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Carbon credits: Are they effective?

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ABSTRACT

In today's sustainable and environmentally responsible world, it is necessary to track and regulate a country's CO_2 emissions. This paper will evaluate if carbon credits in the form of carbon taxes have aneffect on CO_2 emissions and if there is, to what extent. The data used are from countries that have successfully established carbon tax. The paper will investigate the above by using a Linear RegressionModel with the carbon tax, GDP per capita, and Area of the country as the explanatory variables and CO_2 emission as a dependent variable.

Keywords: *Econometrics, Regression, R Programming, Carbon Footprint, Climate Change, Environment, Taxes, Carbon Credits*

1. INTRODUCTION

One carbon credit acts as a permit or a certificate that allows holders the right toemit one ton of carbon (or any equivalent greenhouse gas) during production activities. Businesses that exceed their quotas are required to buy extra credits and those under their quotas can sell the remaining credits. Thus this acts as a monetary incentive for big corporations to reduce their carbon emissions from industrial activities. This helps in combatingglobal warming, which is the biggest problem we, as a world, face today. In general, it is taken that carbon credits harm the carbon emissions of a country. Whetherit stands true is still required to be proven. This paper measures Carbon Credit as the rate at which one ton of CO_2 can be produced. It is presented in the form of US$/mt$CO_2$. CO_2 emission is measured through Carbon dioxide produced in Metric tons (MT).

This paper hypothesizes that the carbon tax in a country is negatively correlated to its CO2 emission, meaning that as the rate decreases, the emission increasesconsequently. The primary independent variable is the carbon tax and the dependent variable is the amount of carbon emission. The above relationship is justified through the reasoning that when there is an increase in the carbon tax, right holders have to pay more for every ton of CO_2 they produce. This means that they have a greater incentive to reduce their production of carbon dioxide which in turn reduces CO_2 emissions. Similarly, when there is a decrease in the rates, right holders can freely produce CO_2. This leads to an increase in carbon emissions.

However, other factors play an essential rolein determining the amount of carbon emissions in a country. Thus this paper aimsto develop a multilinear regression modeltaking other factors such as Gross Domestic Product per capita (GDP per capita), land area (in Km^2), the share of urban population (in %), and manufacturing sector in GDP (in %) and whether a country is an OECD country or not (measured with a dummy variable).

This topic has been significant in recent years because Global Warming has been costing increasingly to the economiesaround the world. With environmentalists debating over policies to reduce carbon footprint, carbon credit has emerged as one of the new ways to do so. Such a system also consciously motivates organizations to use sustainable methods of production so that they can earn profits by selling their remaining credits. Furthermore, if this topic is extended and combined with other studiesthat focus on more regional data and carbon trading as a factor, more useful results couldbe produced. This could also aid in further policy-making and help build huge sustainable economies while also fulfilling global commitments like the Kyoto Protocol.

2. LITERATURE REVIEW

Climate change and carbon emissions have been hot topics for economists and environmentalists for a long time. In the composition of this paper, several journal papers are reviewed and taken reference.

One of those was by Annegrete Bruvoll (2004), who examined if Norway's carbon taxes worked effectively from 1990-1999. This paper's purpose was to evaluate how well the Pigouvian carbon taxes have worked in reducing greenhouse gas emissions like CO_2 and N_2O. This paper aimed at decomposing observed changes in the climate gases CO2, methane, and N2O from 1990 to 1999 into eight different driving forces, to reveal the main driving forces behind the climate gas changes over the last decade. The paper revealed that the carbon tax contributed to a reduction in emissions of 2.3%, which is quite less when compared with the belief that the carbon taxes have been both considerable andpioneering. The small effects are partly related to the exemption from the carbon taxfor a broad range of fossil fuel-intensive industries. The industries, in which one would expect the carbon tax to be most efficient in terms of downscaling productionand reducing emissions, are the same industries exempted from the carbon tax. It was also noticed that the lack of coordination of the multiple climate gas reducing instruments creates huge abatement costs, which demotivates industries from reducing their GHG footprints. The paper concludes that coordination of both the different instruments and a less differentiated carbon tax would improve the cost efficiency of the climate gas policy.

