Short and long-run impacts of climate change on agriculture: an empirical evidence from China

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Abstract

Purpose – The climate change effects on agricultural output in different regions of the world and have been debated in the literature of emerging economies. Recently, the agriculture sector has influenced globally through climate change and also hurts all sectors of economies. This study aims to examine and explore the impact of global climate change on agricultural output in China over the period of 1982-2014.

Design/methodology/approach – Different unit root tests including augmented Dickey–Fuller, Phillips–Perron and Kwiatkowski, Phillips, Schmidt and Shin are used to check the order of integration among the study variables. The autoregressive distributed lag (ARDL) bounds testing approach to cointegration and the Johansen cointegration test are applied to assess the association among the study variables with the evidence of long-run and short-run analysis.

Findings – Unit root test estimations confirm that all variables are stationary at the combination of I(0) and I(1). The results show that CO₂ emissions have a significant effect on agricultural output in both long-run and short-run analyses, while temperature and rainfall have a negative effect on agricultural output in the long-run. Among other determinants, the land area under cereal crops, fertilizer consumption, and energy consumption have a positive and significant association with agricultural output in both long-run and short-run analysis. The estimated coefficient of the error correction term is also highly significant.

Research limitations/implications – China’s population is multiplying, and in the coming decades, the country will face food safety and security challenges. Possible initiatives are needed to configure the Chinese Government to cope with the adverse effects of climate change on agriculture and ensure adequate food for the growing population. In concise, the analysis specifies that legislators and policy experts should spot that the climate change would transmute the total output factors, accordingly a county or regional specific and crop-specific total factor of production pattern adaptation is indorsed.

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Originality/value – The present empirical study is the first, to the best of the authors’ knowledge, to investigate the impact of global climate change on agricultural output in China by using ARDL bounds testing approach to cointegration and Johansen cointegration test.

Keywords China, Climate change, CO2 emissions, Agricultural output, Cointegration approach

Paper type Research paper

1. Introduction

Agriculture is considered most vulnerable to the global climate change, the security of food is another issue that needs great concern to all humankind, and the influence of climate change on agriculture attracted huge attention (Tao et al., 2006; Wang et al., 2009; Xiong et al., 2007). The agriculture has a dominant source of income for most rural communities and it adopts the adverse effects of climate change to protect the livelihoods of poor rural households and also having an essential role to ensure food security. Adoption can make the rural communities better and become accustomed to climate change and unpredictability, mitigate potential damage and help them to cope with the adverse consequences, thereby significantly reducing vulnerability to climate change (Cline, 2008). The agriculture sector’s reliance on climate change is quite important concern for economic development, as the majority of country’s population lives in rural areas is engaged with agricultural and non-agricultural related activities (WB, 2014). Farmers constantly find ways to adapt the variations in the weather and climatic conditions. However, environmental and global climate change has expanded the scale needed for farmers to develop and implement resilience strategies (Aiello, 2009; Collier, 2013; Hess, 2003). Adapting to the current agricultural system is one of the ways to avoid climate change risks and protect livelihoods and local food security. Though the type and scope of adaptation strategies vary from region to region, and socio-economic and agro-ecological environments are constantly changing (Abid et al., 2015). Therefore, the production of food is being affected by weather and climate change. It is necessary to study the influence of global climate change to meet the requirements of people and is estimated by 2100; the world population will reach about 10 billion (Boogaard et al., 2014; Keyzer et al., 2002). The agriculture sector is highly associated with the climatic changes, and also causes dangerous activity. Climate variability is the main source of risk for agriculture and food system. The increasing severity of extreme weather and frequent occurrence of widespread defects the agriculture. Farmers often face erratic rainfall, pests and natural disasters. For instance, farmers experience heavy rains, floods, pests, droughts and market prices (Godfray et al., 2010; Huang, 2014; Iqbal et al., 2016; Ullah et al., 2016). On the other side, in most parts of China, climate warming usually shortens the growth cycle of food crops, which leads to demur the average production (Huang et al., 2010; Wang et al., 2014). Because of the numerous seasonal droughts, there is a spatial and temporal gap among precipitation and irrigation, which ensuring the adequate challenges in irrigation and water supply (Zhang et al., 2006). In the future, the climate change in China may bring more uncertainty in the agricultural productivity. Several previous studies in the agronomic modeling literature have shown that yield and yield of main food crops will decline in the numerous future climates (Xiong, 2014). Furthermore, some studies have been conducted to highlight the association of CO2 emissions with agricultural crops, natural gas and renewable, economic growth and energy consumption (Chandio et al., 2019; Dong et al., 2018; Lin and Xu, 2018; Liu et al., 2016; Luo et al., 2017; Rauf et al., 2018a; Rauf et al., 2018b; Rauf et al., 2018c; Rauf et al., 2018d; Rehman et al., 2019; Wang et al., 2018). However, in this study, authors will investigate the CO2 emissions with rainfall, temperature and agricultural output by using augmented Dickey–
Fuller (ADF)[1] unit root test for the variable’s stationarity and the autoregressive distributed lag (ARDL)[2] bounds testing approach to check the association among the study variables. The time series data was taken from the world development indicators (WDI) to investigate an interrelationship between the variables. The rest of the study is organized as follows: Review of relevant literature is provided in the Section 2, data and methodology are presented in the Section 3, empirical findings of the study and its discussions are described in the Section 4, and Section 5 is conclusion, policy recommendations, and finally, study limitations on Section 6.

