Supplementary Information

Drivers of planting area and yield shifts for three staple crops across China, 1950−2013

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Text S1: Variable Selection

As yield increases with time (mainly due to technological improvement), we should select some explanatory factors that represent technological improvements to construct the regression model. What we selected from the NBS (National Bureau of Statistics), which could represent technological improvements, were chemical fertilizer input, power of agriculture machines and effectively irrigated area. Irrigation is important because over 95% of rice is irrigated. Improvements in irrigation also benefited other crops because it can compensate for the deficiency in precipitation caused by climate fluctuations. The power of agriculture machines represents the level of agricultural mechanization, which can dramatically improve the efficiency of agricultural production. Chemical fertilizer input has a direct yield-increasing effect on crops.

The reasons why we only chose temperature and precipitation could generally be divided into two aspects. On the one hand, there is no doubt that crop production (including crop planting area and crop yield) is largely influenced by climatic factors, including temperature, precipitation, solar radiation, air humidity, wind speed and other factors. However, how much these factors impact crop production differs among one another. Overall, temperature and precipitation have been proven to be two key variables deciding crop production. Rice, maize and wheat, which are widely planted both in China and other regions, are extremely sensitive to temperature and precipitation fluctuations. Plenty of research has pointed out that increased global warming and more fluctuant precipitation are major results of climate change. Therefore, we only considered temperature and precipitation in our study.

For the whole variable selection, we had considered what and how many factors we could use to make the regression before we started our research. Theoretically speaking, the more factors a model can contain, the more reliable the results are. However, more factors conversely increases the complexity of the model and, thereby, reduces its reliability. Therefore, if we only select the proper number of factors, we can guarantee the reliability of the regression model. There were two major concerns when selecting factors to construct the model in our study. 1) We wanted to construct a model that reveals how and why the crop planting area and crop yield changed during the past six decades. Therefore, the factors we selected for the model should be highly related to agricultural production. Only the agro-economic factors directly impact the crop planting area and crop production. Other socio-economic factors may have some slight and indirect impacts on the crop planting area and crop yield. If we put these factors into the model, the reliability of the model does not increase; it decreases due to their low relevance. 2) The historical statistical data for the social economy can only be found in the National Bureau of Statistics (NBS). The agro-economic data are available under the classification of "Agriculture". We selected the five most related factors to construct the model not because the number of available factors is limited but because these five factors are proven to highly impact agricultural production (Fang et al. 2011; Sun et al. 2015; Chen et al. 2015). Other factors may also have a direct impact on agricultural production, such as planting subsidies to farmers. However, these data are not available in the

NBS.

Chen, H., Yu, C.Q., Li, C.S., Xin, Q.C., Huang, X., Zhang, J., et al., 2015. Modeling the impacts of water and fertilizer management on the ecosystem service of rice rotated cropping systems in China.

Fang Q., Wu W.X., 2011. The impact of climate change and technological progress on crop yield in Northeast China. Jilin Agriculture, 03: 203-205. (In Chinese)

Sun, H.Y., Zhang, X.Y., Wang, E.L., Chen, S.Y., Shao, L.W., 2015. Quantifying the impact of irrigation on groundwater reserve and crop production – A case study in the North China Plain. European Journal of Agronomy. 70, 48–56.

Text S2: Growing Season Selection

It is reasonable to use the growing-season temperature and precipitation as explanatory variables when the crop yield is regressed. However, when regressed with the crop planting area, the growing-season temperature and precipitation in the previous year are more reasonable and valid. We explain this rationality to select the previous years' climate conditions for the crop planting areas below.

1) First, crop production is typically weather-dependent in China, which means that climate can directly impact crop yield, even though agricultural technology is advanced. This influence is not direct but indirect, as the crop planting area is significantly influenced by the growing season climate in the previous year. Farmers, as a major part of agricultural production, do not take the risk of expanding the crop planting area blindly, and they decide how much cropland should be cultivated based on the climate conditions in the previous year or even several previous years. Although deciding on the scale of a crop planting area based on the previous climate condition is risky since the climate itself is fluctuating, farmers do not have enough time to change the scale of the crop planting area based on the climate conditions in the current growing season or even around the planting date. Agricultural production is systematic and time-consuming; thus, farmers need to prepare seeds, irrigation facilities and other essential production elements in advance. Furthermore, climate conditions around the planting date cannot be a good predictor of the climate during the growing season since the duration of the growing season is much longer than that of the non-growing season.

2) Second, we separated the different contributions through estimating the impact of climate change in the regression model during the past six decades (especially the past three decades). According to the abundance of research results, the changing climate did have a huge impact on the expansion of the CPA of rice and maize in Northeast China. As climate change occurs at a long time scale, the climate conditions of the previous year and previous years is a good indicator for farmers to plan their agricultural production of the current year and the next few years.

