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Assessing the Effects of Climate Change on Crop Production, Food Production and Crop Yield

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Abstract

This study examines the impact of climate change on crop production, food production, livestock production and crops yields in India. Changes in biodiversity, biosphere and natural resources have major impact on agriculture sector. The study undertook, country level analysis by employing secondary data from 1961 up to 2013. Vector autoregression based estimates reveal negative impact of rise in temperature on overall agriculture sector of India. However, the most negative impact is found on cereal yield which declines by 2.4 percent for 1 standard deviation increase in temperature. Increase in atmospheric Carbon Dioxide (CO_2) content is found to have positive and significant impact on crop yield, food production and crop production. Crop production increases by 1.7 percent over the first year whereas increase in production remains significant over 5 years horizon. Food production also rises significantly over four years horizon. As a major policy implication numerous initiatives relating to irrigation such as subsidies for micro irrigation, artificial recharge to ground water and water shed projects from the side of central government are proposed to lessen the impact of climate change.

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Introduction

Climate change is any significant long term change in the statistical distribution of weather patterns. Elevated levels of temperature, variations in precipitation, and increased air's CO_2 content are certain examples of climate change. Over the long term, climate change could have an effect on agriculture sector productivity such as its impact on quality and quantity of crops, moisture, transpiration and photosynthesis rate. These changes in climate will also impact the frequency of droughts and floods, ground water level, water cycle and agriculture sector (Huntington, 2003; Allen *et al*., 2003; Jianchu *et al*., 2007; Gautam and Sharma, 2012).

Technological advancement and technical expertise have transformed the global agriculture sector and have laid down the way for increased agricultural productivity. Over the years, this increase in food production was a welcomed societal benefit. Along with this technological advancement another ancillary support to the agriculture sector that would confer enormous advantages to the population of the globe in coming centuries is CO_2.

The atmospheric CO_2 content has increased from mean concentration of about 280 parts per million (ppm) at the inception of the Industrial Revolution in 1800 to approximately 393 ppm nowadays. Ironically, the present augmented level of atmospheric CO_2 is sighted by many as major issue not a benefit, as CO_2 emissions are considered as the major reason of global warming. Global warming is also the result of waste management practices releasing strong global warming gases for instance nitrous oxide and methane.

Many studies have been conducted to study the negative impacts of rising CO_2 concentration however very few studies have tried to analyze the positive externalities of rising CO_2. The major among them is the increase in agricultural production mainly food production due to the positive impact of atmospheric CO_2 enrichment on plant growth see for instance Idso and Singer (2009); Idso and Idso (2011). Herbaceous plant biomass is increased by 25 to 55% for a 300-ppm increase in the atmospheric CO_2 content. Literature has reported various discrepancies with respect to computer based predictions of global warming using climate indices see for instance Lupo and Kininmonth (2013). The major parameter used in these models that increases the temperature for insignificant rising of CO_2 is the sensitivity of temperature to CO_2. Though most of the models use average sensitivity of 3.4 °c, various recent studies show the real sensitivity is more lower than that see for instance Annan and Hargreaves (2011), Lindzen and Choi (2011), Schmittner *et al*. (2011), Aldrin *et al*. (2012); Annan and Hargreaves (2012), Ring *et al*. (2012), Van Hateren (2012), Lewis (2013), Masters (2014) and Otto *et al*. (2013).

Kim *et al*. (2003) and Rogers *et al*. (2006) reported that atmospheric CO_2 enrichment increases plant growth in adverse conditions also. Kyei-Boahen *et al*. (2003) and Kim *et al*. (2006) found that water use efficiency increases under augmented levels of CO_2. According to World Resources Institute by the end of 2011, Asia contributed to more than half of the world CO_2 emission. In 2011, the top ten emitters of CO_2 accounts for 78 percent of global CO_2 emissions. India ranked as 4th largest contributor to global CO_2 emissions, Fig. 1. India is considered as major CO_2 emitter excluding land-use change and forestry (LUCF) at global level, Fig. 2.