Another paper by Andrea Baranzini, Jose Goldemberg, and Stefan Speck (2011) evaluates carbon taxes with regard to their competitiveness, distributional and environmental impacts. The paper aims to examine this by analyzing six countries that had implemented taxes at that time. The evidence shows that carbon taxes may be an interesting policy option and that their main negative impacts may be compensated through the design of the tax. The main negative impact could be the increased competitiveness arising out of differences in tax structures. Yet, the paper infers that empirical studies on existing carbon/energy taxes seem to indicate that competitive losses are not significant. The paper also explains that during its composition, carbon taxing was in its nascent stages and couldn't account for all complexities in the model. The results of the empirical studies in the paper show that carbon taxes may be an effective instrument in reducing CO2 emissions when it is accompanied by other measures, in particular the removal of energy subsidies.

To maintain the environmental effectiveness of carbon taxes, rebates and exemptions for trade should be made only in very special cases. The paper concludes that although carbon taxes have a negative impact, they are not as serious. In this context, carbon taxes can be effectively used when they are accompanied by a set of policy packages like removing subsidies and exemptions on taxes and recycling t=carbon taxes by reducing taxes on other things.

The contribution of this paper to the literature on environmental economics is to further research into how economic structures and policies affect the release of harmful greenhouse gases. This paper is unique to the topic because it summarizes the relationship between the two byconducting a regression analysis. Also, the countries included in this study are diverse in terms of area and status as OECDmembers. This study also models into it other factors which haven't been takenbefore to make it more holistic in approach.

Data

This paper aims to find a relationshipbetween a country's CO_2 emissions and its carbon tax measured in US$ per ton of CO_2. For CO_2 emissions, the data used is measured in Metric tons. The year of both data sets is chosen to be 2022 which has the advantage of being both relevant and comprehensive. The data on carbon tax has been obtained from the World Bank which is an authoritative and credible source, especially for worldwide data. The data on carbon emissions, for countries that charge carbon taxes, have also been obtained from the World Bank.

Other variables also play a significant role inaffecting carbon emissions. These are theGDP per capita, land area of a country, the share of urban population andmanufacturing sector in GDP (in %), andwhether a country is an OECD country or not. A country with a higher GDP per capita will have higher carbon emissions, simply because it can produce more. Similarly, the greater the total area of a country, the greaterits capacity to undertake industrial activities, which in turn produce higher carbon emissions. A higher share of themanufacturing sector in GDP will lead tohigher industrial activities and greater carbon emissions thus signifying a positive relationship. A greater share of the urban population could determine the level of urbanization in an area, which could further influence carbon production there. The use of this variable was taken from Apueela Wekulom (2021) who observed a sample size of 97 countries in their study. This studyincorporates 30 carbon taxing countries.

OECD stands for Organization of Economic and Cooperation development. Countrieswith an OECD membership have high-income democracies and suchmembership has the potential to impact the amount spent on controlling carbon emissions. OECD countries are more likely to spend a greater amount on environmental protection and are thus less likely to produceCO_2. This variable is taken as a dummy variable with 1 as countries who are members of OECD and 0 as countries who aren't members. The use of this variable wastaken from Alam and Hasmi (2019) whoobserved a sample size of 29 OECD countries in their study. This study incorporates 30 carbon taxing countries, of which 20 are OECD members.

The sample sizes are the number of countries that have implemented carbontaxes in their specific economies by 2022, which is 30. For the sake of consistency, all data is from the controlled year 2022, exceptfor GDP, urban.pop, and manuf whose latestdata is not available yet. The source for GDP per capita, the share of the urban population, and the share of the manufacturing sector in GDP are again data from the World Bank, which is extremely reliable. The data for land areas of the countries is obtained from the United Nations FAOSTAT which is also an authoritative and authentic source. The data of OECD members are taken from the OECD website itself since that is the primary source. The below figure is a summary of all variables used in the model and their units.

