12

The impact of global warming on Chinese wheat productivity

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The adoption of modern varieties and the increased use of irrigation and fertilisers during the 'Green Revolution' dramatically increased crop yields all over the world (Evenson and Gollin 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 the 1990s (Evenson and Gollin 2003b; Rosegrant and Cline 2003), but continued crop yield increases are required to feed the world in the twenty-first century (Rosegrant and Cline 2003; Cassman 1999) given the continuing decline in the amount of land suitable for grain production due to urbanisation and industrialisation. Food security, in particular in developing countries, remains a challenge. This challenge is made worse by the adverse effects 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 Gollin 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. Our knowledge on the impact of climate on crop productivity, however, remains quite uncertain. While many researchers have evaluated the possible impact of global warming on crop yields using mainly indirect crop-simulation models (for example, Rosenzweig and Parry 1994; Brown and Rosenberg 1997; Reilly et al. 2003), there have been relatively few direct assessments of the impact of observed climate change on past crop yields 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 declined with higher night-time temperatures. Lobell and Asner (2003) showed that corn and soybean yields in the United States could drop by as much as 17 per cent for each degree of increase in the growing-season temperature. Although 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, which were introduced during the Green Revolution. In fact, one major concern with the above-mentioned studies is the simplification of approximating such non-climate contributions as a linear trend (Gu 2003; Godden et al. 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 yields in China, but the magnitude of impact is less than that reported by previous studies in other regions.

Data and method

We use time series and cross-section data from 1979 to 2000 for 22 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 China's *State Statistical Yearbook* and the *Rural Statistical Yearbook* (NBS 1979–2002a, 1979–2002b), and *China Agricultural Cost and Return Yearbook* (State Price Bureau 1979–2002). Climate data are from the Climatic Research Unit at the University of East Anglia. The data-set 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 winter wheat and spring wheat. The majority of wheat production in China, about 80–90 per cent, is winter wheat. Winter wheat is grown throughout most of eastern and southern China, while spring wheat is grown in northeast and western China. 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 effects on crop yields from the climate change effects. We hypothesise 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, labour, chemical fertiliser, seeds, pesticide, machinery, irrigation and other physical inputs; regional production specialisation; 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 labour input is measured in terms of working days from the survey data. The previous study (Stavis 1991) found the marginal return to labour input was negligible due to the huge labour surplus in agriculture in China. Our own estimation confirms this finding: labour and draft animals have a negative sign for the wheat-yield equation, indicating that the impact of these two variables on yield was negligible. The inputs of labour and draft animals are therefore not included in the model. The physical inputs are measured in expenses per unit of harvested area, and are selected based on the sign and level of statistical significance. We included chemical fertiliser, seeds, pesticide and machinery individually, and combined the rest of the inputs into an aggregated category of 'other inputs'. The regional production specialisation variable is represented by the share of wheat in the 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 high share of crop production have more suitable land and a better environment for wheat production and therefore higher wheat yields than other regions. Admittedly, this variable could potentially be an endogenous variable, as the trade-off between the amount of area to sow with a grain crop and the amount of area to sow with 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 planted with 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 is 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 the 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

$$\begin{aligned} \ln Yield_{it} = & (\alpha_0 + \alpha_1 t) + \sum_j \beta_j \ln X_{jit} + \gamma \ln S_{it} + w \ln Climate_{it} \\ & + \sum_{r=2}^7 \delta_r D_r + \sum_{l=1}^2 r_l D_l + \varepsilon_{it} \end{aligned} \quad (1)$$

in which $\ln$ is natural log, $t = 1, 2 \dots 22$ denotes observations from the years from 1979 to 2000. $Yield_{it}$ refers to the wheat yield for Chinese province i at time t (the time trend from 1979–2000); X represents the conventional inputs per hectare of sown wheat area including seeds, fertiliser, pesticide, machinery and other inputs such as irrigation, manure and animal power; S denotes the share of area under wheat in the total sown area, reflecting the regional specialisation (including land quality) in wheat production; $Climate$ is the climate variables including temperature, rainfall and solar radiation during the wheat-growing season. We approximate solar radiation with cloud cover expressed in percentages. Therefore, the higher the cloud cover, the weaker is the sun's radiation. We include a set of regional dummy variables, D_p , to represent time-persistent, regional differences in social, economic and natural endowments not accounted for by other variables.¹ Time-specific dummy variables, D_t , capture the effects of two major policy reforms in agriculture from 1979 to 1985, and from 1995 to 2000. α , β , γ , w , δ and r are parameters to be estimated and ε is the error term.