Climate change is likely to impact agricultural productivity and food production and according to recent estimates it is likely that by 2080 that agricultural output in advanced countries could decrease by 6 percent (Masters *et al*. 2010) where as in developing countries it may decline by 20 percent. In India agricultural production may decline by 24 percent by 2080 due to climate change (Zhai *et al*. 2009). These changes in temperature, CO_2 and precipitation are expected to significantly affect agricultural growth in India (Kumar and Gautam, 2014), Fig. 3. According to Metz *et al*. (2007) millions of people will be facing the risk of chronic hunger due to this rising level of temperature.

Various studies have provided evidence of negative impact of climate change on agriculture sector (Kumar and Parikh, 2002, Kumar *et al.* 2011) but very few studies have simultaneously studied the impact of climate change such as rise in temperature and increase in atmospheric CO_2 on agriculture sector and food productivity.

Most of the previous studies analyzed the impact of climate change on agricultural productivity by studying the impact on single crop or two or more crops limited to only one region or state. Whereas the analysis of overall impact of climate change on agriculture sector at country level is an important issue. This study fills this gap in literature by studying the impact of climate change .i.e. rise in temperature and CO_2 emissions on crop production, food production and livestock production. The main objectives of this study are (1) To analyze the impact of increase in temperature on crop production, food production, livestock production and crop yield in India.(2) To investigate the impact of increase in atmospheric CO_2 on crop production, food production, livestock production and crop yield in India.

Materials and methods

Data and descriptive statistics

Table 1, presents a detailed description of variables used in our analysis. Data is taken from Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, U.S.A., World Bank, World Resources Institute website and India Meteorological Department (IMD). Initially, the data was gathered from the period 1961 to 2015 but due to unavailability of data for certain variables for the year 2014 and 2015, the analysis was carried out from the year 1961 to 2013 to keep the results reliable and consistent.

Model

Assume that climate change is characterized as following a stochastic process by two shocks modeled separately in reduced form vector autoregression (VAR). The first one is temperature shock and second is CO_2 emissions shock, both of these shocks impact all the variables contemporaneously. Letting A denotes climate change variables i.e. temperature and CO_2 emissions separately, the stochastic process can be expressed as moving average such as:

$$\ln \mathrm{A}_t = [\mathrm{B}_{11}(L)\mathrm{B}_{12}(L)][\varepsilon_{1,t}] \quad (1)$$

here $\varepsilon_{1,t}$ is conventional temperature and CO_2 emissions shock. The following process satisfy this assumption

$$\ln \mathrm{A}_t = \ln \mathrm{A}_{t-1} + \varepsilon_{1,t} \quad (2)$$

Identifying temperature shock and CO_2 emissions shock

Consider y_t a $k \times 1$ vector of observables of length T. It can be represented in reduced form moving average representation in levels or in a stationary vector error correction model or as an unrestricted VAR estimated in levels.

$$y_t = \mathrm{B}(L)u_t \quad (3)$$

We assume a linear relationship between innovations and structural shocks.

$$u_t = \mathrm{A}_0 \varepsilon_t \quad (4)$$

This entails following moving average representation.

$$y_t = C(L)\varepsilon_t$$

Here $C(L) = B(L)\mathrm{A}_0$ and $\varepsilon_t = \mathrm{A}_0^{-1} u_t$.

Results and discussion

Table 2, shows a detailed descriptive statistics of all the variables used in our data set. Over the whole sample period all the variables exhibit positive series in mean. The standard deviation remained larger for total CO_2 emissions followed by livestock production in India.

Table 1. Detailed description of data.

S. No.	Variable	Period	Transformation
1	Crop production index (2004-2006 = 100)	1961-2013	Log Levels
2	Food production index (2004-2006 = 100)	1961-2013	Log Levels
3	Livestock production index (2004-2006 = 100)	1961-2013	Log Levels
4	Cereal yield (kg per hectare)	1961-2013	Log Levels
5	Average annual temperature	1961-2013	Log Levels
6	Total CO_2 emissions ($MtCO_2e$)	1961-2013	Log Levels

Table 2. Summary of statistics of all variables transformed in log levels.

