HIGH TEMPERATURE RISK AND FARMERS' TRADE-OFFS BETWEEN ADAPTIVE BEHAVIORS: EVIDENCE FROM CHINA

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Abstract. Climate change profoundly affects farmers' production and life, forcing trade-offs in adaptive actions due to limited resources. This study explores the impact of high temperature risk on Chinese smallholders' irrigation investment and air conditioning use. We employ the multivariate Tobit (MVTOBIT) model, analyzing data from National Meteorological Center (NMC) and the China Nutrition Health Survey (CHNS) from 1991 to 2015. We find that high temperature risk reduces irrigation investment and increases air conditioning consumption. Non-farm employment and heat-related health risks influence farmers' responses to climate change in production. Social services and public investments in irrigation can replace some private irrigation investments and promote air conditioner use. Expanding cultivation encourages irrigation investments, and accessible medical services facilitate air conditioning purchases. This research contributes insights into effective adaptation in developing rural areas, aiding governments in enhancing agricultural resilience to climate change.
Keywords: *climate change, productive investment, living consumption, smallholder farmer*

Introduction

Rising temperature due to climate change poses an enormous risk to crop production systems and the livelihoods of vulnerable rural residents (Maggio et al., 2022). The global annual mean temperature in 2021 was around 1.11 ± 0.13°C above the 1850-1900 pre-industrial average[1]. Particularly in China, the temperature rise caused by climate change is faster than the global average during the same period. From 1951 to 2021, the annual average surface temperature in China increased by 0.26°C every 10 years[2], indicating a significant temperature rise in the country over the past 50 years. High temperature risks, represented by extreme heat events or prolonged temperature increases, are adversely affecting agriculture and farmers.

On one hand, high temperatures threaten global food security. From 1981 to 2002, due to rising temperatures, global wheat, corn, and barley production decreased by 40 million tons annually (Lobell and Field, 2007). According to statistics from the National Food and Strategic Reserves Administration of China, for every 1°C increase in temperature in China, food production will decrease by 10%. Recent studies have shown that crop yields are substantially decreased under high temperatures, and the projected losses in crop production are huge under future climate even with long-run adaptation considered (Chen and Gong, 2021).

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[1] World Meteorological Organization website: https://public.wmo.int/en/our-mandate/climate/wmo-statement-state-of-global-climate/asia.
[2] China Meteorological Administration: https://www.cma.gov.cn/2011xwzx/2011xqxxw/2011xqxyw/202208/t20220803_5016624.html.

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On the other hand, high temperatures increase health risks for residents, especially in rural areas with poor facilities (Shah et al., 2022). A large-scale survey has shown that higher temperature significantly decreases self-rated health scores. In addition, men, the elderly, middle and low-education groups, and rural residents are more likely to be impacted by high temperatures (Yang et al., 2022). Even with customized adaptation strategies implemented, the annual heat-related mortality is projected to increase from 32.1 per million inhabitants annually in 1986–2005 to 48.8–67.1 per million at a temperature rise of 1.5°C (Wang et al., 2019). This issue may be severe in rural areas with low air conditioning prevalence and significant population aging (Yu et al., 2019).

The range of strategies and practices adopted by farmers to safeguard the stability of agricultural production and household welfare in the face of climate change shocks is known as adaptive behavior. In order to withstand the income and livelihood risks brought about by climate change, farmers may increase productive investment and living consumption (Sarker et al., 2014). Specifically, in response to the risk of high temperatures to production, increasing irrigation investment has been a common practice to improve yield stability (Olen et al., 2016). In view of the threat of high temperatures to the comfort of life and the health of family members, air conditioning utilization has been employed by households (Zhang et al., 2020). However, expensive air conditioning is still a tough decision for rural residents even if high temperatures are taking a toll on their quality of life (Yu et al., 2019).

Farmers heavily rely on their savings to sustain household investments and consumption. Rural households, especially in developing countries, make adaptation decisions jointly over both consumption and production margins, involving trade-offs between different strategies given financial and resource constraints (Cui and Tang, 2024). Under budget constraints, it is difficult for smallholders to simultaneously engage in adaptive behaviors of increasing irrigation investment and air conditioning consumption. Most research indicates that farmers will take positive measures to stabilize crop yields. There is little discussion about farmers' adaptive behavior at the livelihood level because increasing income is the top priority for most farmers. However, there are two factors that make it more likely for Chinese farmers to increase their air conditioning consumption than farmers in other developing countries: 1. The "home appliances going to the countryside" policy in China has lowered the cost of purchasing air conditioning for rural residents. Since 2007, the government has provided a 13% subsidy and an exchange program for old appliances, making air conditioning more affordable. 2. Higher urban wage rates and improved regional transportation have led to an increase in the likelihood of non-farm employment. Rural residents have become less dependent on agricultural income, which also affects the prioritization of agricultural investment. Further research is needed to understand what adaptive measures Chinese farmers prioritize to cope with high temperatures.