2. Existing literature
Indeed, China is considered the most populous country in the world, feeding one-fifth of the world’s population and using only 8 per cent of the world’s cultivated land. Ensuring food security for the repaid growing population is a long-term priority of the Chinese Government. In China, the demand of foods will continue to increase because of population growth and economic development, while the arable land and other productive resources will cause shrinkage because the agricultural productivity will subject to the climate change (Cline, 2007; Li et al., 2011; Yao et al., 2007). Furthermore, among the other factors such as socio-economic, cultural, institutional characteristics and political that can promote or hinder the adaptation process. The third part refers to the multiple scales of adaptation. Climate adaptive capacity and adaptation strategies vary from plot to farm level, to national and international levels and also differ in size. Therefore, the analysis of a system’s adaptive capacity and appropriate adaptation strategies should take into account the scale analysis (Vincent, 2007). Abid et al. (2015) reported that livelihoods of the rural households and the yield of major food and cash crops, including wheat, rice, cotton and sugarcane had heavily affected over the past two decades because of variations in the global climate. In developed economies, the concentration of CO₂ is mainly caused by several production and consumption activities. On the other hand, the change in the global climate are largely faced by developing countries, and most of the countries are located in tropical regions and mainly rely on the agricultural sector. Practically, all economic sectors are susceptible to climate change but agriculture is the most. Climate change will address crop productivity issues through changes in the rainfall patterns, sowing and harvest dates, rising temperatures, water supplies and transpiration (Rosegrant et al., 2008; Zenghelis, 2006). The security of food and water supply is greatly vulnerable to rapid change in the climate. In summer, most climate models expect to increase the rainfall. Almost, 75 per cent of the Himalayan glaciers are melted and will disappear by 2035. An upgrade in the strength may result in drought and flooding, respectively. Climate change will adversely affect the production of crops and may contribute to the food security issues (Kirby et al., 2016; Mendelsohn, 2014; Mirza, 1997; Misra, 2014; Pearce et al., 1996; Spash, 2007). In the previous few decades, climate change impact has been evident, mainly in low-income countries. However, it has been pointed out that rural households who have not adopted any strategies have shown that lack of information, access to land and lack of formal agricultural credit are the main factors hindering their adaptation to perceived climate change (Bryan et al., 2009; McCarthy et al., 2001; Smit and Skinner, 2002). Climate change has gained great concern because it can trigger socio-economic disasters. Therefore, assessing the economic vulnerability is the main step in addressing climate change (Field, 2014; Zhang et al., 2011). Furthermore, greenhouse gases also exacerbate climate change, and it is caused by the extra natural solar energy generated by an increase in the ocean heat. This increase in the ocean heat effect the sea level to rise and also cause the sea surface temperature to increase. The diversity of ocean currents and temperatures caused by climate change affects global climate patterns.
However, climate change effects on the oceans suggest that future generations, especially those of small island states, may no longer be able to grow there in a sustainable manner (CCI, 2018). The agronomists have made great efforts to develop adaptation strategies in response to the potential negative impacts of future climate change on agriculture. Wang et al. (2014) reported that in the southern regions of China, the introduction of improved new crop varieties with similar climatic conditions is mainly considered a practical approach to combating climate warming. The consequence of climate change to China’s agriculture and rural economy cannot be overemphasized. About 750 million people and 250 million rural households in China are directly or indirectly affianced in agricultural activities. The challenges of global climate change and how climate change impacts on the yield of crops are important political and economic issues (Lobell et al., 2007; Peng et al., 2004; Wei et al., 2009; Xiong, 2014). Recently, some authors have investigated the impact of climate change on cereal yield, agriculture and economic growth by using several econometric techniques. Dumrul and Kilicaslan (2017) used the ARDL bounds testing approach and found a positive and significant impact of precipitation on agriculture output while temperature has a negative impact on agricultural output in Turkey. Rahim and Puay (2017) examined the nexus between climate change and economic growth in Malaysia. The time frame for the study was 1983 to 2013. The study analyzed the variable using the unit root tests such as the Dickey–Fuller GLS (DF-GLS) and the ADF, the Johansen cointegration approach (JCA) and vector error correction model (ECM). The variables in the study were the gross domestic product (GDP), precipitation, temperature and arable land. Results of the analysis revealed that there is a long-run cointegration association between the study variables. There is a one-way causality nexus from temperature and arable land to GDP. An empirical study has been conducted in India by Alam (2013), which examined the response of agricultural output to climatic change and its long-run effect on economic growth by using time-series data between 1971 and 2011. An ARDL approach and ECM based procedures has been used to inspect the short and long-run nexus between CO₂ emissions, agricultural output and economic growth. Findings revealed that there is a negative and significant linkage between CO₂ emissions and economic growth while there is a positive and significant association between agricultural output and economic growth. As studied by Asuamah Yeboah et al. (2015) examined the impact of CO₂ emissions on cereal production in Ghana by using the ARDL approach. The time-series data for Ghana from the period of 1961-2010 is used, findings of the empirical analysis revealed that there is a significant unenthusiastic linkage between CO₂ emissions and cereal production while there are a positive and significant short and long-run relationships between cereal production and income. Furthermore, Rehman et al. (2019) study on CO₂ emissions and agricultural productivity in Pakistan by using an ARDL bounds testing approach results demonstrated that cropped area, energy usage, fertilizer offtake, GDP per capita and water availability showed a significant association with CO₂ emissions, while improved seed distribution and total food grains revealed a negative association with CO₂ emissions in Pakistan. To the best of our knowledge, no empirical study has been done in the context of China to investigate the effects of climate change on agricultural output. This study aims to examine the short-run and long-run interconnection between climate change factors and agricultural output in the context of China.