Estimation and results

We first perform an augmented Dickey-Fuller unit root test to test the stationarity of dependent and independent variables. No problems are found. The model is estimated by an SAS package. Since the ordinary linear square (OLS) estimation has auto-correlation problems, we also estimate Equation 1 using an auto-regressive error model with a one-year lag (AR1). The constant variance error (no heteroscedasticity) assumptions are examined by plots between the predicted values and residuals using the AR1 estimation. The plot (not reported here) shows that the assumptions for Equation 1 are reasonably held. We also examined another plot between the predicted value and the time trend and found no auto-correlation problem. Another potential problem could be an omitted-variable bias, where some temperature-related variables (such as diseases or pests) that affect wheat yield have been left out of Equation 1. We perform the Ramsey (1969) regression specification error test (RESET) for omitted variables. The test is passed ($P > 28$ per cent). The assumptions of normal distribution for errors, outliers and linearity are also diagnosed and these assumptions are found to still hold. In addition, we estimated the equation with fixed effects and random effects but found little difference.

The estimated results are reported in Table 12.1. The OLS estimates for all parameters for physical inputs are significant at the 10 per cent level or below with the expected signs.

Table 12.1 **Estimated wheat-yield function in China, 1979–2000**

Explanatory variables	OLS	AR1
Constant	7.534 (32.12)***	7.482 (33.22)***
Ln fertiliser	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 (1979–85)	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

* 0.10 level of statistical significance

** 0.05 level of statistical significance

*** 0.01 level of statistical significance

Note: The dependent variable is Ln (wheat yield). Numbers in parentheses are t-values.

The AR1 estimates differ slightly from OLS with some improvements, and all parameters are still significant at or below the 10 per cent level. We will therefore refer only to the AR1 results in the rest of the paper. As expected, the regional specialisation is correlated positively with wheat productivity. The regional dummies in northeast, northwest, central and southwest China are statistically significant. While the institutional dummy between 1979 and 1985 has a positive sign—meaning that the policy reforms during this period did contribute to wheat productivity growth—it is not significant. On the other hand, the changes in agricultural policy after 1995 had a negative impact on wheat productivity, which was measurable at the 10 per cent level of statistical significance. We find no significant relationships between wheat yield and rainfall or solar radiation.

The temperature has, however, a significantly negative effect on wheat yield. Because we use a double-log functional form, the estimated coefficients are elasticities in the above equation. The coefficient for temperature, -0.27 , means a 1 per cent increase in the growing-season temperature could reduce wheat yield by 0.27 per cent.

Since our major focus is to measure the contribution of growing-season temperatures on wheat yields, it is convenient to treat other terms in Equation 1 as 'residual' effects. 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

$$\begin{aligned} \ln Yield^{Climate} = \ln Yield_{it} - (\alpha_0 + \alpha_1 t) - \sum_{j=1}^5 \beta_j \ln X_{jit} - \gamma \ln S_{it} \\ - \sum_{r=2}^7 \delta_r D_r - \sum_{l=1}^2 r_l D_l \end{aligned} \quad (2)$$

Figure 12.1 shows the relationship between this net wheat-yield change and the relative change in wheat growing-season temperatures. The downward slope of the trend line shows clearly the negative impact of rising temperatures on wheat yields in China.

Figure 12.1 **Correlation between growing-season temperatures and wheat-yield change due to climate change**

Note: 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°C to 18°C. A one-degree increase in temperature is therefore equivalent to 5.6–20 per cent of relative change. Since our result shows that a 1 per cent increase in growing-season temperature could reduce wheat yield by 0.27 per cent, this means a 1.5 to 5.4 per cent decline in wheat yield for each 1°C increase in temperature in China. This estimated effect of temperature on wheat yield is smaller than that found in the previous three studies of: rice in the Philippines (Peng et al. 2004), wheat in Australia (Nichalls 1997) and corn and soybean in the United States (Lobell and Asner 2003). Table 12.2 shows a comparison of these studies. The reasons for this difference are twofold: it could reflect the non-linear effect of physical inputs and crop management on crop yields (Gu 2003; Godden et al. 1998), or it could imply that the temperature effect on crop yields varies from one region to another, or from crop to crop.

