Extreme weather, food security and the capacity to adapt – the case of crops in China

Taoyuan WEI[1], Solveig Glomsrød[2] and Tianyi ZHANG[3]

Abstract

Three extreme weather scenarios are examined for agriculture in China in this study. One scenario assumes a year when every province has precipitation corresponding to the lowest level experienced in the province over the last three decades. Another scenario assumes the highest experienced precipitation for every province is happening; and the last one assumes that the most harmful level of precipitation on crops occurs for every province – whether too little or too much. We study the role of autonomous adaptation by farmers and through markets as embodied in a computable general equilibrium model. The results show that observed extreme impacts of precipitation on crop harvests are not serious for China at national level. The maize harvest is the most negatively affected with a reduction of 4% without adaptation and less than 1% reduction with adaptation. However, the impacts within a province may be serious and even become worse with adaptation. Good harvests might not make farmers better off due to lower crop prices even though consumers benefit. Sensitivity analysis shows that the ability to adapt assumed in the analysis may not be present in the short term.

Keywords: Chinese agriculture, Climate change, precipitation, harvest, yield, general equilibrium, autonomous adaptation

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[1] Author address: Center for International Climate and Environmental Research - Oslo (CICERO), P.O. Box 1129 Blindern, 0318 Oslo, Norway (tel: +4722858504; e-mail: taoyuan.wei@cicero.uio.no).

[2] Author address: Center for International Climate and Environmental Research - Oslo (CICERO), P.O. Box 1129 Blindern, 0318 Oslo, Norway (e-mail: solveig.glomsrod@cicero.uio.no).

[3] Author address: State Key Laboratory of Atmospheric Boundary Layer Physics and Atmospheric Chemistry, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing 100029, China (Email: zhangty@mail.iap.ac.cn).

1. Introduction

Climate change and associated extreme climate events has potentially endangered agricultural production and highly impacted the agricultural economy in China (Piao et al. 2010; J. X. Wang 2009). Recurrent droughts and floods have adversely affected crop production. Droughts are affecting around 17% of the sown area every year, whereas the area exposed to floods doubled from 5Mha per year in the 1970s up to 10 Mha per year in the 2000s (Piao et al. 2010). These crop failures have stressed Chinese agriculture and food supply at the regional level. A recent study shows that variation in precipitation is one of the key climate variables driving the change in grain yields in China over the last 30 years (Zhang and Huang 2012). Hence, a critical question is whether the impacts of precipitation on grain harvests will threaten Chinese food security and to what extent adaptation can counteract the impacts.

Climate models project increases in precipitation across most of China, averaging from 5% to 7% by 2050 compared with 1961-1990 (Li et al. 2011). Under the IPCC Representative Concentration Pathway (RCP) scenarios[4], precipitation in northern China tends to increase more than in southern China and precipitation might decrease in southern during 2011-2040 (Xu and Xu 2012). However, the projections are uncertain and subjects to considerable changes from one climate model to another. This motivated us to consider extreme weather scenarios based on historical observations.

The impacts of climate change on agriculture are estimated to be almost neutral for China as a whole (Cline 2007; J. Wang et al. 2010). However, the negative impacts

[4] See http://tntcat.iiasa.ac.at:8787/RcpDb/dsd?Action=htmlpage&page=welcome.

may be underestimated as the consequences of extreme weather, such as droughts and floods, are not accounted for. Generally extreme weather only appears in a limited area and results in serious local damage. Its impacts in a large area such as a province might be small. In addition, the impacts of extreme weather are different at the province level due to various climatic situations and agricultural production technologies (Zhang and Huang 2012). When observing or forecasting the impacts of precipitation, farmers might take some adaptation measures to counteract the impacts (Vermeulen et al. 2012; Tao and Zhang 2010).

According to the fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC 2007), adaptation can be divided into autonomous adaptation and planned adaptation. Autonomous adaptation is the ongoing change in farm practice in response to the changes in climate as experienced. Planned adaptation, on the other hand, means mobilizing production institutions and policies to adapt through investment in technology and infrastructure. In this study, we consider autonomous adaptation through economic behavior embodied in a computable general equilibrium (CGE) model GRACE (Aaheim et al. 2012). GRACE stands for Global Responses to Anthropogenic Change in the Environment and the model GRACE is aiming for long-term economic analysis of climate change impacts and greenhouse gas abatement policy (Aaheim and Rive 2005).

GRACE captures two types of autonomous adaptation. One is factor substitution within the production activity of each industry. The change in precipitation will affect the productivity of crop land. Other things being equal, a change in land productivity means that farmers maximizing on-farm net income can be better off by substituting land with other factors such as labor and man-made capital. The other type of autonomous adaptation is the market responses to the impacts. The extreme weather will affect crop supply and change the market prices to which farmers and consumers adjust.

Both types of adaptation may differ substantially at the provincial level since the impacts of precipitation on crops and socio-economic characteristics like cost of labor are different among provinces. Hence, it is also important to study the regional variation of the impacts.

In the present paper, we assess the effects of precipitation on grain harvests in three extreme scenarios to identify the role of autonomous adaptation. We firstly estimate statistically the effects of precipitation on crop yields at the provincial level, adjusting for the influences of changes in production factors based on data from 1980 to 2008. Secondly, having isolated the effects of precipitation on crop yields we estimate the grain losses (or gains) by province if only the precipitation differs from an economic reference scenario. The reference scenario represents a hypothetical yearly economy where each province receives the same amount of rainfall as its average during 1980 to 2008. Finally we estimate the grain losses (or gains) with adaptation embodied in the GRACE model.

All the scenarios designed in this study are based on historical records of precipitation over the last three decades and a snapshot of the economy in 2007. Hence, all the scenarios have the same economic settings as in 2007 except the precipitation by province. As the extreme precipitation event of any province in the scenarios has been recorded in the recent three decades, the scenarios represent the most extreme situations at the national level, where the extreme outcome in every province is a result of real events from earlier experiences.

2. Data and methods

2.1. Data sources

Data on the three main crops of rice, wheat, and maize from 1980 to 2008 are collected and calculated from China's agricultural statistical yearbooks. These data include yield and cultivated area of rice, wheat and maize by province. Crop growth months are derived from the Chinese Agricultural Phenology Atlas and historical climate data are obtained from the China Meteorological Administration. These data are used for statistical estimation of relations between crop yield and precipitation by province.

To assess the impacts, taking autonomous adaptation into account, we use the GRACE model based on the Global Trade Analysis Project (GTAP) v8 database (Badri et al. 2012) combined with the input-output table of China 2007 (NBSC 2009). In addition, crop harvest data (NBSC 2008) and the regional input-output tables of 2007 (NBSC 2011) are used to decompose crop production to the provincial level.