3. Methodology and data
The ARDL² approach was first introduced by the Charemza and Deadman (1992) and then further enhanced by Pesaran and Shin (1998) and Pesaran et al. (2001). The ARDL² approach has several advantages over the traditional cointegration methods such as Engle and
Granger cointegration approach (EGCA)\cite{1987}, JCA\cite{1988} and Johansen and Juselius cointegration approach (JJCA)\cite{1990}. It takes a small sample size and simultaneity biases in the association between the variables. The main problem in the traditional cointegration approaches was that it requires all the study variables to be non-stationary at I(0) but should be stationary at the same order. The modern cointegration approach like the ARDL overcomes regarding this issue, as it is appropriate regardless of the order of integration among the variables, whether at levels I(0) or at first difference I(1) or both of mixed order of integration. Furthermore, this modern approach also has another advantage in choosing the appropriate numbers of lags for the empirical model. These estimable features validate the usage of ARDL approach to obtain robust estimates. To investigate the association of climate change factors including CO\textsubscript{2} emissions, temperature and rainfall on agriculture in China throughout 1982-2014, the following model can be specified as:

\[
\text{AGR}_t = f(\text{CO}_2t, \text{TEMP}_t, \text{RF}_t, \text{CL}_t, \text{FC}_t, \text{EN}_t, \text{RP}_t)
\]  

In the equation (1), AGR\textsubscript{t} indicates the agriculture value added, CO\textsubscript{2}t represents the CO\textsubscript{2} emissions, TEMP\textsubscript{t} represents the average temperature, RF\textsubscript{t} represents the rainfall, CL\textsubscript{t} represents the land area under cereal crops, FC\textsubscript{t} denotes the fertilizers consumption, EN\textsubscript{t} indicates the energy consumption and RP\textsubscript{t} represents the rural population, respectively. Equation (1) can also be written as:

\[
\text{AGR}_t = \lambda_0 + \lambda_1 \text{CO}_2t + \lambda_2 \text{TEMP}_t + \lambda_3 \text{RF}_t + \lambda_4 \text{CL}_t + \lambda_5 \text{FC}_t + \lambda_6 \text{EN}_t + \lambda_7 \text{RP}_t + \mu_t
\]

To reduce the multicollinearity and volatility of the annual time series data, this study used all the variables in their nature logarithmic form. By applying natural logarithm to equation (2), a log-linear model is specified as follows:

\[
\ln\text{AGR}_t = \lambda_0 + \lambda_1 \ln\text{CO}_2t + \lambda_2 \ln\text{TEMP}_t + \lambda_3 \ln\text{RF}_t + \lambda_4 \ln\text{CL}_t + \lambda_5 \ln\text{FC}_t + \lambda_6 \ln\text{EN}_t + \lambda_7 \ln\text{RP}_t + \mu_t
\]

Mainly, the ARDL model contains two main steps for assessing a long-run association. Step 1 is to examine the presence of a long-run association between the study variables. Equation (4) represents the specification of ARDL model may follow as:

\[
\Delta \ln\text{AGR}_t = \alpha_0 + \sum_{i=1}^{p} \beta_{1i} \Delta \ln\text{AGR}_{t-k} + \sum_{i=0}^{p} \beta_{2i} \Delta \ln\text{CO}\textsubscript{2t-k} + \sum_{i=0}^{p} \beta_{3i} \Delta \ln\text{TEMP}_{t-k} + \sum_{i=0}^{p} \beta_{4i} \Delta \ln\text{RF}_{t-k} + \sum_{i=0}^{p} \beta_{5i} \Delta \ln\text{CL}_{t-k} + \sum_{i=0}^{p} \beta_{6i} \Delta \ln\text{FC}_{t-k} + \sum_{i=0}^{p} \beta_{7i} \Delta \ln\text{EN}_{t-k} + \sum_{i=0}^{p} \beta_{8i} \Delta \ln\text{RP}_{t-k} + \lambda_1 \ln\text{AGR}_{t-1} + \lambda_2 \ln\text{CO}_2_{t-1} + \lambda_3 \ln\text{TEMP}_{t-1} + \lambda_4 \ln\text{RF}_{t-1} + \lambda_5 \ln\text{CL}_{t-1} + \lambda_6 \ln\text{FC}_{t-1} + \lambda_7 \ln\text{EN}_{t-1} + \lambda_8 \ln\text{RP}_{t-1} + \varepsilon_t
\]
where $\alpha_0$ represents the intercept, $p$ denotes the lag order, $\Delta$ stands for the first difference operator and $\varepsilon_t$ denotes the error term. This study used $F$-test to check the long-run equilibrium link among LnAGR, LnCO2, LnTEMP, LnRF, LnCL, LnFC, LnEN and LnRP. The null hypothesis of no cointegration between LnAGR, LnCO2, LnTEMP, LnRF, LnCL, LnFC, LnEN and LnRP is $H_0$: $\delta_1 = \delta_2 = \delta_3 = \delta_4 = \delta_5 = \delta_6 = \delta_7 = \delta_8 = 0$ against the alternative hypothesis $H_1$: $\delta_1 \neq \delta_2 \neq \delta_3 \neq \delta_4 \neq \delta_5 \neq \delta_6 \neq \delta_7 \neq \delta_8 \neq 0$. According to Pesaran et al. (2001), the calculated $F$-test or Wald-test is matched with the values of lower bound and upper bound. If the computed $F$-test goes above the upper level of bound, the null hypothesis of no cointegration between LnAGR, LnCO2, LnTEMP, LnRF, LnCL, LnFC, LnEN and LnRP is rejected. If the computed $F$-test is less to the upper level of bound, it cannot reject the null hypothesis of no cointegration between LnAGR, LnCO2, LnTEMP, LnRF, LnCL, LnFC, LnEN and LnRP. However, If the computed $F$-test lies between the lower and upper level of the bands, the null hypothesis of no cointegration of LnAGR, LnCO2, LnTEMP, LnRF, LnCL, LnFC, LnEN and LnRP becomes inconclusive, which either can be tested through Johansen cointegration approach (1990) or by using the cumulative sum recursive residuals (CUSUM)[6] and cumulative of square of recursive residuals (CUSUMSQ)[7] to check the constancy of the cointegration (Brown et al., 1975). Step 2 is to assess the short-run association between CO2 emissions, temperature, rainfall, land area under cereal crop, fertilizers consumption, energy consumption, rural population and agriculture in China, the following ECM in ARDL formulation can be expressed as:

$$
\Delta \text{lnAGR}_t = \alpha_0 + \sum_{i=1}^{p} \beta_{1i} \Delta \text{lnAGR}_{t-k} + \sum_{i=0}^{p} \beta_{2i} \Delta \text{lnCO2}_{t-k} + \sum_{i=0}^{p} \beta_{3i} \Delta \text{lnTEMP}_{t-k} \\
+ \sum_{i=0}^{p} \beta_{4i} \Delta \text{lnRF}_{t-k} + \sum_{i=0}^{p} \beta_{5i} \Delta \text{lnCL}_{t-k} + \sum_{i=0}^{p} \beta_{6i} \Delta \text{lnFC}_{t-k} \\
+ \sum_{i=0}^{p} \beta_{7i} \Delta \text{lnEN}_{t-k} + \sum_{i=0}^{p} \beta_{8i} \Delta \text{lnRP}_{t-k} + \alpha \text{ECM}_{t-1} + \varepsilon_t
$$

(5)

This study used the annual time-series data of the global climate change factors and other control variables for China over the period 1982-2014. It was collected from the WDI[8]. The details of the study variables are presented in Table I. Figure 1 presents the time plots of the study variables used in the analysis.

4. Empirical results and discussions

The results of the descriptive statistics are shown in Table II, which indicates that all variables are normally distributed in the model with constant variance and zero covariance as showed by JB statistics. Similarly, the results of the correlation matrix are displayed in Table III, which shows that CO2 emissions, temperature, fertilizer consumption and energy consumption are positively associated with agriculture. A positive correlation established between temperature, rainfall and fertilizer consumption and CO2 emissions. A pre-condition is that to check the integration order among the study variables. The estimation of the unit root tests ensures that there are no study variables are static and integrated in the order of I(2) to prevent false outcomes. According to Ouattara (2004), if any of the study variables are stationary and integrated at I(2), then the computed ARDL bounds and $F$-statistics of the cointegration becomes meaningless. The critical bounds in the ARDL
approach are based on an assumption, i.e. all study variables should be stationary and integrated at I(0) or I(1) (Pesaran et al., 2001).

The study has applied different unit root tests such as the Kwiatkowski, Phillips, Schmidt and Shin (KPSS), the ADF and the Phillips–Perron (PP), to find out the integration status of the study variables. The estimated results of the unit root tests (e.g. KPSS, ADF and PP) including at the levels of variables, and then at the first differences are reported in Table IV. The results disclose that all variables are stationary at the combination of I(0) and I(1). It means that stationary properties may display a robust long-run association among the variables and supports to apply the ARDL approach.

This study examines the long-run relationship between climate change factors and other control variables by using the ARDL approach. The initial step is to apply for the selection of appropriate lag length. The results of several selection criteria are presented in Table V, and the order of optimal lag length is decided by adopting the Schwarz information criterion.

The outcomes of ARDL bounds tests shown in the Table VI illustrating that the computed F-tests are 4.828, 7.142, 11.339, 7.214, 3.782, 5.486 and 7.344 go above the upper critical bound at the 1 and 10 per cent levels of significance; when LnAGR, LnCO2, LnRF, LnCL, LnFC, LnEN and LnRP are used as dependent variables, while it means that there are seven cointegration vectors and we may reject the hypothesis of no cointegration. The outcomes of ARDL bounds test for cointegration confirms a long-run association between agriculture (LnAGR), CO2 emissions (LnCO2), average annual rainfall (LnRF), land under cereal crops (LnCL), fertilizers consumption (LnFC), energy consumption (LnEN) and rural population (LnRP) in China.

Furthermore, in this study, JJCA6 has used to check the robustness of long-run connection and test results are reported in Table VII. The estimates are suggesting a rejection of the null hypothesis of no cointegration in the model because the values of the trace statistic and maximum eigenvalue are higher than the critical values at the 1 and 5 per cent levels of significance. Hence, an alternative hypothesis will be accepted where long-run association presence is valid between the agricultural output and climate change factors, by counting with other control variables in China.