Figure 1.1

	DESCRIPTION	YEAR	UNITS	SOURCE
co2	CO_2 emissions (by country)	2022	Metric tons	World Bank
tax	Carbon Credit: the rate at which permit holders are allowed to produce one ton of carbon (by country)	2022	US$/mt CO_2	World Bank

gdp	GDP per capita (by country)	2021	US$ per person	World Bank
land	Total area (by country)	2022	Km^2	United Nations FAOSTAT
oecd	Members of Organization of Economic and CooperationDevelopment	2022	1, OECD member 0, Otherwise	OECD
urban.pop	Share of urban population (bycountry)	2021	Percentage (%)	World Bank
manuf	Share of the manufacturing sectorin GDP (by country)	2021	Percentage (%)	World Bank

VARIABLE	OBSERVATIONS	MEAN	STANDARD DEVIATION	MIN	MAX
co2	30	177.688	238.7155	3.17	1061.77
tax	30	38.39367	43.55288	0.08	137.30
gdp	30	41494.37	35144.27	3847	157492
land	30	808337.6	1860631	160	9984670
oecd	30	0.6667	0.47946	0	1
urban.pop	30	76.93	17.37603	14	100
manuf	30	14.90	7.61282	5	39

Figure 1.2

The figure below shows a scatter plotgenerated with a linearly best-fitted trendline. The x-axis measures the log ofcarbon credit in the given 30 countries, whereas the y-axis measures the log of CO_2 emissions. Observing just the plot, the relationship seems to be a little weak but it still contains some potential. There is one noticeable outlier on the extreme left side and that is Poland with a carbon tax of 0.08 US$/mt CO_2.

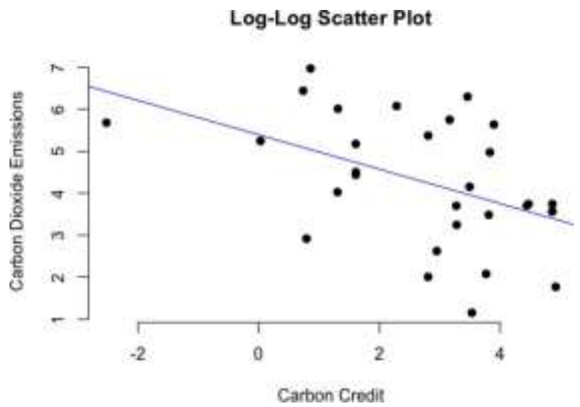

Figure 2: Scatterplot

Before proceeding to compute the regression model, a significant step is to check if the given data satisfies all the Classical Linear Regression Model (CLRM) assumptions:

1. Linear in parameters:

y = $_0$ + $_1x_1$ + $_2x_2$ +...+ $_nx_n$ + u is the general form of a linear regression model. Here logco2which stands for the log of CO_2 emissions represents y, that is, theleft-hand side of the equation.Logtax which is the log of Carbon Tax represents x. $_0$ is the constant intercept term and $_1$ to $_n$ are slopecoefficients. The variables we are taking satisfy the given condition of being linear in parameters.

2. Random Sampling:

Since the data is collected from the World Bank, all of them are collectedin random populations and samples from the world, satisfying theassumption.

3. Perfect Collinearity:

This assumption implies that there is no perfect linear relationship between the independent variables. Ris used to test this assumption. In figure 3, no correlation betweenindependent variables is perfect i.e. 1or -1. This means that the model satisfies the assumption of no perfectcollinearity.