Descriptive statistical data shows that since 2006, the total sown area of crops in China has been on an upward trend[3]. The increase in sown area and the high temperature weather caused by climate change should theoretically increase farmers' demand for irrigation equipment. However, since 2006, the number of irrigation devices in China has continued to decline, while the number of air conditioning per household has rapidly increased, as shown in *Figure 1*. This change may suggest that Chinese

[3] According to National Bureau of Statistics of China, the sown area of crops is the total land where crops are planted and harvested in the same year, and the data source URL is: https://data.stats.gov.cn/easyquery.htm?cn=C01.

farmers' air conditioning consumption has crowded out irrigation equipment investment. When farmers' health is threatened, they may not take active measures to adapt to high temperatures in production. At least, farmers will not allocate all of their resources to production investment, although that seems to be more economically rational.

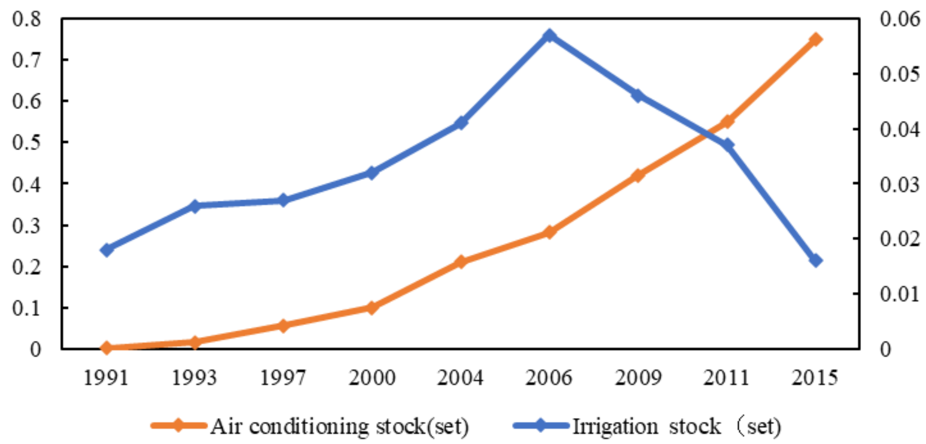

Figure 1. *Household irrigation equipment and air conditioning stock from 1991 to 2015. Data source: The China Health and Nutrition Survey*

Existing research typically focuses on how farmers cope with high temperatures in production. There is little discussion about farmers' adaptive behavior at the livelihood level. However, productive adaptive behavior and life adaptive behavior are inseparable under the household's budget constraint. Therefore, it is necessary to analyze the impact of high temperature risk on production investment and living consumption of farm households in an integrated perspective. In addition, although many studies have examined high temperatures on human health, there has been little such research in developing countries. Households in developing countries generally have limited income and resources with which to adapt to an increasingly severe climate. Therefore, it is important to understand how high temperature risk influences production and living in rural areas of developing countries and determine whether it is possible for farmers to take effective actions to adapt.

This study uses long-term data from CHNS and NMC to analyze the impact and mechanisms of high-temperature risks on farmers' adaptive behaviors. There are three main objectives: Firstly, we attempt to examine how high-temperature risks affect the consumption and production adaptive behaviors in developing countries, providing a reference for related research. Secondly, we reveal the internal mechanisms by which high temperature risks influence farmers' decision-making from both macro and micro perspectives, offering practical insights for policy-making. Lastly, we analyze how climate change affects farmers' trade-offs between agricultural and non-agricultural activities from their dual roles as producers and consumers, supplementing existing research literature.

Most analyses for developed countries show that farmers can take effective adaptations to reduce heat-related yield losses. Therefore, governments do not need to incur additional costs to help farmers adapt to climate change. However, extending this

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optimistic conclusion to developing countries would lead to a serious bias in policy making (Cui and Tang, 2024). We attempt to demonstrate that smallholder farmers in developing countries lack the capacity to simultaneously adapt to high temperature risks in both production and livelihoods. Under limited budgetary constraints, an increase in farmers' consumption of air conditioners reduces their investment in irrigation equipment. This implies that farmers' adaptation to high temperatures cannot be economically optimized without government assistance. Due to the positive externality of agriculture, the social losses caused by inadequate adaptation are higher than the individual losses of farmers. Our study strongly supports the need for policies in developing countries to assist farmers in adapting to climate change.

Review of literature

The impact of high temperature on agriculture production and health

Extreme weather events such as heat waves and droughts can lead to crop failures, posing a threat to agriculture producers and food security around the world. The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) indicates that the global average temperature is projected to increase by the end of the 21st century, and the frequency and duration of heat waves are estimated to increase (IPCC, 2013). When major crops experience brief periods of high temperatures during their reproductive stage, their yield may significantly decrease. Moreover, high seasonal average temperatures increase the risk of drought and limit the rate of photosynthesis (Tubiello et al., 2007). Even just a few hours of high temperature peaks can have a significant impact on the yield of important food crops (Porter and Semenov, 2005). Lobell et al. (2011) demonstrates that corn yield decreases by 1% for every accumulated degree day above the baseline temperature of 30 degrees. Additionally, in 2010, unprecedented extreme high temperatures affected more than 20% of Russia's agricultural regions, leading to a 50% increase in wheat prices on the international market[4]. These research findings indicate that the global temperature rise may seriously affect the global agriculture industry and food security.