	Annual Temperature in India	Total CO_2 emission	Crop Production in India	Food Production in India	Live stock Production In India	Cereal Yield in India
Mean	3.19513	6.16645	4.17565	4.13062	3.97111	7.4057
Median	3.19499	6.16037	4.11643	4.09751	3.99728	7.37289
Maximum	3.23041	7.6378	4.95491	4.93275	4.90698	8.01318
Minimum	3.16716	4.86978	3.53281	3.456	3.20112	6.75045
Std. Dev.	0.01425	0.83243	0.42535	0.45591	0.55572	0.3761
Skewness	0.4451	0.12075	0.08257	0.04257	0.07121	-0.1374
Kurtosis	2.60203	1.70444	1.80043	1.73872	1.67525	1.67019
Jarque-Bera	2.09978	3.83544	3.23794	3.5291	3.92031	4.07204
Probability	0.34998	0.14694	0.1981	0.17126	0.14084	0.13055
Sum	169.342	326.822	221.309	218.923	210.469	392.502
Sum Sq. Dev.	0.01055	36.0328	9.40788	10.8086	16.0591	7.35554
Observations	53	53	53	53	53	53

Overall we find negative impact of rise in temperature on agriculture sector productivity. Our this finding supports the findings of Goswami *et al.* (2005), they find out rise in temperature as the major cause of wheat yield reduction in Ludhiana Province of India.

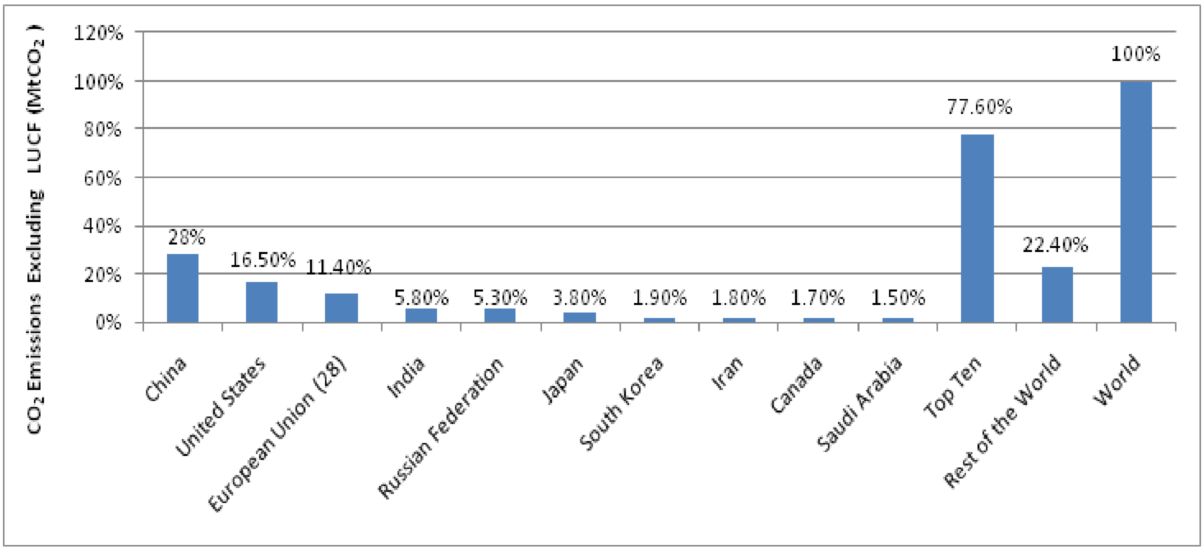

Fig. 1. Top ten CO_2 emitters in 2011 (Source: World resource Institute).

