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March 23rd, 2023

Impact of CO2 Emissions on Agricultural Production

Abstract

The rise in carbon dioxide emissions has been increasing global temperatures for years, and some say it reflects climate change. In the past, climate change has led to disruptions in food availability by reducing access and quality. For instance, increases in temperatures raise the frequency of extreme weather events and reduce water availability. Previous research by the USDA on climate change argues that climate assessments need to be made in the context of socioeconomic scenarios. Thus, as a macroeconomic issue, farmers increase their agricultural production with greater financial support. Farmers with a greater number of acres will receive a higher income, and this lowers the implications of negative externalities like climate change on agricultural productivity. Are crop yields more likely to be affected in countries that encounter more frequent weather changes? The purpose of this paper is to investigate the effect of climate change on agricultural production across 60 countries. The extent of this effect varies by country and region. By using a cross-sectional dataset provided by the *World Development Indicator Database,* we can regress the crop production index on the level of CO2 emissions, percentage of land used for agricultural production, food production index, and gross domestic product per capita. In the regression results, holding control variables constant, and as the level of CO2 emissions increases, this approach fully captures adaptation as each farmer adapts to the climate they live in. However, we have chosen not to include year-to-year changes in temperature (measured in Celsius) and focus on the level of CO2 emission for each country in 2019. These limitations hamper our regression analysis as it does not factor in panel data to avoid errors that can be correlated with countries within the same period. Despite not using regressions on panel data, our report increases the empirical evidence that an increase in the level of CO2 emission reduces agricultural production in the short term.

Hypothesis Question

How does a change in the level of CO2 emissions affect the crop production index of a country?

Data

Our dataset was sourced from the *World Development Indicators (WDI)* which is the primary collection of databases for the *World Bank*. The *WDI* presents the most current and accurate economic development data with the inclusion of global measurements. In our dataset, we selected over 60 countries that are within North America, Latin America/Caribbean, South America, Europe, and Central Asia regions. Then, we included the environmental variables such as carbon dioxide emissions by sector and the percentage of land used for agriculture. In addition, our team wanted to consider economic variables such as the food production index and the growth of the Gross Domestic Product. In total, our dataset contains 21 unique variables, most of which are not utilized due to a lack of significance in the effect of the level of CO2 emissions on crop index.

Dataset: World Development Indicator | agrico2.csv

Descriptive Statistics

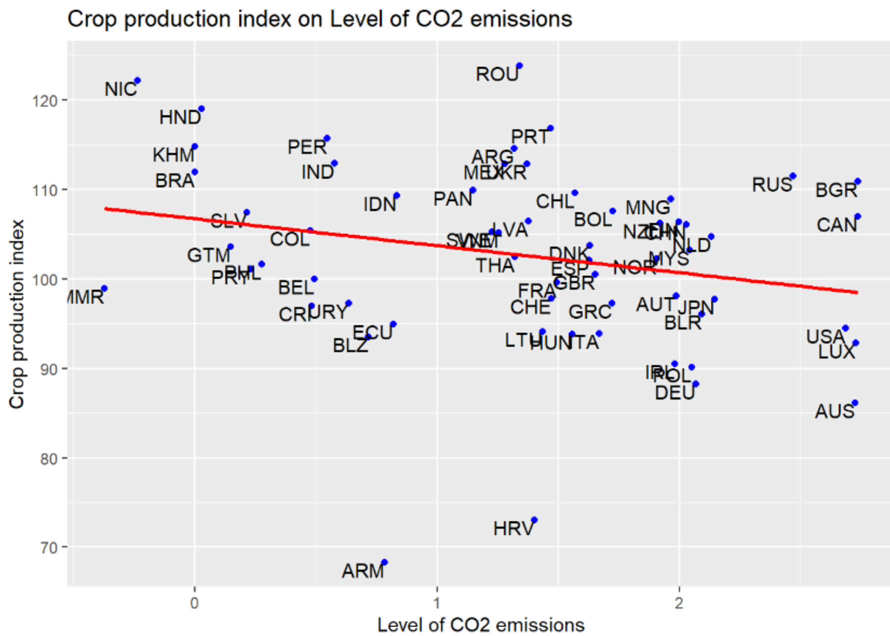
Descriptive Statistics

Statistic	N	Mean	Median	St. Dev.	Min	Max
co2_emission	60	5.18	4.27	3.94	0.69	15.43
land_area	60	40.43	42.36	17.94	2.70	80.72
food_index	60	104.04	102.03	8.69	81.38	136.05
lv_stress	60	15.41	7.44	16.10	0.90	66.49