Most studies on climate change overlook the impact of high temperatures on human health, resulting in a severe underestimation of the welfare loss for the poorest economies globally. In humid tropical regions, humans may be more susceptible to the impact of heat stress than crops (Hertel and Lima, 2020). Extremely high temperatures and relative humidity increase the incidence and mortality rates of humans (Fischer and Schar, 2010). There is now growing evidence that global warming will significantly reduce labor productivity, especially when workers are exposed to solar radiation (Kjellstrom et al., 2016). A 0.5°C increase on the 2°C warming target would expose over 15% of global land area to levels of heat stress that affect human health. Given the populations and areas exposed to heat stress, about 26 countries will face more than double the health-related heat exposure under 1.5°C warming, posing a significant challenge for developing countries such as India, China, and Brazil (Sun et al., 2019). Although a large amount of efforts have been made in non-agricultural sectors, their conclusions may underestimate the impact on the agricultural sector. Outdoor work

[4] FAO Cuts Wheat Production Forecast but Considers Supplies Adequate, http://www.fao.org/news/story/tr/item/44570/icode/en/ (accessed January 2011).

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intensity is typically higher in agriculture than in manufacturing or service industries, and exposure to sunlight increases the likelihood of heat stress (Orlov et al., 2020).

Climate change and farmers' adaptive behavior

The international community calls for integrating climate change adaptation into national development plans (World Bank, 2010). Especially for farmers in developing countries, the potential risks of climate change appear more urgent, and they will be the first to be affected (Seo and Mendelsohn, 2008).

In response to the risks that climate change poses to agricultural production, the academic community generally believes that farmers will adopt some adaptive behaviors. These behaviors include but are not limited to investments in irrigation equipment (Sarker et al., 2014), adjustments in planting and harvesting times (Alauddin and Sarker, 2014), adjustments in agricultural planting structures (Kabir et al., 2017), and selection of adaptive crop varieties (Kahsay and Hansen, 2016). In particular, irrigation equipment investment is considered one of the most critical adaptive behaviors for high temperatures (Nauges, 2017). Compared with precipitation-related factors, extreme temperature-related factors are more strongly associated with yield anomalies, and irrigation can mitigate the negative impacts of extreme heat to a certain extent (Vogel et al., 2019).

Given the persistence of climate change, it is difficult to obtain long-term data on private adaptive behaviors. There is currently no clear understanding of the impact and mechanism of high-temperature risk on household adaptive behavior. Some studies have shown that farmers increase the frequency of using or purchasing household air conditioning and fans to adapt to climate change (Kussel, 2018), but the adaptive capacity of rural households is significantly lower than that of urban households (Khare et al., 2015). With continued warming and frequent extreme heat events, rural residents must take effective adaptive measures to mitigate health risks and deterioration of living environments (Zacharias et al., 2014).

The above studies have made important contributions, but some shortcomings remain. First, farmers' production and consumption decisions are interrelated, but rigorous analyses that examine both production and consumption responses are rare. Second, although farmers in developing countries are highly vulnerable, their ability to adapt to high temperatures in their lives has not received sufficient attention. Studies that include samples of urban residents may underestimate the health hazards of high temperature risk for the population. Third, fewer studies have discussed the impact of high temperature risk in relation to the social characteristics of particular stages of agricultural development. This may result in the neglect of heat-related social consequences.

The main marginal contributions of this paper are threefold: first, we fully consider the indivisibility of farmers' decision-making process. In this study, a MVTOBIT model with a dual endogenous perspective is developed to examine the correlative effects of high temperature risk on farmers' production and consumption. Second, we focusing on farmers in rural China, providing evidence that high temperature risk affects the production and livelihoods of vulnerable groups in transition economies based on unique long-term panel data from CHNS. Third, we provide new evidence on the process by which climate risks accelerate the off-farm transition of rural households in developing countries and explore potential policy designs to mitigate the impact of high temperature risk on farmers' flight from agriculture. Since the 21st century, the large-scale flight of farmers from agriculture in China has led to a growing problem of

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agricultural land abandonment, which has negatively impacted agricultural development and food security. For other developing countries, it is also particularly important to reduce the flight of high-quality farmers from the countryside before the complete modernization and transformation of agriculture is achieved.

Materials and methods

Theoretical frameworks

Figure 2 shows the theoretical analysis framework. First, high temperature risks have a significant influence on the income structure of rural household in China**.** Rising temperatures constrain the production potential of agriculture and exacerbating instability (He et al., 2020). This pushes up agricultural costs and undermines technological advances, such as seed improvement (Schlenker, 2010). As a result, the income of farmers has declined owing to increased risks and costs (Below et al., 2012). Many smallholder farmers turn to non-agricultural activities to supplement their income due to a lack of technical training and a smaller land scale (Trinh et al., 2018).

