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Climate change impacts on crop yield: Evidence from China

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HIGHLIGHTS

- We found non-linear climate change impacts on crop yield in China.
- The climate change impacts are compared with previous studies.
- The implications for crop yield, harvest and food security are analyzed.
- Climate change impacts were modest compared to total yield growth.

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ABSTRACT

When estimating climate change impact on crop yield, a typical assumption is constant elasticity of yield with respect to a climate variable even though the elasticity may be inconstant. After estimating both constant and inconstant elasticities with respect to temperature and precipitation based on provincial panel data in China 1980–2008, our results show that during that period, the temperature change contributes positively to total yield growth by 1.3% and 0.4% for wheat and rice, respectively, but negatively by 12% for maize. The impacts of precipitation change are marginal. We also compare our estimates with other studies and highlight the implications of the inconstant elasticities for crop yield, harvest and food security. We conclude that climate change impact on crop yield would not be an issue in China if positive impacts of other socio-economic factors continue in the future.

1. Introduction

Global food security can be threatened by climate change impacts on crop production (Wheeler and von Braun, 2013). Given the large population in China, there is considerable interest in the ability of China to manage the risks related to the climate change impacts. In China, agricultural production is potentially endangered by climate change and associated extreme climate events (Piao et al., 2010; Wang, 2009). Though localized impacts may be masked in national data (Carter and Zhang, 1998; Zhang and Huang, 2012), Chinese agricultural production has increased during the past 30 years despite rising average temperature and declining land area sown. Presuming that higher temperatures negatively affect crop production, this historical observation suggests that factors other than climate change have positive impacts. Hence, it is important to distinguish impact of climate change from other key determinants of crop production in order to evaluate the role of climate change impacts in Chinese agricultural production and food security.

A widely applied approach to estimating climate change impact on crop yield is crop simulation modeling (e.g., Lin et al., 2005; Liu et al., 2010; Tao et al., 2009; Xiong et al., 2007, 2012; Zhang et al., 2014), where key socio-economic factors other than climate variables in crop production are typically out of consideration (Challinor et al., 2009). To overcome the disadvantage, some efforts have been made to consider both variables in these models (Challinor et al., 2010; Ye et al., 2013). The impacts estimated from these models depend on specific model structures and parameter values besides climate projections (Asseng et al., 2013; Liu and Tao, 2012; Osborne et al., 2013).

On the other hand, many researchers adopt a statistical approach to estimating climate change impact on crop yield (e.g., Lobell and Asner, 2003; Lobell et al., 2011; Nicholls, 1997; Zhang et al., 2008). Several

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studies have made efforts to isolate impact of climate change on crop yield in China by statistical approach (e.g., Carter and Zhang, 1998; Peng et al., 2004; You et al., 2009; Zhou and Turvey, 2014). These inter-regional studies on the basis of data at either site or regional scale (Shi et al., 2013) do not treat climatic variables as pure random terms since regional differences in these variables are known by local farmers to a reasonable extent (Demir and Mahmud, 2002).

One typical assumption in these studies is constant elasticity of crop yield with respect to a climate variable, meaning that one percentage change in a climate variable leads to the same percentage change in crop yield for all the reasonable values of the climate variable (e.g., You et al., 2009). The constant elasticity is then used to estimate climate change impact on crop yield. In a large region such as China, the elasticity is, on the contrary, likely to vary with changes in climate variables such as temperature (Aaheim et al., 2012; Li et al., 2011; Schlenker and Roberts, 2009). For example, the average temperature of wheat growth season from 1980 to 2008 is as low as 6 °C in Shanxi and as high as 18 °C in Guangdong while the national average is around 12 °C. It might be too cold for wheat growth in Shanxi and too warm in Guangdong. We could not expect that the same change rate in temperature has the same effect in both regions (i.e., constant elasticity). In crop science, non-linear response curves (Normal Heat Hours methods) have been proposed to study effects on thermal resources for crops (e.g., Mariani et al., 2012; Wang and Engel, 1998; Yan and Hunt, 1999). Hence, it is necessary to relax the assumption of constant elasticity in the case of China as indicated by a study showing nonlinear temperature impact on crop yield in the United States (Schlenker and Roberts, 2009).

Recently Zhou and Turvey (2014) examine the interaction between a climate variable and a socio-economic variable in addition to the constant elasticity of the climate variable. They do not, however, check whether or not the elasticity of a climate variable alone is constant. In addition, their dependent variable is total value product per area, where price effect is included. Xin et al. (2013) examine the variable elasticity of a climate variable as well as interaction between a climate variable and a regional dummy on the basis of rural household survey data for three years (2003, 2005, and 2008). The climate variables in their study are seasonal averages and their elasticities vary considerably across regions in China. While the hypothesis of variable elasticity is supported by household survey data (Xin et al., 2013), we will, in the present paper, study whether or not the hypothesis is supported by the aggregated provincial data, compare our results with other studies, and analyze its implications for crop harvest and food security.