2.2. Statistical analysis

After comparing with previous studies on climate change impacts on crop yields in China, Wei et al. (2014) show that the average precipitation by province changes slightly during 1999 - 2008 compared to that during 1980 – 1989 due to small changes in average precipitation between the two ten-year periods. Hence, the precipitation has marginal effect on crop yields in China over the period. However, the inter-annual variation of precipitation is much larger than that of temperature and precipitation may dominate the estimated climate change impact on crop yields. The dominant role of precipitation has been noticed and discussed by a previous analysis on relationships between crop yields and key climate variables from 1980 to 2008

(Zhang and Huang 2012). Their results show a clear spatial distribution for the correlation between crop yield and changes in precipitation. Generally, higher precipitation was associated with higher rice yield in northern and southwestern China and lower rice yield in other regions. For wheat, higher precipitation reduced yield in eastern, central and southern China. In contrast, higher precipitation always increased maize yield. Crop production was affected much more strongly by drought than floods in northern China and more weakly in southern China.

As the present paper focuses on impacts of extreme weather events on crop production, we follow the approach of Zhang and Huang (2012) to estimate the effects on crop yields in the cases of extreme precipitation even though this might exaggerate the impact of precipitation as the estimated impacts of precipitation may capture effects of other key climate and socio-economic variables in China. In addition, the statistical relationships may be uncertain due to various reasons such as errors in climate data (Lobell et al. 2008) and nonlinearity of the relationships (Wei et al. 2014; Schlenker and Roberts 2009).

We adopted a linear regression approach to estimating the relations between precipitation and crop yields at the provincial level based on a 1980-2008 time series. For a province and a single crop in mainland China, we have

$$\Delta Y = \hat{\alpha} + \hat{\beta} \Delta P, \tag{1}$$

where ΔY is changes in yearly crop yield; ΔP is changes in yearly average precipitation during the season of crop growth; $\hat{\alpha}$ is the estimated intercept and $\hat{\beta}$ is the estimated partial impact of one unit change in precipitation on crop yield. This first difference approach (Nicholls 1997) is commonly adopted to remove the effects of the trends in time series and minimize the influence of non-climatic factors such as irrigation and crop management.

By multiplying the estimated slope $\hat{\beta}$ with changes in precipitation, we can calculate total partial impact of precipitation on crop yield. The impact on total crop harvest in a year is then calculated as the impact on crop yields multiplied by cultivated crop area, which is assumed to be the same for all the scenarios[5].

2.3. CGE approach to adaptation

Over the past three decades, a long-term adaptation for the extreme precipitation cases is unlikely to take place as the long-term precipitation (e.g. over ten-year periods) changed only slightly in China. If an extreme precipitation case becomes more frequent in the future, crop producers may autonomously adopt certain long-term adaptation measurements such as more irrigation infrastructure and other socio-economic inputs. If so, the marginal impact of precipitation identified by the statistical analysis above can be taken as the impact before any long-term adaptation measurements are adopted. To estimate the impact with the autonomous adaptation measurements, a computable general equilibrium (CGE) model is suitable as these measurements are embodied in decisions by farmers and other economic agents as represented by the model.

In the CGE model GRACE (Aaheim and Rive 2005), the precipitation is assumed to change land productivity in farming. This triggers input factor substitutions, leading to changes in crop harvest and price. The disturbance penetrates the whole economy through the market mechanism. Since 1978, China has transformed from a centrally-

[5] This assumption is somewhat arbitrary since it excludes the impact of precipitation on the boundary of cultivated crop area.

planned economy to a more efficient market economy where prices play the dominant role in the whole economy including food production and consumption (Liu et al. 2012; Zhuang and Abbott 2007; Park et al. 1994).

In this study, China's provincial agriculture and national economy is modeled as a separate region within the global economy. China and the rest of the world (ROW) each specify 14 production activities including 3 crop sectors: rice, wheat, and maize. Each of the 3 crops is produced by 31 provincial representative farmers. In the GRACE model, producers pursue profit maximization and consumers pursue utility maximization, by assumption having access to perfect information on the market mechanism, price signals, and other external constraints for their decision.

The production of crops as well as other goods is the outcome of a nested structure of equations with a constant elasticity of substitution (CES) function at the top, aggregating the contribution of natural resources (RES) and other inputs to highlight the high dependence of crop production on natural resources (Figure 1). At the middle level, these other inputs are represented as an aggregate of intermediate goods and value added, where the value added combines capital (CAP) and labour (LAB). A parameter with its names starting with a small "e" indicates the elasticities of substitution.

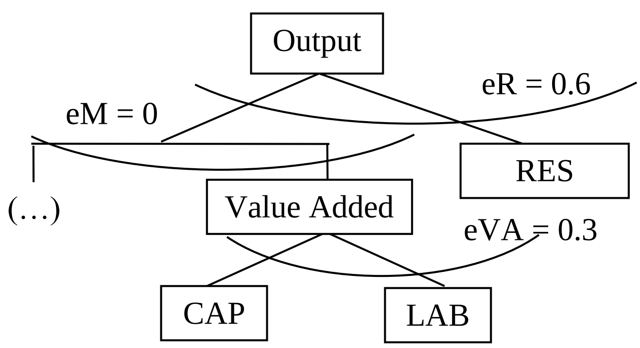


Figure 1: Production structure of agricultural goods

More details on the data processing and modeling work are provided in the Appendix.

We emphasize two advantages of using a CGE model. One is related to the endogenous crop prices. Climate impacts on agriculture might affect non-agricultural activities through the food prices and wage level. A CGE model captures the adjustment by food consumers to changes in crop production and market prices as determined by behavior of both demand and supply sides. The other advantage of a CGE model relates to the input factor constraint on crop production. A CGE model assumes exogenous supply of productive resources in the whole economy and allows certain input factors like labor and produced capital to flow between agriculture and other production activities. These two advantages enable us to capture the *autonomous adaptation* to climate change.

Scenarios

In the model base year 2007, the precipitation of a province generally does not correspond to the average level of the period 1980-2008. We deal with this by calibrating the base yearly economy to match this average level of rainfall, i.e., mimicking the impacts of the average precipitation on the Chinese economy of 2007. This modified economic 2007-scenario represents the "reference scenario" in our study.

In addition to the reference scenario, we consider three extreme scenarios for the base year economy by introducing impacts on crop yield of the observed lowest precipitation (low.pcp), highest precipitation (high.pcp), and the most negative (neg.pcp). The low.pcp scenario assumes that the lowest yearly precipitation in each province during 1980-2008 occurs simultaneously for all provinces in the modified base year (2007). Accordingly, the precipitation of provinces in the low.pcp scenario is only 50-80% of their yearly average.

The high.pcp scenario goes to the other extreme and assumes that the highest yearly precipitation in each province happens simultaneously with precipitation at 120-170% of the yearly average in provinces except for wheat in Guangxi (over 200%) and in Guangdong (over 300%). However, these exceptions have very limited impact on the total wheat harvests as little wheat is produced in these two provinces[6].