Table 12.2 Comparison: impact of 1°C increase in growing-season temperature

Study	Crop	Location	Impact (%)
Nichalls (1997)	Wheat	Australia	+30~+50
Lobell and Asner (2003)	Corn, soybean	United States	-17
Peng et al. (2004)	Rice	Philippines	-10
Our study	Wheat	China	-2~-5

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

$$\begin{aligned} \frac{\partial \ln Y_{it}}{\partial t} = & \alpha_1 + \sum_j \beta_j \frac{\partial \ln X_{jit}}{\partial t} + \gamma \frac{\partial \ln S_{it}}{\partial t} + w \frac{\partial \ln Climate_{it}}{\partial t} + \\ & \sum_{r=2}^7 \delta_r \frac{\partial D_r}{\partial t} + \sum_{l=1}^2 r_l \frac{\partial D_l}{\partial t} + \frac{\partial \varepsilon_{it}}{\partial t} \end{aligned} \quad (3)$$

Table 12.3 reports the growth accounting based on the estimate of the wheat-yield function in column 1 of Table 12.1. The total wheat-yield growth from 1979 to 2000 was 85.41 per cent. From the accounting in Table 12.3, it

Table 12.3 **Accounting for wheat-yield growth**

Explanatory variable	Estimated coefficient	1979–2000	
		Change in explanatory variable	Contribution to growth (%)
	(1)	(2)	(3)=(1)X(2)
Inputs			64.25 (75.23)
Chemical fertiliser	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)
Specialisation	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)

* an accounting residual derived by netting out the effects of inputs, specialisation and temperature. Here it reflects mainly the impact of agricultural research and development and institutional change.

Note: The estimated coefficients are taken from Table 12.1, 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 years). The numbers in parentheses are the percentage shares of contribution to total wheat-yield growth, with total yield growth set at 100.

appears that 75.23 per cent of this yield growth comes from the increased use of physical inputs. Rising temperatures attributed to 2.37 per cent of the decline in wheat yield. This negative contribution is relatively small compared with that of physical inputs, which underlines the necessity of including physical inputs in the regression analysis of crop yield–climate interactions.²

Conclusion

Since the introduction of rural reforms in China in the late 1970s, agricultural production of and productivity for wheat have increased significantly. While the majority of wheat productivity increase is due to the increased use of physical inputs and institutional change, the gradual increase in growing-season temperatures in the past 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 found that a 1 per cent increase in wheat growing-season temperatures reduced the yield by about 0.3 per cent. The rising temperatures from 1979 to 2000 cut wheat-yield growth by 2.4 per cent. There is a deficiency in the current literature about how to measure

the influence of climate on productivity. Authors fail frequently to distinguish between climate factors and the influence of modern inputs and management practices on productivity. We emphasise 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 about the potential impacts of climate change, it is essential to first evaluate the impacts past climate changes have had on agricultural productivity. Our study demonstrates a clear need to synthesise climate and crop-specific management and inputs data in order to investigate the impact of climate change.

In China, providing enough food to feed more than 1.3 billion people is always a challenge. There is 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 will probably become worse with accelerating climate change in the future. 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 will have the most severe adverse impacts on crop productivity.

Notes

- 1 The seven regions in China are: Northeast (Heilongjiang, Liaoning, Jilin), North (Beijing, Tianjin, Hebei, Henan, Shandong, Shanxi, Shaanxi), Northwest (Nei Menggu, Ningxia, Xinjiang, Tibet, Qinghai, Gansu), Central (Jiangxi, Hunan, Hubei), Southeast (Shanghai, Jiangsu, Zhejiang, Anhui), Southwest (Sichuan, Guizhou, Yunnan), South (Guangxi, Fujian, Hainan, Guangdong).
- 2 Simple de-trending of wheat yields and temperature while ignoring the physical inputs finds no significant relationship between wheat yield and temperature ($R^2 < 0.001$).

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