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Early warning information, farmers' perceptions of, and adaptations to drought in China

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Abstract Farmers' perceptions of the local climate reflect their own judgments of climate change and may thus affect their adaptation behavior. However, the mechanisms between the provision of early warning information and farmers' perceptions and adaptation behavior are under-researched. To address this gap in the literature, this study uses original household survey data from nine provinces in China to examine the major factors influencing farmers' perceptions of drought and examines how perceptions affect adaptation behavior. The results show that over half of the sample farmers perceived that drought severity had increased during the past 10 years. Moreover, econometric analysis indicates that about 8% more farmers will adopt surface pipes in response to drought if early warning information about drought is provided. Farmers that perceived increasing drought severity are more likely to attempt to adapt by adopting water-saving technologies. The paper concludes by offering some policy implications for the presented results.

1 Introduction

Among the several types of extreme weather events driven by climate change, drought has become a worldwide concern (Sheffield et al. 2012). The area of the world classified as very dry has doubled since 1970, and the proportion of land threatened by drought will double again in the twenty-first century (Trenberth et al. 2007; Heffernan 2013). Drought has also become more frequent in China and is now considered to be the major extreme weather event in the country. For example, the return period[1] of droughts in the 1920s and 1930s was 105 years, while the major 1997 drought in the downstream Yellow River basin had a return period of only 4.4 years (Shiau et al. 2007). More frequent and severe droughts aggravate water scarcity, particularly in the already dry northern China.

[1] The Return period is defined as the average elapsed time between the occurrence of an event with a certain magnitude or greater (Shiau et al. 2007).

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In the face of increasing drought periods, a number of international, national, and local adaptation strategies have been formulated (IPCC 2014). For example, 26 Organization for Economic Co-operation and Development (OECD) countries and 49 least-developed countries have developed or are currently developing strategic frameworks in this regard. China released its National Adaptation Scheme for Responding to Climate Change in 2007. Two years later, the State Council released the Drought Control Regulation, and the National Adaptation Strategies to Climate Change (NASCC) was published in 2013. In the same year, several Chinese provinces also issued a Provincial Adaptation Strategy to Climate Change under the guidance of the NASCC. The adaptation strategy varies by region so that it can be customized to address the specific needs of each local economy. For example, Jilin, which is an agricultural province, has promoted a black soil conservation program to adapt to climate change, while building up dykes along the coast is one of the major adaptation measures in Guangdong, where rising sea level is a major concern.

In addition to these strategic policies, some concrete efforts have been made to improve adaptation capacity. The first important effort was to enhance early warning information systems related to extreme events.[2] The World Meteorological Organization (WMO) has been working with its international and national partners to integrate such early warning systems into emergency management and response strategies. In China, a daily drought monitoring and early warning system was developed and put into operation in 1999 (WMO 2006). Additionally, the Chinese government paid considerable attention to water-saving technologies and released National Guidelines for Water Saving in the Agricultural Sector (2012–2020) in 2012.

While issuing adaptation policies is an essential first step, it is even more important to understand how these policies can be translated into actions by improving farmers' adaptive capacity. In recent years, an increasing number of researchers have begun to examine farmers' adaptive responses and their determinants (Yohe and Tol 2002; Chen et al. 2014; Wang et al. 2015; Devkota and Bhattarai 2015). However, studies have seldom empirically examined the role of farmers' perceptions in the process of adapting to climate change or extreme weather events. The existing literature has stated that farmers' perceptions are an essential first step in the adaptation process (Dijksterhuis and Bargh 2001; Gbetibouo 2009; Moser and Ekstrom 2010; Hou et al. 2015; Devkota et al. 2016); however, the body of empirical evidence in this case remains scarce. If farmers' perceptions do affect their behavior, as would seem logical, early warning systems related to extreme events may affect their perceptions.

Given this knowledge gap and the likely impact of perceptions on adaptive behaviors, this study adopts a two-stage endogenous switching model and survey data on over 3000 farmers to test the mechanisms between early warning information, farmers' perceptions, and their adaptation behavior empirically. Specifically, this study answers the following research questions. How do farmers perceive local climate change, especially changes in drought severity? Does the provision of early warning systems influence farmers' perceptions of drought severity? How do farmers' perceptions affect their adaption decisions, particularly with regard to adopting water-saving technologies? Answering these questions not only improves our understanding of the mechanisms among early warning information, farmers'

[2] China's national and local meteorological administrations release information providing early warnings of natural disasters, depending on the expected magnitude and scale. Early warning information is distributed from the upper level of government to lower-level administrators, then to farmers. Once village leaders obtain such information, they are expected to inform residents through messages, phone calls, posters, and other documents. The information usually includes the type of disaster, expected magnitude and scale, and potential ways in which to mitigate and reduce vulnerability to it.

perceptions of climate change, and their adaptive actions but may also have implications for improving early warning policies to improve farmers' adaptive capacities.