The neg.pcp scenario assumes that the most negative impact of precipitation of each province happens simultaneously in the base year. The most negative impact could be caused by either the lowest or the highest yearly precipitation in a given province.

The study is essentially comparative since inputs to GRACE other than provincial precipitation are constant for all scenarios including the reference scenario. Hence, any difference of results between scenarios should be attributed to the difference in provincial precipitation and associated yield and adaptation. In the reference scenario, farmers are assumed to produce crops in an optimal scale and with optimal mix of inputs such that they can maximize profit within market and weather conditions. When the impacts of precipitation on land productivity are observed or expected, the production in the reference scenario is no longer optimal and the farmers pursuing profit maximization will adjust their practice to reach a new optimal point.

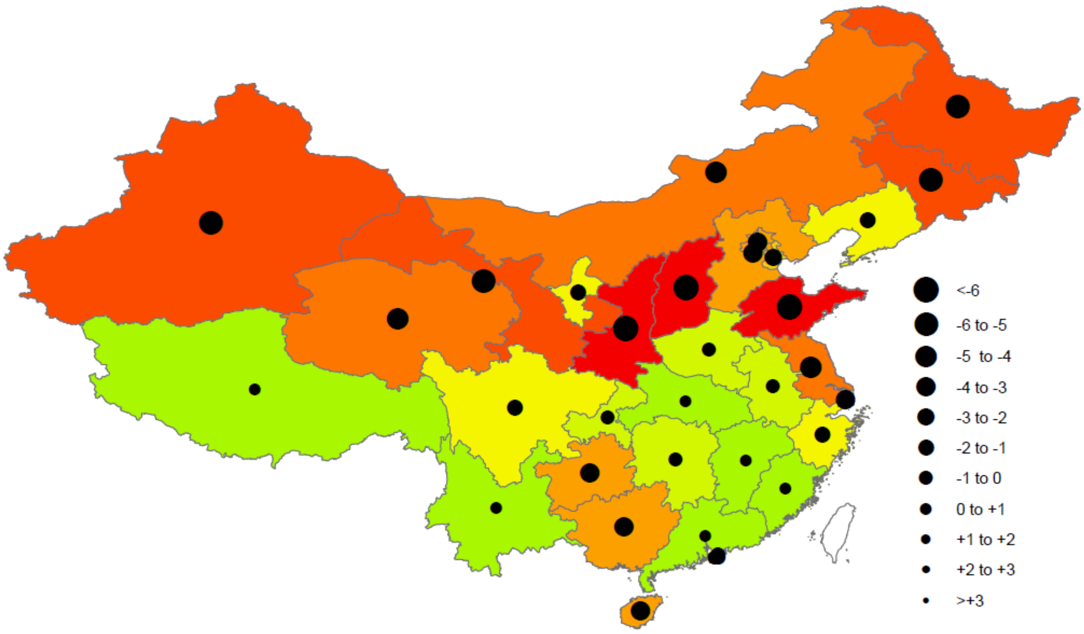
[6] They account for less than 0.01% of national wheat harvests in 2007 (NBSC 2008).

3. Results and discussion

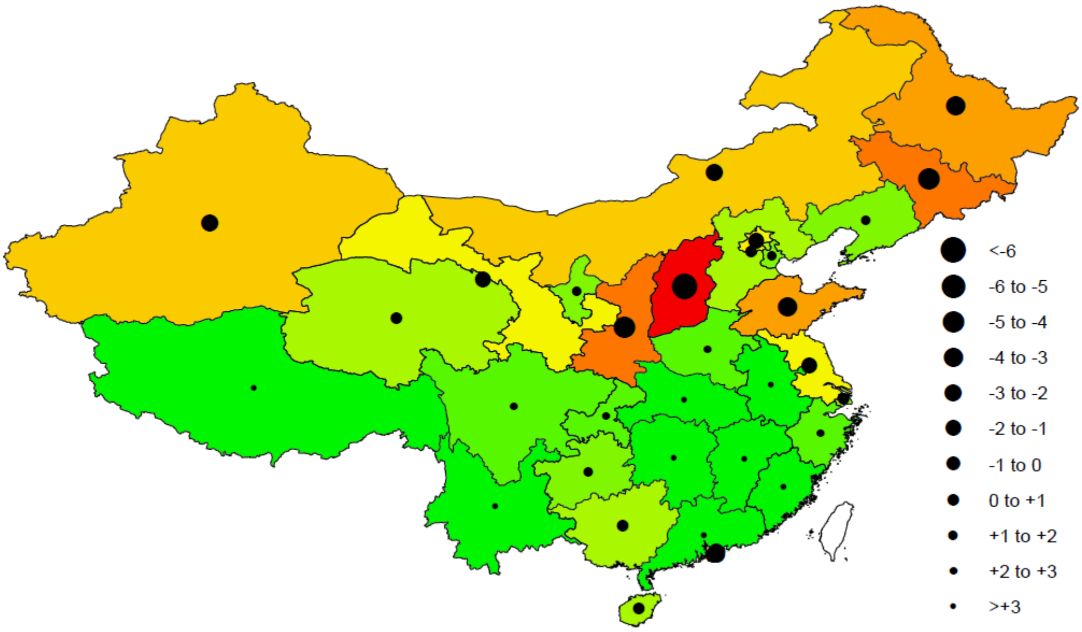
3.1. Impacts on crop harvests by regions

The impacts of precipitation clearly differ across provinces as illustrated by Figure 2, presenting the provincial impacts on maize harvests with and without adaptation in the neg.pcp scenario. The figure shows percentage deviations from the reference scenario, which corresponds to the historical average precipitation level. The negative impacts on maize harvests are stronger in the north than that in the south, with or without the adaptation. As maize is mainly produced in the north, the negative impacts on northern maize harvests dominate at the national level. With adaptation, the negative impacts are smaller than without adaptation for all involved provinces. The most vulnerable province is Shanxi, where the negative effects on maize harvests are as large as 13% without adaptation and 8% with adaptation.

To facilitate the communication of results, we combine the 31 provinces into 7 regions as shown in Figure 3 and report the impacts of precipitation by region instead of by province. Table 1 lists the regional shares of crop harvests in the reference scenario, i.e., if the average precipitation of each province occurs simultaneously in 2007.