The results of the long-run analysis are shown in Table VIII (Panel A). The results of the long-run analysis are shown in Table VIII (Panel A). The estimated results display that CO2 emissions have a positive long-run impact on the agricultural output at 5 per cent significance level. A 1 per cent increase in CO2 emissions can increase the agricultural output by 0.061325 per cent. This result is similar to Janjua et al. (2014). Similarly, the estimated long-run coefficients of temperature and rainfall are showing negative linkage with the agricultural output. It shows that temperature and rainfall increase, agricultural output decrease as well. The findings of this study are in line with

| Variables | Explanation | Data source |
|-----------|-------------|-------------|
| AGR       | Agriculture value added (constant 2010 US$) | WDI         |
| CO2       | CO2 emissions (metric tons per capita) | WDI         |
| TEMP      | Average annual temperature (°C) | WDI         |
| RF        | Average annual rainfall (mm) | WDI         |
| CL        | Land area under cereal crops (hectares) | WDI         |
| FC        | Fertilizers consumption (kilograms per hectare of arable land) | WDI         |
| EN        | Energy consumption (kg of oil equivalent per capita) | WDI         |
| RP        | Rural population (% of total population) | WDI         |

Table I. Variables description
Ahmed and Schmitz (2011), Mahmood et al. (2012), Peng et al. (2004), Saseendran et al. (2000) and their studies concluded that temperature has a negative impact on the rice production. Similarly, Ali et al. (2017) reported that maximum temperature has an adverse impact on wheat production. Furthermore, the coefficient of land area under cereal crops to agricultural output is positive and significant. In the long-run analysis, the area under cereal crops will play a key role in boosting agricultural output. The outcomes reveal that a 1 per cent increase in the land area of cereal crops, agricultural output increased by 1.277362 per cent. The result of this study is in line with Ahmad (2011) and Chandio et al. (2016). Likewise, fertilizers can also play a significant role to cope with any adverse effect toward agricultural output in the long-run. Appropriate usage of fertilizers could improve soil nutrition and soil fertility. The effect of fertilizer consumption on agricultural output is also notable. For example, this study finds out that a 1 per cent increase in fertilizer consumption could raise agricultural output by 0.383519 per cent. This result is similar to Chandio et al. (2018)b; Rehman et al. (2017). In the
long-run estimation, energy consumption and rural population as a proxy of the labor force are indicating positive linkage with agricultural output. The energy consumption and rural population are statistically insignificant with the coefficients of 0.032058 and 0.084486. It implies that a 1 per cent increase in energy consumption and rural population will increase the agricultural output by 0.032058-0.084486 per cent, respectively.

The outcomes of the short-run estimation are also shown in Table VIII (Panel B). The estimated short-run results reveal that the explanatory variables (such as CO2 emissions, land under cereal production, fertilizer consumption and energy consumption) are statistically positive and significant that influenced the agricultural output. Among all the repressors, the coefficient of the impact of CO2 emissions in the long-run, as well as in the short-run analysis on agricultural value added is distinguished. The short-run coefficient of CO2 emissions is 0.010115, which means a 1 per cent increase in CO2 emissions will boost the output of about 0.010115 per cent. In the short-run estimation, this study does not find out any significant or negative effect of climate change factors, for instance, temperature and rainfall, on agricultural output. This result is similar to Janjua et al. (2014). In both long-run and short-run analyses, the results found that land area (area under cereal crops) is highly significant and showing to enhance the agricultural output in China. The land as a prime input displays its coefficient 0.366496; this implies a 1 per cent increase in area under cereal crops will boost the output almost by 0.366496 per cent. Similarly, in the long-run and short-run estimation, fertilizer consumption has a positive and significant influence on agricultural output. The short-run coefficient of energy consumption is 0.287169, concerning agricultural output is highly significant at 1 per cent, which is in the line of earlier findings (Abbas and Choudhury, 2013; Chandio et al., 2018a; Lili et al., 2011). These estimates suggest that a 1 per cent increase in energy consumption, agricultural output increases about by 0.287169 per cent. The error correction term $ECM_{t-1}$ denotes the speed of adjustment toward the long-run equilibrium from any short-run shock in the repressors. The elasticity estimates of $ECM_{t-1}$ is negative, and it is highly significant at the 1 per cent. The estimated results of diagnostic tests in the ARDL model, which are also described in Table VIII (Panel C) shows the model has passed several diagnostic tests (for example, $\chi^2$ SERIAL, $\chi^2$NORMAL, $\chi^2$ARCH, $\chi^2$White and $\chi^2$RESET), respectively. For the stability of
### Table III.
Correlation analysis

| Variables | LnAGR | LnCO2 | LnTEMP | LnRF |
|-----------|-------|-------|--------|------|
| LnAGR     | 1.00000 |     |        |      |
| LnCO2     | 0.61758*** [4.371985](0.0001) | 1.00000 |        |      |
| LnTEMP    | 0.653508*** [4.807084](0.0000) | 0.259548 [1.496384](0.1447) | 1.00000 |      |
| LnRF      | -0.100633 [0.563161](0.5774) | -0.386284** [-2.331724](0.0264) | 0.090667 [0.506898](0.6158) | 1.00000 |
| LnCL      | -0.181616 [-1.028296](0.3118) | -0.027397 [-0.152598](0.8797) | -0.400964** [-2.436949](0.0207) | 0.146113* [0.822347](0.4172) |
| LnFC      | 0.960188*** [19.13723](0.0000) | 0.511468*** [3.314006](0.0023) | 0.647124*** [4.726011](0.0000) | -0.065914 [-0.367793](0.7155) |
| LnEN      | 0.955049*** [17.93731](0.0000) | 0.615140*** [4.344086](0.0001) | 0.568548*** [3.847980](0.0006) | -0.139592 [-0.783756](0.4391) |
| LnRP      | -0.346658* [-2.053661](0.0485) | -0.363643** [-2.173476](0.0375) | 0.172236 [0.973519](0.3378) |      |