The remainder of the paper is organized as follows. Section 2 describes the data used. Section 3 presents a descriptive analysis of drought trends as well as farmers' perceptions and adaptations. Section 4 econometrically analyzes how the provision of early warning information affects farmers' perceptions and thus their adaptation behavior. Section 5 discusses the results and then concludes.

2 Data

The data used in this study are a subset of a large-scale survey conducted from late 2012 to early 2013 in nine Chinese provinces. All the nine provinces are located in the five major grain-producing regions: Hebei, Henan, Shandong, Anhui, and Jiangsu in North China Plain, Jilin in the Northeast China, Jiangxi in Central China, Yunnan in Southwest China, and Guangdong in South China (Fig. 1). With the exception of the North China Plain, we randomly selected one province from each of the other four major areas. These nine provinces accounted for 41% of rice production, 77% of wheat production, and 45% of maize production in China in 2013 (NBSC 2014). In our study areas, rice was fully irrigated, while 77% of maize and 58% of wheat were irrigated in 2012.

Three counties in each province, except for Jiangxi (10 counties) and Guangdong (6 counties)[3], were randomly selected from all of the counties that met the following two conditions during 2010–2012: (1) experienced a severe drought or flood in 1 year and (2) experienced normal weather in 1 year. A normal year was defined as a year in which the degree of natural disasters (e.g., drought, flood) is less than moderate (natural disaster level 3).[4] A drought (flood) county is defined as one that experienced a drought (flood) as well as normal weather within these 3 years.[5]

Within each county, stratified random sampling was used to select three townships. These townships were then stratified into three groups based on their rural water infrastructure resources: one-third of the sample had high-quality infrastructure, one-third had medium-quality infrastructure, and one-third had low-quality infrastructure. The quality of water infrastructure for each township is assessed by the county's Water Conservancy Bureau based on the share of irrigated land areas and reliability of water supply for irrigation. Within each township, three villages were randomly selected, and 10 farm households were randomly selected within each village. In total, the sample includes 3330 households from 330 villages in 37 counties across nine provinces in China. For more details on the sampling process, please refer to Huang et al. (2014).

Household heads and village leaders were interviewed face-to-face. Farmers were asked about their perceptions on the changing trend of severity of drought (i.e., the days that drought lasted) over the past 10 years with the following alternative answers: increased, no clear

[3] The surveys in Jiangxi and Guangdong were funded by two other projects; however, they had the same sampling framework and survey questionnaires.
[4] According to China's national standard for natural disasters (CMA 2004), the severity of a drought or flood has four categories: most severe, severe, moderate, and small.
[5] While this study focuses on drought, our samples include all counties surveyed (i.e., both drought and flood counties). Using the entire sample can help avoid sampling bias and increase the variations in the frequency and drought severity and therefore farmers' perceptions over the past decade.

