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RESEARCH ARTICLE

EVALUATING THE BIDIRECTIONAL NEXUS BETWEEN CLIMATE CHANGE AND AGRICULTURE FROM A GLOBAL PERSPECTIVE

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ABSTRACT

Understanding the complex and dynamic nexus between climate change and agriculture has become crucial for our civilization. Thus, this paper aims at estimating the impact of those two concepts on one another using world data spanning from 1980 to 2018. On the one hand, the results show that the rising sea level inherent to climate change has a positive and significant impact on arable land and a negative and significant impact on livestock production. It is also found that rising sea level and global temperature constitute significant obstacles to crop production while a surge in greenhouse gas emissions significantly boosts it. On the other hand, the paper reveals that livestock production significantly increases greenhouse gas emissions while agricultural activities –crop production, livestock production and arable land– are found to have a negative and significant impact on global temperature. Finally, as agriculture is both a cause and a victim of climate change, some adaptation (shift in farming timing, intercropping) and mitigation (carbon sequestration, organic farming) strategies are recommended.

KEYWORDS

Global warming, agricultural emissions, greenhouse gas, adaptation, mitigation.

1. INTRODUCTION

The Earth is warmer than it should be due to a natural greenhouse effect taking place within its atmosphere (IPCC, 2019). Over time, the emission of greenhouse gases (GHG) –like carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4)– resulting from human activity have reinforced that greenhouse effect and triggered a global dynamic environmental threat known as climate change. The scientific literature abounds with robust evidence proving the existence of human-induced climate change (Backlund et al., 2019). In line with that literature, the Intergovernmental Panel on Climate Change (IPCC) estimates that on average, human activities have led to an increase in global temperature equivalent to 1.0°C above pre-industrial levels (IPCC, 2018). Furthermore, the panel argues that global warming could reach 1.5°C between 2030 and 2052 if GHG emissions keep on increasing at the current pace.

Climate change and agriculture are intrinsically connected because agricultural activities are contingent on climatic conditions (Ellis, 2015; Rosegrant et al., 2008). Thus, number of studies argue and/or prove that by altering temperature, precipitation, sea level and the volume of CO_2 in the atmosphere among others, climate change negatively affects agricultural activities (Keane et al., 2009; Nelson et al., 2009; Ignaciuk, 2015; OECD, 2016; IPCC, 2007). Changes in precipitation patterns for instance, have substantial repercussions on water resources, irrigation mechanisms, droughts, insect outbreaks and forest fires. Meanwhile, changes in atmospheric CO_2 affect the expansion of the flora through its impact on photosynthesis.

As highlighted in the literature, the effects of climate change on agriculture are not uniform across regions. Indeed, it is argued that upsurges in temperature slightly improve yields in mid to high latitudes and depress them in tropical and sub-tropical regions (Keane et al., 2009; Nelson et al., 2009; Ignaciuk, 2015). Thus, in sub-Saharan Africa, South-East Asia and Latin America, climate change increases the exposure and vulnerability of farmers to environmental disasters. For instance, it is projected that by 2080, Africa will host up to 75% of the world population exposed to food insecurity; while, a country like Guinea-Bissau is expected to lose almost a third (32.7%) of its agricultural production. Overall, it is estimated that the developing world needs some additional $7 billion worth of annual investment in rural infrastructure, research, and irrigation to offset the adverse effects of climate change on living conditions.

The nexus between climate change and agriculture becomes even more complex when taking into consideration the feedback effect of agriculture on climate change. Indeed, agriculture substantially contributes to climate change as enteric fermentation, forest conversion, rice cultivation, agrochemicals, livestock, and manure management are associated with GHG emissions, water, air and soil pollution (Bellarby et al., 2019; Paul et

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al., 2009; Wreford et al., 2010; INTRACEN, 2008). Rosegrant et al. reveal that agriculture accounted for 13% of global anthropogenic GHG emissions in 2000 while the OECD estimates that agriculture directly accounted for 17% of those emissions in 2015 (Keane et al., 2009; IPCC, 2007). Moreover, the OECD reveals that agriculture was also indirectly responsible for an additional 7 to 14% of global GHG emissions through land use changes (IPCC, 2007).

It should be noted that agriculture mainly releases N_2O and CH_4 in the atmosphere and that it accounts for more than half of the global emission of those non-CO_2 gases (Keane et al., 2009). The fact that the global warming potential of those two gases is significantly higher than that of CO_2 highlights the feedback effect of agriculture on climate change (IPCC, 2007). The ITC estimates the GHG emissions associated with some agricultural activities and reveals that the production of a kg of beef is associated with more than 10000 g of CO_2 equivalent emissions (Prais et al., 2019). It is followed by pork, poultry and egg production (2000 - 3000 g of CO_2 equivalents), milk production (1000 of CO_2 equivalents) and plant production (500 g of CO_2 equivalents).