There seems to be a negative relationship between the level of CO2 emissions and the crop production index of all 60 countries. There are two European country outliers - Croatia (HRV) and Armenia (ARM) - that have much smaller crop production index compared to the rest of the countries, but it does not seem to affect the negative linear relationship between the level of CO2 emission and crop production index.

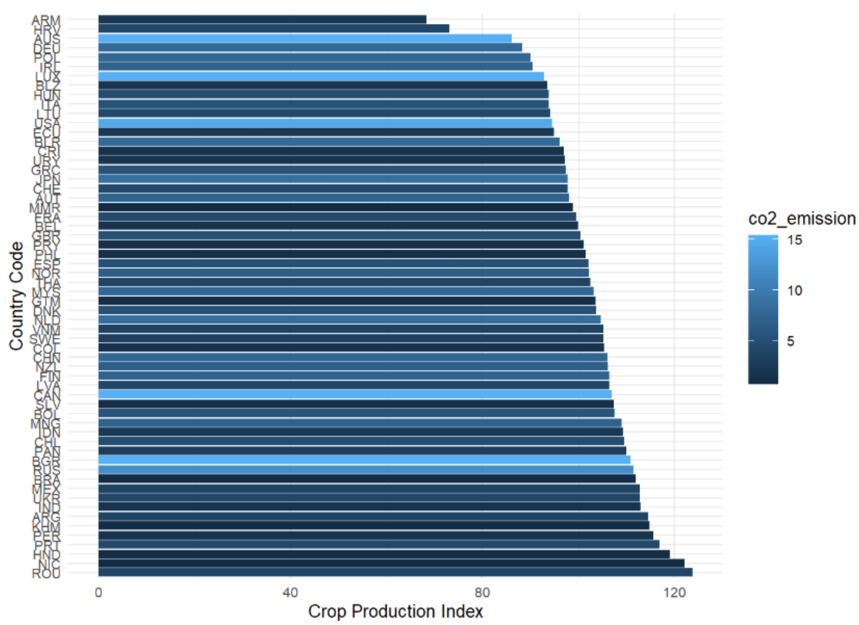
Data Visualizations

Crop production index on Level of CO2 Emissions



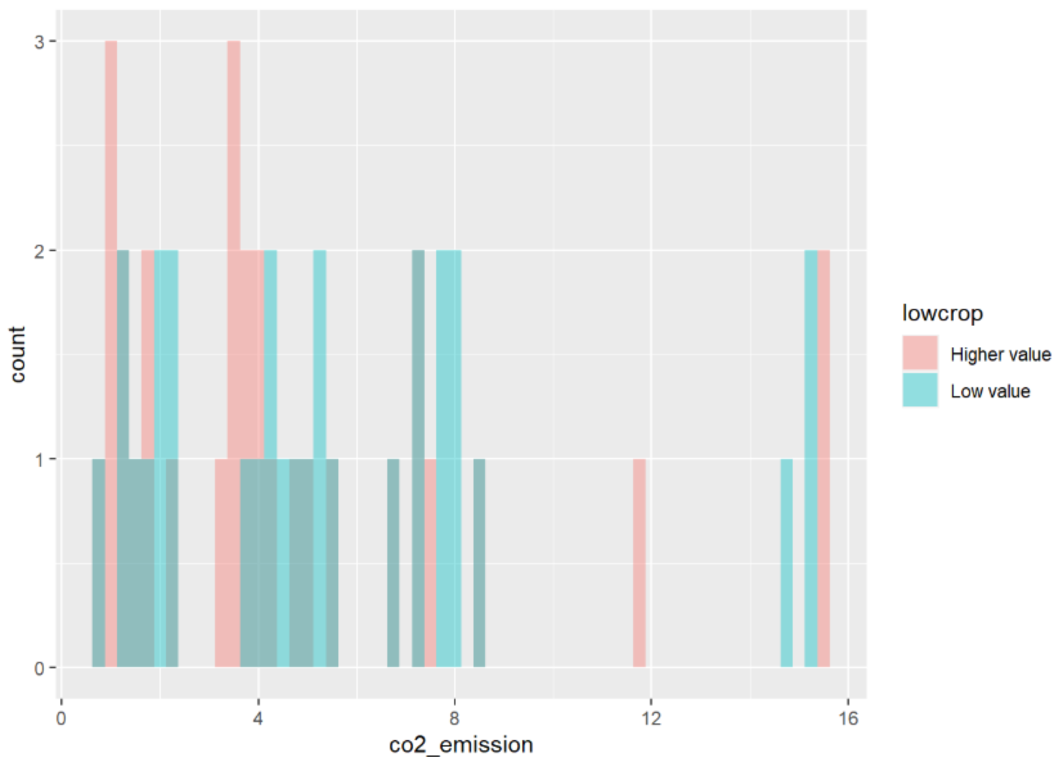
There seems to be a negative relationship between the level of CO2 emissions and the crop production index of all 60 countries. There are European country outliers such as Croatia (HRV) and Armenia (ARM) that have much smaller crop production index compared to the rest of the countries, but other than that it resembles a linear relationship with the average level of CO2 emission located where crop production index is 100.