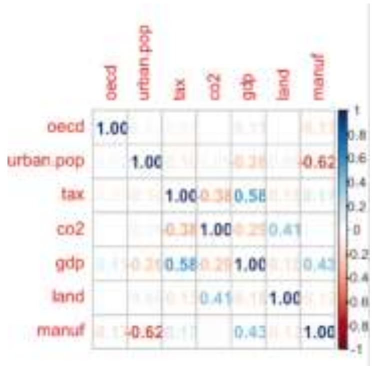

Figure 3

4. Mean of Residuals:

According to this assumption, given the values of the independent variables, the expected value for the error term u is always zero. The residual plot is used to evaluate this assumption. In Figure 4, it is apparent that the expected value of the residuals is very close to 0 from the red line. Also, through R it has been calculated that the mean of residuals for the given model is 1.017343e-17, which is very closeto 0. Thus this assumption is satisfied. Although other variables affect Carbon Dioxide emissions, and not all of them can be accounted for, this data will be treated with some caution.

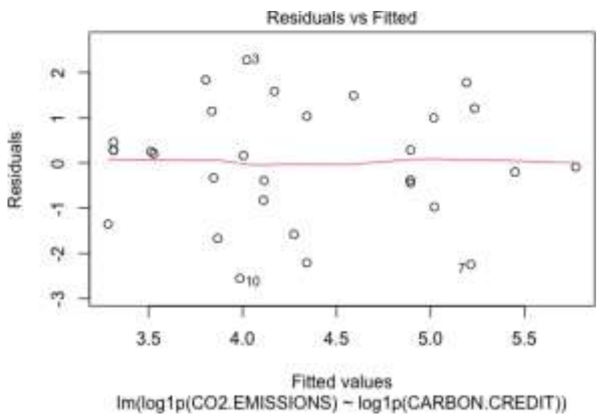

Figure 4

5. Homoscedasticity:

This assumption assumes that the variance of the error term remains constant for all the given independent values. This assumptionis evaluated from the Normal Q-Qplot in Figure 5. The standardizedresiduals are roughly evenly distributed and when approximated, will be nearly constant. Thus this assumption holds. However, since other variables affect Carbon Dioxide emissions, and not all of them can be accounted for, this data will be treated with some caution.

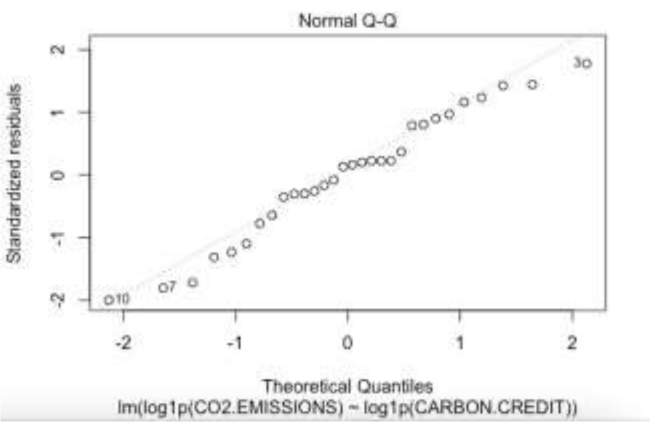

Figure 5

6. Normality of Residuals: According to this assumption, the residuals are supposed to follow a normal distribution. From Figure 5,it can be deduced that the residuals follow a normal distribution withsome deviation near the ends. Butsince the deviations are small, it canbe said that this assumption holds.

7. No Autocorrelation:

This assumption requires the residuals of the model to be uncorrelated with each other. Since the data we have taken iscross-sectional, the likelihood of data being autocorrelated is low.Autocorrelation is measured through the ACF plot shown in Figure 6 in this paper. The lag-0 value is equal to one because it represents thecorrelation of the residual with themselves. Since the other lag values lie very less and lie within thesignificance level, the data is not autocorrelated and the assumption holds.