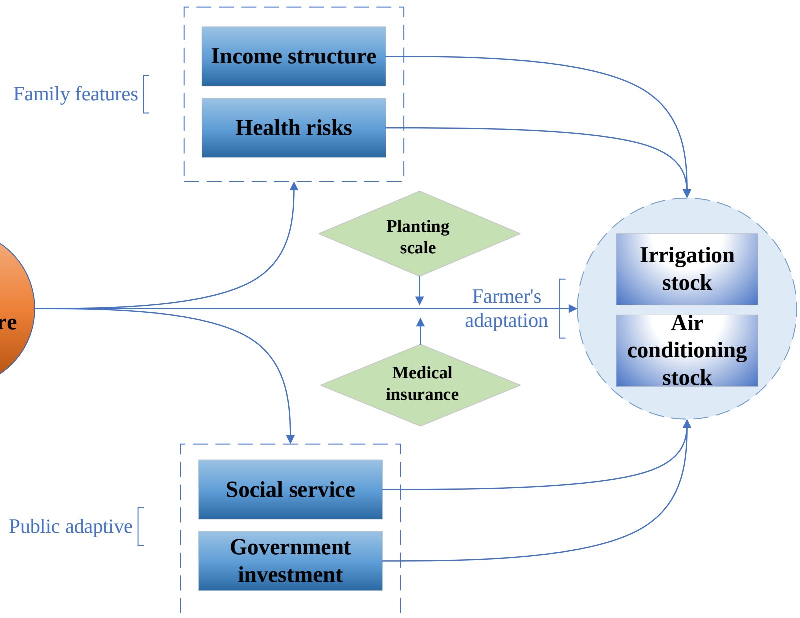

Figure 2. *Theoretical analysis framework*

Second, high temperature risk affects household adaptation behavior by changing health risks. Farmers often rely on their savings to sustain household investments and consumption. Takasaki et al. (2004) surveyed villages in tropical rainforests and discovered that selling small livestock such as dogs, chickens, and ducks played a significant role in maintaining daily consumption during times of floods and health risks. Compared to the United States and other developed countries, China's healthcare services are inefficient, particularly in rural areas where medical services are inadequate (Yip et al., 2012). In 2017, the proportion of people over 65 years old in China who was vulnerable to extreme heat reached 31.3%, a 25% increase compared to 1990 (Watts, 2018). As a result, excessive health expenditure caused by high temperatures could have

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changed household budgets for investment and consumption. Medical insurance not only reduces the medical expenses of rural households but also alleviates their preventive savings for risks, thus improving the vulnerability of rural households (Vo and Van, 2019) and influencing their investment and consumption budgets and behaviors.

Third, social services and government investment not only replace irrigation investment but also promotes farmers' consumption. Adaptation to climate change can be broadly classified into private and public adaptation. The former pertains to the responsibility of production, while the latter is governed by the government's public adaptation strategies. In most cases, the government provides public goods and services that support the agricultural production, participates in agricultural adaptation to climate change, and influences farmers' adaptation (Abid et al., 2017). For instance, China is implementing a pilot project to reform the property rights of farmland water facilities, which aims to address the issues of chaotic end-of-pipe governance and inefficient irrigation among farmers. In the sample area of this paper, government investment projects and village collectives provide unified irrigation services for departmental land. Additionally, government investment projects in farmland and water conservancy can promote local economic development, thereby impacting the income structure of farmers.

Consequently, this paper posits the following hypotheses:

H1: High temperature risk decreases irrigation investment and increases air conditioning consumption.

H2: High temperature risk increases non-farm employment, reducing irrigation investment and promoting air conditioning consumption.

H3: High temperature risk threatens health, increasing air conditioning purchases and reducing irrigation investment.

H4: High temperature risk increases village social services, substituting household irrigation investments and increasing air conditioning use.

H5: High temperature risk drives government irrigation investment, replacing household irrigation and increasing air conditioner stock.

Empirical model

As Chinese farmers have dual attributes of producers and consumers, their production investment decision-making equation and durable goods consumption decision-making equation will interact under the constraint of income. Irrigation investment and air-conditioning consumption are jointly endogenized in the expenditure decisions of farmers, constituting a system of multiple equations with possible interactions between them. In order to estimate the above set of equations, we introduce the MVTOBIT model to jointly estimate these equations. The basic idea is to investigate whether the two factors are substituted or not. One factor can be included in the decision equation of another factor. Specifically, the decision-making model of farmers is established as follows:

$$y_{1i}^{*} = \beta_1' CI_{1i} + \gamma X_i + \varepsilon_{1i} \quad \text{(Eq.1)}$$

$$y_{2i}^{*} = \beta_2' CI_{2i} + \gamma X_i + \varepsilon_{2i} \quad \text{(Eq.2)}$$

For the explained variable, the equation can be set as:

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$$y_m = 1, 2, 3 \cdots m \qquad \text{(Eq.3)}$$

where y_m refers to the total number of irrigation equipment or air conditioners owned by farmers, and i refers to the number of independent variables. The ε_{im} error term does not obey the multivariate normal distribution and the mean value is 0 and the variance is 1.

Then, to test the mechanism of high temperature risk affecting farmers' investment and consumption, this study uses the following models for mechanism analysis:

$$M_i = \alpha + \beta * CI_i + \gamma * X_i + \varepsilon_i \qquad \text{(Eq.4)}$$

where M_i indicates the potential mechanism, mainly including the proportion of wages and commercial income, health risks, the proportion of farmland irrigated collectively by the village, and the government's investment in water conservancy construction. CI_i indicates high temperature risks, X_i represents a series of control variables, and ε_i represents a random error term.