Country Crop Production Index relative to Level of CO2 Emissions



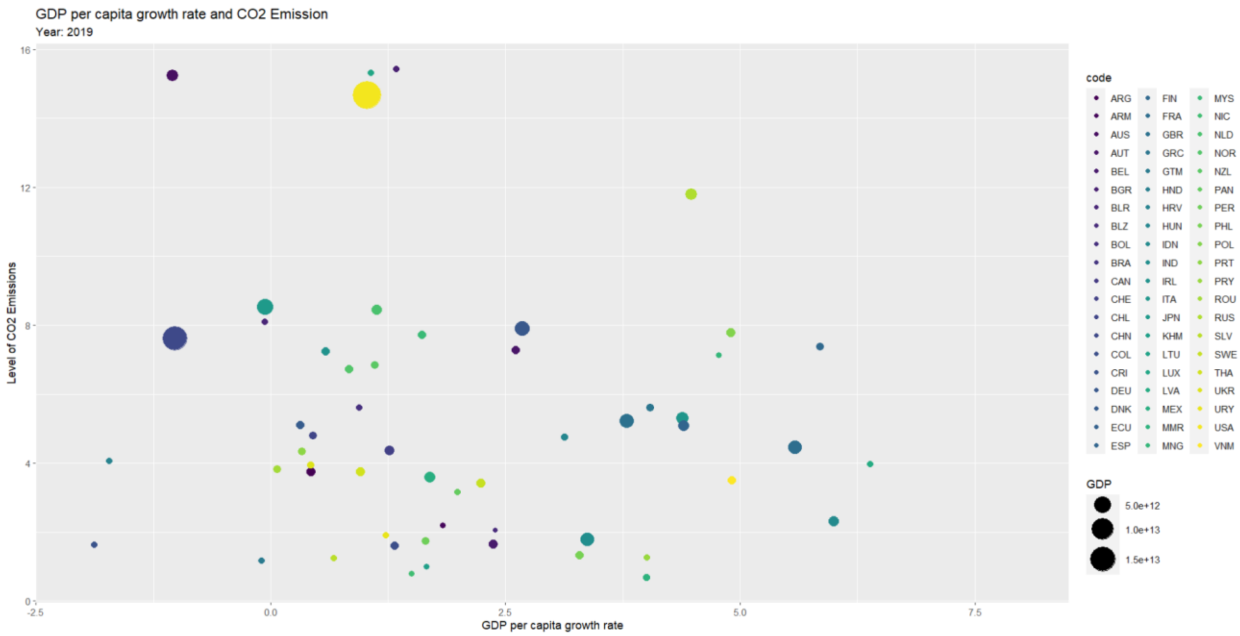
The countries with the higher crop production index were smaller countries Romania, Nicaragua, and Honduras which also had some of the lowest levels of CO2 emissions. On the other hand, the countries with lower crop production index were larger countries Australia, Germany, and Poland. These countries also had some of the highest levels of CO2 emissions. These trends suggest that a larger country will have a lower crop production index and higher levels of CO2 emissions. Intensive commercial agriculture such as the production of bananas, pineapples, and other tropical fruits can explain the high crop production index for countries like Honduras, Nicaragua. The same applies to countries like Romania where their agriculture is geared toward commercial crops like soybean.