(a)



(b)

Figure 2. Impacts of precipitation on maize harvests in the most negative (neg.pcp) scenario without adaptation (a) and with adaptation (b): solid circles indicate the percentage deviations from reference scenario

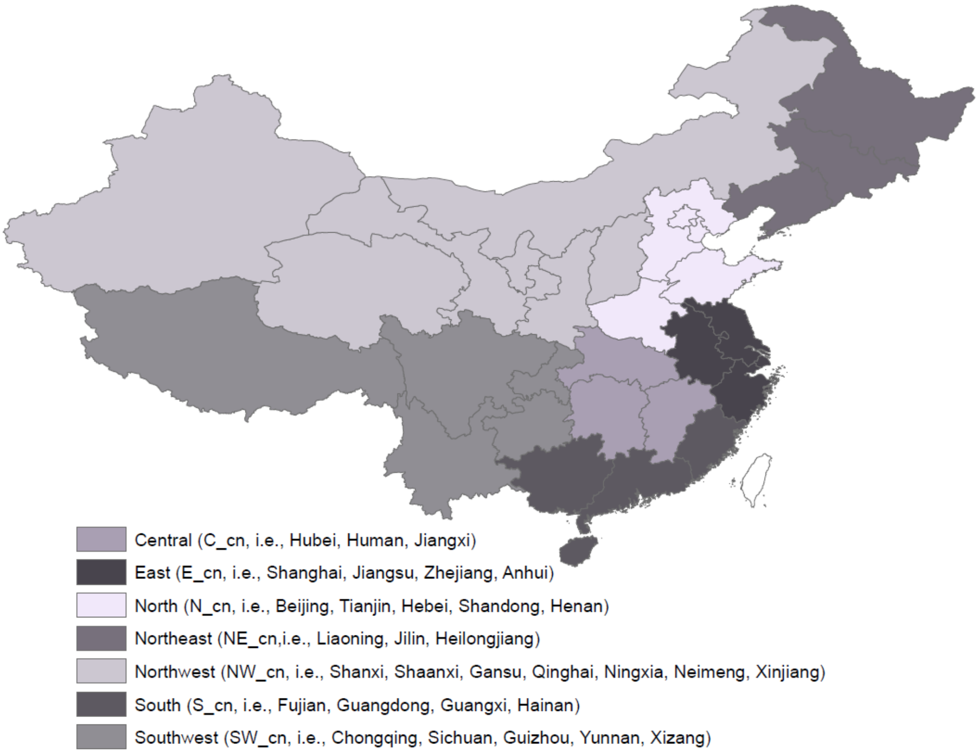


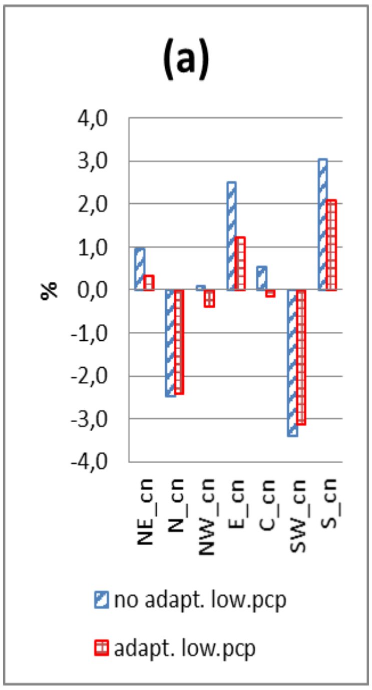
Figure 3. Seven regions used in the analysis

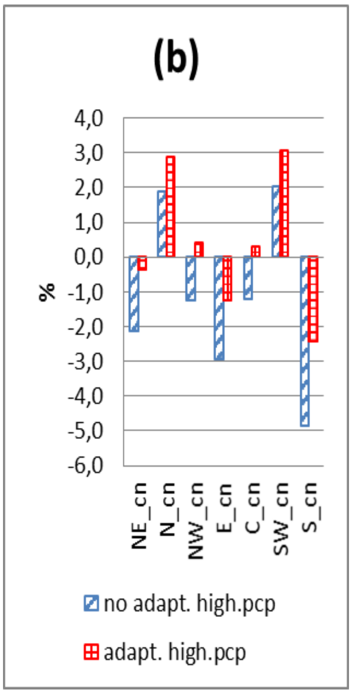
Table 1. Regional shares of crop harvests in the reference scenario (%)

Region	Rice	Wheat	Maize
Northeast (NE_cn)	13	1	30
North (N_cn)	3	57	32
Northwest (NW_cn)	1	13	20
East (E_cn)	21	19	3
Central (C_cn)	31	3	2
Southwest (SW_cn)	16	6	11
South (S_cn)	15	0	2
China	100	100	100

Rice

Rice is produced quite evenly over the whole country (Table 1) except that very little is produced in the North and Northwest.





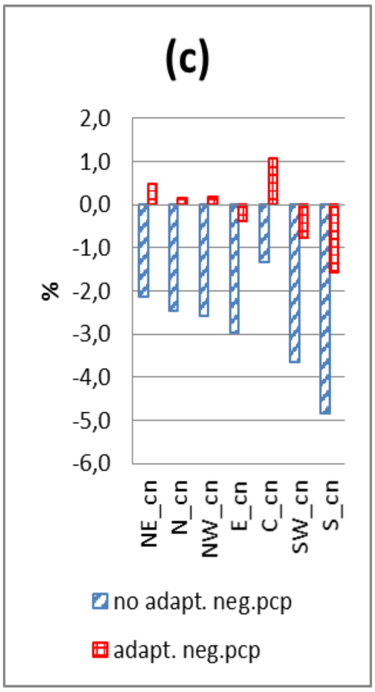


Figure 4 shows the impacts of precipitation on rice harvests. The low.pcp scenario has positive impacts are positive in main rice producing regions without adaptation (except Southwest) since the average precipitation in these regions is already sufficient and above the optimal level for rice growth. Adaptation reduces the positive impacts to some extent. Particularly in the Central Region, the positive impact without adaptation becomes slightly negative due to reduced input of other factors in the rice production.

The high.pcp scenario is the opposite. The impacts without adaptation are negative in the main rice producing regions except the Southwest. With adaptation all the negative impacts are reduced considerably but remain negative. On the other hand, a positive impact in the Southwest is enhanced because of increased food demand from regions suffering crop decline.

In the neg.pcp scenario, the effects of adaptation become more pronounced. Without adaptation, the rice harvests in all regions are expected to decline as the precipitation causing the most negative impacts. Farmers respond by taking counter-measures to reduce the negative impacts. Finally in 4 of the 7 regions slightly positive impacts appear when adaptation is considered.

