positive impact on the economic growth of the EU.

In an empirical assessment carried by Trica et al. (2019) in EU countries with data from 2007 to 2016, resource productivity, environmental employment, recycling rate, and environmental innovation were found to have strong and positive impact on the economic growth. Grdic et al. (2020) concluded countries with greater GDP have greater municipal waste per capital, those countries using more secondary materials have reduced municipal waste generation and developed countries having higher number of patents in a CE have higher GDP. Likewise, in a study carried out in the European Union (EU) between 2006 to 2016, Robaina et al. (2020) conducted a study across three clusters of RPs (RP growth rate-low, medium and high). While a negative relation was observed between R&D and RP for high cluster countries, the signal was positive for low and medium growth countries.

Methods and Materials

Resource Productivity (RP) which was taken as a proxy variable of CE in this quantitative study is a dependent variable. The Real GDP per capita (GDP), Renewal Energies as the percent of total energy consumption (REN), Research and Development expenses as the percent of GDP

(RD) and Municipal Waste Recycled (MWR) were the independent variables. Equation 1 represents the modality of the study where the impact of GDP, REN, RD, and MWR on RP was assessed.

RP= $f(GDP, REN, RD, MWR)$ (1)

To employ empirical estimation, a linear transformation on equation (1) was performed yielding equation (2).

$$lnRP_t = a_1 + \beta_1 lnGDP_t + \beta_2 REN_t + \beta_3 RD_t + \beta_4 lnMWR_t + \varepsilon_t \quad (2)$$

Where *ln* represents the natural logarithms of the variables, t and ε_t represents the time and error term respectively and β_1, β_2 β_3, β_4 denote the coefficients associated with the different explanatory variables. Further *β's* represents the long run elasticities to be estimated.

Stationary and Nonstationary Time Series

To test the stationarity of the time series data, Augmented Dickey-Fuller (ADF), Dickey and Fuller (1981), and Phillips and Perron (1988) (P-P) were conducted. P-P noted the limitation of ADF to test the stationarity in small samples and time series data where structural break occurs. Further Zivot-Andrews (2012) (Z-A) unit root test was conducted to analyze the structural break in the time series data.

ARDL Method

The Autoregressive Distributed Lag (ARDL) model is the most general dynamic unrestricted model in econometrics and was developed by Pesaran and Shin (1988) and Pesaran et al. (2001). In ARDL model the dependent variable is expressed by the lag and current value of independent variables and its own lag value (Ghouse et al., 2018). ARDL test is more suitable for small size of data and hence could be choice for this study, since the time for each variable is 47 years only. Nepal and Paija (2019) highlighted the merits of ARDL model with its benefit to remain statistically significant even after the nature of integration orders of variables: I (0), I (1) or both. While the unit root test allows identifying the maximum orders of integration of the time series, ARDL estimates help in confirming the presence or absence of long run and short run equilibrium relationships (Nepal & Paija, 2019). For the purpose of time series analysis, EViews software was employed.

As per Pesaran and Shin (1998) and Pesaran et al. (2001), the ARDL Bounds test for cointegration which consists of long run terms can be stated as:

$$ARDL: \Delta Y_t = \beta_0 + \sum_{i=1}^{p} \beta_i \Delta Y_{t-1} + \sum_{i=0}^{q} \theta_i \Delta X_{t-1} + \emptyset_1 Y_{t-1} + \emptyset_2 Y_{t-1} + \varepsilon_t \quad (3)$$

After replacing the variables under study in above Equation 3, we get:

$$lnRP_t = b_0 + \sum_{i=1}^{p_1} b_{1i} lnRP_{t-i} + \sum_{i=0}^{q_1} b_{1i} lnGDP_{t-i} + \sum_{i=0}^{q_2} b_{2i} REN_{t-i} + \sum_{i=0}^{q_3} b_{3i} RD_{t-i} + \varepsilon_t \quad (4)$$

Moreover, the possible cointergration in Equation 4 is tested through Bounds test which examins the presenc of long run relationship between the variables in an ARDL model. For Equation 4, the null and alternative hypotheses are as follows:

$H_0 : b_1 = b_2 = b_3 = 0$

$H_1 : b_1 \neq b_2 \neq b_3 \neq 0.$

We reject the H_0 if the test statistic exceeds the respective upper critical value in favor of confirming the existance of long run relationship in the model (the error correction term). In contrast, if test statistics falls below the respective lower critical values, we cannot reject H_0 and conclude that there is no long term adjustment mechanism. But, if the F statistic lies between the upper and lower critical values, the bound test result becomes inclusive.

