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Estimating the Impact of Weather Shocks on Agricultural Production and Migration in China

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SHAANXI PROVINCE, CHINA -- Zhao Yifa winnows grain farm in the village of Yin Jai Yan in the county of Liu Quian He county, Yuan Yang distirict, Yulin City, Shaanxi Province.
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1 January, 2014

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ESTIMATING THE IMPACT OF WEATHER SHOCKS ON AGRICULTURAL PRODUCTION AND MIGRATION IN CHINA

Yazhen-Gong

EXECUTIVE SUMMARY

This research used a unique panel data set to explore the impact of fluctuations in weather conditions on rural-urban migration in China. The main findings of the study are as follows:

1. Both reduced-form and structural models indicate that weather shocks appear to have a significant impact on rural-urban migration in China.
2. Weather shocks may have indirectly affected past rural-urban migration in China, most probably through their effect on crop yields. However, to identify the relationship between weather shocks and migration in future research, more attention must be given to finding appropriate estimation methods and proper measures for agricultural production and household migration decisions.
3. When studying the effect of weather shocks on crop yields, it may be critical to pay closer attention to extreme weather conditions, particularly extreme temperatures, instead of mean temperature/precipitation in growing seasons.
4. Unobserved factors associated with time play a significant role in households' migration decisions. Policy makers in China should consider the effects of other driving forces, along with the effects of weather shocks, when designing policies to better address issues related to rural-urban migration.

1.0 INTRODUCTION

The link between climate change and migration is an emerging research topic that requires further empirical study. In migration literature, rural-urban migration is conventionally driven by two major incentives: (1) the need to seek the higher income expected of urban areas (Todaro 1969) and/or (2) to overcome constraints in the credit or insurance market in rural areas (Stark 1991). Some emerging views hold that climate change may cause changes in human-migration patterns (Glantz and Ausubel 1988; Myers 2002) as changes in climatic conditions could increase both rural-urban income disparities and risks faced by rural households (Tacoli 2009; McLean and Smith 2006; Sahota 1968). Using a panel-data approach, Feng, Kruegera, and Oppenheimer (2010) and Feng, Oppenheimer, and Schlenker (2011) conducted two pioneering empirical studies to demonstrate that climate change could indirectly affect migration through its effect on changes in crop yield. Compared to a cross-sectional data approach, which gives rise to the concern of omitted variable bias due to potential effects caused by some time-invariant site-specific factors, the panel data approach may be better in identifying the impact of climate change on economic outcomes by controlling for time-invariant site-specific effects (Burke and Emerick 2012). In their US study, Feng, Oppenheimer, and Schlenker (2011) found that net out-migration in rural areas within the US corn belt had a significant statistical relationship with weather-driven changes in crop yields. However, they cautioned that the underlying relationship between climate change and migration still required closer scrutiny and careful identification (Feng, Kruegera, and Oppenheimer 2010).

In the particular context of China, existing studies have indeed shown rural-urban migration to be driven largely by regional disparities in economic development (Zhu 2002) and individuals' incentives to overcome constraints in credit or insurance markets in rural areas (Rozelle, Taylor, and Brauw 1999). However, it may be that climate change has accelerated China's rural-urban migration. During the 20th century, China's rainfall patterns changed and its average temperature increased by 0.5–0.8°C. In Northern China, a more significant warming trend and a more severe decrease in rainfall were observed (Wang et al. 2010a). Climate change has had a notable impact on China's agricultural production, primarily through its impact on crop yields. It has also affected agricultural prices and farmers' incomes (for a comprehensive review for existing studies, please refer to Wang, Huang, and Yang 2014). In addition, climate change may have led to increased rural-urban income disparities and may have imposed income shocks/risks on rural households. Therefore, in combination with rapid economic development and urbanization, climate change may have induced more intensive rural-urban migration in China.

Thus far, almost no empirical research has been conducted in China to analyze the impact of climate change on rural households' migration behaviors, particularly through the lens of agricultural production. Although a very limited number of economic studies—which essentially used a Ricardian approach based on cross-sectional data—have attempted to analyze the impact of climate change on agricultural production (e.g., Wang et al. 2010a; Liu et al. 2001), they did not attempt to analyze the link between climate change and migration. One study (Zhou 2011) did attempt to investigate empirically the effect of climate change on migration; but did so through the lens of human health, and focused primarily on the urban population.

This study provides some micro-level empirical evidence regarding the impact of climate change on migration decisions at the household level using a unique panel data set collected by household surveys in six provinces in rural China. In particular, it analyzes the effect of weather shocks, i.e., short-term changes in temperature and precipitation, on rural households' migration decisions. This study largely follows the identification strategy used by Feng, Kruegera, and Oppenheimer (2010) and Feng, Oppenheimer, and Schlenker (2011), but focused its lens on household-level migration decisions. To our knowledge, this study is one of the first in China to use a panel data approach to explore how rural households may have responded to short-term climate fluctuations.