Understanding the complex and dynamic nexus between climate change and agriculture has become crucial for our civilization because we ought to provide enough food for the growing population without degrading future environmental prospects. Thus, this paper aims at estimating the impact of those two concepts on one another using world data spanning from 1980 to 2018. The remainder of the paper is organized as follows: the methodology is presented in the next section; the main findings are reported and discussed in section 3 and section 4 respectively; and section 5 concludes the study with some recommendations.

2. Material and Methods

Global data related to climate change and agriculture are obtained from the National Aeronautics and Space Administration (NASA) and the World Bank. The data set covers each year from 1980 to 2018 and is composed of seven variables. As reported in table 1, arable land, crop production index, and livestock production index account for agricultural activities while total GHG emissions, land-ocean temperature index, global mean sea level, and sea ice extent account for climate change.

The data are analyzed using the estimation method developed by (Cochrane et al., 1949). This generalized least squares method is suitable for the estimation of parameters in a linear regression model in which errors are assumed to follow a first-order autoregressive process. The model is transformed using the consistent estimates proposed by a researcher and a search is performed for the value of the autoregressive parameter minimizing the sum of squared errors in the transformed model (White, 1980). Finally, robust standard errors are obtained using the approach developed by a researcher (Fischer et al., 2002).

Table 1: Description of variables

	Variables	Definition	Source
Agriculture	**Arable**	Arable land expressed as percentage of total land area	World Bank
	Crop	Crop production index (2004-06 = 100)	World Bank
	Livestock	Livestock production index (2004-06 = 100)	World Bank
Climate Change	**Ghg**	Total greenhouse gas emissions (in Kt of CO_2 equivalent)	World Bank
	Temperature	Land-ocean temperature index (1951-1980 base period)	NASA
	Sea	Global mean sea level variations	NASA
	Ice	Sea ice extent measures the area of ocean containing some sea ice (in millions of square Km)	NASA

Table 2 reports some descriptive statistics related to the data set while equation 1 and equation 2 represent the models used to estimate the impact of climate change on agriculture and the impact of agriculture on climate change respectively.

Table 2: Characteristics of the variables

Variables	Obs.	Mean	Std. Dev.	Min	Max
Arable	39	10.755	0.145	10.313	10.991
Crop	39	88.653	24.689	52.133	129.447
Livestock	39	88.563	23.131	53.845	127.035
Sea	39	-13.263	35.308	-69.509	51.890
Temperature	39	0.490	0.232	0.110	1.01
Ghg	39	4.30×10^7	7,280,291	3.24×10^7	5.48×10^7
Ice	39	6,107,627	1,141,376	3,404,543	7,862,303

$$\mathrm{Agriculture}_t = \alpha_t + \beta_{1t}\mathrm{Ghg}_t + \beta_{2t}\mathrm{Sea}_t + \beta_{3t}\mathrm{Temperature}_t + \beta_{4t}\mathrm{Ice}_t + \mathrm{Trend}_t + \varepsilon_t \quad (1)$$

Where Agriculture stands for arable land, crop production or livestock production; t and Trend stand for time and time trend respectively; α and β_i (i = 1, 2, 3, 4) are parameters to be estimated; and ε is the error term.

$$\mathrm{Climate}_t = \gamma_t + \delta_{1t}\mathrm{Arable}_t + \delta_{2t}Crop_t + \delta_{3t}Livestock_t + \mathrm{Trend}_t + \mu_t \quad (2)$$

Where Climate stands for total GHG emissions and land-ocean temperature index; γ and δ_j (j = 1, 2, 3) are parameters to be estimated; and μ is the error term.

3. Results

Table 3: Unit root tests

Variables	ADF		PP		NgP	
	I	TI	I	TI	I	TI
Level						
Ghg	-0.163	-3.780**	0.901	-3.164	1.173	-12.032
Sea	-3.959**	-5.249**	-6.849**	-13.502**	1.025	-0.001
Ice	-0.243	-5.007**	-1.913	-5.004**	-2.284	-18.480**
Temperature	-1.560	-1.696	-1.856	-5.005**	-0.690	-1.519
Land	-3.117**	-2.618	-3.117**	-2.618	-0.284	-3.026
Crop	-1.176	-2.993	-1.298	-3.128	-1.560	-13.069
Livestock	-1.802	-0.415	-1.827	-0.415	-4.260	1.941
First difference						
Ghg	-5.908**	-5.819**	-10.788**	-10.477**	-17.695**	-18.216**
Sea	-13.386**	-13.502**	-14.233**	-16.259**	0.402	0.036
Ice	-6.643**	-6.532**	-16.077**	-15.846**	-0.733	-1.979
Temperature	-6.636**	-6.833**	-11.294**	-10.956**	-27.723**	-0.135
Land	-5.190**	-5.558**	-5.316**	-5.653**	-17.567**	-17.906**
Crop	-7.847**	-7.869**	-8.200**	-8.365**	-18.175**	-17.343**
Livestock	-5.626**	-6.150**	-5.669**	-6.152**	-18.321**	-18.301**