Once the long run relationship among the vairables was ascertained and cointegration was confirmed in the model, the next step was to develop corresponding error correction model as shown in Equation 5, which could be obtained by reparamatization of Equation 4. Here we investigate the short run dynamics of the respective variables along with the speed of the adjustment towards the long run.

$$\Delta lnRP_t = a_0 + \sum_{i=1}^{p} \gamma_i \Delta lnRP_{t-i} + \sum_{j=0}^{p} \gamma_j \Delta lnGDP_{t-j} + \sum_{k=0}^{p} \gamma_k \Delta REN_{t-k} + \sum_{l=0}^{p} \gamma_l \Delta RD_{t-l} + \lambda ECM_{t-1} + \varepsilon_t \quad (5)$$

In Equation 5, Δ represents the lag operator, ECM_{t-1} indicates error correction term and λ is the coefficient of adjustment. ECM_{t-1} is the lagged oridinary least square (OLS) residuals obtained from running the long run model. The coefficient of ECM_{t-1} is the speed of adjustment to the long run equilibrium. Further, to ensure covergence towards the long run equilibrium, λ has to be less than zero and statistically signficant; otherwise the model is considered unstable or explosive (if λ is positive).

Data

The data for the variables incorporated in this study was extracted from the dataset maintained by National Science Foundation (2019), United Nation- International Resource Panel (2021), U.S. Energy Information Administration (2021), U.S. Environmental Protection Agency (2020), and World Bank (2021).

Real GDP per capita was expressed in an absolute term of dollars, R&D expenses as a percent of GDP, renewal energy as a percent of total energy consumption and RP in U.S. dollar per Kg. Log transformation was taken for GDP per capita (lnGDP) and RP (lnRP) which is a general practice in data analysis that reduces or removes the skewness of the data and helps eliminate heteroscedasticity.

Dependent and Independent Variable

Blomsma and Brennan (2017) asserted RP is an important indicator of CE; calculated as the ratio of GDP of country and its Domestic Material Consumption (DMC) (Haas et al., 2015). Plethora of research across the literatures have kept RP as a proxy variable of CE (Busu and Trica, 2019; Robaina et al., 2020; Trica et al ., 2019), and same practice is continuted in this study.

With an increase in the GDP, the consumption increases and ultimately generates higher waste (Cautisanu et al., 2018); CE could help to bring this waste back as resources for another P&C cycle. The link between CE and economic growth was also emphasized by Bocken et al. (2016); Geissdoerfer et al. (2017); Ghisellini et al. (2016). R&D promotes innovation bringing newer modalities of P&C which could be more efficient and effective. Research and science provide fact-based knowledge that brings technological knowledge required for circular transition (Bassetti, 2020). Investment in R&D is the most to assist complex transition from a LE to a CE. Higher levels of municipal waste symbolizes higher domestic material consumption. This waste could be treated and further given a new life. In CE, waste represents a main resource for P&C. In respect to the renewable energy, a significant positive relation between the use of renewable energy and economic growth exists (Pires and Martinho, 2019).