2.0 DATA

Both primary and secondary data were used for this research. The primary data were collected via two rounds of household surveys conducted in six provinces, including (1) Hebei, Shaanxi, and Liaoning in Northern China; and (2) Sichuan, Jiangxi, and Zhejiang in Southern China. The secondary data included weather data maintained by 753 national meteorological stations across China, and cropping patterns and growing seasons of main crops such as rice, wheat, and corn in surveyed provinces.

The household survey data were collected in 58 randomly selected villages in 2000 and 2008. To reflect varying income distributions within each province, one county was randomly selected within each of five income quintiles in the province, as measured by the gross value of industrial output. In each county, two villages were randomly selected; in each village 20 households were randomly selected from village rosters. In total, 1,199 households were surveyed in 2000, and 1,018 households were surveyed in 2008.[1]

The survey data contained information on household socioeconomic characteristics, migration, and crop information. Key information related to family members' migration included (1) number of family members who migrated, (2) places they migrated to, and (3) months they worked as migrants. Crop information mainly included sown area and yield of each crop. Major crops surveyed included wheat, corn, and rice.

The weather data (1995–2008) was derived from actual measurements from 753 national meteorological stations across China. Geographic information system tools were used to impute weather data for each of the surveyed villages based on geographic information (longitude and latitude) for each village and configured with a 10 km × 10 km resolution.

[1] The difference of 181 households was due to the following: (1) six households moved to urban areas permanently, while 81 households migrated to earn off-farm income in 2008; (2) 21 households were not surveyed because the heads of these households had passed away; and (3) 40 households from one county in Sichuan province were not surveyed in 2008 due to the earthquake. The panel data used for the analysis in this paper only composed of 1,018 households for each year.

3.0 DESCRIPTIONS OF SURVEY AND WEATHER DATA

3.1 Description of Individual and Household Characteristics

Table 1 summarizes the statistics for individual and household characteristics in 2000 and 2008.

Table 1. Summary statistics for individual and household characteristics

Variables	2000	2008
Household size (persons)	4.00 (1.30)	4.00 (1.40)
Age of family head (years)	46.00 (11.00)	53.00(11.00)
Education of family head (years)	6.50 (3.40)	6.50 (3.50)
Family labor (persons)	3.00 (1.00)	3.00 (1.00)
Dependant ratio	0.24 (0.22)	0.21 (0.26)
Number of migrants (persons)	0.37 (0.56)	0.56 (0.78)
Proportion of families in family labor	0.12 (0.20)	0.18 (0.25)
Total months migrants worked (months)	3.22 (6.07)	5.43 (7.88)
No. of observations	1018	1018

Note: Standard deviations are in parenthesis.

In both years, the surveyed households had an average household size of four people with three family members working, aged between 18 and 60 years. The average dependant ratio was 0.24 and 0.21 in 2000 and 2008, respectively. The average age of family heads was 46 in 2000 and 53 in 2008; most had completed primary school education.

Overall, the migration activities of the families surveyed intensified between 2000 and 2008. On average, the number of migrating laborers increased from 0.37 in 2000 to 0.56 in 2008; and the proportion of migrants who migrated to urban areas to engage in off-farm work, in total family laborers (aged between 18 and 60) increased from 12% in 2000 to 18% in 2008. The total number of migrants' working months rose from slightly above three months (3.22) in 2000 to more than five months (5.43) in 2008.

3.2 Surveyed Households' Agricultural Production

The surveyed households cultivated small family plots with an average farmland size of 0.44 ha in 2000 and 0.47 ha in 2008. During the survey period, rice, wheat, and corn yields all increased (Table 2). These higher crop yields might be attributed to technological developments in the agricultural sector.

Table 2. Main grain crops and their yields in 2000 and 2008

Variables	2000		2008	
	Mean	# of obs.	Mean	# of obs.
Rice (kg/ha)	1,2502.00 (3,018.00)	532	13,257.00 (3,054.00)	348
Wheat (kg/ha)	6,694.00 (3,110.00)	479	9,347.00 (3,211.00)	258
Corn (kg/ha)	8,498.00 (3,354.00)	549	12,170.00 (4,184.00)	484
Size of farm plots (ha)	0.44 (0.58)	1,018	0.47 (2.53)	1,018
Value of agricultural production (CNY)	2,858.80 (4,129.47)	1,018	5,094.80 (10,624.88)	1,018
Share of value of agricultural production in total family income (%)	50.34 (35.96)	1,000	32.61 (34.38)	997

Note: Standard deviations are in parenthesis.