Data source and variable description

Data source

The data used in this paper is from the CHNS, which is an international collaborative survey conducted by the University of North Carolina at Chapel Hill and the Chinese Center for Disease Control and Prevention. The CHNS used a multi-stage randomized cluster sampling method to conduct questionnaire surveys in representative provinces in China. The survey mainly covers health, nutrition, health care coverage, economic sources, socio-economic characteristics, health behaviors, family structure, and sociological characteristics of the population. To be consistent with the start year of the control variables, we keep the sample collected in 1991, 1993, 1997, 2000, 2004, 2006, 2009, 2011, and 2015. Furthermore, we matched the meteorological data with the latitude and longitude of the village. The meteorological data comes from China's surface climate data released by the NMC. Considering that the impact of climate change on the adaptive behavior of farmers has a lag (Paudel et al., 2014; Aragón et al., 2021), this study collated the annual average temperature, annual average rainfall, heating degree day (HDD), and cooling degree day (CDD) of the regions in 1990, 1992, 1996, 1999, 2003, 2005, 2008, 2010, and 2014. Provincial per capita GDP, government investment in water conservancy construction, and other data are calculated based on China Statistical Yearbook and China Financial Statistical Yearbook. Totally, there are 23,361 valid data distributed across provinces at different latitudes in China.

Variable description

Dependent variable. Among farmers' production investments and living consumption, irrigation equipment and air conditioning are most directly related to high temperature risk. Thus, investment in irrigation is widely viewed as a rural household's adaptation to high temperatures in production (e.g., Wang et al., 2024), and consumption of air conditioning is widely viewed as a rural household's adaptation to high temperatures (Randazzo et al., 2020). In this paper, farmers' investments in irrigation equipment and air conditioning equipment are taken as the explained variables, whiles the cumulative ownership of irrigation equipment and air conditioning equipment is used to characterize the investment stock of farmers in irrigation and air conditioning.

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Climate change variables. According to Deschênes and Greenstone (2007), the use of the degree day indicator can be used to measure the intensity of demand for refrigeration or heating under a specific temperature scenario. Therefore, this paper constructs the degree day indicator to measure climate change, as shown in *Equation 1*. The comfortable temperature range in China is between 18-26℃, following the Code for Design of Heating Ventilation and Air Conditioning. Thus, we select 26℃ as the appropriate reference temperature for China (Shi et al., 2016).

$$CDD = \sum_{i=1}^{365} rd_c(T_i - 26)\ rd_c = \begin{cases} 1 & T_i > 26℃ \\ 0 & T_i \leq 26℃ \end{cases} \quad \text{(Eq.5)}$$

where T_i is the temperature of the day, and *CDD* of cooling degree day represents the sum of the difference between the actual temperature and 26℃ when the temperature is higher than 26℃ within a year. The higher the *CDD*, the higher the local weather is.

Control variables. There are many factors that affect farmers' adaptive behavior to climate change, but through sorting and synthesis, they are mainly affected by personal characteristics, family characteristics, regional characteristics, and other factors. In terms of personal characteristics, male farmers showed strong motivation to adapt to climate change (Deressa et al., 2009). The development of village-level industries and the proportion of migrant workers are closely related to agricultural production, and the level of regional economic development will also affect the development of farmers. In addition, because rainfall will affect the degree of drought in the region, and low temperature will also affect air conditioning consumption, this paper controls the annual average rainfall and low temperature index HDD.[5] Based on the achievements of Schlenker et al. (2005), 26 variables are selected for descriptive statistical analysis, and their definitions are shown in *Table 1*.

Results and discussion

Benchmark regression results

In *Table 2*, columns (3) and (4) indicate that the coefficients for high temperature risk in the regression of irrigation equipment investment are negative, while those for air conditioning consumption are positive and significant at the 1% level. The likelihood ratio test indicates that Chi2(1) = 29.12, which is significant at the 1% level, suggesting that farmers' decisions regarding irrigation investment and air conditioning consumption are not independent but are somewhat correlated. Therefore, it is appropriate to use the MVTOBIT model to estimate the production and consumption adaptive behaviors of farm households. Therefore, the empirical results confirm hypothesis 1. Our discussion is closely related to the recent findings in Cui and Tang (2024). Our findings extend their study in two ways. On the one hand, we find that in addition to precautionary savings, farmers may reallocate resources between production and consumption to minimize the impact of high temperature risk on household welfare. On the other hand, we provide new evidence that farmers' adaptive behavior to climate change is not always conducive to improving the resilience of agriculture in developing

[5] HDD represents the sum of the difference between the actual temperature and 18°C when the temperature is lower than 18°C in a year. The higher the HDD, the higher the cold degree of the local weather.

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countries. We will further explore potential mechanisms in the subsequent sections. The effects of control variables are generally consistent with existing studies.