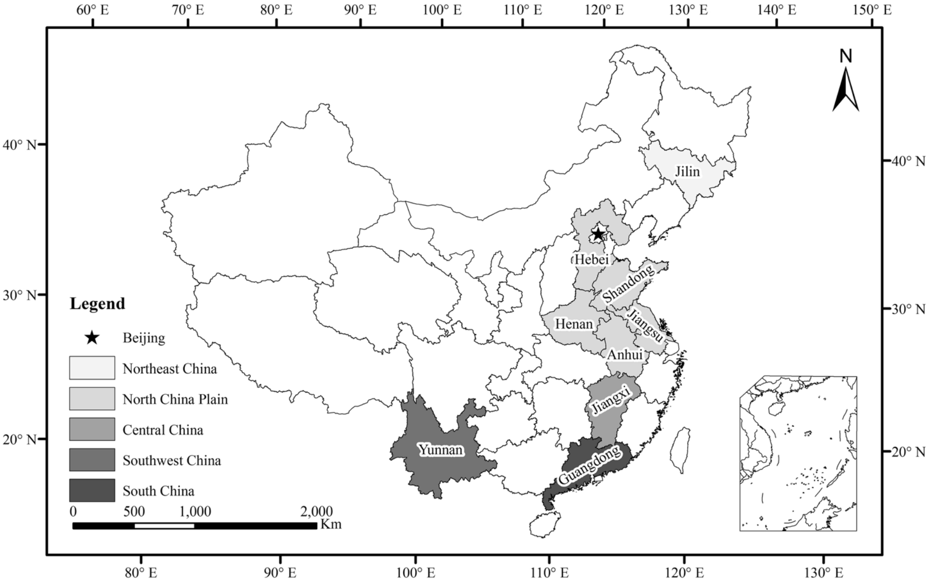

Fig. 1 Location of the study areas

change (or unchanged), decreased, or do not know. We used these answers as indicators of the change in drought severity. A series of potential adaptation measures were listed, and a yes-or-no response was noted for each respondent.

Farmers were also asked if they had implemented any other adaptations that are not given in our list. Examples of adaptation measures included adopting surface pipes, using drought-resistant crop varieties, and changing irrigation frequency. In the same village, the village leader was asked whether his/her village had been provided with early warning information about drought during 2010–2012. The survey also covered basic information on the farmers' characteristics (e.g., age, education, gender, wealth), farm characteristics (e.g., farm size), and village characteristics (e.g., topography, distance to the county seat, whether it had a continuous residential area).

3 Descriptive results: drought trends and farmers' perceptions and adaptation behavior

3.1 Drought trends in study areas

Historical data indicate that drought severity has shown an increasing trend in most sample provinces. From 1981 to 2011, drought in five provinces (Jilin, Hebei, Jiangsu, Jiangxi, and Yunnan) among nine provinces has become more severe. In Jilin, the hazard rate[6] of drought increased from approximately 40% in 1981 to 55% in 2011 (NBSC 2012). On average, the hazard rates in Jilin and Hebei have increased by approximately 0.75% per year since 1980. Jiangsu, Guangdong, and Yunnan had a moderately increasing severity of drought with a

[6] The hazard rate of drought is measured by the share of crop sown areas with yield loss higher than 30% due to drought over the total crop sown areas suffering the drought.

Table 1 Farmers' perceptions of changes in drought severity, 2003–2012

	Percentage of farmers (%)			
	Increasing	Decreasing	Unchanged	Did not know
All counties	52.3	17.0	27.6	3.1
Drought counties	63.1	12.2	22.0	2.7
Flood counties	32.4	25.9	38.0	3.8

Source: authors' survey

hazard rate at approximately 0.5% over the same period. Jiangxi has also witnessed an increasing severity of drought, although the hazard rate was only 0.16% per year. The drought severity in Shandong and Henan has been relatively stable over the past three decades. Anhui, as an exception among the nine provinces, has seen a declining severity of drought.

3.2 Farmers' perceptions of drought

Our data showed that the majority of farmers felt comfortable making judgments about recent drought trends. Only 3.1% of respondents were unable to state whether drought severity had increased, decreased, or remained the same in the past 10 years (Column 5, Table 1). Similarly, Falaki et al. (2013) found that only 2.4 and 3.4% of respondents in Nigeria had no opinion regarding trends in air temperature and rainfall amounts, respectively, over the past 30 years. Research in Kenya has also found that only around 3% of farmers did not know whether there had been any changes in temperature and rainfall (Silvestri et al. 2012). In developed countries, Battaglini et al. (2009) showed that 94% of German winegrowers, 88% of Italians, and 80% of the French have noticed climate change over the past 10–20 years. These results indicate that farmers are aware of local climate change.

Over one half of farmers (52%) perceived a trend of increasing drought severity from 2003 to 2012 (Table 1), while only 17% reported a decreasing trend. Hence, three times as many farmers perceived rising drought severity than falling severity, suggesting growing concern regarding drought in the study areas. Maddison (2007) showed that very few farmers in Egypt, Ethiopia, and South Africa reported a change in drought frequency, whereas most of those in Senegal and Kenya believed they had lived through such a change.

To control for the effects from different county types, we separately report farmers' perceptions in drought and flood counties. Farmers' perceptions differed largely between drought and flood counties. Nearly twice as many farmers perceived a trend of increasing drought severity in the drought counties than in the flood counties (63 versus 32%). Nearly one-third of farmers in the counties experiencing serious floods in the past 3 years reported increasing drought severity. Although some counties experienced serious floods in the recent 3 years, the Palmer Severity Drought Index (PSDI) in one-third of flood counties showed an increasing trend of drought severity.[7] In addition, over 30% farmers in the drought counties reported decreasing flood severity, while only 18% in the flood counties reported decreasing flood severity.