Table 1

Expected Impact of Independent Variables on Dependent Variable

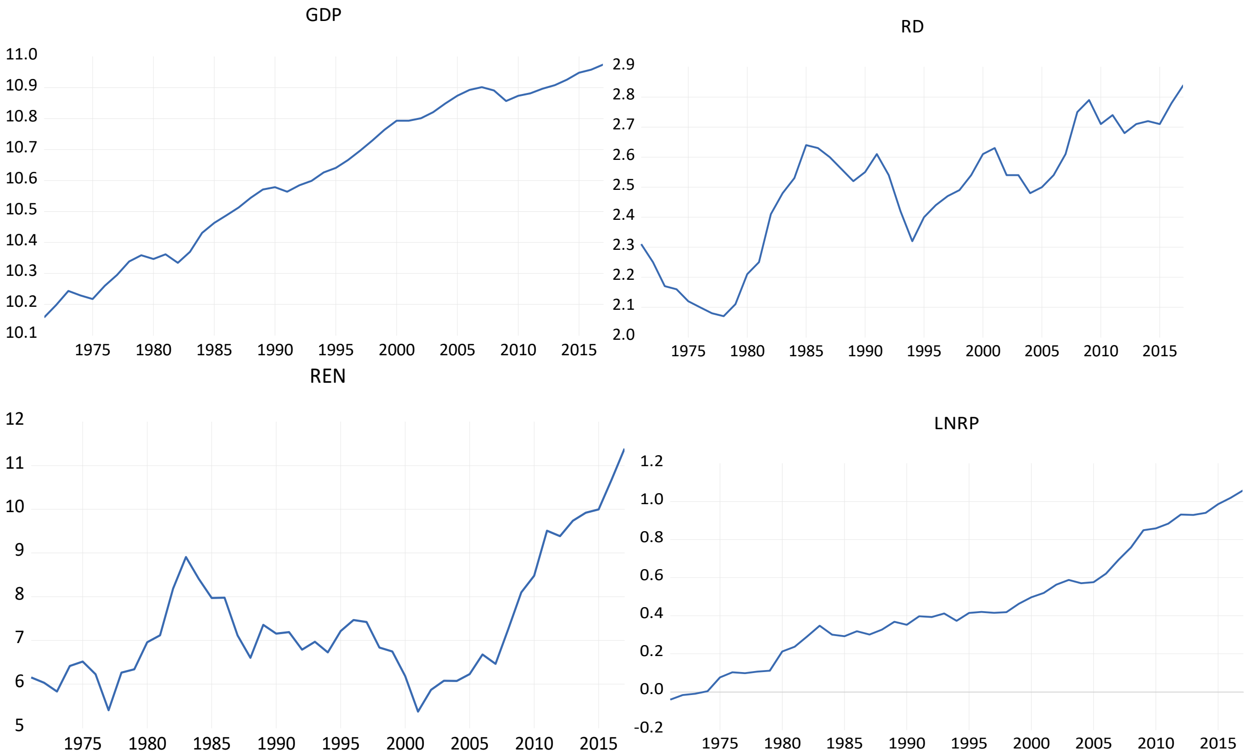
Variables	Type	Expected relation
Resource Productivity	Dependent	Proxy of CE
Gross Domestic Product per capita	Independent	Increases Municipal waste, RP, and CE
Municipal waste recycled	Independent	Increases RP and CE
Total renewable energy consumption	Independent	Increases RP and CE
Resource and Development	Independent	Increases/Decrease RP and CE

Results

Test of Stationarity and Unit Root Tests

All of variables in Figure 1 shows an upward trend; however, RD and REN indicate the existence of structural breaks.

Figure 1
Data Series Used in the Study



ADF and Phillips-Perron tests were employed to assess the stationarity of the time series data. All the varaibles under study were non-stationary at their levels, and stationariy at their first difference.

Table 3
Test of Stationarity

	Augmented Dickey-Fuller Test Statistic		Phillips-Perron Test Statistic	
	Intercept Only	Trend and Intercept	Intercept Only	Trend and Intercept
InGDP	-1.592, (p=0.479)	-1.996, (p=0.588)	-1.792, (p=0.38)	-1.687, (p=0.741)
DInGDP	-5.065, (p=0.000)*	-5.0895, (p=0.001)*	-4.899 (p=0.000)*	-4.924, (p=0.0012)*
InRP	0.666, (p=0.9901)	-1.068, (p=0.923)	0.637, (p=0.989)	-1.999, (p=0.898)
DInRP	-6.151, (p=0.000)*	-6.202, (p=0.000)*	-6.151, (p=0.000)*	-6.202, (p=0.000)*
MWR	-1.890, (p=0.334)	-0.0971, (p=0.993)	-1.768, (p=0.3909)	-0.277, (p=0.989)
DInMWR	-5.492, (p=0.000)*	-5.981, (p=0.000)*	-5.697, (p=0.000)*	-6.089, (p=0.000)*
RD	-1.269 (p=0.636)	-2.807, (p=0.202)	-0.855, (p=0.793)	-2.468, (p=0.342)
DRD	-4.435, (p=0.000)*	-4.393, (p=0.006)*	-4.417, (p=0.001)*	-4.378, (p=0.0058)
REN	0.396, (p=0.981)	-0.424, (p=0.984)	0.008, (p=0.954)	-0.781, (p=0.960)
DREN	-5.610, (p=0.000)*	-5.772, (p=0.000)*	-5.625, (p=0.000)*	-5.785, (p=0.000)*

Note. Critical values reported in this table are based on levels of the variables. Slight changes exist when the first differences of the variables are used in unit root tests. Reported critical values are obtained from EViews 11 output. * represents 1% of significane level.