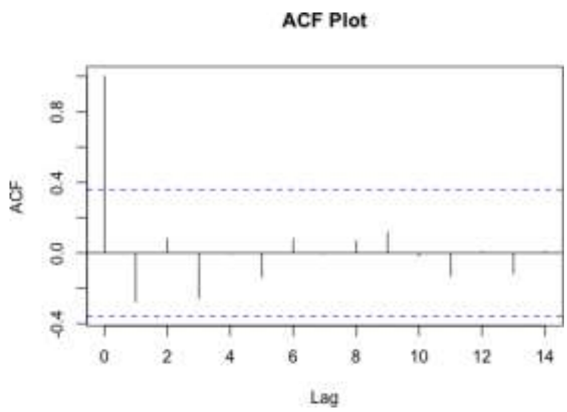

Figure 6

3. RESULTS

Simple Linear Regression (Model 1): The following model is used to evaluate thehypothesis:

$$log(co2)=\beta_0 + \beta_1 log(tax) + u$$

where co2: the CO_2 *emissions of a country inMetric ton; tax: the rate at which these given countries charge taxes, in US$, per ton.*

After conducting the regression through R, the following model is generated. Figure 7 isshown below.

```
Call:
lm(formula = log1p(co2) ~ log1p(tax), data = Data)

Residuals:
    Min      1Q  Median      3Q     Max
-2.5578 -0.7306  0.1842  1.0229  2.2764

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)   5.8134     0.5682  10.231  5.8e-11 ***
log1p(tax)   -0.5130     0.1755  -2.924  0.00678 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 1.305 on 28 degrees of freedom
Multiple R-squared:  0.2339,	Adjusted R-squared:  0.2065
F-statistic: 8.548 on 1 and 28 DF,  p-value: 0.00678
```

Figure 7

Estimated Equation:

$$log(co2)=5.8134 - 0.5130log(tax)$$

The simple regression model given abovehas an adjusted R-squared value of 0.2065,which implies that Carbon Credits explainapproximately 20% of the variation inCarbon emissions. This means that therelationship between log(co2) and log(tax) is relatively weak, which is not ideal forconcluding. What one must also observe isthe slope coefficient for tax, which has a negative sign. Thus an increase in the log oftax is followed by a decrease in the log ofcarbon emission. An increase of 1% in thetax rate, leads to a 1% decrease in emissions.This proves the relationship is negative, so apart of the initial hypothesis is proved here. Since this relationship doesn't provide allthe useful information we need, we move onto create a multiple linear regression model to account for omitted variables in Model 1.The next model will aim to provide more useful insights into the relationship between carbon emissions and carbon taxes.

I. Multiple Linear Regression (Model 2): Now the model tries to take into account allthe other variables i.e. the GDP per capita,land area, whether the country is an OECD country, percentage of the urban population,and the share of the manufacturing sector inGDP. The given model will then take theform of:

$$log(co2)=\beta_0 + \beta_1 \, log(tax) + \beta_2 \, log(land) + \beta_3 \, oecd + \beta_4 \, urban.pop + \beta_5 \, log(gdp) + \beta_6 manuf + u$$

Where ***co2****: the* CO_2 *emissions of a country in Metric ton;* ***tax****: the rate at which these given countries charge taxes, in US\$, per ton;* ***land****: total land area in* Km^2*;* ***OECD****: 1,if the country is an OECD country. 0, otherwise;* ***urban.pop****: percentage of urban population;* ***GDP****: the GDP per capita;*

manuf*: share of the manufacturing sector inGDP.*

After running the regression through R, the following coefficients are generated for β_0, β_1, β_2, β_3, β_4, and β_5. The regression is shownin Figure 8.

```
lm(formula = log1p(co2) ~ log1p(tax) + log1p(land) + oecd + urban.pop +
    log1p(gdp) + manuf, data = data4)

Residuals:
    Min      1Q  Median      3Q     Max
-2.2286 -0.5125 -0.0418  0.6968  1.4651

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept) -11.797867   4.637841  -2.544 0.018146 *
log1p(tax)   -0.819011   0.214774  -3.813 0.000893 ***
log1p(land)   0.636324   0.128852   4.938 5.43e-05 ***
oecd         -1.372315   0.537268  -2.554 0.017731 *
urban.pop    -0.026863   0.015566  -1.726 0.097809 .
log1p(gdp)    1.363978   0.453685   3.006 0.006294 **
manuf        -0.003937   0.036524  -0.108 0.915088
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.9923 on 23 degrees of freedom
Multiple R-squared:  0.6362,	Adjusted R-squared:  0.5412
F-statistic: 6.702 on 6 and 23 DF,  p-value: 0.0003338
```

