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Modeling the impacts of climate change on China´s agriculture

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Abstract: The impacts of climate change on China´s agriculture are measured based on Ricardian model. By using county-level cross-sectional data on agricultural net revenue, climate, and other economic and geographical data for 1275 agriculture-dominated counties in the period of 1985-1991, we find that both higher temperature and more precipitation will have overall positive impact on Chinaˇs agriculture. However, the impacts vary seasonally and regionally. Higher temperature in all seasons except spring increases agricultural net revenue while more precipitation is beneficial in winter but is harmful in summer. Applying the model to five climate scenarios in the 2020s and 2050s shows that the North, the Northeast, the Northwest, and the Qinghai-Tibet Plateau would always benefit from climate change while the South and the Southwest may be negatively affected. For the East and the Central China, most scenarios show that they may benefit from climate change. In conclusion, climate change would be beneficial to the whole China.

Modeling the impacts of climate change on China´s agriculture LIU Hui1, LI Xiu-bin1, Guenther Fischer2, SUN Lai-xiang 2 (1. Institute of Geographic Sciences and Natural Resources Research, CAS, Beijing 100101, China; 2. International Institute for Applied System Analysis, A-2361 Laxenburg, Austria) 1 Introduction Since recognition of the potential climate change [IPPC, 1990], efforts have been made to estimate the economic impacts of projected changes in climate on important sectors, such as agriculture, forestry and ecosystem, coastal zones and fisheries, water resource, and energy development. Although several sectors have been studied, none have received more attention than agriculture. Countrywide economic analysis has been completed for the United States[1-4], India[5] and Brazil. In the United States, a recent study suggests that global warming may be slightly beneficial to American agriculture[4]. But the recent results from India suggest that overall warming will hurt agriculture in India relatively to temperate countries[5]. Studies from both the Unites States and India suggest that adaptation of private producers would reduce the damage to agriculture caused by climate change. However, it is not clear what effect of climate change will have on the rest of the world because agricultural systems vary from country to country. Given the inherent global nature of the issue, it is essential to study the impacts of climate change on agriculture in other countries as well, especially for the countries where agriculture is the key component of GDP. Geographically, China touches the tropics in the south and extends into the cold temperate zone in the north is also a large agricultural country where agriculture constituted 18.7% of GDP in 1997. Chinaˇs agriculture has fed more than one-fifth of the world population. China has been famine-prone in history. As recently as the late 1950s and the early 1960s a great famine claimed about thirty million of lives[6]. Since economic reform, there has been an unprecedented conversion of arable land into non-agricultural uses with rapid economic development and industrialization. This loss of agricultural land, together with the trend towards a much higher demand for agricultural products for the growing and large population, has resulted in a debate about the countryˇs long-term capacity to feed itself[7]. How China will avoid national chronic food insecurity in the future remains an issue, which is inevitably of significant global implication. Whether China can feed itself in the future not only depends on agricultural land resource but also on the impacts of climate change on its agriculture in the future. Some studies on the impacts of climate change on Chinaˇs agriculture have been made. However, these studies are either in the limited area or for the yield of single crop, such as rice, wheat or maize[8-10]. Although some scientists assessed the impacts of climate change on Chinaˇs farming system, they did not consider farmerˇs adaptations[11]. Recently, some scientists use AEZ model developed by International Institute of Applied System Analysis (IIASA) and FAO to assess the impact of climate change on Chinaˇs agricultural land productivity[12]. All of them on ly focused on the impacts of climate change on grain yield or plant boundary. Studies on the impacts of climate change on China˘s total output value of agriculture have not been done yet. This paper provides the first detailed estimates of the economic impact of climate change on the agricultural sector in China. The analysis computes the impacts of changes in temperature and precipitation on agricultural net revenue per hectare. We utilized county-level agricultural, climatic, socio-economic and edaphic data for 1275 agriculture-dominated counties for the period of 1985-1991, to examine farmer-adapted response to climate variations across the country. Although we applied methodologies developed in the United States, much attention is paid to adapting these methods to China˘s conditions, such as farm labor, management, and technology development. 