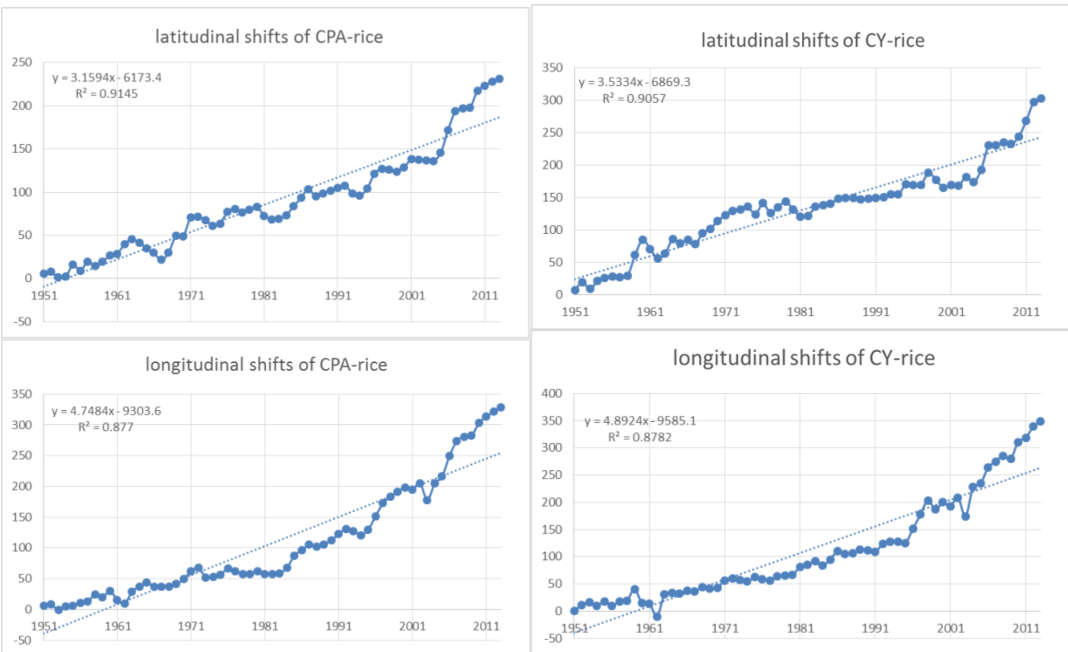
In conclusion, climate conditions in the previous year could be an impact factor for the crop planting area.

Text S3: Growing Seasons of Rice and Maize

There is no doubt that the specific start and end times of the growing seasons for rice and maize are usually different depending on where they are planted. However, the entire growing seasons of these two crops overlap for most months. There are two types of rice grown in China: single rice and double rice. Single rice, which is almost always planted in Northeast China, usually begins its growing season in late April and ends in mid-October. Double rice, which is widely planted in Southwest, South and Southeast China, starts its growing season in late March and ends in early November. Therefore, the total growing season of rice in China, which was used in my study, is from March to November. Maize is divided into two types in China: spring maize and summer maize. The growing season of spring maize varies in different regions. In Northwest, North and Northeast China, spring maize is usually planted in mid-to-late April and harvested in mid-to-late September. In Southwest, South and Southeast China, the growing season of spring maize starts at an early date (mid-to-late March) and ends in late July to early August. In general, summer maize is planted in Northwest, North and Northeast China, with a growing season that starts in early-to-late June and ends in late September to early October. In this study, we set the same growing season, which is from March to November, for both rice (including the two types of rice) and maize to simplify the model complexity. This setting was based on the reality that rice and maize share almost the same growing seasons from mid-to-late March to late October.

Text S4: Significance Test for Geographical Movements

Because the coordinates of the centroids cannot directly be associated with the time series, we used the distances of the centroids from the centroid in 1950. Moreover, we separated the distances between the two centroids in two dimensions (latitudinal distance and longitudinal distance) to test the significance of eastward movements and northward movements, respectively. The results of the rice planting area and rice yield showed high significance both in latitudinal shifts (for CPA-rice, R^2=0.91, $p<0.01$; for CY-rice, R^2=0.90, $p<0.01$) and longitudinal shifts (for rice planting area, R^2=0.87, $p<0.01$; for rice yield, R^2=0.87, $p<0.01$), indicating that the northeast shift in the rice planting area and rice yield was significant. As discussed in the manuscript, the centroids of the maize planting area and maize yield did not move to the northeast each year. In some decades, these centroids were distributed randomly without any significant northeastern shifts. Thus, the significance test for the maize planting area and maize yield showed a lower R^2 both for the latitudinal distance (for maize planting area, R^2=0.82, $0.01<p<0.05$; for maize yield, R^2=0.44, $0.05<p<0.1$) and longitudinal distance (for maize planting area, R^2=0.82, $0.05<p<0.1$; for maize yield, R^2=0.63, $0.05<p<0.1$). However, the temporal extent in our study was during the past six decades. Therefore, even if there was not a northeastern movement each year, we cannot deny a significant northeastern movement during the entire period.