Table 1. *Descriptive statistics*

Variable name	Definition	Mean	SD
Dependent variable			
Irrigation stock	Number of irrigation equipment owned by farmers (set)	0.034	0.199
Air conditioning stock	Number of air conditioners owned by farmers (set)	0.269	0.681
Core independent variable			
CDD	Days of high temperature in a year	99.842	73.694
Control variable			
HDD	Days with low temperature in a year	1281.596	707.784
Annual rainfall	Total rainfall of the year (mm)	745.709	314.975
Age	Age of head of household (years)	52.643	13.853
Education	Education level of household head (year)	6.851	4.114
Gender	Gender of head of household (1 = male, 0 = female)	0.821	0.382
Area	Per capita housing area of households (m^2)	36.646	31.163
Income	Total family income (ten thousand yuan)	4.116	7.656
Family size	Total household population (person)	3.670	1.559
Electricity	Annual total household electricity charge (yuan)	568.214	84.126
Workers	Last year, I worked in areas other than the village/neighborhood committee for more than one month (%)	27.169	23.955
Labor force	Mainly engaged in agricultural labor (%)	37.647	33.648
Development	Whether there are development zones nearby (0 = none, 1 = yes)	0.428	0.494
GDP	Regional average output value (thousand yuan/person)	22.885	17.965
Drought index	Whether drought index is < 20	0.188	0.391
Mechanism variables			
Non-agricultural income	Non-agricultural income/total income	0.273	0.298
Health risks	Proportion of the family sick population in the past four weeks	0.111	0.226
Social services	Proportion of farmland irrigated collectively by the village	30.752	39.764
Government investment	Completed amount of government water conservancy investment (100 million yuan)	116.091	110.595
Scale	Household cultivated land area (mu)	4.715	7.659
Insurance	Proportion of people with medical insurance in their families	0.435	0.413

Robustness test

Table 3 reports the results of robustness tests. In column (1), we analyzed all variables with a 1% tail reduction. In column (2), we exclude years without agricultural machinery subsidies and rural subsidies. Since drought and high temperature often occur simultaneously, we construct a drought index based on temperature and precipitation in column (3), following Paltasingh et al. (2012). When rainfall is

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constant, a smaller aridity index means higher temperatures. All results indicate that the direction of the coefficient of high temperature risk is completely consistent with the benchmark regression, and the variable is generally significant, indicating relatively stable estimation results, hypothesis 1 was confirmed again.

Table 2. *Benchmark regression results*

Variables	MVTOBIT model	
	Irrigation stock	**Air conditioning stock**
CDD	-0.010*** (0.003)	0.003** (0.001)
Age	-0.017*** (0.004)	0.001 (0.002)
Education	-0.003 (0.011)	0.116*** (0.010)
Gender	0.576*** (0.149)	-0.212*** (0.070)
Area	0.000 (0.001)	0.005*** (0.001)
Income	-0.008 (0.005)	0.023*** (0.003)
Family size	0.188*** (0.032)	0.162*** (0.027)
Electricity	0.006*** (0.002)	-0.001 (0.001)
Annual rainfall	-0.002*** (0.000)	-0.000 (0.000)
HDD	-0.001** (0.000)	-0.000*** (0.000)
Workers	0.001 (0.003)	-0.005*** (0.001)
Labor force	0.019*** (0.003)	-0.022*** (0.002)
Development	-0.394** (0.186)	0.260*** (0.076)
GDP	0.017 (0.015)	0.007 (0.006)
Time fixed effect	Yes	Yes
Regional fixed effect	Yes	Yes
Chi(2)1	29.168	
P	0.000	
Constant	-3.727** (1.631)	-1.294 (0.797)
Observations	23,361	23,361

Standard errors are shown in parentheses. Asterisk (*), double asterisk (**), and triple asterisk (***) denote the 10%, 5%, and 1% significance levels, respectively. The same in below

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Table 3. *Robustness test*

Variables	Tail reduction		2008-2015		Drought	
	Irrigation stock	**Air conditioning stock**	**Irrigation stock**	**Air conditioning stock**	**Irrigation stock**	**Air conditioning stock**
CDD	-0.010*** (0.003)	0.002* (0.001)	-0.012*** (0.004)	0.004* (0.002)		
Drought index					0.600*** (0.194)	-0.071 (0.105)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Regional fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Chi(2)1	31.854		14.640		28.258	
P	0.000		0.000		0.000	
Constant	-3.124** (1.294)	-3.664*** (0.608)	-7.728*** (1.753)	-1.148 (0.791)	-8.957*** (1.621)	0.252 (0.953)
Observations	23,361	23,361	8,863	8,863	23,361	23,361

Heterogeneity analysis

Due to significant differences in climate conditions between North and South China, this study groups sample regions along the Qinling-Huaihe line[6]. Cities north of this line are categorized as the Northern sample, while those south of it are categorized as the Southern sample. We examine regional differences in how high-temperature risks affect farmers' investment and consumption decisions under different climate conditions. The grouped regression results are presented in *Table 4.* Columns (1) and (2) represent the regression results for the Northern sample, where high-temperature risks significantly reduce irrigation investments, and the coefficient for air conditioning consumption is positive but not significant. Columns (3) and (4) represent the regression results for the Southern sample, where high-temperature risks significantly reduce irrigation investments but effectively increase farmers' air conditioning consumption. It is clear that high-temperature risks have a negative impact on the production activities of farmers in both North and South China, but show heterogeneity in their effect on farmers' air conditioning consumption. This may be due to the fact that, on the one hand, there is a significant temperature difference between North and South China, with the North being mostly heated through centralized heating systems, while the South relies more on individual purchases of air conditioning units to regulate temperature. On the other hand, the overall climate in Northern rural areas is cooler than that of the South, making the demand for air conditioning higher among Southern residents. Our data shows that the CDD is significantly lower in the North than in the South, which is consistent with the actual situation in China.