Notes: ** denotes significance at the 5 percent level; I stands for intercept and TI stands for trend and intercept. ADF, PP and NgP stand for augmented Dickey-Fuller, Phillips-Perron and Ng-Perron unit root tests respectively.

To avoid spurious regressions or misleading statistical evidence describing the relationship between climate change and agriculture, the stationarity of the variables is tested using the augmented Dickey-Fuller, Phillips-Perron and Ng-Perron unit root tests. The outputs of those tests reported in table 3 reveal that the data are all stationary at first difference. Thus, equation 1 is estimated on the first difference of the data using Prais-Winsten regressions with Cochrane-Orcutt consistent estimates, minimization of the sum of squared errors in the transformed models and robust standard errors.

Table 4: Estimated impact of climate change on agriculture

Variables	Arable	Crop	Livestock
Ghg	0.001 (0.021)	0.131 (0.068)*	0.033 (0.074)
Sea	0.031 (0.010)***	-0.060 (0.020)***	-0.038 (0.017)**
Ice	-0.007 (0.005)	0.028 (0.021)	-0.005 (0.016)
Temperature	-0.001 (0.002)	-0.049 (0.008)***	-0.018 (0.012)
Trend	0.001 (0.001)	-0.001 (0.001)	-0.001 (0.000)***
Constant	-0.002 (0.002)	0.041 (0.009)***	0.039 (0.006)***
Observations	37	37	37
R-squared	0.381	0.517	0.419
F-statistic	4.05**	7.40**	5.51**

Notes: * denotes significance at the 10 percent level; ** denotes significance at the 5 percent level; *** denotes significance at the 1 percent level.

Table 4 reporting the estimated impact of climate change on agriculture reveals that GHG emissions and sea level both have a positive impact on arable land. The impact of GHG emissions is insignificant while that of sea level is significant. Furthermore, it is found that land-ocean temperature and sea ice extent both have a negative and insignificant impact on arable land.

Table 4 also shows that land-ocean temperature and sea level both have a negative and significant impact on crop production while GHG emissions and sea ice extent both have a positive impact on crop production. The impact of GHG emissions is found to be significant while that of sea ice extent is insignificant. Besides, it is found that sea level, land-ocean temperature and sea ice extent negatively affect livestock production; with the impact of sea level being significant. Finally, it is found that GHG emissions have a positive and insignificant impact on livestock production.

Table 5: Estimated impact of agriculture on climate change

Variables	GHG	Temperature
Crop	-0.028 (0.212)	-8.351 (1.834)***
Arable	0.495 (1.028)	-16.555 (7.546)**
Livestock	0.548 (0.239)**	-9.239 (3.534)**
Trend	-	-0.005 (0.003)
Constant	-	0.574 (0.154)***
Observations	37	37
R-squared	0.140	0.458
F-statistic	3.61**	10.09**

Notes: * denotes significance at the 10 percent level; ** denotes significance at the 5 percent level; *** denotes significance at the 1 percent level.

Table 5 reporting the estimated impact of agricultural activities on climate change shows that arable land and crop production do not significantly affect global GHG emissions. Contrarily, livestock production significantly contributes to global GHG emissions. The table also reveals that livestock production, arable land and crop production significantly reduce land-ocean temperature.

4. Discussions

The results reported in table 4 shows that sea level is the only climate change parameter having a significant impact on arable land. It is found that an increase in sea level induces an increase in arable land as higher sea level could irrigate more lands and make them more conducive for agriculture.

It is also found that GHG emissions are positively and significantly associated with crop production. Indeed, as argued by a researcher, the volume of CO_2 in the atmosphere which is a fundamental input for photosynthesis affects the growth of crop plants (Nelson et al., 2009). Thus, an increase in GHG emissions leading to more CO_2 in the atmosphere could well boost crop production. As for sea level and temperature, they are found to be associated with a fall in crop production. Indeed, the former could flood cultures while the latter could lead to droughts, forest fires, insects and diseases outbreaks (Nelson et al., 2009; Prais et al., 2019). Moreover, these findings are in line with several studies who argue that climate change will lead to a fall in the yield of cereal and horticultural crops respectively (Rashid et al., 2010; Backlund et al., 2008).