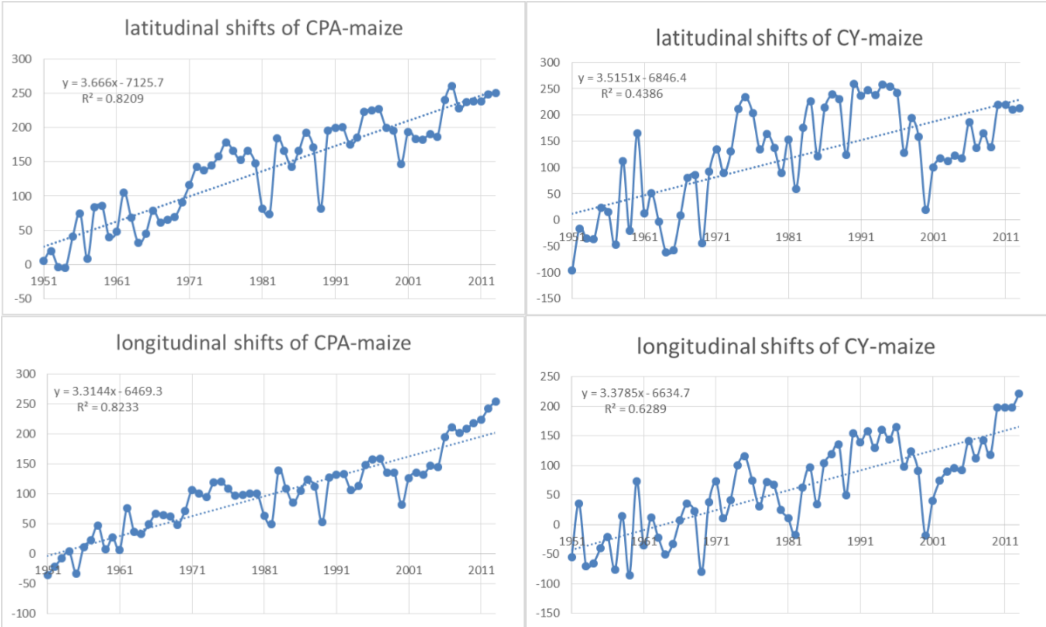


Fig. S1. The latitudinal and longitudinal shifts of the crop planting area and crop yield since 1950.

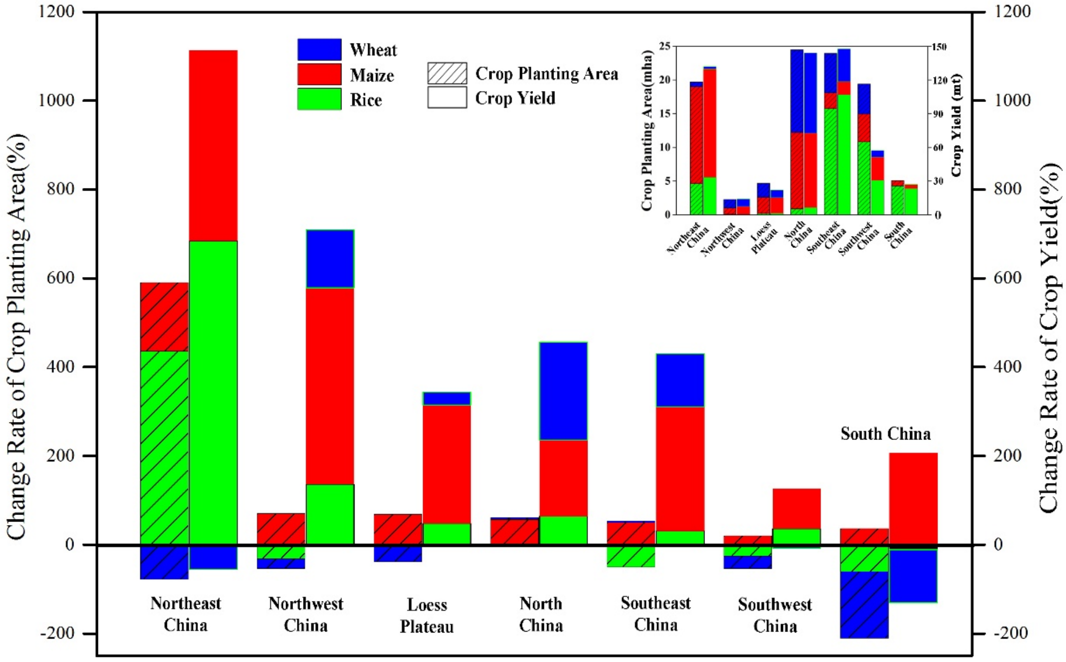


Fig. S2. The regional change rate of the crop planting area and crop yield between 1980 and 2013. The top right corner shows the Chinese CPA and CY in 2013.