**Notes:** The values of t-statistics are displayed in [] and the values of probability are shown in (). ***, ** and * denote the significant levels at 1, 5 and 10%, respectively.

**Source:** The authors’ calculations

(continued)
### Table III

Impacts of climate change on agriculture

| Variables | LnCL    | LnFC     | LnEN | LnRP     |
|-----------|---------|----------|------|----------|
| LnAGR     | 1.000000|          |      |          |
| LnCO₂     | -0.179751 [-1.017382] (0.3168) |          |      |          |
| LnTEMP    | -0.094059 [-0.526028] (0.5025) | 0.884768*** [10.57053] (0.0000) |      |          |
| LnRF      | -0.044537 [-1.104525] (0.2779) | -0.446625*** [-2.779305] (0.0092) | -0.617711*** [-4.373407] (0.0001) | 1.000000 |
| LnCL      |          | 1.000000 |      |          |
| LnFC      |          |          | 0.884768*** [10.57053] (0.0000) |      |
| LnEN      |          |          |      | 1.000000 |
| LnRP      |          |          | -0.617711*** [-4.373407] (0.0001) | 1.000000 |
the ARDL model, this study used CUSUM and CUSUMSQ tests suggested by Brown et al. (1975). Figures 2 and 3 show the plot of both stability tests such as CUSUM and CUSUMSQ that fall inside the critical boundaries at 5 per cent level of significance. Hence, it means that the estimated parameters of the model are stable over the periods.

Table IV. Unit root tests results

| Variables      | Deterministic component | KPSS  | ADF   | PP    |
|----------------|-------------------------|-------|-------|-------|
| LnAGR          | Intercept               | 0.672293** | -1.570751 | -1.528224 |
| LnCO2          | Intercept               | 0.750558*** | -1.427441 | -4.372953*** |
| LnTEMP         | Intercept               | 0.587621**  | -2.647526*  | -2.468565 |
| LnRF           | Intercept               | 0.149017   | -8.242308*** | -8.242308*** |
| LnCL           | Intercept               | 0.475547**  | -2.594935   | -7.551133*** |
| LnFC           | Intercept               | 0.746897*** | -2.994883*** | -3.145724*** |
| LnEN           | Intercept               | 0.626046**  | 0.222899    | 1.046705  |
| LnRP           | Intercept               | 0.624067**  | -1.321100   | 3.147199  |
| LnAGR          | Trend and intercept     | 0.117321   | -2.103766   | -4.366799*** |
| LnCO2          | Trend and intercept     | 0.206014**  | -6.491043*** | -7.836178*** |
| LnTEMP         | Trend and intercept     | 0.115075   | -4.224725**  | -4.232195*** |
| LnRF           | Trend and intercept     | 0.088666   | -8.246404*** | -8.246404*** |
| LnCL           | Trend and intercept     | 0.190082**  | -2.249160   | -6.341822*** |
| LnFC           | Trend and intercept     | 0.168940***| -3.456561***| -3.008186  |
| LnEN           | Trend and intercept     | 0.181219***| -1.748692   | -1.300633  |
| LnRP           | Trend and intercept     | 0.195166**  | -2.372337   | -0.148433  |
| ΔLnAGR         | Intercept               | 0.229273   | -5.053966***| -5.200618*** |
| ΔLnCO2         | Intercept               | 0.235533   | -5.925019***| -5.535077*** |
| ΔLnTEMP        | Intercept               | 0.129931   | -6.448628***| -11.42700*** |
| ΔLnRF          | Intercept               | 0.513000***| -5.495487***| -6.166705*** |
| ΔLnCL          | Intercept               | 0.607482***| -4.385566***| -2.652982*** |
| ΔLnFC          | Intercept               | 0.500000***| -3.859721***| -7.445075*** |
| ΔLnEN          | Intercept               | 0.301828   | -2.786180*  | -2.787299* |
| ΔLnRP          | Intercept               | 0.416955*  | -0.355692   | -0.359966  |
| ΔLnAGR         | Trend and intercept     | 0.125228*  | -5.049756***| -5.091460*** |
| ΔLnCO2         | Trend and intercept     | 0.229399***| -5.800776***| -7.005120*** |
| ΔLnTEMP        | Trend and intercept     | 0.081803   | -6.363626***| -10.90011*** |
| ΔLnRF          | Trend and intercept     | 0.536700***| -5.311940***| -5.435658*** |
| ΔLnCL          | Trend and intercept     | 0.197214***| -2.619441   | -1.853489  |
| ΔLnFC          | Trend and intercept     | 0.326033***| -4.867117***| -11.212177*** |
| ΔLnEN          | Trend and intercept     | 0.083175   | -5.206732***| -10.01048*** |
| ΔLnRP          | Trend and intercept     | 0.130864*  | -3.342693*  | 6.964039*** |

Notes: KPSS, ADF and PP represent the Kwiatkowski, Phillips, Schmidt and Shin test; the augmented Dickey–Fuller test and the Phillips–Perron test. ***, ** and * denote the significant levels at 1, 5 and 10%, respectively.