Figure 8

Estimated Equation:

$$log(co2)=-11.7979 - 0.8190log(tax)+ 0.6363log(land)- 1.3723oecd- 0.0269urban.pop +1.3640log(gdp) -0.0040manuf+ u$$

The adjusted R-squared value has increased from 0.2065 to 0.5412 because more variables that contribute to the relationship are added. This is a significant increase and indicates a better model. The independent variable log(tax) has a slope coefficient of -0.8190. This again supports the hypothesis that there exists a negative relationship between carbon taxes and carbon emissions.

Moreover, since it is statistically significant at all 10%, 5%, and 1% levels of significance, it can be said that this model is promising. However, taking 5% as the default level of significance, it can beinferred that 'manuf' is not as statistically significant as the others. Thus further improvement in the model can be made by removing this variable from the model.

II. Multiple Linear Regression (Model 3): Now the model tries to take into account allvariables except the share of the manufacturing sector in GDP. The givenmodel will then take the form of:

$$log(co2)=\beta_0 + \beta_1 \, log(tax) + \beta_2 \, log(land) + \beta_3 oecd + \beta_4 \, urban.pop + \beta_5 \, log(gdp) + u$$

Where ***co2****: the* CO_2 *emissions of a countryin Metric ton;* ***tax****: the rate at which thesegiven countries charge taxes, in US\$, perton;* ***land****: total land area in* Km^2*;* ***oecd****: 1, ifthe country is an OECD country. 0,otherwise;*

urban.pop*: percentage of urbanpopulation;* ***gdp****: the GDP per capita.*

After running the regression through R, the following coefficients are generated for β_0, β_1, β_2, β_3, and β4. The regression is shown inFigure 9.

```
Call:
lm(formula = log1p(co2) ~ log1p(tax) + log1p(land) + oecd + urban.pop +
    log1p(gdp), data = data4)

Residuals:
     Min       1Q   Median       3Q      Max
-2.22213 -0.51779 -0.03754  0.68109  1.47945

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) -11.74637    4.51718  -2.600 0.015691 *
log1p(tax)   -0.81113    0.19776  -4.102 0.000408 ***
log1p(land)   0.63470    0.12531   5.065 3.52e-05 ***
oecd         -1.34880    0.48077  -2.805 0.009804 **
urban.pop    -0.02576    0.01147  -2.245 0.034224 *
log1p(gdp)    1.34300    0.40131   3.347 0.002688 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.9717 on 24 degrees of freedom
Multiple R-squared:  0.636,	Adjusted R-squared:  0.5601
F-statistic: 8.386 on 5 and 24 DF,  p-value: 0.0001063
```

Figure 9

Estimated Equation:

$$log(co2)=-11.7463 - 0.8111log(tax)+ 0.6347log(land)- 1.3488oecd- 0.0258urban.pop +1.3430log(gdp)+ u$$

This is the new model after removing the variable that seemed to be insignificant in evaluating the carbon emissions in a country. The adjusted R-squared value is 0.5601 which has increased from the previous model. Here too, a definitive negative relationship exists between log(co2) and log(tax). It is clear from the adjusted R-squared value that Model 3 issuperior to Model 2, however a more clearerpicture will be shown after runningstatistical tests to examine these models.

According to this model, a 1% increase in taxes leads to a 0.81% increase in CO_2 emissions.

In the next stage, each variable in the three models will be tested on its statisticalsignificance. In figure 10, a summary is given. The box below contains a summaryof the slope coefficients corresponding tothe given variable and model along with their significance levels. One star represents statistical significance at the 10% level of significance, two stars represent statistical significance at all 10% and 5% levels ofsignificance, and three stars statistical significance at 10%, 5%, and 1% levels of significance. The standard errors of the parameters are also mentioned in the parenthesis.