[6] According to the Central People's Government of the People's Republic of China. http://www.gov.cn/test/2005-07/27/content_17425.htm.

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Table 4. *Heterogeneity analysis: North-South*

Variables	North		South	
	Irrigation stock	**Air conditioning stock**	**Irrigation stock**	**Air conditioning stock**
CDD	-0.010* (0.006)	0.006 (0.004)	-0.015*** (0.003)	0.003* (0.002)
Control variables	Yes	Yes	Yes	Yes
Time fixed effect	Yes	Yes	Yes	Yes
Regional fixed effect	Yes	Yes	Yes	Yes
Constant	-5.254* (3.082)	0.051 (1.695)	-6.701** (3.381)	1.403 (1.595)
Chi(2)1	34.295		4.339	
p	0.000		0.037	
Observations	8,297	8,297	15,064	15,064

The policies of these major grain-producing areas included raising the minimum grain purchase price, increasing subsidies, constructing large-scale commodity grain bases, and providing agricultural insurance support, all of which have a direct or indirect impact on farmers' income. Therefore, farmers in grain-producing areas[7] and non-grain-producing areas may have different responses to high-temperature risks. This article uses a grouped regression based on whether the sample area is a major grain-producing area. As in *Table 5*, columns (1) and (2) show the results for major grain-producing areas, while columns (3) and (4) show the results for non-grain-producing areas. Farmers in major grain-producing areas reduce their irrigation investment to a lesser degree than farmers in non-major areas. Furthermore, although air conditioning consumption has increased in the sample of major grain-producing areas, the coefficient is not significant. For farmers in major grain-producing areas, the proportion of agriculture in their production activities may be higher. The importance of agricultural investment for household income makes them less inclined to consume air conditioning.

Table 5. *Heterogeneity analysis: main producing area - general region*

	Main producing area		General region	
Variables	**Irrigation stock**	**Air conditioning stock**	**Irrigation stock**	**Air conditioning stock**
CDD	-0.007* (0.004)	0.003 (0.002)	-0.017*** (0.004)	0.007** (0.003)
Control variables	Yes	Yes	Yes	Yes
Time fixed effect	Yes	Yes	Yes	Yes
Regional fixed effect	Yes	Yes	Yes	Yes
Constant	-7.864*** (2.415)	0.992 (1.070)	-10.325** (5.169)	-1.958 (2.118)
Chi(2)1	24.200		2.730	
p	0.000		0.098	
Observations	16,869	16,869	6,492	6,492

[7] In 2001, China divided its regions into 13 major grain-producing areas to adapt to changes in the production and distribution of grain.

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Mechanism analysis

Previous analysis shows that farmers in the sample provinces decrease their productive irrigation investment and increase their air conditioning consumption. This section delves into the mechanism of high temperature risk and its effects on farmers' investment and consumption.

Table 6 shows the regression results of the mediation effect model. Column (1) shows the impact of high temperature risk on farmers' non-farm employment. The coefficient of high temperature risk on non-agricultural income is positive and significant at the 5% level. The empirical results show that, high temperature risk induces small farmers to increase their income by increasing their working hours in non-farm employment. The reduced importance of investment in agricultural production and higher non-farm incomes allow this group of farmers to have a larger budget for consumption. Therefore, Hypothesis 2 was confirmed.

Table 6. *Mechanism analysis of first-step equation*

Variables	Non-agricultural income	Health risks	Social services	Government investment
CDD	0.000** (0.000)	0.000* (0.000)	0.057*** (0.017)	0.056*** (0.006)
Control variables	Yes	Yes	Yes	Yes
Time fixed effect	Yes	Yes	Yes	Yes
Regional fixed effect	Yes	Yes	Yes	Yes
Pseudo R2	0.166	0.055	0.019	0.215
Constant	0.976*** (0.054)	-0.947*** (0.101)	15.493 (14.241)	-121.576*** (4.463)
Observations	23,122	23,361	17,624	19,089

Column (2) shows the impact of high temperature risk on the health of rural households. The coefficient of high temperature risk on health risk is positive and passes the 10% significance test. The research results show that, high temperature risk significantly increases the proportion of household members with sickness. This implies that high temperature risk not only poses a challenge to agricultural production but is also detrimental to the health of rural residents. Adopting appropriate behaviors to cope with rising temperatures is important for rural dwellers, especially those with chronic diseases. Thus, high temperature risk increases the willingness to purchase air conditioners. Therefore, Hypothesis 3 was confirmed.

Column (3) demonstrates the impact of social services provided by village collectives. The coefficient of high temperature risk on socialized services is positive and significant at the 1% level. The results mean that, high temperature risk promotes the government to increase the share of adaptive social services. Uniform irrigation by the village replaces part of the farmers' investment in production and promotes adaptation to high temperatures in their daily lives. Therefore, Hypothesis 4 was confirmed.