2 Methodology Two broad methodologies have evolved so far in the literature for assessing the impacts of climate change on agriculture: the traditional ¨production function〃 approach, and more recently, the ¨Ricardian approach〃. The production function approach estimates the climate changes in yield directly from crop-response models. It takes an underlying production function and estimates impacts by a varying one or a few input variables, such as temperature, precipitation and carbon dioxide levels. It is used a lot for assessing the impact of climate change on China˘s agriculture. The Ricardian approach, instead of looking at the yield of specific crops, examines how climate in different places affects the net rent or value of farmland[2]. This approach is a cross-sectional empirical analysis designed to capture the effect of ¨natural experiments〃 practiced by farmers across different climate zones or locations. In other words, the farming activities across a large country with sufficiently varying climate can be used as samples for comparing farmers˘ response to climate change. The method uses the typical economic measure of farm performance: net revenue or net farm income. By examining the economic performance of farms across different climates and regressing farm performance on long-term climate, one can empirically estimate long-term climate sensitivity. The most important advantage of this approach is its ability to capture the adaptation that farmers make in response to local environmental conditions. It captures the actual response rather than the controlled ones. In addition, it is capable of capturing the farmer˘s choices over crop mix instead of yield. A valid criticism of Ricardian approach is that it has historically assumed the price to be equilibrium, and in case of great climate change the crop price could change for prolonged period. Under such circumstances, the Ricardian estimate would be either over or under estimating the impacts of climate change, depending on how the prices change. But the bias has been calculated to be small in most relevant examples of climate change[3]. Besides, it is difficult to incorporate carbon dioxide fertilization into the regression. 2.1 Ricardian model This section summarizes the theoretical understandings of the Ricardian model by R. Mendelsohn et al.[3,5] If i is the optimum use for land Li given the environment E and factor prices R, the observed market rent of the land will be equal to the annual net profit from the production of crop i., therefore, land rent per hectare is equal to net revenue per hectare[5], i.e., where Pi and Qi are respectively the price and quantity of crop i, and Ci( ) is the function of all purchase inputs other than land. R = [R1??Rj] is the vector of factor prices, E is an exogenous environmental input into the production of goods, e.g., temperature, precipitation, and soils, which would be the same for different goods˘ production. The present value of the steam of current and future revenues gives land value: We assume that the change of environment from EA to EB will leave market prices of inputs (fertilizer, labor) and outputs unchanged. The change in annual welfare from this environmental change is given by: Substituting Eq. (1) into Eq. (3) gives: where pLA and LA are at EA while pLB and LB are at EB. The present value of this welfare change is as follows: The Ricardian model takes the form of either (1) or (5) depending on whether the dependent variable is annual net revenues or farm value. The value of the change in the environmental variables is captured exactly by the change in land values under different conditions. Cross-sectional observation, where normal climate and edaphic factors vary, can hence be utilized to estimate the impacts of farmer-adapted climate on production and land value. 2.2 Modified Ricardian model in China Due to imperfect land markets and lack of documentation of agricultural farm values in China, in this paper, we estimate (1), using annual net revenue as independent variable. According to the Ricardian model, theoretically, the net revenue should be: where Pi and Qi are respectively the price and quantity of crop i, Ci( ) is the function of all purchase inputs other than land, and Li is the area planted for crop i. However, in practice, due to the limitations of documentation in China, it is better to use net income as net revenue. where Pi and Qi are respectively the price and quantity of crop i, Pn and Mn are respectively the price and quantity of input material n, such as fertilizers, pesticides, seeds, electricity, etc., W, L, and days are respectively the labor cost, numbers of agricultural labor, and the average number of working days of the county farm workers. Actually, there is no price for each crop and farm labor in the statistical data. Fortunately, there is a pure agriculture output in China Statistical Yearbook. In China, the pure agriculture output is defined as the total output of agriculture minus the whole expenditure of material˘s input except for labor force. Therefore, the net income can be defined as: where PAO is the pure agriculture output. A key characteristic of