Countries with Lower versus Higher Number of Crop Production Index on CO2 Emission



The countries with high or low crop production indexes have distributions that are negatively skewed since the median is greater than the mean level of CO2 emissions. The higher crop production indexes are located near lower levels of CO2 emissions, while a few countries have high crop production indexes and high levels of CO2 emissions. These outliers represent countries that rely on machinery and factory production when processing their crops to be sold.

GDP per capita growth rate against Level of CO2 Emission



The relationship between GDP per capita growth rate and level of CO2 emissions is slightly negative relative to the size of the GDP. Specifically, the USA is an outlier in this relationship due to its higher level of CO2 emissions but lower GDP per capita growth rate. The size of the GDP shows that larger countries such as the USA, India, and China have the highest GDP. As a result, they all have higher levels of CO2 emission but the GDP per capita growth rate is relatively smaller than the rest of the countries.

Regression Analysis

Level of CO2 emissions on Crop Production Index

	Dependent variable:					
	crop_index					
	(1)	(2)	(3)	(4)	(5)	(6)
lco2	-3.015**	-1.991*	-1.912*	-2.009*	-2.144*	-4.461*
	(1.505)	(1.186)	(1.130)	(1.211)	(1.255)	(2.378)
food_index		0.866***	0.887***	0.893***	0.897***	0.898***
		(0.198)	(0.177)	(0.171)	(0.176)	(0.169)
land_area			-0.091*	-0.100*	-0.101*	-0.103*
			(0.051)	(0.057)	(0.057)	(0.057)
lstress				0.343	0.348	-1.122
				(0.749)	(0.756)	(1.085)
l_GDP					0.170	0.314
					(0.980)	(1.019)
I(lco2 * lstress)						1.168
						(0.888)
Constant	106.725***	15.246	16.606	15.810	13.932	15.255
	(2.592)	(21.390)	(19.994)	(19.119)	(23.405)	(22.694)
Observations	60	60	60	60	60	60
R2	0.056	0.585	0.610	0.611	0.612	0.622
Adjusted R2	0.040	0.571	0.589	0.583	0.576	0.579
Residual Std. Error	10.078	6.741	6.593	6.642	6.701	6.677
Note:				*p<0.1; **p<0.05; ***p<0.01		

Results

In regression 1, an increase in a country's level of CO2 emission by 1% reduces its crop production index by 0.0315. With an absolute t-statistic of 2.00, the level of CO2 emission is statistically significant at the 5% significance level.

In regression 2, holding the food production index constant, an increase in a country's level of CO2 emission by 1% reduces their crop production index by 0.0199. With an absolute t-statistic of 1.68, the level of CO2 emission is statistically significant at the 10% significance level. Since the estimate of the co2_emission variable increases from regression 1 to 2, we can conclude that regression 1 suffers from downward omitted variable bias.

In regression 3, the control variable agricultural land has a standardized beta coefficient of -0.091. Holding the co2_emission and food production index constant, an increase in agricultural land by 1% decreases the crop production index by 0.091. This control variable also changes the effect of a country's levels of CO2 emission on the crop production index. Holding everything else constant, an increase in a country's level of CO2 emission by 1% reduces the crop production index by 0.0191. With an adjusted R2 of 0.589, we can say that this model explains 58.9% of the variation in the crop production index, which is relatively high.