Column (4) shows the mediating effect of government investment in irrigation. The coefficient of high temperature risk on socialized services is positive and significant at the 1% level. High temperature risk significantly contributes to government investment in irrigation. This both relieves the pressure on farmers to irrigate and provides

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employment opportunities that increase farmers' ability to purchase air conditioners. Therefore, Hypothesis 5 was confirmed.

Among these mechanisms, non-farm employment and health risks are spontaneous adaptive behaviors of farmers. As previously emphasized, farmers in developing countries can experience severe shocks to their farm income and health status under the duress of high temperature risk. They may try to minimize the loss of household welfare by cutting their dependence on agricultural income and increasing their investments in quality of life. Although their decisions are rational in an individual perspective, their spontaneous adaptive behavior reduces the resilience of agriculture to climate change. Social services and public investments in irrigation are adaptive behaviors of the village collectives and the government to assist farmers in coping with high temperature risks. Government investments can ease farmers' budget constraints without losing agricultural resilience. Data from the National Bureau of Statistics of China shows that irrigable arable land has increased from 54.48 million hectares in 2004 to 71.57 million hectares in 2023[8]. With farmers' irrigation stock unchanged, this growth reflects increasing investment in agricultural irrigation by the government and society.

Expansion analysis

To test the moderating effects of medical insurance and planting scale on high-temperature risk and air conditioning consumption, we conducted regression analyses with the interaction terms of household medical insurance coverage and high-temperature risk, as well as planting scale and high-temperature risk, as the core explanatory variables. In the investment equation, the coefficient of "planting scale * CDD" is positive and significant, while the coefficient of "household medical insurance ratio * CDD" is not significant (see *Table 7* columns (1) and (3)).

Table 7. *Expansion analysis*

Variables	Irrigation stock	Air conditioning stock	Irrigation stock	Air conditioning stock
CDD	-0.011*** (0.003)	-0.002 (0.002)	-0.011*** (0.003)	-0.001 (0.002)
Scale * CDD	0.000*** (0.000)	-0.000 (0.000)		
Insurance * CDD			0.001 (0.002)	0.006*** (0.001)
Control variables	Yes	Yes	Yes	Yes
Time fixed effect	Yes	Yes	Yes	Yes
Regional fixed effect	Yes	Yes	Yes	Yes
Chi(2)1	1.649		29.718	
P	0.199		0.000	
Constant	1.167 (1.462)	-6.610*** (1.087)	-3.784** (1.633)	-1.371* (0.741)
Observations	10,087	10,087	23,361	23,361

[8] Data resource: National Bureau of Statistics of China. Irrigable arable land refers to flat land with a reliable water source and equipped with irrigation infrastructure, allowing for normal irrigation under typical conditions.

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In the consumption equation, the coefficient of "planting scale * CDD" is not significant, while the coefficient of "household medical insurance ratio *CDD" is positive and significant (see *Table 7* columns (2) and (4)). The results indicate that large-scale farming can mitigate the negative impact of high-temperature risk on farmer irrigation investment, and the negative effect of high-temperature risk on farmer investment is evident when the scale is low. The widespread use of medical insurance can promote the use of air conditioning by rural residents to resist high-temperature risks: a high household medical insurance coverage rate can reduce the preventive savings demand brought about by future health risks, and farmers will be more willing to purchase air conditioning to resist the effects of high temperatures. Our conclusion suggests that the government can enhance farmers' climate adaptation capacity and increase the resilience of agriculture by promoting agricultural production scale and improving rural social security.

Conclusion

Agricultural transformation in developing countries is usually accompanied by significant rural hollowing out. Climate risks can accelerate the process of farmers fleeing agriculture, leading to a lack of incentives for agricultural development. Smallholder farmers with limited capital face great difficulties in adapting to climate change in their production and livelihoods. In rural China, the risk of high temperatures reduces smallholders' investments in irrigation and increases their consumption of air conditioning. Non-farm employment and health risks associated with high temperatures are important reasons for farmers to respond negatively to climate change in production. Social services effectively promote climate adaptation among smallholder farmers, while the impact of water conservancy investment remains less apparent. Regulating production scale and enhancing health services could facilitate farmers' climate change adaptive behavior.

Government's provision of public water facilities and irrigation services replacing private irrigation investments can help farmers adapt to climate change in their production. However, in many mountainous areas, the cost of large water projects far outweighs the returns. Government should assess the efficiency of water investments and increase the proportion of investment in small and medium-sized irrigation projects. Improving the accessibility of social services, such as uniform irrigation services with financial subsidies for villages or cooperatives, could reduce the pressure on individual farmers to invest in production. This would allow small-scale farmers to have more funds to deal with the health threats posed by high temperatures and partially reduce the likelihood of labor withdrawal from agriculture.

From a livelihood perspective, it is worthwhile to continue to subsidize farmers' consumption of air conditioning. This could save farmers more capital for agricultural investment and protect their health and labor capacity. In addition, with reference to the heat subsidies provided to urban workers, the government could increase transfer payments to compensate farmers for the loss of health and welfare when working in hot environments. Designing more farmer-friendly social security systems including health insurance and pension insurance can also help reduce their precautionary savings and encourage them to increase their consumption of air conditioning to improve their welfare.

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