To identify the point of single most significant structural break in the timeseries data, Zivot-Andrew test was employed further (Table 4). In line with findings from ADF and P-P test, Zivot-Andrew test also reported the same level of integration for all study variables which confirmed that no series was intergated of order 2 or more which justifies the relevenace of ARDL bounds test approach to cointegration.

Table 4

Zivot-Andrews Test

Variables	Z-A test for level			Z-A test for 1st difference		
	t-statistics	Break Year	Outcome	t-statistics	Break Year	Outcome
lnRP	-3.178	1994	Unit Root	-5.871	2008	Stationary
lnGDP	-4.677	2008	Unit Root	-5.917	2008	Stationary
REN	-3.034	2000	Unit Root	-7.547	1984	Stationary
RD	-5.398	1992	Unit Root	-5.642	1986	Stationary

Note. The critical value at 1%, 5%, and 10% is -5.57, -5.08, and -4.82 respectively.

For lnRP, lnGDP, REN and RD the structural break appeared in 2008, 2008, 1984 and 1986. A dummy variable was defined and added to the list of variables under study, Dummies are categorical (binary) variables used in regression models to account for anomalies of structural break in the data. A value of 1 was assigned to Dummy starting from the year 2008 till 2017.

Assessment of Correlation between the Independent Variables

During the process, two of the independent variables, GDP per capita (lnGDP) and Municipal Waste Recycled (MWR) reported a high level of autocorrelation (0.98). With the increase in GDP, the consumption in the economy also increases and so does the creation of waste and ultimately recycling of waste (Cautisanu et al., 2018; Grdic et al., 2020). To get rid of the high level of autocorrelation which may influence the statistical analysis in this test, in further analysis, MWR was dropped from the model and study was carried out only with three independent variables: lnGDP, REN, and RD.

Bounds Test and ARDL Estimations

Table 5 shows the result of the cointegration F test from which we can infer a long-run relationship exists between RP, GDP per capita, RD and REN.

Table 5

Result of Bounds Test of Cointegration

Dependent variables	SIC lag length	F-Statistics	Decision
lnRP (lnGDP, RD, REN, Dummy)	(1,1,0,0,0)	12.36	Co-integration
Critical Value	I (0)	I (1)	
1 Percent significance level	3.29	4.37	
5 Percent significance level	2.56	3.49	
10 Percent significance level	2.2	3.09	

Schwarz information criterion (SIC) model was employed (Robaina et al., 2020); since Akaike information criterion (AIC) often overfits the data and leads to over parameterization (Lin & Tsai, 2016). The calculated F statistics was 12.36 which is greater than the upper limit of critical value at 5 % of significance level, this verified the presence of cointegration among the variables, i.e., RP, GDP, RD, and RE. After confirming the presence of cointegration, long run relationships amongst the variables were studied (Table 6).

Table 6

Long Run Relationship of the Models

Levels Equation				
Long Run Estimation: Restricted Constant and No Trend				
Variables	Coefficient	Std. Error	t-Statistics	Prob.
LNGDP	0.8543	0.1149	7.4331	0.000
RD	-0.0282	0.1416	-0.1988	0.8435
REN	0.0489	0.0184	2.6531	0.0115
DUMMY	0.1547	0.0656	2.3566	0.0236
C	-8.8097	1.0231	-8.611	0.000
EC= LNRP - (0.8543*LNGDP - 0.0282*RD + 0.0489*REN + 0.1547*DUMMY - 8.8097)				

From Table 6, it is inferred, there exists a significant positive long run relationship of GDP per capita and REN with the RP of the USA. In contrast, no significant long run relationship was observed between RD and RP of the USA. Finally, short run relationships between the variables along will the error correction mechanism was estimated (Table 7).