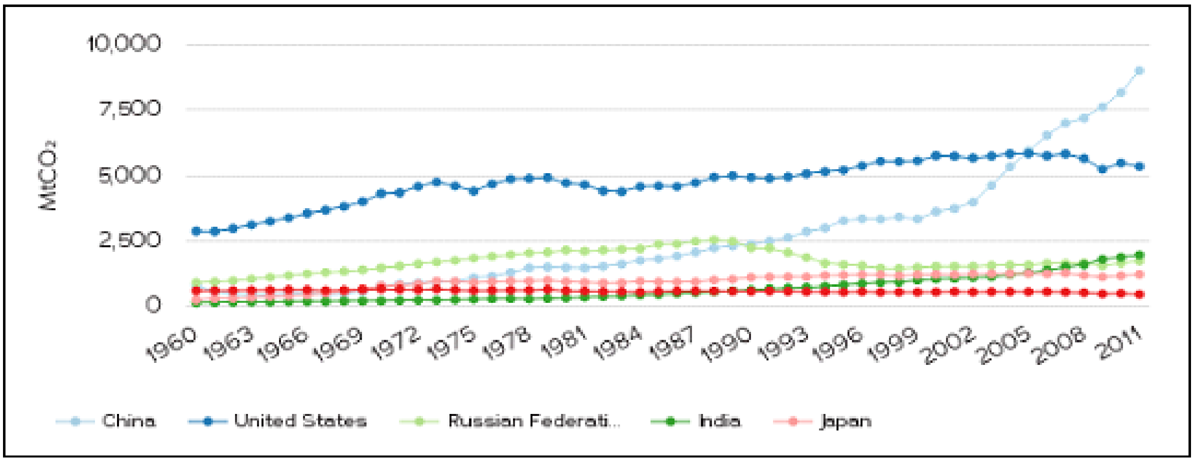

Fig. 2. Total CO_2 emissions excluding land-use change and forestry.

The most negative impact of rise in temperature is on cereal yield where 1°C rise in temperature decreases cereal yield by - 2.4 percent, Fig. 4. Our this finding is in line with previous research findings, such as Ajay Kumar and Pritee Sharma (2013), reported that the yields of soybean, wheat, groundnut, mustard and potato may reduced by 3-7% due to 1°C rise in temperature.

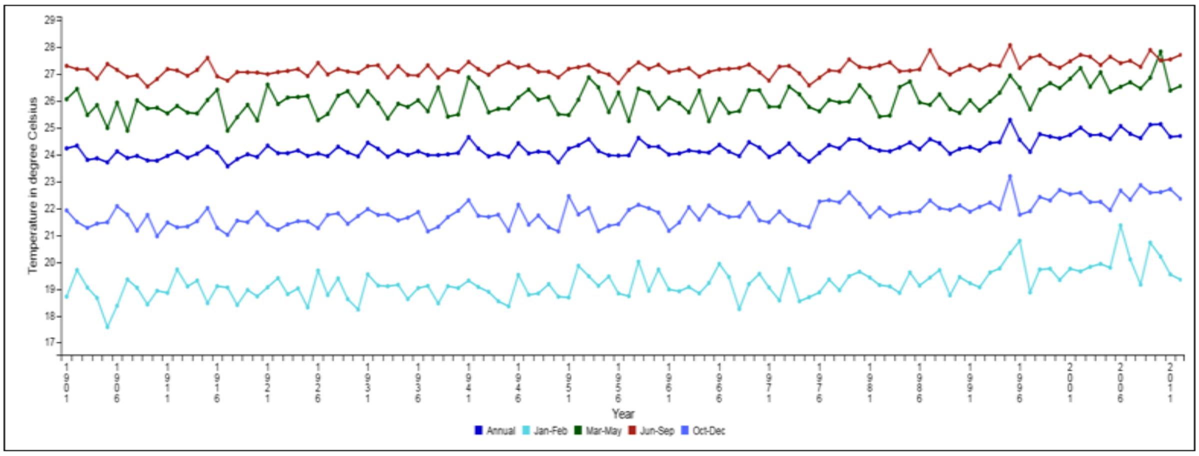

Fig. 3. Time series plot of Temperature of India over time.