Chinese agricultural sectors is the large share of non-hired household labor in agriculture and the absence of the labor price, ignoring non-hired labor underestimates input costs, and hence overestimates net revenue. For these reasons, the cost of labor force is removed from the function of net income and will be considered as an independent variable in the Ricardian climate regression. From the above analysis, net revenue in China is modified as pure agriculture output per hectare of agricultural land. For county K in the year y, the net revenue is: where La is the total agricultural area including the cultivated land area, forest area, grassland area, and water area of a county because the pure agriculture output in China includes the output of agriculture, forestry, stock-raising and fishery. 3 Data processing and empirical specification 3.1 Data sources and data processing For the most part, the data are actual county averages, from the IIASA database of LUC project for the period of 1985-1991. Those data are the source for most of the agricultural data used here, including pure agricultural output, irrigated area, land use data, agricultural labor, etc. All of these are at county level in mainland China except Taiwan and Hong Kong. 3.1.1 The dependent variable: net revenue As discussed in the second section, the pure agricultural output per agricultural hectare is used as the net revenue for each county, which can be calculated from formula (9). Table 1 The agricultural net revenue in China (yuan/ha) However, as inflation was very high in the late 1980s in China, the pure agricultural output of each county in different years needs to be modified by price index of gross output value of agriculture (GOVA). In addition, because the price index of GOVA varied much from province to province, it needs to use different indexes in different provinces. The indexes in different years are calculated based on the assumption that the index of 1985, the first year for the analysis, is 1. Table 1 shows the difference between the original agricultural net revenue and modified agricultural net revenue in different years. 3.1.2 Explanatory variables Table 2 shows the explanatory variables and their processing. Table 2 Explanatory variables 3.2 Climate scenarios Three general circulation models (GCMs), i.e., HadCM2, CGCM1, and ECHAM4, are used to simulate China˘s climate change under five climate change scenarios for the periods of the 2020s (2010-2039) and the 2050s (2040-2069) based on data from 310 meteorological stations during 1958-1997[12]. Table 3 shows some information of the GCMs, climate scenarios and simulated climatic factors that would be used to simulate the impacts of climate change on China˘s agriculture which will be discussed in section 4 of this article. Table 3 Three GCMs and climate scenarios 3.3 Units of analysis The units of observations for this analysis are 1275 counties in thirty provinces and autonomous regions of China for the period of 1985-1991, which do not cover all the counties of China. Some counties are removed from our analysis because of changes in administrative divisions and county code˘s variation from year to year. So, first of all, it needs to match the county code in each year to the standard county code. During the match work, some counties are removed from the analysis, which are: (1) the counties that have no county codes in the standard code system, and (2) the counties missing crucial data, such as, pure agricultural output, land use data, climate data, soil data etc. In order to reduce the impacts of non-cropping factors, such as forestry, fishery, and livestock raising, on the agricultural net revenue and emphasize the influence of climate on grain crops, counties in which the arable land area is less than 25% of the total macro-agriculture area (the total area of arable land, forestland, grassland, and water area) are also removed from our analysis. Finally, 1275 agriculture-dominated counties are chosen as the basic observations for this analysis. 3.4 Ricardian regression The data are pooled and county level net agricultural revenues per hectare are regressed on climate, soil, and other controlled variables, such as share of irrigated land, agricultural labor, distance to the market, etc., to estimate the optimum-use value function across different counties. There are 7650 pooled cross-sectional observations. The independent variables include temperature and precipitation terms for spring, summer, autumn, and winter, pH and OM% of soil, slope, elevation, agricultural labor per hectare, share of irrigated land, and distance to market. For each variable, linear and quadratic terms are included to capture its nonlinear effects on agricultural net revenue. On the other hand, we should separate the irrigated agriculture and rain-fed agriculture for the cultivated land and horticultural land because parameters on climate variables in counties that rely heavily on irrigation differ from parameters on climate variables in counties where there is no irrigation. Besides, the cultivated land and horticultural land are more sensitive to seasonal climate variables while forestland and grassland are more sensitive to the annual average climate variables. To illustrate these problems, the agricultural net revenue should be described as: where (C+H)ir and (C+H)rf are respectively irrigated and rain-fed cultivated land and horticultural land, GF is grassland and forestland. Table 4 shows the regression results of the above model, where DM, OM, SLR, ELEV, PSH. GF and TSH.GF are respectively