Some households switched crops between 2000 and 2008. In general, fewer farm households grew rice, wheat, or corn in 2008 than in 2000. In 2000, 532 families grew rice, but only 348 of these families continued to grow rice in 2008. Similarly, the number of families growing wheat decreased from 479 in 2000 to 258 in 2008; the number of families growing corn decreased from 549 in 2000 to 484 in 2008. The decreasing number of families growing rice, wheat, or corn suggests that some families may have switched their crops in response to changes in weather conditions, market prices, or agricultural policies. Meanwhile, agricultural production appeared to play a less important role in total household income, although the total value of agricultural production—derived from seven main crops including rice, wheat, corn, peanuts, soybeans, rapeseed, and potatoes—increased. Table 2 shows that the value of agricultural production in 2008 was CNY 5,094.80, or about two times higher than that in 2000 (CNY 2,858.80). However, the percentage value of agricultural production in total family income decreased from around 50% in 2000 to around 33% in 2008. The increased value of agricultural production may be the result of a combination of increased yield crops (as discussed above) and increased market prices.

3.3 Description of Cropping Patterns in Surveyed Provinces

Among the six surveyed provinces, all but Liaoning province are traditional winter wheat production areas, in which winter wheat is commonly rotated with corn or late rice. In the study sample, winter wheat is grown exclusively in three provinces, including Hebei, Shaanxi, and Sichuan; no spring wheat is grown. Although corn is grown in most provinces in China, it is not grown in Zhejiang province, which is included in the study sample. Likewise, because Hebei Province is not suitable for growing rice, no rice was included in Hebei in the study sample.

Agricultural production in Hebei, Shaanxi, and Liaoning relies heavily on irrigation. Although Sichuan and Hubei both have large irrigation districts, they also have a relatively high share of rain-fed agriculture. While agriculture in Zhejiang province is mainly rain fed, agriculture in Hebei almost exclusively depends on groundwater irrigation. In the study sample, wheat was grown on irrigated land, which implies that wheat production may be less constrained by levels of rainfall. Corn was partly rain fed and partly irrigated. Rice was partly rain fed and partly irrigated. In the study sample, since rice is mainly grown in Southern China (which has more rainfall than Northern China) rain-fed rice may be less susceptible to rainfall changes than rain-fed corn.

Growing seasons for winter wheat in the three provinces (Hebei, Shaanxi, and Sichuan) in the study sample span from September of the previous year to June of the following year. The growing seasons for corn span from late spring to early fall, depending on the regions where they grow. For instance, the growing season for corn in Liaoning province is limited to the period between late April and early October. In Sichuan province, the season can stretch from mid-April to early August or from early June to early October. The growing seasons for late rice in the five provinces in the study sample are from July to October.

3.4 Changes in Weather Conditions in Surveyed Villages

Table 3 presents information on key weather variables in the 58 surveyed villages and the results of the t-test of the weather variables between 2000 and 2008.

Table 3. Weather conditions in the surveyed villages

Variables	2000	2008	t statistic (p-values)
Mean annual precipitation (cm)	26.27 (12.80)	26.18 (9.72)	0.17 (0.87)
Mean annual temperature (°C)	13.53 (3.79)	13.84 (3.43)	–2.04** (0.04)
Mean annual precipitation in previous year (cm)	26.94 (15.47)	26.18 (9.39)	1.33 (0.19)
Mean annual temperature in previous year (°C)	13.99 (3.41)	14.52 (3.30)	–3.56*** (0.00)

Table 3 continued

Variables	2000	2008	t statistic (p-values)
Mean spring precipitation (cm)	11.57 (12.54)	9.88 (8.44)	18.56*** (0.00)
Mean spring temperature (°C)	3.01 (5.87)	3.27 (4.69)	60.89*** (0.00)
Mean summer precipitation (cm)	32.12 (21.65)	34.74 (16.84)	19.81*** (0.00)
Mean summer temperature (°C)	19.28 (2.81)	19.20 (2.65)	52.90*** (0.00)
Mean fall precipitation (cm)	44.61 (14.61)	47.78 (12.81)	–39.77*** (0.00)
Mean fall temperature (°C)	23.87 (2.50)	23.89 (2.49)	–70.78*** (0.00)
Mean fall precipitation in previous year (cm)	20.97 (9.85)	20.54 (13.12)	0.83 (0.41)
Mean fall temperature in previous year (°C)	14.98 (3.77)	14.79 (3.52)	1.16 (0.25)
Mean winter precipitation in previous year (cm)	3.44 (4.32)	8.48 (8.46)	–16.94*** (0.00)
Mean winter temperature in previous year (°C)	3.04 (5.51)	3.70 (5.14)	–2.79*** (0.00)
No. of observations	58	58	

Notes: (1) Standard deviations or p-values are in parenthesis; (2) *, **, and *** represent significance levels at 10%, 5%, and 1%, respectively.