According to both regression 2 and 3, the level of CO2 emission in regression 3 has a slightly smaller negative effect on the crop production index. The addition of agricultural land slightly increases the level of CO2 emission beta coefficient from -1.99 to -1.91. This is a sign of downward omitted variable bias in regression 2.

In regression 4, the control variable logarithm of level of freshwater stress has a standardized beta coefficient of 0.34. Holding everything else constant, an increase in the level of freshwater stress by 1% increases the crop production index by 0.34. In this regression, the level of freshwater stress is not statistically at the 10% level. This explains the adjusted R2 of 0.583 meaning the model explains 58.3% of the variation in the crop production index, which is a slight drop from the previous model. Holding everything else constant, an increase in a country's level of CO2 emission by 1% reduces the crop production index by 0.02.

According to both regressions 3 and 4, the level of CO2 emission has a larger negative effort on the crop production index. The addition of level in freshwater stress increases the level of CO2 emission beta coefficient from -1.91 to -2.00. This is a sign of downward omitted variable bias in regression 3.

In regression 5, an increase in a country's level of CO2 emission by 1% reduces their crop production index by 0.0214, holding everything else constant. If a country has a higher GDP per capita, the level of CO2 emission reduces the crop production index by more. In this regression, GDP per capita is also not statistically at the 10% level, despite the variable of interest is statistically significant at the same level. This explains the adjusted R2 of 0.576 meaning the model explains 57.6% of the variation in the crop production index, which continues the drop from the previous model. Holding everything else constant, an increase in a country's level of CO2 emission by 1% reduces the crop production index by -0.0214.

In regression 6, the addition of interaction term between the level of freshwater stress and level of CO2 emissions drastically increases the negative impact of CO2 emissions on crop production index. Holding everything else constant, the effect of increasing the level of CO2 emission by 1% on the crop production index is -0.0446+0.0117*log(lv_stress)%.

A country with a higher level of freshwater stress (or the proportion of total renewable freshwater resources) reduces the negative effect of CO2 emission on the crop production index. While the interaction term between the level of freshwater stress and level of CO2 emissions is slightly statistically insignificant at the 10% level, the model explained 57.9% of the variation in crop production index, which increased from the previous model.

In regression 6, any change in crop production index by an increase in level of CO2 emissions by 1% is economically significant, especially with the minimum crop production index reducing by 0.0446. Despite this, when looking at the regression of level of freshwater stress on crop production index is economically insignificant due to the control variable being statistically insignificant at the 10% level. The difference in crop production index comes from the food production index and percentage of agricultural land.

F-Test on the Interaction Term

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Linear hypothesis test

Hypothesis:
lco2 - lstress = 0

Model 1: restricted model
Model 2: crop_index ~ lco2 + food_index + land_area + lstress + l_GDP + 
    I(lco2 * lstress)

Note: Coefficient covariance matrix supplied.

  Res.Df Df      F  Pr(>F)  
1     54                    
2     53  1 2.8295 0.09843 .
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

The F-test above suggests that the interaction term between the logarithm of CO2 emission and logarithm of freshwater stress is not statistically significant at a 10% significance level. This means we fail to reject the null and the coefficient of the logarithm of is equal to 0.

Predict for Crop Production Index

Using the best performing regression model (explaining 58.9% of the variation in the crop production index), a country with an increase in the level of CO2 emission around 2%, a food production index around 110, and the percentage of agricultural land slightly above 50% has a crop production index of 105.13. This crop production index was reduced from the 75th percentile to an index closer to the 50th percentile.

Probit- and Logit- Model

Probit- and Logit- Model of Medium-Sized Countries Crop Index

	Dependent variable:	
	medcrop	
	probit	logistic
	(1)	(2)
lco2	0.151	0.210
	(0.250)	(0.429)
food_index	-0.183***	-0.316***
	(0.044)	(0.084)
land_area	0.013	0.020
	(0.011)	(0.019)
Constant	18.252***	31.711***
	(4.552)	(8.635)
Observations	60	60
Log Likelihood	-25.597	-25.603
Akaike Inf. Crit.	59.194	59.207
Note:	*p<0.1; **p<0.05; ***p<0.01	

