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Impact of Global Warming on Chinese Wheat Productivity

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ABSTRACT

Climate change continues to have major impact on crop productivity all over the world. While many researchers have evaluated the possible impact of global warming on crop yields using mainly indirect crop simulation models, there are relatively few direct assessments on the impact of observed climate change on past crop yield and growth. We use a 1979-2000 Chinese crop-specific panel dataset to investigate the climate impact on Chinese wheat yield growth. We find that a 1 percent increase in wheat growing season temperature reduces wheat yields by about 0.3 percent. This negative impact is less severe than those reported in other regions. Rising temperature over the past two decades accounts for a 2.4 percent decline in wheat yields in China while the majority of the wheat yield growth, 75 percent, comes from increased use of physical inputs. We emphasize the necessity of including such major influencing factors as physical inputs into the crop yield-climate function in order to have an accurate estimation of climate impact on crop yields.

Keywords: global warming, wheat yield, production function, marginal impact, panel data

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1. INTRODUCTION

The adoption of modern varieties and the increased use of irrigation and fertilizers during Green Revolution dramatically increased crop yields all over the world (Evenson and Gollins 2003b; Rosegrant and Cline 2003). The Green Revolution enabled food production in developing countries to keep pace with population growth (Conway and Toenniessen 1999). Crop yield growth has slowed since 1990s (Evenson and Gollins 2003b; Rosegrant and Cline 2000). But continued crop yield increases are required to feed the world in the 21st century (Rosegrant and Cline 2003; Cassman 1999) given the continuing decline of area suitable for grain production due to urbanization and industrialization. Food security, in particular in developing countries, remains a challenge. This challenge is made worse by the adverse effect of predicted climate change in most food insecure developing countries (Rosenzweig and Parry 1994).

Given the large body of research that has been done to quantify the contributions of crop productivity (Evenson and Gollins 2003a; Evenson and Gollin 2003b), we know factors such as modern varieties, increasing input use, and better farm management contribute greatly to crop yield growth. However, our knowledge on the impact of climate on crop productivity remains quite uncertain. While many researchers have evaluated the possible impact of global warming

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on crop yields using mainly indirect crop simulation models (e.g., Rosenzweig and Parry 1994; Brown and Rosenberg 1997; Reilly *et al*. 2003), there are relatively few direct assessments on the impact of observed climate change on past crop yield and growth except for a few studies (Nichalls 1997; Carter and Zhang 1998; Naylor *et al.* 2002; Lobell and Asner 2003; Peng *et al*. 2004). In a recent study, Peng *et al* (2004) reported that rice yields decline with higher night temperatures. Lobell and Asner (2003) showed that corn and soybean yields in the US could drop by as much as 17 percent for each degree increase in the growing season temperature. Though climate is the major uncontrollable factor that influences crop development, it is difficult to separate this influence from other factors such as the increased use of modern inputs and intensified crop management that were introduced during the Green Revolution. In fact, one major concern for the above-mentioned studies is the simplification of approximating such non-climate contributions as a linear trend (Gu 2003; Godden, Gatterham and Drynan 1998).

In this paper, we use crop-specific panel data to investigate the climate contribution to Chinese wheat yield growth. We find that global warming has a significantly negative impact on wheat yield in China, but the magnitude of impact is less than those reported by previous studies in other regions.

2. DATA AND METHOD

We use time series and cross-section data from 1979 to 2000 for twenty-two major wheat producing provinces in China and the corresponding climate data such as temperature, rainfall, and solar radiation during this period. Wheat input and output data are from State Statistics Yearbook (1979-2002) and China's Rural Statistical Yearbook (1979-2002) published by China's National Statistical Bureau, and China Agricultural Cost and Return Yearbook (1979-2002) published by China's Price Bureau. Climate data are from Climate Research Unit at

University of East Anglia. The dataset used is CRU TS 2.0 (Mitchell et al. 2004). The provincial climate parameters are calculated by averaging all the values of those pixels within the provinces. China grows both winter wheat and spring wheat. The majority of wheat production in China, about 80-90 percent, is winter wheat. Winter wheat is grown throughout most of eastern and southern China while spring wheat in northeast and western China. Both winter and spring wheat are grown in Northern China. The growing season for wheat varies from province to province. The annual climate data are monthly averages during the wheat growing seasons, taking account of the changing growing seasons by province.