distance to market, organic materials, slope, elevation, annual precipitation for the share of grassland and forestland, and annual temperature for the share of grassland and forestland. It can be seen from the table that the squared terms for most of the climate variables are significant, implying that the observed relationship is nonlinear. However, some of the squared terms are positive implying that there is a minimal production level of those terms and that either more or less of these terms will increase net agricultural revenue according to the observation˘s cu rrent condition. The negative quadratic coefficient implies that there is an optimal level of these climate variable s from which the value function decreases in both directions. For grassland and forestland, precipitation is not sign ificant while temperature is important. For cultivated land and horticultural land, both temperature and precipitatio n are significant except winter precipitation for the rain-fed farmland. The remaining control variables behave large ly as expected. Socio-economic and soil variables play the role in determining the value of farm. Higher slope and el evation lead to land revenue decrease and farther to the market also decrease the value. The characteristics of soil are not significant to the value of farm in China. 4 Simulation the impacts and interpretation of climate coefficien t 4.1 Simulation of net agricultural revenue per hectare According to GCM results based on HadCM2 model runs, the ave rage temperature and precipitation in China under the scenario of HadCM2-gx may increase by 2.5 ?C, 2.3?C, 2.5?C, 2.8?C and 49.3%, 24.2%, 0.6%, 10.2% respectively in winter, spring, summer and autumn in the 2020s[12]. These change s are applied uniformly by region to China in simulating their impacts on the country˘s agriculture. Table 4 Result of Ricardian regression The change of net revenue is simulated by utilizing estimated regression coefficients from th e pooled analysis for each of 1275 counties for the analysis year. County-level changes in net revenue per hectare ar e then aggregated to get a measurement of the net impact for all China as a whole. The change of net revenue per hect are of the given scenario in the year y is given by: where: y is the year 1985, 1987, 1988, 1989, 1990, 1991 (Td, P d) describes the climate for the county d (Td+?TCS, Pd+?PCS) describes the new climate under a simulated climate scen ario Netrevndy (Td, Pd) is the predicted value of the net revenue per hectare for the county d in the year y Netrevnd y (Td+?TCS, Pd+?PCS) is the forecasted value of net revenues under a climate scenario for the county d in the year y Yearly changes in the net revenue per hectare are correspondingly averaged over the period 1985-1991 to yield an aver age net impact. The change in net revenue per hectare is calculated for the new climate for each of the four season s. Table 5 presents these impacts by season. Overall, both rise in temperature and increase in precipitation is benef icial for the increase of net revenue per hectare of China˘s agricultural land. Moreover, net revenues are much mor e sensitive to temperature than to precipitation. Table 5 Changes in net revenue (1990) by seasonal temperature and p recipitation (yuan/ha) As shown in Table 5, there is significant seasonal variation in both temperature and precipita tion effects. Temperature rise in all seasons except spring is positive. Summer and autumn temperature effects are po sitive because warmer temperature during these two harvest seasons may facilitate the ripening process and ensure opt imal crop production. Positive winter temperature effect could be the result of increasing the growing period by warm er winter. Warmer spring not only makes the winter crop grow too quickly, which leads to increasing the incidence of pests and insects that reduce the production, but also causes high evaporation of soil water which would increase th e damage to crops by spring drought that happens frequently in China. Increase of precipitation in winter and autumn is beneficial. More precipitation in winter can increase soil moisture for the winter crop. Autumn precipitation is g ood for planting winter crop. The negative effect of rainfall increase in summer is expected for a summer-dominated r ainfall climate regime. It may lead to more flood disasters in China. Although more precipitation in spring is negati ve, the impact is practically negligible. This is because the impact changes a lot in different regions of China.

4.2 Spatial variation of seasonal impacts The wide-ranging effects described above suggest that climate change is no t risky to China˘s agriculture on the whole. However it does not protect local areas, as China has so many differen t climate types. So, the regional variations in temperature and precipitation in each season have been discussed. Fig ures 1-8 exhibit the regional distribution of net revenue changes per hectare in different seasons. In winter, all o f China has positive impact from temperature increase (Figure 1). The most benefited areas are the North China Plain and the Northeast China. This is because in the northern part of China, the warmer winter may prolong the growing per iod. The warmer winter in the southern part may be beneficial for the farmers to produce more fruits and vegetables.