Focusing on livestock production, it is found that sea level is the only climate change parameter exhibiting a significant impact. Indeed, a rising sea level is associated with a fall in livestock production. This could be due to the fact that an increase in sea level could inundate farms and create an environment suitable for insect and disease outbreaks. Everything being equal, the proliferation of pathogens and parasites will negatively affect livestock production.

Paying attention to the impact of agriculture on climate change, table 5 reveals that livestock production significantly increases GHG emissions. This finding is in line with the abundant literature highlighting the substantial contribution of livestock to GHG emissions. The IPCC even reveals that livestock is responsible for about a third of global anthropogenic emissions of CH_4.

Table 5 also reveals that crop production and arable land have a negative and significant impact on temperature. This is in line with the well-known heat island effect according to which a built up area is often significantly warmer than its surrounding rural neighborhood because vegetation has a natural cooling effect (Dinesh, 2019). Finally, it is found that livestock production also has a negative and significant impact on temperature. This counter-intuitive finding might be due to the fact that livestock production usually takes place in rural area and is often associated with crop production for animal feed.

In sum, agriculture is both suffering from the consequences of climate change and reinforcing climate change through GHG emissions. Thus, agriculture is both a part of the problem and a credible solution to climate change. This inherent duality of agriculture gives rise to two different policy responses to climate change, namely adaptation and mitigation. As defined by the IPCC, adaptation recommends to adjusting ecological, social and economic systems in order to take advantage of the positive effects of climate change on agricultural activities and/or minimize the negative ones. As for mitigation, it consists to reduce the impact of climate change by cutting down GHG emissions and/or by boosting carbon sinks. These two policy approaches are those upon which are built the recommendations formulated in this paper.

5. Conclusion

On the adaptation front, a wide range of on-farm measures could be implemented in agriculture. For instance, farmers should choose crops and varieties that are suitable to the shifts in growing season, temperature, and precipitation induced by climate change. They should also adjust the timing of planting, treatment, and sowing operations to suit current weather conditions. Finally, farmers should preserve landscapes providing shelter to animal, improve the ventilation system of livestock shelters and invest in efficient irrigation, water storage and recycling systems.

Dinesh describes some successful on-farm adaptation strategies implemented around the world. Among others, he talks about coffee-banana inter-cropping implemented in Rwanda, Burundi and Uganda (UN, 2015). He reveals that this measure is effective in adapting to the rising temperatures which negatively affect coffee production in those countries. Indeed, compared to mono-cropping, it is found that the combination of those two crops can lead to a 50% increase in income.

In spite of the appealing nature of on-farm adaptation strategies, their effectiveness is often limited by market failures, access to information, access to credit, and harmful subsidies. Thus, public authorities are invited to incentivize those strategies through the adoption of suitable policies.

On the mitigation front, the Paris Agreement reached in 2015 under the United Nations Framework Convention on Climate Change dealing with GHG emissions, mitigation, adaptation, and finance acknowledges the active role of agriculture in the reduction of GHG emissions. Indeed, agriculture can help mitigate climate change through carbon sequestration and on-farm GHG emissions reduction.

Carbon sequestration is a mitigation strategy that consists to boost and protect carbon sinks. Non-tillage agriculture is one method through which carbon sequestration can be implemented. As revealed by, in the absence of tillage, soil carbon is not released and agriculture helps reduce GHG emissions. Technically, in non-tillage agriculture, seeds are often sowed into the residues of the previous crops and weeds are eliminated with herbicides. This mitigation strategy has been implemented on a large scale (17 million hectares) in Argentina but its environmental outcomes are dubious.

As for on-farm GHG emissions reduction, organic farming appears to be the most sustainable strategy. Indeed, as argued by previous researcher, the global warming ability of organic farming is substantially below that of conventional farming. The ITC argues that organic farming is a symbiosis of low external input, recycling mechanisms, and high output boosting soil fertility and making soils less vulnerable to erosion. Thus, under weather conditions characterized by high water stress, organic plants outperform conventional ones for each crop area as well as for each harvested crop unit. Furthermore, it is found that by being self-sufficient in nitrogen, organic farming releases less N_2O in the atmosphere; and by focusing on animal longevity, organic cattle husbandry is associated with less CH_4 emissions. However, as in the case of adaptation strategies, mitigation strategies and especially organic farming have to be incentivized by public authorities.

Given that the main limitation of this paper is related to the nature of the data used (aggregate world data), future studies should preferably be done with data collected at the level of an ecosystem, a climatic zone or a country. The studies should also take into consideration some control variables related to that specific ecosystem, climatic zone or country. Finally, future researches on the nexus between climate change and agriculture in developing countries should pay a particular attention to the quality of governance.

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