The analytical challenge is to separate the non-climate effect on crop yields from the climate change effect. We hypothesize the crop yield as a function of crop inputs, technology, management, land quality, and climate factors. The initial explanatory variables for the yield equation include inputs such as land, labor, chemical fertilizer, seeds, pesticide, machinery, irrigation and other physical inputs; regional production specialization; climate variables such as temperature, precipitation and solar radiation; a set of regional dummy variables; and two institutional change dummy variables. In this study, the labor input is measured in terms of working days from the survey data. Previous study (Stavis 1991) found the marginal return to labor input was negligible due to the huge labor surplus in agricultural in China. Our own estimation confirms this finding: labor and draft animals have a negative sign for wheat yield equation, indicating the impact of these two variables on yield were negligible. Therefore the inputs of labor and draft animal are not included in the model. The physical inputs are measured in expenses per unit harvested area, and are selected based upon the sign and level of statistical significance. We included chemical fertilizer, seeds, pesticide, machinery, individually and combined the rest of inputs into an aggregated category of “other inputs”. The regional production specialization variable is represented by the share of wheat area in total crop area in that province. This variable is created to reflect the other factors such as soil quality and other regional government supports to wheat production. It is expected that the regions with a higher share of the crop production have better suitable land and better environment for wheat production and therefore higher wheat yield. Admittedly, this variable may be a potentially endogenous variable, as the trade-off between how much area to grow in a grain crop and how much to grow in a cash crop depends on trade-offs that involve yields and relative productivity and profitability. The Hausman-Wu procedure (Wu 1973; Hausman 1978) was used to test the exogeneity of the share of area under wheat. Predicted wheat areas are not significant in the test equation, indicating that it is exogenous for the yield equation. A set of regional dummy variables are used to represent time-persistent, regional differences in social, economic, and natural endowments not accounted for by the other variables. During our study period (1979 – 2000) China undertook major policy reforms: the Household Responsibility System in the early 1980s and the new development in agricultural policy in late 1990s. We used time-specific dummy variables to reflect these two major policy changes. Finally, a time trend is used to represent the factor due to technological change during this period.

Finally, a Cobb-Douglas form of wheat yield function is specified as follows:

$$\ln Yield_{it} = (\alpha_0 + \alpha_1 t) + \sum_j \beta_j \ln X_{jit} + \gamma \ln S_{it} + w \ln Climate_{it} + \sum_{r=2}^{7} \delta_r D_r + \sum_{I=1}^{2} r_I D_I + \varepsilon_{it} \qquad (1)$$

where ln is natural log, $t = 1, 2, \ldots, 22$ denotes observations from the years from 1979 to 2000. $Yield_{it}$ refers to wheat yield for Chinese province i at time t (the time trend from 1979 to 2000); X represents the conventional inputs per hectare of sown wheat area including seeds, fertilizer, pesticide, machinery, and other inputs such as irrigation, manure, and animal power; S denotes the share of wheat area in total sown area, reflecting the regional specialization (including land quality) in wheat production; *Climate* is the climate variables including temperature, rainfall and solar radiation during wheat growing season. We approximate the solar radiation with cloud cover expressed in percentage. Therefore, the higher the cloud cover, the weaker the run radiation. We include a set of regional dummy variables, D_r, to represent time-persistent, regional difference in social, economic and natural endowments not accounted for by other variables[‡]. Time-specific dummy variables, D_I, capture the effects of two major policy reforms in agriculture from 1979 to 1985, and from 1995 to 2000. $\alpha, \beta, \gamma, w, \delta, r$ are parameters to be estimated and ε is the error term.