Table 7

Short Run Relationship and ARDL Error Correction Model

ECM Regressor				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(LNGDP)	-0.6616	0.226	-2.9276	0.0057
D(RD)	-0.0073	0.0365	-0.2002	0.8424
D(REN)	0.0127	0.0068	1.8624	0.0701
D(DUMMY)	0.0401	0.0221	1.8267	0.0754
CointEq(-1)	-0.2594	0.103	-2.5171	0.0161

Table 7 portrays the short run estimate of the study, we can infer GDP per capita and renewal energy have significant negative and positive impact on RP respectively in the short run while RD has insignificant negative impact on RP in the short run. The error correction term (ECT1-t) was significant with a coefficient of -0.259 which symbolizes that the short run deviations widen the gap between the dependent and independent variables.

The ARDL model was tested for its stability, fitness and robustness (Table 8). Jarque-Bera (J-B) test of normality, LaGrange Multiplier test for serial correlation, Breusch-Pagan-Godfrey and ARCH test for heteroskedasticity and Ramsey RESET test were within the limit.

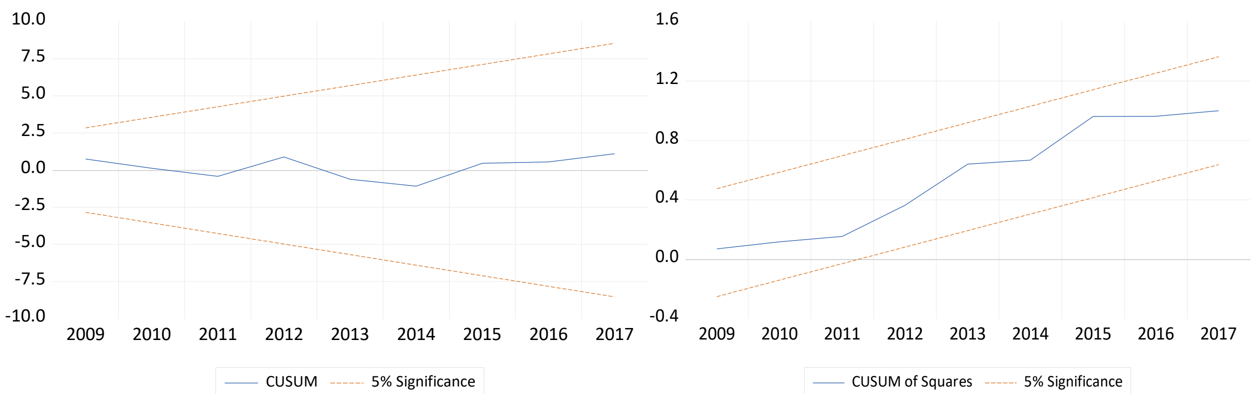
Table 8

Diagnostic Test of ARDL Model

Test	F-statistics	p-value
Normality (Jarque-Bera)	0.0054	0.9974
Serial correlation (LM test)	0.7299	0.4887
Ramsey RESET	0.9954	0.3247
ARCH	2.6047	0.1139
Heteroscedasticity (Breusch-Pagan-Godfrey)	0.9061	0.5005
R-Square	44.7%	
Adjusted R-Square	43.53%	

Finally, CUSUM (cumulative sum) and CUSUMQ (cumulative sum of square) test was carried out to test the stability of the model. Figure 2 indicates the model is stable since the residuals are within the critical bounds at the 5% significance level.

Figure 2
CUSUM and CUSUM Square Test



Note. The straight lines represent critical bounds at 5% level of significance.

Discussion

Hypothesis 1: RP is Positively Influenced by GDP per Capita

In the long run, a 1% increase in GDP per capita of the USA will increase resource productivity by almost 0.85%. Whereas, in the short run, a 1% increase in the GDP per capita will reduce the resource productivity of the USA by almost 0.66%. An increase in GDP per capita represents the expansion of a country's economy which provides numerous opportunities to practice and employ circular strategies, which requires changing the existing P&C patterns. The short-run variations in our existing economic model, which as per Circular Economy (2020) is only 9% circular, could exert pressure on the resources (technical as well as non-technical) which are accustomed to thriving in the linear model of P&C. However, at the same time, it should not be forgotten that CE is a long-term process (Kirchherr et al., 2017; van Buren et al., 2016).