[7] The PSDI is calculated by meteorologists based on meteorological data from the National Meteorological Information Center. A simple linear regression model was used to examine the trend of the PSDI.

Farmers' perceptions of drought severity over 2003–2012 also varied by province (Table 2). Among the drought counties, around 60% of farmers in all northern provinces (Jilin, Hebei, Shandong, Henan) reported increasing drought severity, while the percentages in southern provinces varied widely, from 37.6% in Jiangxi to 94.4% in Yunnan. In the flood counties of Hebei, 60% of farmers perceived increasing drought severity. By contrast, a smaller percentage of farmers in the flood counties of Shandong reported increasing drought severity (18.9%).

Most farmers' perceptions were consistent with the actual drought trends in their counties. In the 19 counties with increasing drought severity according to the PSDI, at least 70% of local farmers perceived a rising trend with the exception of Xiangshui and Xinghua County in Jiangsu (29 and 18%, respectively) and Lingxian County in Shandong (19%). Of the 18 counties with declining drought severity, in 13 counties, one-third of farmers perceived an increasing trend, while in the other five counties, 57% of farmers considered drought frequency to be rising.

To check for a correlation between the provision of early warning information and farmers' perceptions of drought, we compared the percentages of farmers perceiving increasing drought severity between villages with the provision of early warning information and those without. Our survey results showed that farmers' perceptions of drought severity trends were highly correlated with the provision of early warning information (Table 3). Considering all counties together, about 60% of farmers living in villages that received such early warning information perceived increasing drought severity over the past 10 years (p value < 0.01). Considering this relationship separately for drought and flood counties, we found that a significantly higher percentage of farmers in both types of counties perceived a trend of increasing drought severity in villages where drought early warning information was provided (p value < 0.01).

3.3 Farmers' adaptation measures

Previous studies have shown that when farmers in China encounter drought, they often adopt a number of adaptation measures (Sun et al. 2013; Chen et al. 2014; Wang et al. 2014). These include investing in irrigation systems, adopting water-saving technologies, changing crop varieties, and adjusting planting and harvesting dates. In this study, we focused on water-saving technologies and crop management.

Table 2 Percentage of farmers, by province, who perceived a trend of increasing drought from 2003 to 2012

Province	All counties	Drought counties	Flood counties [a]
Jilin	67.8	67.8	–
Hebei	63.7	65.6	60.0
Shandong	48.2	62.8	18.9
Henan	65.2	65.2	–
Jiangsu	35.2	58.9	23.3
Anhui	62.6	62.6	–
Jiangxi	31.3	37.6	25.1
Guangdong	51.6	70.0	42.5
Yunnan	94.4	94.4	–

Source: authors' survey

[a] Jilin, Henan, Anhui, and Yunnan provinces do not include sample counties that experienced serious floods

Table 3 Percentage of farmers who perceived increasing drought severity over the past 10 years, by provision of drought early warning information

Provision of early warning information to villages	Percentage of farmers (%)		
	All counties	Drought counties	Flood counties
With provision [a]	60.9***	64.9***	40.4***
Without provision	40.5	57.6	29.5
All samples	52.3	63.1	32.4

Source: authors' survey

[a] *t* test is used to compare levels of perception between villages with and without early warning information. Villages without provision are the base category

***$p < 0.01$

Water-saving technologies include surface pipes, underground pipes, and sprinkler systems. A surface pipe is a coil of hose used to transport irrigation water to a farmer's field, whereas underground pipe systems comprise cement, metal, or plastic pipes used to transport water underground for irrigation (Blanke et al. 2007). Field experiments have shown that surface and underground pipes can reduce water use by up to 30% compared with unlined canal systems (Zuo 1997).

For crop management strategies, we asked about changing planting and/or harvesting dates, planting drought-resistant crop varieties, and using plastic sheeting. Adjusting planting and/or harvesting dates can help farmers avoid yield losses from drought (He et al. 2012), while plastic sheeting can be used to cover soil and help retain soil moisture. Drought-resistant crop varieties include those able to tolerate dry conditions to a certain extent.

Over half of those surveyed farmers responded to drought by adopting some type(s) of water-saving technologies. A larger proportion of farmers in drought counties than in flood counties noted taking measures to adapt to drought. Approximately 58% of farmers adopted at least one of the six common adaptation measures during 2010–2012 (Table 4). In drought counties, this proportion was as high as 70%, twice that of the flood counties.