Their study reports the latest research carried out at Indian Agricultural Research Institute documenting that there is the likelihood of losing 4 to 5 million tons of wheat for every 1°C rise in temperature. Hundal and others (2007) found that increase in minimum temperature from 1 to 3 degree °C above normal may decrease the wheat production by 3 to 10 percent in Punjab. Smith and Davey (2008) documented that in case of corn, yield increased up to 29^0C, for soybean, up to 30^0C and for cotton, up to 32^0C. Elevated temperatures than these levels are damaging. This is followed by agricultural production index which declines over short term during initial 1 year by 1.7 percent whereas as a response to 1 standard deviation increase in temperature, food production index declines by 1.4 percent though the impact is significant over medium term. Livestock production also declines significantly over the medium term.

We find positive impact of rise in CO2 on agricultural productivity. As a response to 1 standard deviation innovation to CO2 crop production increases significantly over five years horizon where the maximum impact reaches at 1.7 percent over the first year of this shock, Fig. 5.

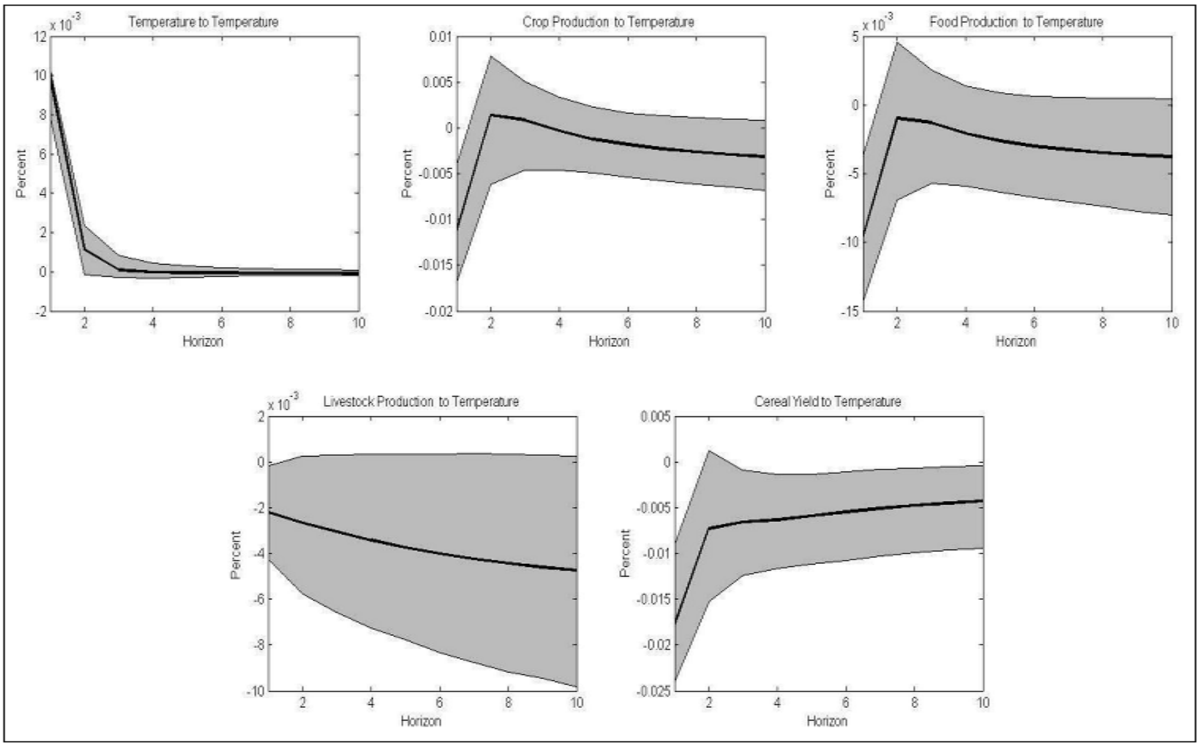

Fig. 4. Impulse responses to temperature innovations.

Note: These are impulse responses from a 5 variable VAR with Temperature, crop production, food production, livestock production and cereal yield. The system features 1 lag. Temperature is ordered first. The shaded areas are one standard error bootstrap confidence bands.