Source: The authors’ calculations

Table V. VAR Lag length selection

| Lag | LogL   | LR    | FPE    | AIC    | SC     | HQ     |
|-----|--------|-------|--------|--------|--------|--------|
| 0   | 273.0696 | NA    | 5.17e−18 | −17.1012 | −16.7312 | −16.9806 |
| 1   | 584.6489 | 442.2415 | 6.86e−25 | −33.0741 | −29.7435* | −31.9884 |
| 2   | 693.1771 | 98.0254* | 9.98e−26* | −35.9469* | −29.6558 | −33.8691* |

Note: *Lag order selected by the criterion

Source: The authors’ calculations

the ARDL model, this study used CUSUM and CUSUMSQ tests suggested by Brown et al. (1975). Figures 2 and 3 show the plot of both stability tests such as CUSUM and CUSUMSQ that fall inside the critical boundaries at 5 per cent level of significance. Hence, it means that the estimated parameters of the model are stable over the periods.
### Table VI. Results of ARDL bounds testing to cointegration

| Variables | LnAGR | LnCO₂ | LnTEMP | LnRF | LnCL | LnFC | LnEN | LnRP |
|-----------|-------|-------|--------|------|------|------|------|------|
| F-statistics | 4.8289*** | 7.1426*** | 2.739003 | 11.3391*** | 7.2146*** | 3.7827* | 5.4862*** | 7.3442*** |
| Optimal lag structure | (1, 1, 0, 0, 1, 1, 1) | (1, 0, 1, 0, 0, 0, 0) | (1, 0, 0, 0, 0, 1, 0) |
| Critical values | 1% | 5% | 10% |
| Lower bounds I(0) | 2.96 | 2.32 | 2.03 |
| Upper bounds I(1) | 4.26 | 3.84 | 3.13 |
| Diagnostic tests | R² | 0.7189 | 0.7536 | 0.515594 | 0.8263 | 0.7840 | 0.7041 | 0.7721 | 0.9747 |
| Adj-R² | 0.5260 | 0.6572 | 0.326044 | 0.7584 | 0.6544 | 0.6367 | 0.6328 | 0.9615 |
| F² statistic | 3.7321** | 7.8186*** | 2.720096** | 12.1645*** | 6.0514*** | 3.9675*** | 6.4713*** | 8.7784*** |

**Notes:** *** and * denote the significant levels at 1 and 10%, respectively

**Source:** The authors’ calculations
5. Conclusion and policy implications

Climate change is projected to unfavorably distress to the agricultural output and countryside incomes in an economy. Therefore, sensible adaptation is looked-for to diminish the potential sufferers in agricultural productivity. The main aim of this empirical study was to assess the association of climate change impacts on the agricultural output in China over the period of 1982-2014. The study used several unit root tests including the KPSS, the ADF and the PP to check variables stationarity, while the ARDL approach was used to check the causality association between the study variables with long-run and short-run analysis. Unit root test estimations confirmed that all variables are stationary at the combination of I(0) and I(1). Furthermore, the results of the ARDL approach showed the long-run association between agricultural output, CO2 emissions, temperature, rainfall, land area under cereal crops, fertilizer consumption, energy consumption and the rural population at 1, 5 and 10 per cent levels of significance. The analysis results of the long-run and short-run coefficients show that CO2 emissions, land area under cereal crops, fertilizer consumption and energy consumption have a positive impact on the agricultural value added. On the other hand, temperature and rainfall have a negative effect on agricultural value added in the long-run but have a positive effect in the short-run. Based on the findings of current study, it is recommended that possible steps should be taken from the Government of China to adopt new policies and modern technology regarding accurate weather forecasting, and precautionary and direct actions are also needed to develop and underpin an improved irrigation system. The construction of farmland also needed to improve to address future climate change.

In concise, the analysis specifies that legislators and policy experts should spot that the climate change would transmute the total output factors, accordingly a county or regional specific and crop-specific total factor of production pattern adaptation is indorsed. In general, climate change has hostile effects on the yield of the main food crops. Thus, the

| Hypothesis | Test statistic | 5% CV | p-value |
|------------|---------------|-------|---------|
| Trace statistic |
| r ≤ 0 | 287.3931*** | 159.5297 | 0.0000 |
| r ≤ 1 | 205.2882*** | 125.6154 | 0.0000 |
| r ≤ 2 | 142.6606*** | 95.7536 | 0.0000 |
| r ≤ 3 | 95.02472*** | 69.81889 | 0.0001 |
| r ≤ 4 | 51.60431** | 47.85613 | 0.0213 |
| r ≤ 5 | 25.78058 | 28.79707 | 0.1354 |
| r ≤ 6 | 10.00833 | 15.49471 | 0.2801 |
| r ≤ 7 | 0.932574 | 3.841466 | 0.8567 |

| Maximum eigenvalue |
| r ≤ 0 | 82.10488*** | 52.36261 | 0.0000 |
| r ≤ 1 | 62.42757*** | 46.23142 | 0.0005 |
| r ≤ 2 | 47.83898*** | 40.07757 | 0.0055 |
| r ≤ 3 | 43.42041*** | 33.87687 | 0.0027 |
| r ≤ 4 | 25.82373 | 27.58434 | 0.0826 |
| r ≤ 5 | 15.77224 | 21.13162 | 0.2384 |
| r ≤ 6 | 9.975757 | 14.26460 | 0.2135 |
| r ≤ 7 | 0.032574 | 3.841466 | 0.8567 |