Spring temperature effects are negative to most parts of China, only some counties in the northern part of the Northe ast can benefit from warmer spring (Figure 2). This may indicate that in the northern part of China, warmer spring ma y cause wheat to grow too quickly and intensify spring drought. For the southern part, since it is warm enough, the t emperature rise in spring may be too high for crops growing there. Distribution of summer temperature and autumn temp erature effects is almost opposite. Warmer summer is good for the Northeast, the Northwest and the Loess Plateau whil e warmer autumn is harmful to these regions. However warmer summer is harmful to the North China Plain, the Yangtze R iver Delta and the Sichuan Basin while warmer autumn is beneficial to these regions (Figures 3 and 4). Figure 1 Impac t of winter temperature in China in the 2020s Figure 2 Impact of spring temperature in China in the 2020s Figure 3 Im pact of summer temperature in China in the 2020s Figure 4 Impact of autumn temperature in China in the 2020s The effe cts of precipitation in winter and spring almost have the same regional distribution. For the Northeast, the Loess Pl ateau, and the Yangtze River Delta, they may benefit from the increase of winter and spring precipitation, while the North China Plain, Northwest and South China may have negative effects from the increase of winter and spring precipitation (Figures 5 and 6). This implies that winter and spring precipitation almost have the same effect direction in one region. But the effect of winter precipitation is much more than that of spring. The increase of summer precipitation benefits the North China Plain and Northwest China, but is harmful for the Northeast, the Loess Plateau, the Yangtze River Delta and the Sichuan Basin (Figure 7). Increase of autumn precipitation has different impacts on different parts of China. It is negative in the Northeast, the Loess Plateau and southern Sichuan Basin while positive in the Northwest, the North China Plain, and the southeastern coastal area of China (Figure 8). Figure 5 Impact of winter precipitation in China in the 2020s Figure 6 Impact of spring precipitation in China in the 2020s Figure 7 Impact of summer precipitation in China in the 2020s Figure 8 Impact of autumn precipitation in China in the 2020s 4.3 Regional distribution of annual total impacts The results based on the runs of three GCMs and five scenarios mentioned in section 3 are applied by county to simulate their impacts on Chinaˇs agriculture. Table 6 shows the impact of regional distribution of climate change on Chinaˇs agricultural net revenue under different models and different scenarios in the period of the 2020s (2010-2039) and the 2050s (2040-2069). Table 6 Changes of agricultural net revenue under different climate change scenarios in the 2020s and the 2050s (Yuan/ha) It can be seen from Table 6 that all scenarios except cggs would have positive effect on Chinaˇs agriculture. Moreover, the opposite effect from cggs is less than the most positive effect. On the other hand, different regions have different reactions to climate changes. Results from all scenarios (Table 6) show that northern China including North, Northeast, Northwest and the Qinghai-Tibet Plateau (excluding Tibet) always benefit from climate change. In East, Central, South and Southwest China, there are different results from different scenarios. Most scenarios indicate that climate change would be harmful to South China but beneficial to East and Central China. Although only one scenario shows the opposite effect in Southwest, the region is the highest of the eight regions in terms of uncertainty. 5 Conclusions and discussion The Ricardian approach is a feasible alternative method to provide an assessment of the economic impacts of climate change on agriculture. But it needs to be modified in China according to the database and characteristics of the countryˇs agriculture. The Ricardian approach is not offered as a replacement for other methods, such as production function approach, instead as a complement for cross-checking each other. Besides, when using Ricardian approach in China, we face the difficulties on how to measure input price, wage, and marginal contributions of family labor and animal work. These prices are crucial for the calculation of net revenues. Therefore, other alternatives are necessary for cross checking each other. Findings from the study indicate that climate change will have an overall positive impact on Chinaˇs agriculture, with varying seasonal and regional implications. The regions in northern China and the temperate zones are likely to benefit from climate change while the regions in the southern part, especially the tropical and sub-tropical zones, will probably suffer losses. With the benchmark climate scenario, we calculate the impact to increase by 135.39 yuan in net revenue per hectare for the average of China. We also calculate separately the effects of the rise in temperature as well as the increase in precipitation. We find that both rise in temperature and increase in precipitation are beneficial for Chinaˇs agriculture and the impact of temperature is much more than that of precipitation. However, either temperature impact or precipitation impact varies seasonally and regionally. Just as any new technique, there are still some problems which need to be studied further. 1) Some omitted variables may play an important role in agricultural net revenue. Labor force is one of these variables. At first we took into account of labor force in the Ricardian regression model. We found that when we used it as a variable, many other variables did not behave as expected, such as higher elevation and slope leading to higher farm value, which is obviously wrong. When we removed it we got the result as we expected. This problem may be the results of data source that does not include the input of non-hired household labor. Therefore, it is not to say that labor force is not important for net revenue. For the further study, we need to take it in each county into account as an important variable and to find out how to calculate the input of labor force. 2) The effects of CO_2 fertilization should be included, for some studies indicate that this may lead an increase in yield. 3) This paper only examines the existing farm and does not explore the possibility that climate may affect whether land is farmed or not. As for analyzing the overall impact of climate change on Chinaˇs agriculture, it also needs to analyze climate effects on the fraction of land farmed. 4) China is so big that the regions differ greatly in the effects of temperature and precipitation on agriculture. It seems too rough to put 1275 counties in one pool to take regression. For the further study, if regressions are done separately in different big regions, such as Northeast, Southwest, North China, etc., the results probably gear to actual circumstances much better. References

关键词： climate change; Ricardian model; China´s agriculture