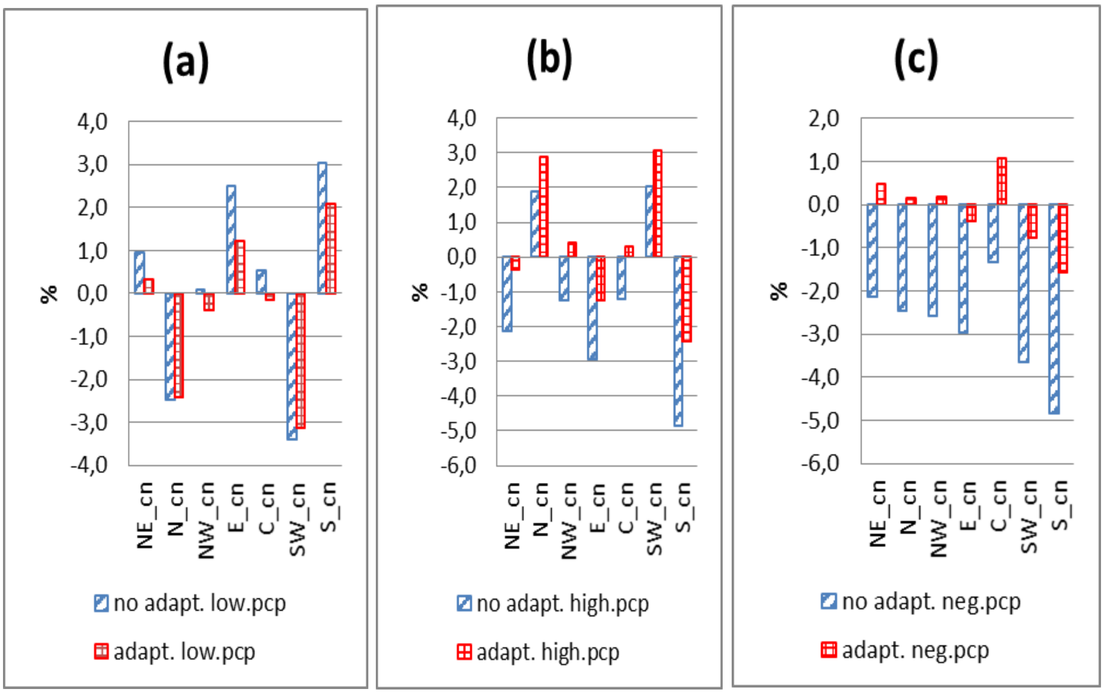


Figure 4. Impacts of precipitation on rice harevsts: deviation from the reference scenario: (a) the low.pcp case; (b) the high.pcp case; and (c) the neg.pcp case.

Wheat

In the reference scenario (Table 1), nearly 60% of wheat harvests are grown in the North, nearly 20% in the East and 13% in the Northwest. The national wheat harvest is mainly determined by the production in these three regions.

Figure 5 shows the impacts of precipitation on wheat harvests. Unlike rice production in the North (N_cn), which is affected quite substantially by precipitation without adaptation, the wheat production in the North is only modestly affected by precipitation even without adaptation. Considering the large share of this region in the wheat harvest, we would therefore only expect modest harvest impacts for wheat in the country as a whole in the three simulated scenarios. The impacts on wheat harvests in the East and Northwest are considerable without adaptation, particularly in the East, reaching 14% below the baseline in the high.pcp and neg.pcp scenarios. Unlike in the Northwest, more precipitation does not benefit wheat in the East as precipitation on average has been sufficient in the last three decades.

With adaptation the impacts of precipitation decrease considerably in the low.pcp scenario. In the North, less rain is no longer harmful for wheat production - the impact is almost neutralized by adaptation. In the East, less precipitation enhances wheat production. Even with adaptation, the positive impact on the harvest is still 4% and considerable. On the contrary, in the Northwest region, less precipitation is really bad for wheat in the region. The negative impact of about 3.5% of the regional harvests is only slightly moderated by adaptation. In other words, the negative impacts in this region to some extent cancel out the positive impacts in the North and East.

In the high.pcp scenario, the impacts are the opposite. Strong negative impacts are observed in the East with a 14% reduction of regional harvests without adaptation and

8% reduction after adaptation. In the North, the modest negative impact without adaptation turns into a positive effect after adaptation and the positive impact without adaptation in the Northwest is enhanced after adaptation.

In the neg.pcp scenario, the impacts without adaptation for all regions are negative due to our definition of this scenario, where we assume that there is a shortage of rainfall in the Northwest but surplus rain in both the North and the East. With adaptation, the wheat harvests in the North and Northwest are even higher than in the reference scenario, particularly in the North, where the harvest is nearly 2% above the reference scenario. The positive impacts of adaptation on harvests fully cancel out the negative impact in the East, keeping the national harvests very close to the national average level.

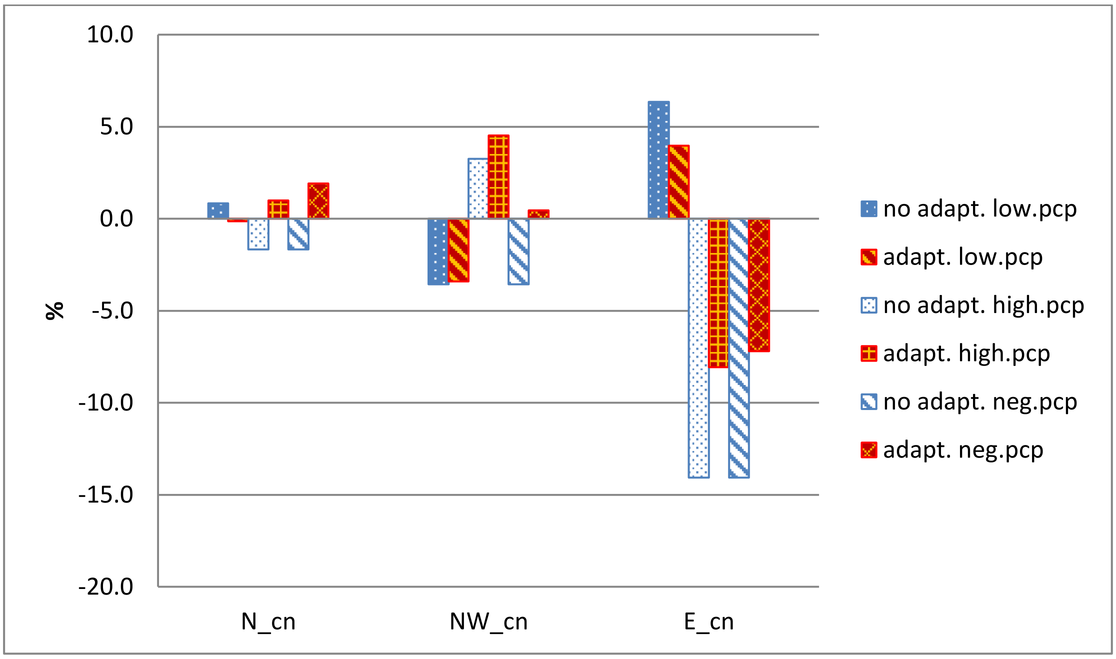


Figure 5. Impacts of precipitation on wheat harevsts: deviation from the reference scenario

Maize

In the reference scenario (Table 1), the maize harvests in the North and Northeast account for 32% and 30% of the whole country respectively. Other main production regions are the Northwest (20%) and the Southwest (11%). Hence, more than 80% of maize harvests are from the three northern regions.