Table VII. Results of the Johansen cointegration test

Notes: *** and ** denote 1 and 5% levels of significance, respectively.
Source: The authors’ calculations
government should propose some solid strategies in this regard to attaining the sustainable productivity of main food crops by familiarizing the modern agriculture technological approaches. In addition, being China’s population is multiplying, and in the coming decades, the country will face food security challenges. Therefore, the possible initiatives are also needed to constitute Chinese Government to cope with the adverse effects of climate change on agriculture and ensure adequate food for such massive population.

On the whole, the study also approves and calculates that climate change adaptation for agriculture productivity would offer extensive paybacks to the agriculturalists through upgraded proceeds and to society via better-quality food surety. However, agriculturalists are so far powerless to be blessed with all compensations of accustom because of several restrictions and absence of knowledge on enhanced adaptation possibilities. At this point, the Chinese administration, private formed companies and non-governmental organizations can perform a key part in focusing these restrictions by way of vagarious coordination for capacity building and schooling of agriculturalists, effortless access to micro and macro climate-specific knowledge and understanding on better-quality adjustment processes.

| Dependent variable: lnAGR; selected model: ARDL (1, 1, 1, 0, 1, 1, 1) | Regression Coefficient | Standard error | t-ratio | Probability |
|---|---|---|---|---|
| **Panel A: long-run estimation** | | | | |
| LnCO₂ | 0.061325*** | 0.025531 | 2.402036 | 0.0267 |
| LnTEMP | -0.142749 | 0.262364 | -0.544087 | 0.5927 |
| LnRF | -0.687591* | 0.361563 | -1.901719 | 0.0725 |
| LnCL | 1.277362*** | 0.516779 | 2.471777 | 0.0231 |
| LnFC | 0.383519*** | 0.141095 | 2.718160 | 0.0136 |
| LnEN | 0.032058 | 0.214315 | 0.149586 | 0.8827 |
| LnRP | 0.084486 | 0.533271 | 0.158431 | 0.8758 |
| C | -7.759671 | 12.206394 | -0.635705 | 0.5326 |
| **Panel B: short-run estimation** | | | | |
| ΔLnCO₂ | 0.010115** | 0.004975 | 2.033183 | 0.0562 |
| ΔLnTEMP | 0.063575 | 0.060118 | 1.057493 | 0.3035 |
| ΔLnRF | 0.080722 | 0.061896 | 1.304152 | 0.2078 |
| ΔLnCL | 0.366496*** | 0.116836 | 3.136829 | 0.0054 |
| ΔLnFC | 0.110038** | 0.048459 | 2.270722 | 0.0350 |
| ΔLnEN | 0.287169*** | 0.104579 | 2.745959 | 0.0128 |
| ΔLnRP | -6.471040*** | 1.308158 | -4.946680 | 0.0001 |
| ECM(−1) | -0.286916*** | 0.051357 | -5.586710 | 0.0000 |
| **Panel C: residual diagnostic tests** | | | | |
| R² | 0.7294 | | | |
| F-stat | 4.2166*** | | | |
| DW-statistic | 2.5560 | | | |
| \(\chi^2\) SERIAL | 1.3597 (0.2833) | | | |
| \(\chi^2\) NORMAL | 1.5738 (0.4552) | | | |
| \(\chi^2\) ARCH | 0.3619 (0.6995) | | | |
| \(\chi^2\) White | 1.0691 (0.4358) | | | |
| \(\chi^2\) RESET | 1.4675 (0.1595) | | | |
| CUSUM stable | | | | |
| CUSUM square stable | | | | |

**Note:** *** and ** indicate significance levels at 1, 5 and 10%, respectively

**Source:** The authors’ calculations

Table VIII.
Long-run and short-run coefficients using the ARDL model

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Supplementary, agricultural guidelines need to be restructured based on modern technological research and consideration should also be granted to resource-restrained and small-tier agriculturalists, who constitute in excess of two-thirds of the entire agricultural inhabitants in China. All these inferences may spread to improved adaptation of food crops to climate change and possibly will adept to sponsor the agriculturalists for expanding their crop yields and certify the homegrown food safety.

6. Limitations
The study has used a countrywide data set, which could not illustrate the factual portrait of the influence of climate change on unlike agro-environmental regions. Thus, to grasp the counties and regional disparities into consideration, area or zones-specific research investigations should be performed for better insights. The aggregated and disaggregated yields corps studies should be conducted to evaluate the impacts of climate change on such dissimilar food crops. The association between CO₂ emissions and the yield of cereal crops should be examined by using the latest econometric techniques in future studies, as the present study considered agricultural output.
Notes
1. See Augmented Dickey-Fuller (1979).
2. The ARDL bounds testing approach of cointegration.
3. See EGCA (Engle and Granger, 1987).
4. See CA (Johansen, 1988).
5. See JJCA (Johansen and Juselius, 1990).
6. CUSUM.
7. CUSUMSQ.
8. See WDI (WDI, 2014).

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