The remainder of the paper is organized as follows. The next section describes data and methodology. Section 3 reports the estimated results and offers a discussion on the implications of the results on crop yield and food security and the last section concludes the paper.

2. Data and methodology

Crop yields are a function of agricultural inputs such as climate, land, capital and labor. To empirically investigate the impact of climate changes on crop yields, we constructed a panel data set that included yields of three crops (wheat, rice and maize) and related inputs from 1980 to 2008. Data include provincial yield and cultivated area of rice (including early, late, and single rice), wheat (including spring and winter wheat) and maize, and irrigated area, agricultural machine power, fertilizer use, and employment in the agriculture sector. The relevant crop growth calendar was derived from the Chinese Agricultural Phenology Atlas and can be found from the online Supporting Information (Appendix S2) in Zhang and Huang (2012). Climate data were obtained from the China Meteorological Administration. Table 1 provides the definition and related remarks of the data used in this study.

Table 1
Variable definitions and descriptive statistics.

Variable	Definition (source)	Mean	SD
Agricultural Yield	Crop-specific agricultural yield (tons/ha)		
Wheat	Source: China Statistical Yearbooks	2.89	1.15
Rice		6.01	1.31
Maize		4.18	1.37
Temperature	Crop-specific average temperature during growth season (Celsius)		
Wheat	Source: China Meteorological Administration	11.60	3.16
Rice		22.05	3.02
Maize		23.10	3.48
Precipitation	Crop-specific total rainfall during growth season (mm)		
Wheat	Source: China Meteorological Administration	353.96	221.08
Rice		567.83	208.51
Maize		586.56	308.72
Land	Crop-specific total area sown (1000 ha)		
Wheat	Source: China Statistical Yearbooks	1011.03	1201.35
Rice		1171.55	1240.47
Maize		868.08	839.33
Agri Machine Pwr	Total power of agricultural machinery (10,000 kw) Source: (NBSC, 2010)	1409.40	1628.49
Irrigated Area	total irrigated area (1000 ha) Source: (NBSC, 2010)	1808.11	1276.67
Fertilizer	Total chemical fertilizer usage (10,000 tons) Source: (NBSC, 2010)	149.29	137.84
Employment	Total agricultural employment (10,000 persons) Source: (NBSC, 2010)	1190.50	896.76

*Data summary: 29 periods (1980–2008); 27 units (provinces); due to missing data, omit Hainan, Qinghai and Tibet for all periods, Tianjin, Fujian, and Zhejiang for 1980–84 and Gansu for 1980–82.

To examine the relationship of changes in climate on crop yields, we estimate the following panel model of crop yields for wheat, rice and maize:

$$Y_{it} = \beta_1 Climate_{it} + \beta_2 Land_{it} + \beta_3 Capital_{it} + \beta_4 Labor_{it} + \omega_i + \phi_t + \varepsilon_{it}, (1)$$

where Y_{it} is the agricultural yield of province i in time t; $Climate_{it}$ is a vector of climate outcomes in province i in time t and includes mean crop-specific temperature and crop-specific rainfall during crop growth season; $Land_{it}$ is the crop-specific total area sown for province i in time t (1000 ha); $Capital_{it}$ is a vector of capital measures for province i in time t and includes the total power of agricultural machinery (10,000 kw), total irrigated area (1000 ha), and total chemical fertilizer usage (10,000 tons); $Labor_{it}$ is the total agricultural labor (10,000 persons) in province i in time t; ω_i is the province-specific effects that capture unobservable time-invariant province characteristics; ϕ_t is the time-specific effects that capture potential non-linear time trends; and ε_{it} is the contemporaneous additive error term. Table 1 provides the descriptive statistics for all the variables, along with definitions and sources.

A few aspects of Eq. (1) warrant further discussion. First, we estimate crop-specific models for wheat, rice and maize. In explaining the crop yields separately, these models include crop-specific temperatures, precipitation, and land sown along with the remaining general measures of capital and labor. Second, all models employ a double-log specification and therefore estimated coefficients are elasticities that measure the proportional responsiveness of one variable to changes in another. Third, since inputs tend to have interior optima (e.g., yields will fall with too much or too little rain), we estimate a second set of models that considers nonlinearities by including squared terms for inputs. With this specification, nonlinear elasticities must be calculated for a specific input value, which is defined as the linear coefficient plus the coefficient of the squared term multiplied by two and the logarithm of the specific input value. Fourth, all models take advantage of the