Figure 6 shows the impacts of precipitation on maize harvests. Among the three crops, maize harvest is the most sensitive to the amount of rain. Without adaptation, less rainfall is always bad for maize in the main four regions: the three northern regions and the Southwest. Hence, the neg.pcp scenario is similar to the low.pcp scenario for maize[7].

Adaptation reduces the negative impact considerably in all the main four regions and for all the scenarios. For maize in the low.pcp scenario the negative impacts become less or even slightly positive after adaptation (North, Southwest). However, adaptation does not enhance maize harvests in the high.pcp scenario since positive impacts are considerably reduced or even turn to be negative in the Southwest (SW_cn).

[7] At the provincial level, the neg.pcp case is not the same as the low.pcp in several provinces, such as Henan in the North (N-cn).

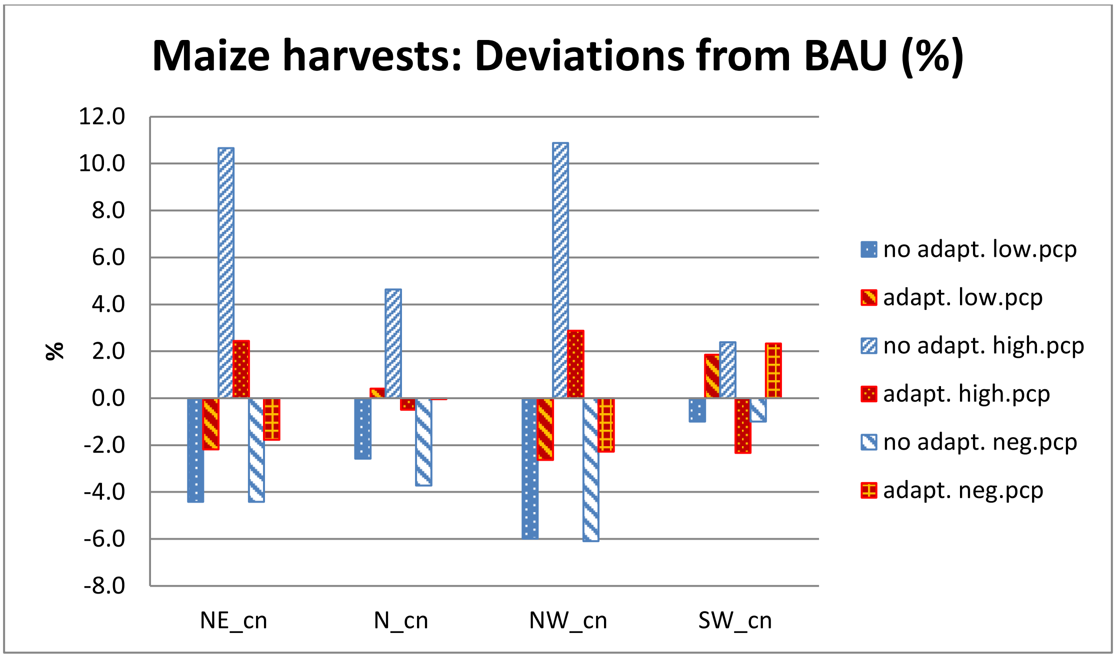


Figure 6. Impacts of precipitation on maize harevsts: deviation from the reference scenario

3.2. Impacts on harvests at the national level

The impacts of precipitation on national harvests are modest for each of the three main cereal crops even though impacts without adaptation are considerable in some cases. In general, the impacts are moderated to a large extent when adaptation is considered in the simulated scenarios (Figure 7).

To illustrate how strong the impacts are, we can compare national harvests of the scenarios with the trends of harvests of the 3 cereal crops in China over the last decades. In the 1980s, the annual growth rates of harvests were 3.1%, 5.9% and 4.5% for rice, wheat and maize, respectively. Since 1990, the harvests of rice and wheat have fluctuated around an average level while the harvests of maize kept increasing by 3.1% annually during 1990-2010 (NBSC 2010).

In the low.pcp scenario, the impacts of precipitation without adaptation are positive for both rice (0.65%) and wheat (1.05%) but markedly negative for maize (-3.28%).

However, after adaptation the impacts are modified and almost canceled out for both rice and wheat. The negative impact on maize is reduced to only half a percent, but not totally compensated through adaptation.

In the high.pcp scenario, more precipitation is harmful for both rice and wheat but very helpful for maize. Adaptation almost cancels out the damage for both rice and wheat. The impact for maize is still positive but reduced from over 7% to around 0.5%.

In the neg.pcp scenario, the direct impacts on harvest are markedly negative for all the three crops but modified through adaptation to be slightly negative for both rice and wheat while still somewhat negative for maize.

Figure 7. Impacts of precipitation on Chinese cereal crop harvests: deviation from the reference scenario

3.3. Discussion

Maize is the most sensitive of the three cereals to precipitation, followed by wheat. Less precipitation is good for both rice and wheat but bad for maize at the national level. In all the three extreme scenarios, the impacts on harvests at national level become trivial for both rice and wheat but marked for maize even after the adaptation is taken into account.

Why are the impacts reduced after the adaptation is considered? The adaptation is driven by two opposing forces. One is the market responses to climate impacts on cropland productivity, changing the optimal composition of factor demand. As a consequence, both factor and crop prices will be affected (Figure 8). As demand for food is relatively inelastic to price compared with other goods, the changes in crop prices may be considerable and encourage the farmers to increase or decrease production correspondingly. In some cases as shown above, the effects of market responses may be so strong that a harvest loss without adaptation increase prices, which turn the loss into a harvest increase after adaptation, and vice versa.

The other driving force is the input factor substitution within crop production. If negative impacts without adaptation are observed or expected, the farmers take counter-measures, for instance, labor use for drainage or other methods to reduce the impacts. On the other hand, if the positive impacts without adaptation are observed or expected, the farmers might also save costs by using less input of factors such as fertilizer and labor.

In China, the irrigation and drainage system will be efficient in overcoming the negative impacts of precipitation. Irrigation can explain why the negative impacts are reduced considerably through adaptation. When rainfall reduces crop supply, higher crop prices will increase use of input factors in crop production.

On the contrary, if the impacts are positive, fewer efforts are necessary to sustain the harvests. The positive impacts increase supply of crops forcing prices downwards.

Expecting lower prices, the farmers also reduce inputs in crop production. Both effects dampen the positive impacts of precipitation as seen without adaptation. In some cases the positive impacts might become negative after adaptation is considered.