3. ESTIMATION AND RESULTS

We first perform Augmented Dickey-Fuller Unit Root Test to test the stationarity of both dependent and independent variables. No problems are found. The model is estimated by SAS package. Since the OLS (ordinary linear square) estimation has autocorrelation problems, we also estimated Equation (1) using an autoregressive error model with one year lag (AR1). The constant variance error (no heteroscedasticity) assumptions are examined by plots between the predicted values and residuals using AR1 estimation. The plot (not reported here) shows that the assumptions for Equation (1) is reasonably held. We also examine another plot between predicted value and time trend and found no autocorrelation problem. Another potential problem may be omitted variable bias where some temperature-related variables (such as disease or pests) that affect wheat yield but have been left out of Equation (1). We perform the Ramsey (1969) regression specification error test (RESET) for omitted variables. The test is passed (P> 28 percent). The assumptions of normal distribution for errors, outliers, and linearity are also

[‡] The seven regions in China are: Northeast (Heilongjiang, Liaoning, Jilin), North (Beijing, Tianjin, Hebei, Henan, Shandong, Shanxi, Shaanxi), Northwest (Nei Mongguo, Ningxia, Xinjiang, Tibet, Qinghai, Gansu), Central (Jianxi, Hunan, Hubei), Southeast (Shanghai, Jiangsu, Zhejiang, Anhui), Southwest (Sichuan, Guizhou, Yunnan), South (Gangxi, Fujian, Hainan, Guangdong).

diagnosed and these assumptions are found to still hold. In addition, we estimate the equation with both fixed-effects and random-effects but found little difference.

The estimated results are reported in Table 1. The OLS (ordinary linear square) estimates for all parameters for physical inputs are significant at the 10 percent level or below with the expected signs.

Table 1--Estimated wheat yield function in China 1979-2000. Dependent variable =Ln(wheat yield). Numbers in parentheses are t-values. *, ** and * represent 0.10, 0.05 and 0.01 levels of statistical significance, respectively.**

Explanatory variables	OLS	AR1
Constant	7.534(32.12)***	7.482(33.22)***
Ln Fertilizer	0.127(1.60)***	0.136(4.47)***
Ln Seeds	0.180(4.64)***	0.153(4.19)***
Ln Pesticide	0.056(4.71)***	0.051(4.66)***
Ln Machinery	0.024(1.95)**	0.027(2.29)**
Ln Other inputs	0.043(1.60)*	0.042(1.76)*
Ln Share of wheat	0.065(2.32)**	0.057(2.41)**
Ln Temperature	-0.269(-10.01)***	-0.268(-11.97)***
Ln Precipitation	-0.043(-1.34)	-0.039(-1.26)
Ln Cloud cover	0.083(0.96)	0.067(0.78)
Time	0.021(4.96)***	0.021(4.15)***
Regional Dummy (Northeast)	-0.141(-2.29)**	-0.193(-3.44)***
Regional Dummy (North)	-0.113(-0.29)	-0.120(-0.35)
Regional Dummy (Northwest)	-0.414(-9.88)***	-0.407(-9.47)***
Regional Dummy(Central)	-0.119(-2.49)***	-0.107(-2.63)***
Regional Dummy(Southeast)	-0.011(-0.27)	-0.015(-0.43)
Regional Dummy(Southwest)	-0.387(-7.74)***	-0.403(-9.16)***
Institutional Dummy (1979-1985)	0.051(1.40)	0.048(1.03)
Institutional Dummy (1995-2000)	-0.093(-2.54)***	-0.098(-2.11)*
Degree of freedom	462	461
Adjusted R^2	0.801	0.835