Among these adaptation measures, surface pipes ranked the highest in terms of adoption (31.3%), followed by changing planting and/or harvesting dates (22.8%) and growing drought-resistant varieties (15.6%). However, the percentages of farmers adopting underground pipes or sprinklers were quite low (2.1 and 1.1%, respectively). This low proportion of adoptees

Table 4 Percentage of farmers who adopted adaptation measures between 2010 and 2012

Adaptation measures	Percentage of farmers (%)		
	All counties	Drought counties	Flood counties
At least one of the following six adaptation measures	57.7	70.2	34.5
Surface pipe	31.3	42.0	11.6
Planting and/or harvesting dates adjustment	22.8	25.8	17.2
Drought-resistant crop varieties	15.6	21.3	4.9
Plastic sheeting	7.9	10.5	3.1
Underground pipe	2.1	3.1	0.3
Sprinkler	1.1	1.4	0.6

Source: authors' survey

might be caused by the high level of investment (both money and labor) required to install underground pipes and sprinkler systems.

To check whether farmers' adaptation behaviors differ with their perceptions of drought, we compared the percentage of farmers adopting adaptation measures across different perception groups (Table 5), using farmers who had noted increasing drought severity as the baseline for the t tests. Whether adaptation measures were taken was highly correlated with the farmer's perceptions of trends in drought severity. Farmers who perceived increasing drought severity were more likely to adopt adaptation measures: about 65% of them adopted at least one of the six adaptation measures, while only 48.6% of those perceiving a decreasing trend did so (p value < 0.01). The same pattern can be observed for each of the main adaptation measures, such as using surface pipes, adjusting planting and/or harvesting dates, and growing drought-resistant crop varieties. For example, the adoption rate for the most commonly adopted adaptation measure, surface pipes, was 35.9% for farmers perceiving an increasing trend versus 29.7% among those noting a decreasing trend and 25.7% among those noting an unchanged trend (p values < 0.01).

4 Factors affecting farmers' perceptions and adaptation behavior

From the above descriptive analysis, which did not control for the influence of other factors, it is difficult to separate the effects of early warning information on farmers' perceptions and those of farmers' perceptions on their adoption of adaptation measures. In addition, farmers' socioeconomic characteristics and local economic and geographical conditions are also likely to affect their perceptions and adaptation behavior (Below et al. 2012; Chen et al. 2014). To better quantify the influences of different factors on farmers' perceptions and adaptation behavior, this section econometrically examines how the provision of early warning information influences farmers' perceptions and how farmers' perceptions affect the adoption of adaptation measures.

4.1 Econometric model and estimation method

Farmers' adaptation behaviors follow a two-stage decision process: The first stage requires farmers to perceive or detect a change in climate, and the second stage involves adapting to it through appropriate actions (Moser and Ekstrom 2010). Farmers' perceptions are likely to be

Table 5 Percentage of farmers who adopted adaptation measures, by perceived change in drought severity

Perception of drought severity	Percentage of farmers (%)			
	Any type of the six adaptation measures	Surface pipe	Planting and/or harvesting dates adjustment	Drought-resistant crop varieties
Increasing	65.6	35.9	25.3	14.3
Decreasing	48.6***	29.7***	20.3***	4.8***
Unchanged	50.1***	25.7***	20.0***	5.4***
Did not know	39.8***	13.6***	20.4	3.9***

Source: authors' survey

*** denotes that the number in the given row is significantly less than that in the "increasing" row at a 1% significance level endogenous to the process of adaptation, i.e., unobserved factors affecting farmers' perceptions may thus also affect farmers' adaptation behaviors. In such a situation, standard regression techniques result in biased and inconsistent estimators. We thus use a two-stage endogenous switching model to characterize the key relationships. The first stage characterizes the relationship between the provision of early warning information and farmers' perceptions; the second stage captures the impact of farmers' perceptions on their adoption of adaptation measures. In each stage, we include variables for farm- and village-level characteristics and a set of provincial dummy variables.