At the regional level, however, the above analysis may be violated if a region does not dominate the production of a crop. For example, the positive impacts of less rain on maize are enhanced in the East and Central regions in the low.pcp scenario because of the negative impacts at the national level, leading to a higher maize price in a unified national market.

4. Welfare implications

Market implication

After autonomous adaptation the crop prices and supply settles as shown in Figure 8. For rice and wheat the harvests are practically unaffected in the three scenarios, whereas prices are declining somewhat in the low precipitation scenario and increasing 0.3-1.3 % in the other scenarios. For maize the low precipitation reduces the harvest, which comes with a price rise of 1.7 per cent. The negative scenario is similar, but with slightly stronger impacts. Maize production benefits from high precipitation and harvest increases by 1.5 per cent.

For rice and wheat, the prices increase markedly although the harvests are reduced marginally. In most cases prices and levels of harvests move in opposite direction, and price effects more than compensate for changes in volume, as clearly seen for maize. For wheat and rice the price effect is, however, particularly strong compared with the effect of climate on production. If consumers want to switch from more expensive maize to the other crops in the low precipitation scenario, the prices of other grains would be expected to increase, but in fact, they decline. The reason is the budget effect of higher maize prices – increasing the share of income spent on maize reduces the capacity to consume the other goods, including rice and wheat. In the high precipitation scenario the maize yield is increasing, prices decline and the budget effect enhances capacity to increase other food consumption. In this case, the prices on rice and wheat increase markedly. For maize the negative scenario is similar to the low precipitation scenario, but with somewhat lower harvest and higher price. In this case, it seems that the substitution effect dominates and consumers tend to switch to other grains so that the prices increase also with some help from slightly lower harvest of the other two crops. Price effects tend to be strong because the demand for food is relatively inelastic. In our study, the area for cultivation of the each crop is also fixed by province, thus contributing to the marked price effects.

Income of farmers

One might expect that the negative impacts on land productivity means less income for farmers. However, it is generally opposite since demand for crops is relatively inelastic to prices, i.e., prices always change in the opposite direction and to a larger extent than harvests in a scenario (Figure 8). For example in the low.pcp scenario the reduced maize harvest leads to a markedly higher maize price and higher income for farmers. On the contrary, a good harvest does not mean high income for the farmers even though it benefits consumers and food security.

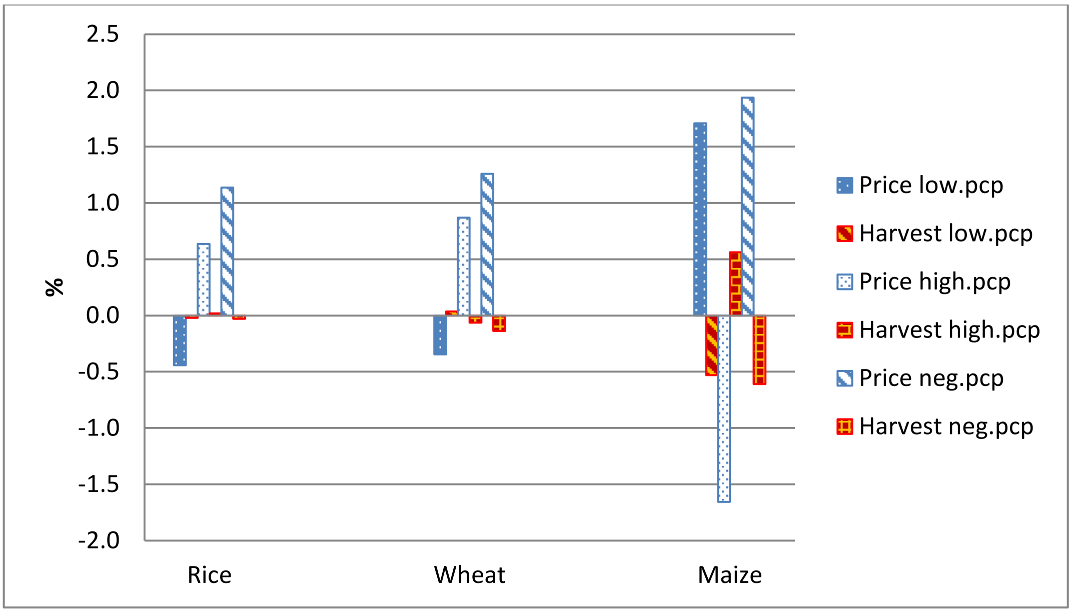


Figure 8. Crop prices and harvests after adaptation: Deviation from the reference scenario

One may ask why farmers cannot produce less to obtain more income as a collective group. In China, this is not possible as the producers are typically smallholders based on the family responsibility system and cooperative marketing is not organized. Hence, a smallholder farmer cannot influence the market price and the best policy is to maximize net income by assuming given product prices.

For farmers in China the income from crop production accounts for less than 30% of total income earned by most households in rural China[8]. In many villages, farming is mainly carried out by the elderly and children as many adults work off-farm to earn the main part of a household's net income. Hence, when positive impacts on harvests are observed, the elderly and children are likely to reduce their inputs in crop production. This is different from the 1980s and the beginning of the 1990s when a rural household earned over half of net income from on-farm activities. At that time, a rural household would probably think they could keep efforts at the same level or

[8] In recent years, more than 70% of net income of a rural household comes from off-farm activities in China (NBSC 2010, Table 10-20). As crop production is only part of on-farm activities, the net income from crop production should account for a smaller share than 30% of total.

higher and save additional crop products for own use or sale later if the market price is low in the harvest season. Hence, they were more inclined to produce as much as they can in any case given the lower bounds of crop prices set by the government.

5. Sensitivity analysis

If land productivity falls because of climate change, the crop price will generally rise and encourage farmers to improve yield by adding more of other input factors such as labor and fertilizer. However, at some point the farmers gain more by channeling such variable factors to other activities, for instance other grain production. The underlying substitution factors between land and other input factors determines the potential for intensifying production rather than withdrawing input factors from a specific crop. In our reference scenario there is no possibility for substitution between land losing its productivity and other input factors. With substitution options, the picture will be different. Hence, the choice of the substitution elasticities of the production function has considerable effects on the results. To examine the implications of parameter values set in GRACE, we simulated with 5 different values of the elasticity between land and other inputs in maize production. The values of the elasticity (eR in Figure 1) were chosen to be 0, 0.05, 0.10, 0.15, and 0.3. A zero elasticity (eR=0) implies no possibility to substitute land with other input factors in response to the impacts of precipitation. The larger the elasticity, the easier the substitutions between land and other inputs. The impacts on maize harvests are shown in Figure 9 for the three extreme scenarios.