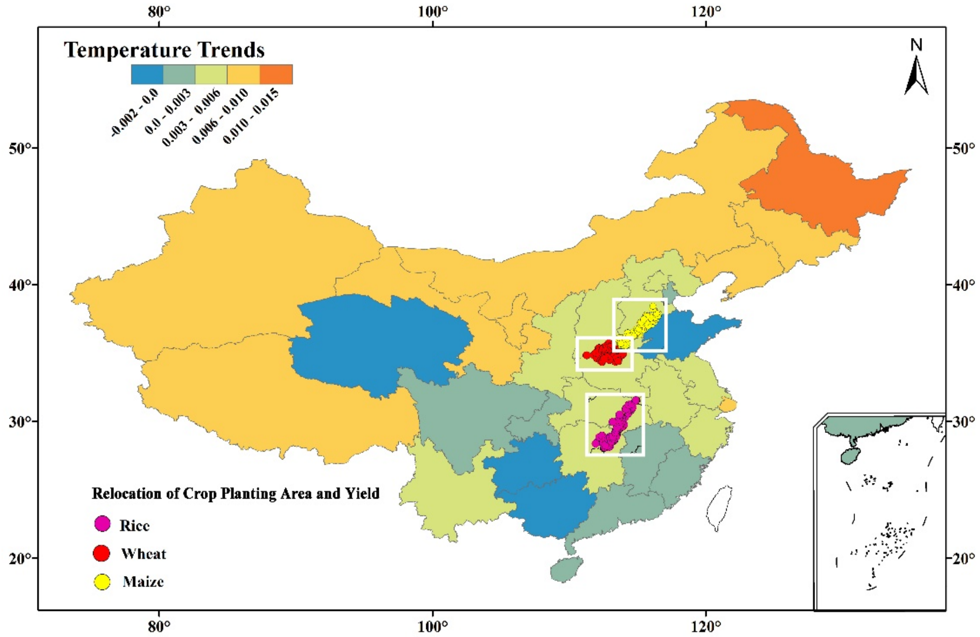


Fig. S3. Temperature trends in China from 1980 to 2013.

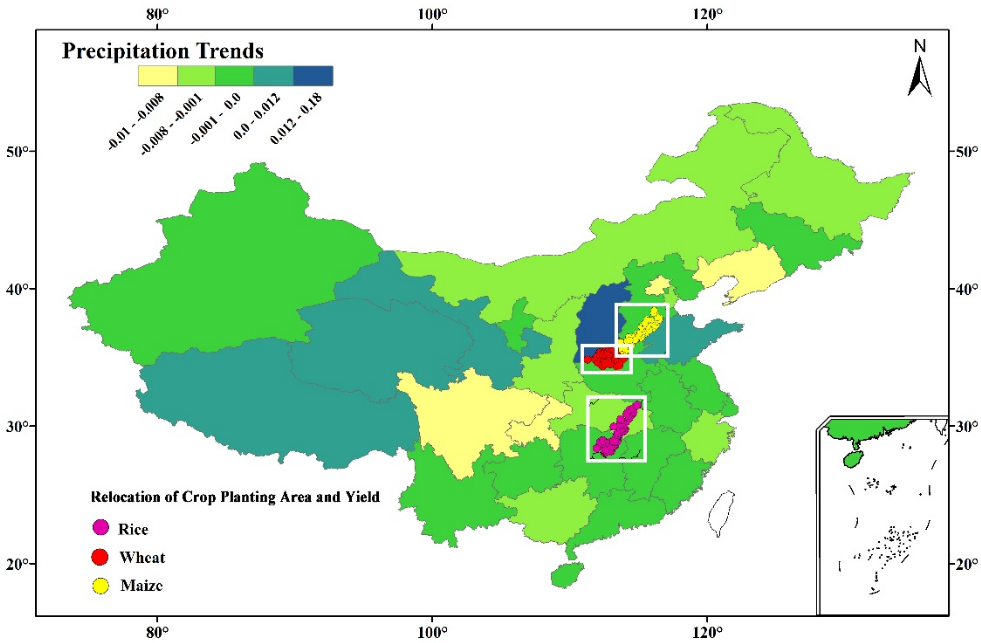


Fig. S4. Precipitation trends in China from 1980 to 2013.