The empirical model is specified as follows:

$$FP_{ijkp} = \alpha_0 + \alpha_1 EWI_{jkp} + \alpha_2 FC_{ijkp} + \alpha_3 VC_{jkp} + \alpha_4 DD_k + \alpha_5 PD_p + \varepsilon_{ijkp} \tag{1}$$

$$AM_{ijkp} = \beta_0 + \beta_1 FP_{ijkp} + \beta_2 FC_{ijkp} + \beta_3 VC_{jkp} + \beta_4 DD_k + \beta_5 PD_p + e_{ijkp} \tag{2}$$

where i, j, k, and p represent the ith farmer in village j in county k in province p. In Eq. 1 (the perception equation), the dependent variable, *FP*, indicates whether a farmer perceived a trend of increasing drought severity (yes = 1, no = 0). The first independent variable in Eq. 1, *EWI*, indicates whether a village was provided with early warning information on drought events (yes = 1, no = 0). In Eq. 2 (the adaptation equation), the dependent variable, *AM*, denotes whether a farmer adopted an adaptation measure (yes = 1, no = 0). In this study, we choose surface pipe usage as a typical adaptation measure, as it is commonly used and generally accessible to farmers.

We include other explanatory variables based on feasibility and a literature review (Maddison 2007; Gbetibouo 2009; Below et al. 2012; Chen et al. 2014). In both equations, we include variables representing farmer/farm characteristics, village characteristics, a county-level disaster dummy variable, and province-level dummy variables. Farmer and farm characteristics are represented by a vector of variables, *FC*, including the respondent's education level (number of years of schooling), age in years, and gender (male = 1, female = 0) as well as farm size (hectares) and household wealth level (the total value of durable consumption assets and housing, in thousands of RMB[8]). Alternatively, we also include a set of crop area structure variables (i.e., share of rice, maize, wheat, and other crops area) in *FC* to check whether the crop structure affects farmers' perceptions and adaptation behavior. The village characteristic variables (*VC*) include whether a village is located on a plain or in a mountainous area (plain = 1, mountain = 0), the distance to the county seat (kilometers), and whether a village has a continuous residential area (yes = 1, no = 0). *DD* is a dummy variable representing the type of county (drought county = 1, flood county = 0). *PD* refers to a set of province-level dummy variables, while ε and e are the respective error terms in the two equations. The αs and βs represent the parameters to be estimated in Eqs. 1 and 2, respectively.

We use maximum likelihood techniques to simultaneously obtain the estimators for the two equations. The estimators that would be inconsistent were the two equations estimated separately, since the unobserved factors affecting farmers' adoption behaviors and those impacting perceptions may be correlated (i.e., $\text{cov}(\varepsilon_{ijkp}, e_{ijkp}) \neq 0$). Specifically, we use the STATA *ssm* command, developed by Miranda and Rabe-Hesketh (2006), to estimate the model. The dependent variables, *FP* and *AM*, are assumed to follow logistic and binomial distributions, respectively.

[8] RMB is the unit of Chinese currency. 1 RMB = 0.1526 US$ in 2016.

4.2 Estimation results

The estimation results suggest that both equations in the endogenous switching model perform well (Table 6): The Wald *chi*-squared statistic is statistically significant at the 1% level, and the likelihood ratio test for *rho* indicates that the error terms of Eqs. 1 and 2 are correlated. The variance inflation factor for all variables is less than 10 (ranging from 1.03 to 4.32), indicating that multicollinearity is not a concern.

Table 6 Estimation results for the determinants of adopting surface pipes and perceiving increasing drought severity (endogenous switching model)

Variables	Perception equation	Adaptation equation
Provision of early warning information on drought (yes = 1; no = 0)	0.190*** (1.91)[a]	–
Perceptions of drought severity (increasing = 1; not increasing = 0)	–	0.414** (2.07)
Respondent's characteristics		
Age (years)	−0.006** (−2.34)	−0.004 (−1.06)
Gender (male = 1; female = 0)	−0.005 (−0.06)	0.092 (0.87)
Education (years)	0.012 (1.53)	−0.022* (−1.86)
Farm characteristics		
Farm size (ha)	−0.021* (−1.92)	0.033** (2.35)
Wealth [b]		
Low (44,450-103,990 RMB)	−0.016 (−0.24)	−0.043 (−0.48)
Medium (104,000-196,800 RMB)	−0.044 (−0.65)	0.102 (1.11)
High (>196,800 RMB)	−0.082 (−1.21)	0.215** (2.03)
Village characteristics		
Topography (plain = 1; mountain = 0)	−0.132* (−2.10)	0.981*** (3.62)
Distance to county (km)	−0.0002 (−0.18)	−0.004* (−1.85)
Village with continuous residential area (yes = 1; no = 0)	−0.006 (−0.11)	0.060 (0.80)
County type (drought = 1; flood = 0)	0.488*** (7.72)	0.662** (2.41)
Province dummy variables	Not reported here	Not reported here
Constant	0.176 (0.84)	−0.879*** (−2.92)
rho	−0.196	
Number of observations	3330	
Wald *chi* squared	778.5***	

[a] All numbers in parentheses are robust z-statistics.