Although the crop area of each grain by province is fixed, the effect of adding other inputs to compensate for a yield reduction might vary among crops and provinces. In the low.pcp (or neg.pcp) scenarios for maize, the negative impacts of too little rain on harvests are enhanced if no substitutions between land and other inputs are allowed, i.e., eR=0 in GRACE. The reduced land productivity leads to lower harvests and lower productivity of other inputs if other inputs are constant. A rational producer then reduces other inputs in maize production and allocates them to other activities to increase income. Reducing other inputs results in additional negative impacts on harvests. This explains why adaptation enhances the negative impacts if no substitutions between land and other inputs are allowed. When the substitution between land and other inputs is easier, the negative impacts are mitigated gradually.

On the other hand, in the high.pcp scenario, the positive impacts with adaptation are always smaller than without adaptation, even in the case of no substitution between land and other inputs. Following the same logic as in the low.pcp scenario, other inputs in maize production are increased due to positive impacts on harvests initialized by better precipitation, even though not serving as substitutes of land input in the case of eR=0. However, the increase of maize harvest also leads to a much lower maize price and returns to any kind of input in its production. The effects are so strong that inputs other than land are finally reduced as a result of adaptation, for instance, labor input is reduced reflecting that other farming or off-farm work is better paid - or more appreciated in the case of leisure. As a result, harvests are lower than under the positive impacts without adaptation. When substitutions are easier, the positive impacts are mitigated gradually by less input of other factors in production.

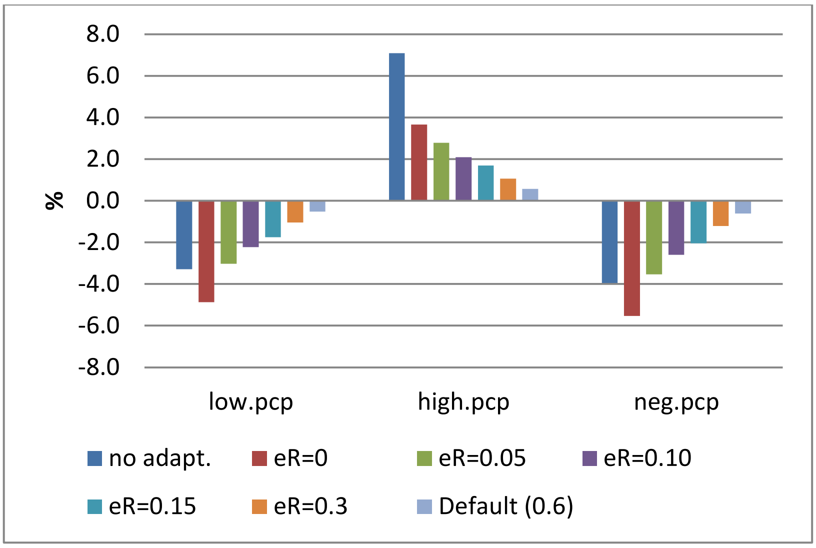


Figure 9. Maize harvests without adaptation and with adaptation under different elasticity of substitution between land and other input factor (eR): deviation from the reference scenario

6. Conclusion

In the paper, we have split production of the three main cereal crops in China into 31 provinces to study impacts of extreme precipitation levels as experienced during the years 1980-2008. The effect on national grain supply has been studied with and without autonomous adaptation as embodied in the CGE model GRACE. The impacts of alternative precipitation levels on yields are the only differences imposed on agriculture and the economy as a whole between any scenarios in the paper. The results show that even if the most negative impacts of precipitation of each province during 1980-2008 occurred simultaneously, they would not lead to serious reduction of crop harvests for China at the national level. However, climate change may hit crops within a province seriously in some cases and even worsen after autonomous adaptation by farmers and through market fluctuations.

The reduction of crop harvests due to too much or too little rain generally makes farmers better off economically as crop prices increase significantly and more than compensate for the loss of harvest. However, the increase in crop prices may have considerable effects on the daily life of poor urban households who have to pay more for food, implying certain food security problems.

The estimated effect of adaptation should be interpreted with caution. As illustrated in the sensitivity analysis, the elasticity of substitution between land and other input factors in crop production are set quite high in GRACE as our goal was to see the results after full adaptation over a relatively long time horizon. In reality, the adaptation may not appear so quickly and the possible negative impacts of precipitation might be stronger than those shown in the paper.

Appendix. The GRACE model with crop farming by province

In GRACE, the endowment of production factors, i.e. labour, capital and natural resources within each region and time period are exogenous. Labour can move freely among production activities within a region, whereas natural resources are activity-specific and cannot be reallocated among sectors. The newly formed capital and depreciation of capital in the previous period can be freely allocated among activities and the other part of capital is activity- specific. The model assumes full utilization of all available resources within China (and the rest of the world). Producers pursue profit maximization and consumers pursue utility maximization.

Trade is modelled as bilateral with substitution among regional contributions. The substitution elasticities are based on those in the MIT EPPA model (Paltsev et al. 2005). Income of a region includes the remuneration to primary factors of production (labour, capital and natural resources) and direct and indirect taxes.

Saving is a fixed share of total income by region. All savings are used to invest in the world economy such the expected rates of returns to capital change at the same rate for all regions. Within each region, the investment is allocated to production activities such that the rates of returns to the new capital are equalized while the capital stock already existing at the beginning of each period is assumed to be activity-specific even though 4 per cent of it is depreciated and becomes one part of regional savings. The rates of returns to capital are equalized among regions in the long run.

In the standard GRACE model (Aaheim and Rive 2005), there is only one representative producer to produce one type of product in a sector. In order to utilize GRACE to analyse the impacts of precipitation at the provincial level, the output of each of the three cereal crops is disaggregated into 31 provinces proportional to the crop harvests shares by province. By assuming production technology of each crop is the same as in the agricultural sector in provincial input-output tables[9] (NBSC 2011), we then utilize the direct input shares in agricultural output (direct input coefficients) to derive preliminary input values of commodities and productive resources in each province. Then a weighted least squares method is adopted to determine provincial inputs such that the final inputs of each commodity or resource in a crop production sum up to the corresponding national level in GTAP v8 database. The method aims to minimize the objective function defined as the sum of squared differences between final and original direct input coefficients (input share in total output of a crop) weighted by provincial shares of crop harvests (NBSC 2008). In doing so, the input structure in a province with high share of crop output is much closer to the original

[9] As there is no input-output table for Xizang, we assume the crop production technology in Xizang is the same as the national one.

one stated in the provincial input-output table than a province with low share of crop output.

Acknowledgments: Thanks to Karianne de Bruin, Zhu Qin, Shi Qinghua, and Liu Huifen for valuable comments. This study has been carried out as part of a project on Climate change and Chinese agriculture: Effects on food production and options for adaptation, jointly funded by Research Council of Norway (Project No.: 209671/E10) and Chinese Academy of Sciences (Project No.: GJHZ1204), and National Natural Science Foundation of China (grant no. 41021004 and 71333010).

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