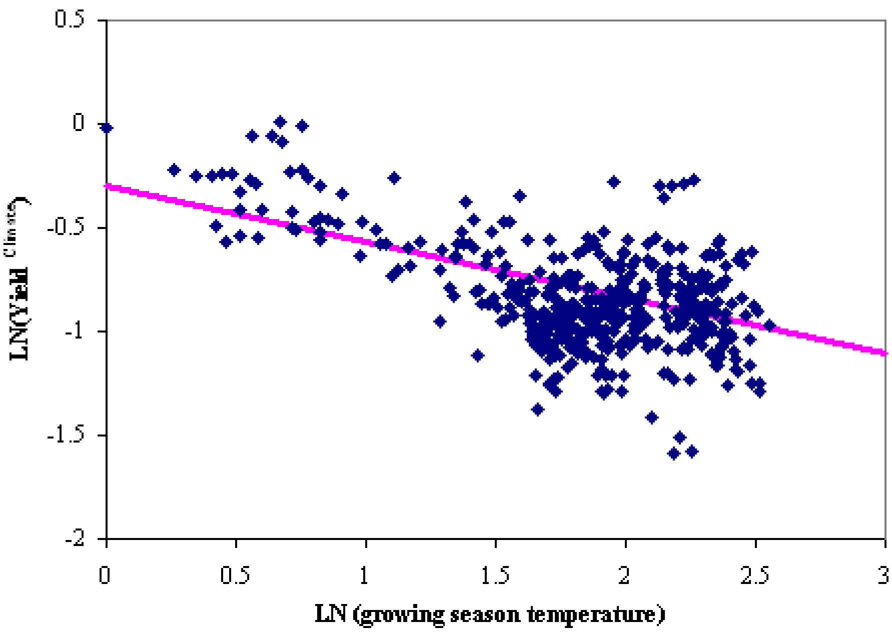
The AR1 estimates differ slightly from OLS with some improvements, and all parameters are still significant at the 10 percent level or below. So we will only refer to the AR1 results in the rest of the paper. As expected, the regional specialization is positively correlated with wheat productivity. The regional dummies in Northeast, Northwest, Central, Southwest China are statistically significant. While the institutional dummy between 1979 -1985 has a positive sign, meaning the policy reform during this period does contribute to the wheat productivity growth, it is not significant. On the other hand, the change in agricultural policy after 1995 has a negative impact on wheat productivity that is measurable at the 10 percent level of statistical significance. We find no significant relationships between wheat yield and rainfall or solar radiation. However, the temperature has a significantly negative effect on wheat yield. Because we use double-log functional form, the estimated coefficients are elasticities in the above equation. The coefficient for temperature, –0.27, means a one percent increase of growing season temperature could reduce wheat yield by 0.27 percent.

Since our major focus is to measure the contribution of growing season temperature on wheat yield, it is convenient to treat other terms in Equation (1) as "residual" effect. By subtracting the non-climate terms from the wheat yield, we single out the wheat yield change due to climate change. We define $Yield^{Climate}$ as:

$$\ln Yield^{Climate} = \ln Yield_{it} - (\alpha_0 + \alpha_1 t) - \sum_{j=1}^{5} \beta_j \ln X_{jit} - \gamma \ln S_{it} - \sum_{r=2}^{7} \delta_r D_r - \sum_{I=1}^{2} r_I D_I \qquad (2)$$

The following figure shows the relationship between this net wheat yield change and the relative change of wheat growing season temperature. The downward slope of the trend line clearly shows the negative impact of rising temperature on wheat yield in China.

Figure 1--Correlation between growing season temperature and wheat yield change due to climate change. The slope for the regression line is –0.268, R^2=0.84, *n*=461.



Across wheat growing provinces in China, the growing season temperatures vary from 5 to18°C. Therefore, 1°C increase of temperature is equivalent to 5.6 to 20 percent of relative change. Since our result shows one percent increase of growing season temperature could reduce wheat yield by 0.27 percent, this means 1.5 to 5.4 percent decline of wheat yield for each 1°C increase of temperature in China. This estimated effect of temperature on wheat yield is smaller than the previous three studies: rice in Philippines (Peng *et al. 200*4), wheat in Australia (Nichalls 1997), corn and soybean in USA (Lobell and Asner 2003). Table 2 shows the comparison among these studies. The reason for this is two-fold: this might reflect the nonlinear effect of physical inputs and crop management on crop yields (Gu 2003; Godden, Batterham and Drynan 1998), or imply that the temperature effect on crop yields varies from one region to another, or from crop to crop.