[b] We divide the sample into four equal groups based on wealth (i.e., lowest, low, medium, and high). The lowest group is used as the base category.

***$p < 0.001$; **$p < 0.01$; *$p < 0.1$

Our estimation results show that the provision of early warning information on drought events increases the likelihood that farmers perceive a trend of increasing drought severity. In the perception equation, the coefficient of the dummy variable representing the provision of such information is positive and statistically significant at the 1% level (row 1, Table 6); farmers are 19% more likely to perceive increasing drought severity if their village has been provided with early warning information on droughts.

Our estimation results also reveal that farmers are much more likely to use surface pipes when they perceive increasing drought severity. In the adaptation model, the coefficient of the dummy variable representing a perceived increase in drought severity is positive and statistically significant at the 5% level (row 2, Table 6). This result, consistent with our descriptive analysis in Table 3, indicates that farmers' perceptions play a critical role in their adaptation behavior. Over 40% more farmers would adopt surface pipes when they perceive drought severity to be increasing and about 8% would use surface pipes when early warning information is provided combing perception and adoption results.

Some farmer and farm characteristics also affect farmers' perceptions and/or adoption of surface pipes. The coefficient of age is negative in both equations but statistically significant only in the perception equation, implying that older farmers are less likely to perceive a trend of increasing drought severity. Although a farmer's age does not directly affect the likelihood that he or she will adopt surface pipes, it negatively affects adoption through perceptions. The results show no significant differences, however, between male and female farmers in either perceptions or adoption of surface pipes. In contrast to expectations, less educated farmers are more likely to adopt surface pipes; however, there are no significant differences in perceptions depending on education level. According to the literature (e.g., De Brauw et al. 2002), more educated farmers may be more likely to have off-farm jobs or migrate to nearby cities, which may partly explain this finding. Less educated farmers may also have more farming experiences in responding to drought, which may lead them less likely to take other adaptation actions.

There are no significant differences in perceptions between poor and wealthy farmers, indicating a similar capacity to pass judgment on drought severity regardless of wealth class. However, the coefficient of the highest wealth level dummy variable is positive and statistically significant at the 10% level, which means that farmers in the wealthiest group are more likely to adopt surface pipes than other wealth groups.

Farmers managing larger farms are more likely to adopt surface pipes but less likely to perceive increasing drought severity. The coefficient of farm size is negative and statistically significant at the 10% level in the perception equation, while it is positive and statistically significant at the 5% level. This indicates that small farmers are more sensitive to drought severity than large farmers. Despite the lower likelihood of perceiving increasing drought severity, large farmers are more likely to adopt surface pipes as a means of improving crop yields and/or mitigating input costs.

Village topography affects both farmers' perceptions and likelihood of adopting surface pipes, but in opposite directions. The coefficient of living in a village with mountainous land is negative and statistically significant at the 10% level in the perception equation but positive and statistically significant at the 1% level in the adaptation equation: Farmers in mountainous areas are more likely to perceive increasing drought severity but less likely to adopt surface pipes. First, water resource accessibility may be limited in these areas. Second, mountainous plots make it more inconvenient for farmers to adopt surface pipes. This result suggests a need for policymakers to pay particular attention to farmers in mountainous areas when reinforcing climate change adaptive capacity.

We also added the share of different crops as control variables in Eqs. 1 and 2. The results from these alternative specifications of Eqs. 1 and 2 (Appendix Table 8) are robust and consistent those presented in Table 6. This additional analysis also shows that wheat farmers are more likely to adopt surface pipes than others.

5 Discussion and conclusion

This study examined the factors influencing farmers' perceptions of drought severity and the mechanism between their perceptions and adaptation behavior. The analysis focused particularly on how early warning information influenced farmers' perceptions of drought and thus their responses to drought risk. If early warning information about drought is provided to farmers, they are about 20% more likely to perceive an increasing drought severity, which can result in 8% more of them to adopt surface pipes in response to drought. While we do not have data to analyze the benefit of adopting surface pipes when farmers suffered from serious drought, our survey data show that it is not costly. The average cost of one time investment on surface pipes per ha is 675 RMB (about US$107 in 2012), and they can be used for 5 years. The average annual cost is only 135 RMB per ha, equivalent to about 0.8% of crop revenue. This implies that a very small increase in reducing yield loss due to drought can fully cover the cost.