INDEPENDENT VARIABLE	MODEL 1	MODEL 2	MODEL 3
log(tax)	0.5130*** (0.1755)	0.8190*** (0.2148)	0.8111***(0.1978)
log(land)		0.6363*** (0.1288)	0.6347*** (0.1253)
oecd		1.3723*** (0.5373)	1.3488*** (0.4807)
urban.pop		0.0269** (0.0155)	0.0258** (0.0114)
log(gdp)		1.3640*** (0.4536)	1.3430*** (0.4013)
manuf		0.0040 (0.0365)	
Intercept	5.8134 (0.5682)	11.7979 (4.6378)	11.7463 (4.5171)
Number of observations	30	30	30
Adjusted R-squared	0.2065	0.5412	0.5601

Figure 10

It can be inferred that manuf is the leastsignificant variable, which brought in the need to construct Model 3. The next stage accounts for determining whether model 3 isjointly significant or not.

4. RESULTS

Robustness Test

After removing 'manuf' from Model 2, it is necessary to check if these variables are jointly significant to the model. To checkthis, an F-test has to be performed. If the null hypothesis is rejected, then the variablesare all jointly significant. If not then these variables are statistically insignificant.

Model 3:

$$log(co2)=\beta_0 + \beta_1 log(tax) + \beta_2 log(land) + \beta_3 oecd + \beta_4 urban.pop + \beta_5 log(gdp) + u$$

Testing the joint significance of log(tax), log(land), oecd, urban.pop and log(gdp), the following hypothesis has been formulated.

$$\mathbf{H_0: \beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = 0}$$

$$\mathbf{H_A = H_0 \text{ not true}}$$

F value: 8.386

$F_{critical}$ at 10% level of significance: 2.10 $F_{critical}$ at 5% level of significance: 2.62 $F_{critical}$ at 1% level of significance: 3.90

At all three levels of significance, $F > F_{critical}$.

We reject the null hypothesis

Therefore, log(tax), log(land), OECD, urban.pop, and log(gdp) are jointly significant.

In conclusion, it can be testified that model3 is the best model because

1. It has a higher Adjusted-R^2 than the other two models
2. All its independent variables are both individually and statisticallysignificant when taking at least 5%as the minimum level of significancerequirement.

5. CONCLUSIONS

This paper conducted a study on the relationship between carbon credits in theform of carbon taxes and the CO_2 emissions of a country. This paper hypothesizes a negative relationship between the two variables and it is supported by the negative sign of the slope coefficient β_1 of *log(tax)* in the model. The factors affecting CO_2 emissions are countless and it is extremely difficult to incorporate all of them. Some countries such as Estonia have low carbon tax rates, but they also have one of the lowest CO_2 emissions. This phenomenon is not a disapproval of the relationship between carbon taxes and their subsequent emissions, but it rather tells that each country handles its economy differently depending upon the already existing state of socio-economic factors. Estonia has managed to produce approximately 32% of its electricity from renewable energy sources which contribute majorly to the low carbon emissions.

Despite there being several factors that couldn't be modeled, an attempt was madeto add and remove variables to refine the model and bring it to an improved version. This can be noticed clearly as the Adjusted R-squared value increases model by model.

This study, therefore, demonstrates thatCarbon Credits in the form of taxes are essential to reducing a country's carbon footprint, which is an issue that concernscitizens globally. Since lesser emissionscreate a better quality of life for the citizens of a country, it can also be said that higher carbon taxes improve the quality and standard of life. Thus charging taxes from big corporations does pay off. When it comes to policy making, it should be noticedthat more and more economies of the world should consider charging taxes per ton ofCO_2 produced because not only would this be a step to lead everyone into a sustainable world, but also contribute to the growth of nations. Since the industrial revolution, policymakers have been set to increase production and create huge economies, neglecting other factors such as the pollutioncreated. However, in today's world with increasing awareness, there has been a conscious movement towards a greenerenvironment and this study could potentially provide a tool for them to promote products at a renewable scale.

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