Table 2--Comparison: Impact of $1^{o}C$ increase of growing season temperature

Study	Crop	Location	Impact
Nichalls (1997)	Wheat	Australia	+30~+50%
Lobell & Asner (2003)	Corn, Soybean	USA	-17%
Peng et al (2004)	Rice	Philippines	-10%
Our Study	Wheat	China	-2%~-5%

To assess the relative contribution of rising growing season temperature on the wheat yield, we take the first derivative of Equation (1) with respect to *t* (Lin 1992; Fan and Pardey 1997).

$$\frac{\partial \ln Yield_{it}}{\partial t} = \alpha_1 + \sum_j \beta_j \frac{\partial \ln X_{jit}}{\partial t} + \gamma \frac{\partial \ln S_{it}}{\partial t} + w \frac{\partial \ln Climate_{it}}{\partial t} + \sum_{r=2}^{7} \delta_r \frac{\partial D_r}{\partial t} + \sum_{r=1}^{2} r_I \frac{\partial D_I}{\partial t} + \frac{\partial \varepsilon_{it}}{\partial t} \quad (3)$$

Table 3 reports the growth accounting based on the estimate of the wheat yield function in column 1 of Table 1. The total wheat yield growth from 1979 to 2000 was 85.41 percent. From the accounting in Table 3, it appears that 75.23 percent of this yield growth comes from increased use of physical inputs. Rising temperature attributed to 2.37 percent of decline in wheat yield. This negative contribution is relatively small compared to that of physical inputs, which underlines the necessity of including physical inputs in the regression analysis of crop yield-climate interactions.[§]

Table 3--Accounting for wheat yield growth. The estimated coefficients are taken from Table 1, and the change in explanatory variable refers to percentage growth of that variable from 1979-81 to 1998-2000 (three year averages are taken to avoid atypical year). The numbers in parentheses are the percentage shares of contribution to total wheat yield growth, with total yield growth set at 100.

		1979-2000		
				Contribution to growth
Explanatory variable		Estimated coefficient (1)	Change in explanatory variable (2)	(percentage) (3)=(1)X(2)
INPUTS				**64.25 (75.23)**
	Chemical fertilizer	0.136	255.00	34.68 (40.60)
	Pesticide	0.051	220.33	11.13 (13.03)
	Machinery	0.027	324.62	8.70 (10.19)
	Seeds	0.153	64.39	9.85 (11.53)
	Other inputs	0.043	-2.43	-0.10 (-0.12)
SPECIALIZATION		0.057	-7.80	**-0.44 (-0.52)**
TEMPERATURE		-0.268	7.57	**-2.03 (-2.37)**
RESIDUAL*				**23.63 (27.67)**
TOTAL GROWTH				**85.41 (100)**

Note: *An accounting residual derived by netting out the effects of inputs, specialization and temperature. Here it mainly reflects the impact of agricultural R&D and institutional change.

[§] Simple de-trending of wheat yield and temperature while ignoring the physical inputs finds no significant relationship between wheat yield and temperature ($R^2 < 0.001$).

4. CONCLUSION

Since the introduction of rural reforms in China in the late 1970s, agricultural production and productivity for wheat has increased significantly. While the majority of wheat productivity increase is due to increase use of physical inputs and the institutional change, the gradual increase in growing season temperature in the last few decades has had a measurable effect on wheat productivity. In this paper, we have evaluated the impacts of climate and non-climate factors on wheat yield growth in China, and find that a one percent increase in wheat growing season temperature reduces the yield by about 0.3 percent. The rising temperature from 1979-2000 cut wheat yield growth by 2.4 percent. There is a deficiency in the current literature about how to measure the influence of climate on productivity. Authors frequently fail to distinguish between climate factors and the influence of modern inputs and management practice on productivity. We emphasize the necessity of including such major influencing factors as physical inputs into crop yield-climate functions in order to have an accurate estimation of climate impact on crop yields. With so much uncertainty on the potential impacts of climate change, it is essential to first evaluate what past climate changes have had on agricultural productivity. Our study demonstrates a clear need to synthesize climate and crop-specific management and inputs data in order to investigate the impact of climate change.

In China, providing enough food to feed over 13 billion people is always a challenge. There is an increasing concern about the impacts of climate change on Chinese food security. Our study shows that climate change does have a measurable negative impact on wheat productivity. This negative impact would probably become worse with accelerating change of future climate. Our study demonstrates the need to consider climate change and its effects on crop productivity in order to meet the food security goals in China as well as in other developing countries. There is also a need to extend such studies to other regions, in particular to food insecure countries where climate change would have the most severe adverse impact on crop productivity.

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