Over time, with an increase in the circular expertise, enhanced know-how about CE, greater diffusion of CE in the industries, strong formation of alliance amongst the firms in the industry to share the circular knowledge, symbiosis, and cross-pollination of CE-related skills across the industries, in the long run, all the intermediaries would start to adapt themselves with circular P&C, and the positive benefits from the CE could be observed in the economy.

Hypothesis 2: RP is Positively Influenced by Renewable Energy Consumption

In the long run, a 1% increase in the REN will increase the RP of the USA by almost 0.05 %. Similarly, in the short run, a 1% increase in the consumption of renewal energy would increase the resource productivity of the USA by 0.013%. With the consumption of renewable energies, the RP of the USA exhibited a significant positive relationship both in the short run and in the long run at 10% and 5% of significance respectively. Investment in renewable energies has a multiplier effect throughout the economy. It reduces emission and improves health, benefits society by avoiding costly illness and job creation, boost the economy by lowering energy costs and helps in diversifying the fuel mix, and reduces the dependency on hydrocarbons (EPA, 2018).

Hypothesis 3: RP is Positively Influenced by the R&D Expenses

In both the long run and the short run, there exists no significant relationship between the Research and Development and resource productivity of the USA. While, in general, it is assumed that the impact of R&D on RP is to be positive and significant, research by Hammar and Belarbi (2021) concluded that the effect of R&D expenditures and innovation on productivity is mixed, i.e., positive, negative and no impact based on the level of the economy.

While the researcher of this study expected a significant and positive relationship between the R&D and RP of the USA, the finding came opposite. This contradictory signal may be because R&D investments might have been in sectors that do not help improve productivity (Robaina et al., 2020). Griliches (1979) pointed out the importance of stock of R&D knowledge and cumulative R&D effort made to date. These could create a spillover effect of R&D achievements, i.e., make the R&D findings quickly diffused in the economy. However, since CE is a new and emerging concept, there is a lack of expertise related to circular innovation, low awareness of CE, a lack of R&D focusing on CE, and a gap in R&D commitment and its actual realization. All of these factors in the USA have abstained the USA from forming the required CE-related pool of knowledge and expertise, which could have negatively impacted the RP.

The error correction term in this estimation as calculated in Equation 7 indicated the causal relationship of the explanatory variables with the dependent variable. The negative sign infers the convergence from short run to long run and could be concluded that approximately 26% of the disequilibrium due to shocks to the system is corrected within one year, and adjustment to the long run path is completed in less than four years.

Conclusion

The study demonstrated there exist a long run as well as short run relation between the GDP per capita and renewable energy consumption to the RP of the USA. However, no relationship existed between R&D and RP of the USA. While there was a negative relation between the GDP per capita and RP in the short run, the relationship would turn positive with higher unit of GDP generated per unit of resource consumed; this could be attributed to the implementation of circular strategies which would focus on RLES.

The findings of this study are in line with the study by Robaina et al. (2020), amongst the EU countries, concluded a positive relationship between renewable energy consumption with countries depicting high growth rates in RP. Similarly, a negative relation between R&D expenditure and RP was obtained in EU countries (Robaina et al., 2020), which is consistent with this study, except the relation was insignificant between R&D and RP in this study. Finally, consistent with this study's findings, Busu and Trica (2019) and Trica et al. (2019) had inferred a positive relationship between the GDP per capita and RP in their study carried out in the EU. The same rule of thumb might not be applicable in determining the factors that would impact the transition from the LE to the CE mode of P&C; Upadhayay and Alqassimi (2020) defined the Good Point for Transition (GPT) which depends on the stock of CE related skills, expertise, and resources.

For the effective and efficient transition to CE in the USA, policies and programs should be in place to increase awareness about CE through the initiation of CE and sustainability related courses and trainings in schools, universities and corporations; there should be sufficient allocation of fund for R&D involving CE related experimentations and innovations; here agencies like U.S. Environmental Protection Agency, U.S. Energy Information Administration, U.S. National Science Foundation, World Bank, and International Monetary Fund could play pivotal role; a creation of regional blocks and special interest committee to foster adoption of CE in national and global arena is a mandate which would dissipate CE related toolkits, data, and measures, and finally, promoting the consumption of renewable energies through various financial and non-financial incentive would support the transition to CE for the sustainable future in the USA.

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