Given that the incidence of drought has increased in the past and is expected to continue to increase in the future, the results of this study have policy implications for both China and the rest of world. The findings of this study support China's recent efforts to enhance early warning information systems related to extreme events. In our study areas, there are still about 42% of villages that are still not able to access to this early warning information service. The results of this study also have important implications for many international communities that have prepared their adaptation strategies as we discussed in the introduction section but are still looking for opportunities to finance the adaptation to climate change.

The findings of this study also suggest some farmers may need more assistance than others when they face climate risks. For example, our results show that the elderly farmers are less sensitive to drought severity than young farmers. This will become an even bigger issue with the rising aging in farming. The other farmers who also need more attention include those with small-scale farms and the poor because they are less likely to take adaptation measure to mitigate drought risks. More efforts to improve adaptation capacity should also be made for the farmers in mountainous areas as they are more vulnerable than those in the plains.

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Appendix

Table 7 Descriptive statistics for the regression variables

Variables	Mean	Std. dev.
Adoption of surface pipes	0.313	0.464
Perceptions of drought severity (increasing = 1; others = 0)	0.523	0.500
Provision of early warning information on drought (yes = 1; no = 0)	0.577	0.494
Farm characteristics		
Age of the respondent (years)	52.83	10.10
Gender of the respondent (male = 1; female = 0)	0.890	0.312
Education of the respondent (years)	6.649	3.104
Farm size (ha)	1.150	2.570
Wealth (1000 yuan)	152.0	276.5
Share of maize area (%)	24.54	29.80
Share of wheat area (%)	17.55	24.03
Share of rice area (%)	35.24	40.04
Share of other crops (except maize, wheat and rice) areas (%)	22.57	27.33
Village characteristics		
Topography (plain = 1; mountain = 0)	0.637	0.481
Distance to county (km)	31.50	21.01
Village with continuous residential area (yes = 1; no = 0)	0.580	0.494
County type (drought = 1; flood = 0)	0.648	0.478

Note: Number of observations = 3330

Source: authors' survey

Table 8 Estimation results for the determinants of adopting surface pipes and perceiving increasing drought severity with control of crop structure (endogenous switching model)

Variables	Perception equation	Adaptation equation
Provision of early warning information on drought (yes = 1; no = 0)	0.184***	–
	(3.24)[a]	
Perceptions of drought severity (increasing = 1; not increasing = 0)	–	0.399**
		(2.04)
Respondent's characteristics		
Age (years)	−0.006**	−0.005
	(−2.24)	(−1.23)
Gender (male = 1; female = 0)	0.004	0.092
	(0.06)	(0.86)
Education (years)	0.012	−0.022*
	(1.54)	(−1.88)
Farm characteristics		
Farm size (ha)	−0.020*	0.033**
	(−1.84)	(2.53)
Wealth [b]		
Low (44,450–103,990 RMB)	−0.012	−0.057
	(−0.18)	(−0.62)
Medium (104,000–196,800 RMB)	−0.037	0.070
	(−0.54)	(0.76)
High (>196,800 RMB)	−0.074	0.183*
	(−1.08)	(1.81)
Share of maize area	0.002	0.002
	(1.09)	(1.24)
Share of wheat area	−0.005**	0.014***
	(−2.14)	(3.48)
Share of other crops (except maize, wheat and rice) areas	0.003*	−0.002
	(1.91)	(−0.85)
Village characteristics		
Topography (plain = 1; mountain = 0)	−0.097*	0.889***
	(−1.51)	(4.03)
Distance to county (km)	−0.0004	−0.003
	(−0.35)	(−1.47)
Village with continuous residential area (yes = 1; no = 0)	−0.004	0.018
	(−0.07)	(0.24)
County type (drought = 1; flood = 0)	0.485***	0.685***
	(7.64)	(2.77)
Province dummy variables	Not reported here	Not reported here
Constant	0.313	−1.531***
	(1.25)	(−3.94)
rho	−0.174	
Number of observations	3330	
Wald *chi* squared	815.6***	

[a] All numbers in parentheses are robust z-statistics

[b] We divide the sample into four equal groups based on wealth (i.e., lowest, low, medium, and high). The lowest group is used as the base category

***$p < 0.001$; **$p < 0.01$; *$p < 0.1$

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