Marginal Error (Binary Model)

Marginal Effects

	Dependent variable:			
	medcrop			
	probit	binary model (marginal effect)	logistic	binary model (marginal effect)
	(1)	(2)	(3)	(4)
lco2	0.151	0.036	0.210	0.029
	(0.250)	(0.060)	(0.429)	(0.059)
food_index	-0.183***	-0.044***	-0.316***	-0.044***
	(0.044)	(0.011)	(0.084)	(0.012)
land_area	0.013	0.003	0.020	0.003
	(0.011)	(0.003)	(0.019)	(0.003)
Constant	18.252***	4.368***	31.711***	4.389***
	(4.552)	(1.087)	(8.635)	(1.186)
Observations	60	60	60	60
Log Likelihood	-25.597		-25.603	
Note:				*p<0.1; **p<0.05; ***p<0.01

In the probit model, the estimates suggest that everything else is the same, an increase in the level of CO2 emission by 1%, on average, will increase the probability of crop index for most of the countries, on average, 3.6% more than other countries. The effect is not statistically significant at more than a 10% significance level.

In the logit model, the estimates suggest that everything else is the same, an increase in the level of CO2 emission by 1%, on average, will increase the probability of a country within the vast majority of crop index by 2.9%. The effect is also not statistically significant at more than a 10% significance level.

Internal and External Validity

Despite the accuracy of the dataset, we need to keep in mind that we're only considering one year's worth of data. To generate a more accurate result, we must look at multiple years' worth of data to fully understand the impact of CO_2 emission on crop production over time. The other consideration we need to make is the volume of CO_2 emission data in developed countries versus developing countries. Typically developed countries tend to have more resources available to collect information pertaining to climate change, which makes it difficult to compare data from the US and Sub-Saharan Africa.

The impact of CO_2 emission on crop production may vary from one crop to another and one country to another. Some crops, such as wheat, corn, and other cereals are still being produced at record numbers despite the rise of CO_2 emissions. Places with more water for irrigation tend to remain non-impacted by CO_2 emissions. There has been some significant progress in genetically modified crops such as corn and wheat. Scientists are developing breeds that tend to be more resistant to drought. This is another variable to consider as well.

Over the years, farming communities in multiple parts of the world have not necessarily been behaving in the most responsible way when it comes to the use of resources such as irrigation water. California is one of the top producers of a variety of crops. However, some of the irrigation practices have been done in a very irresponsible manner. Furrow irrigation is still being used in many parts of Central California. This is a problem because we know that drip irrigation is the best way to conserve water. When considering the impact of CO_2 emission on the crop production index in California for example, we must think of the other variables such as the number of years farmers have used furrow irrigation instead of drip irrigation. This practice has decreased some crop production because fewer acres are being planted as a result of the lack of irrigation water.

Conclusion

In our regression analysis, an increase in the level of CO2 emission reduces the crop production index across all 60 countries. In regression 3, an increase in a country's level of CO2 emission by 1% reduces the crop production index by 0.0191, holding everything else constant. This best performing model explains 58.3% of the variation in the crop production index. The level of CO2 emission coefficient is statistically significant at the 10% level, and compared to the previous regression, this model reduces the upward omitted variable bias from regression 2.

Despite the performance of regression 3, the regressions that includes the control variables GDP per capita and level of freshwater stress has a higher negative effect of CO2 emissions on the crop production index. In regression 6, conducting an F-test on the interaction term of levels in freshwater stress and levels of CO2 emission shows that the interaction term was statistically insignificant at the 10% level. Our team still believes that changes in water supply and other irrigation control variables are economically significant, and the standardized beta coefficient of the level of CO2 emissions is statistically significant at the 10% level.

Ultimately, the negative effect of an increase in the level of CO2 emissions on crop production index supports other empirical evidence that suggests an increase in CO2 emissions reduces agricultural production. There are internal and external validity issues in this regression analysis – one year's worth of data, type of crops, and lack of statistically significant irrigation level variable. Despite these constraints, using this *WDI* cross-sectional agricultural dataset from 2019 gives a snapshot into the causal relationship between CO2 emissions and crop production.