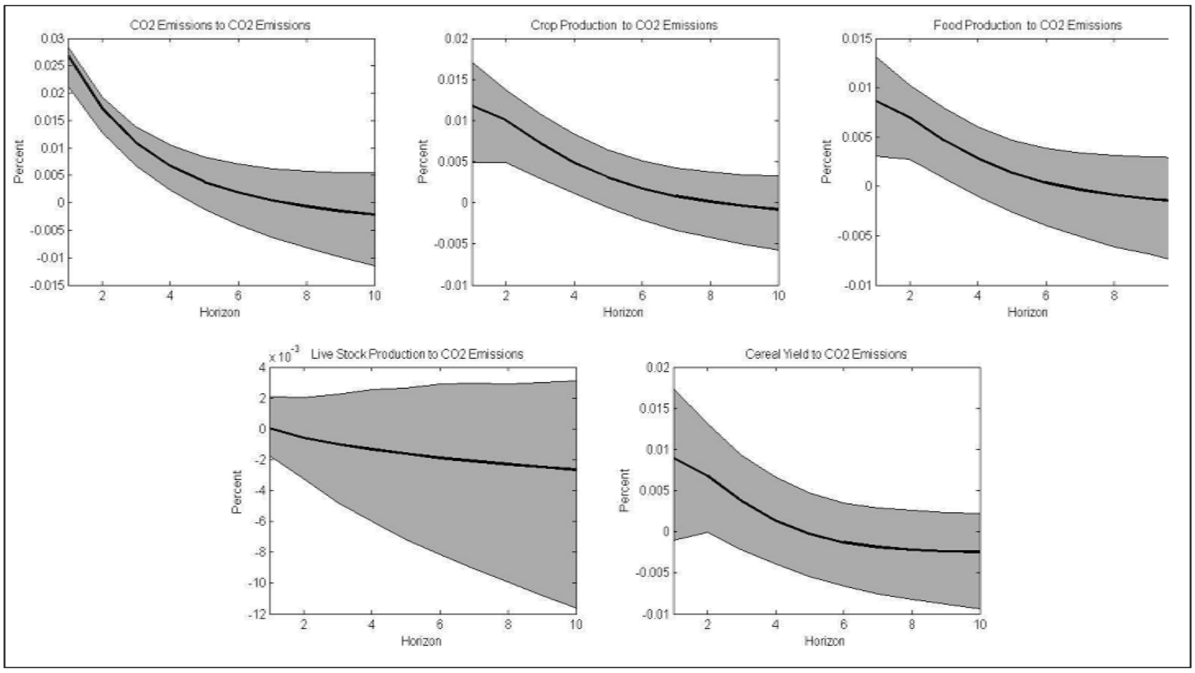

Fig. 5. Impulse responses to CO_2 emissions innovations.

Note: These are impulse responses from a 5 variable VAR with CO_2 emissions, crop production, food production, livestock production and cereal yield. The system features 1 lag. CO_2 emissions is ordered first. The shaded areas are one standard error bootstrap confidence bands.

Food production also rises significantly over four years where the upper bound reaches at 1.4 percent after the initial shock. No significant impact of CO_2 emission is found on live stock production. Overall the impact on cereal yield is positive for initial two years though not significant. Our this finding supports the findings of Mahato (2014), according to her rise in CO_2 to 550 ppm increases yields by 10-20% of oilseeds, rice, legumes and wheat.

Conclusion

India has a large and diverse agriculture sector. While the outlook for growth in food demand appears to be robust and sustainable due to increasing level of population the limited progress in crop yields is a key concern in India's agricultural outlook. We find that increase in temperature impacts crop production, food production and crop yields negatively.

In case of CO_2, increase in CO_2 atmospheric content have positive and significant impact on crop yield, food production and crop production. In the light of these results we can conclude that agricultural productivity in India is climate sensitive and increase in temperature and CO_2 affect differently. One of the major policy implication that can be made on the basis of these findings is that irrigation is a key factor that may alleviate the adverse impacts of temperature increase on agricultural crops and agricultural production could be raised by CO_2. Various initiatives such as subsidies for micro irrigation, watershed projects for rain fed regions, artificial recharge to ground water for example, digging wells in rocky areas are needed to be taken at national level by central government to mitigate the impact of rise in temperature.

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