In general, weather in the surveyed villages became significantly warmer and slightly drier from 2000–2008. The annual mean temperature was higher in 2008 than in 2000 at a 5% significance level and with a magnitude of 0.31°C (row 2, Table 2). The mean annual precipitation in 2000 was 0.09 cm higher than that in 2008, but the difference was not significant (row 1, Table 2). Similarly, the mean annual temperature in 2008 was 0.53 °C higher than that in 1999 at a 1% significance level (row 4, Table 2). The mean annual precipitation in 2000 was 0.76 cm higher than that in 2008, but the difference was not significant.

During crop-growing seasons, mean precipitation and mean temperature varied between 2000 and 2008 and across seasons. There was significantly more precipitation in summer and fall in 2008 than in 2000, but there was significantly less precipitation in the spring of 2008 than in the spring of 2000. The mean temperature in spring and fall in 2000 was significantly lower than in 2008, but the summer mean temperature was significantly higher in 2000. In 1999 and 2007, the previous years of our surveys, there was no significant difference in mean precipitation and mean temperature in the fall seasons. However, the winter season in 1999 was significantly drier and warmer than in 2007.

4.0 EMPIRICAL SPECIFICATIONS

To identify the effect of weather shocks on household migration decisions, we first used a reduced-form model to analyze the overall effect (i.e., direct and indirect). We also considered the possibility that weather shocks may not be sizable enough to drive massive migration directly, but may only indirectly affect migration patterns through their effects on crop yields. We then employed a structural model.

4.1 The Reduced-Form Model Specifications

In the reduced-form model, weather variables were directly regressed on migration variables. The reduced-form model is specified as follows:

$$Y_{it}=a_0+a_2W_{it}+H_i+T_t+\eta_{it} \qquad \text{Equation (1)}$$

`

In Equation (1), Y_{it} is the degree of family members' migration, measured by the proportion of the number of migrants in the total number of family laborers. W_{it} is a set of weather variables, including (1) mean annual temperature and mean annual precipitation in the previous year and their squared terms, as weather conditions in the previous year[2] may have had an effect on household migration decisions in the survey years, and (2) mean annual temperature and mean annual precipitation in the current year and their squared terms. We used mean annual temperature and mean annual precipitation rather than mean temperature and mean precipitation in crop-growing seasons in our main model specification, assuming that weather variables may affect migration directly and indirectly. We added squared terms of weather variables to account for a nonlinear relationship between changes in weather conditions and changes in migration behaviors. X_{it} is a set of variables associated with household characteristics. H_{it} is the time-invariant variables specific to households, such as a family's preferences for migration and household initial endowment, as well as locations and slopes of family farm plots. T_t is the time dummies capturing time effect that was common to all households, including exemption of agricultural taxes and fees, implementation of free compulsory primary education in rural areas, and changes in macroeconomic conditions. N_{it} is an error term.

To estimate Equation (1), the standard approach is to use a household fixed effect (FE) model or random effect (RE) model, depending on the assumptions one makes for possible correlation between the error term and the dependant variable. When such a correlation is present, the RE model may not come up with a consistent estimator, and therefore the FE model should be more appropriate.

We assumed that the household FE model would be appropriate, considering that time-invariant characteristics specific to households may affect household migration decisions. Such characteristics include differences in family preferences for migration and household initial endowment. In addition, it is likely that unobserved household characteristics (e.g., gender and habits) can be correlated with a family's dependant ratio, which is a key explanatory variable included in the analyses. The above information suggests that the household FE model is preferred because it can control the time-invariant effect specific to households on household migration decisions. We used the Hausman test to verify our assumptions.

We also included province dummies to control for province fixed effects, such as topography and the distance from provinces to coastal areas, where the highest number of jobs are available to migrants from inland China. We used village-level clustered standard errors to account for unobserved heterogeneity within the villages.

4.2 The Structural Model Specifications

We employed the structural model, implicitly assuming that weather shocks have only an indirect effect on migration through their effect on crop yields. However, the relationship between crop yields and migration is subject to a potential endogeneity problem arising from simultaneity. On one hand, a reduced crop yield may drive more people to migrate from rural to urban areas; on the other hand, with more family laborers migrating to urban areas, families have fewer family laborers to engage in agricultural production. As a result, crop yield may be reduced. To address this potential endogeneity problem, we replicated the identification strategy used in Feng, Kruegera, and Oppenheimer (2010), i.e., changes in climatic conditions served as instrumental variables (IV) for changes in crop yields. By assuming that weather shocks may not be sizable enough to induce migration directly, changes in weather conditions do not have a direct effect on migration. However, mounting evidence has shown that changes in weather conditions could greatly affect agricultural production, particularly crop yields (e.g., Wan et al. 2008; Tao et al. 2006; Mendelsohn et al. 1994). Therefore, weather variables could serve as potential IVs. In addition, because a family's agricultural productivity and migration decisions could be the outcome of allocations of a family's time, labor, and other resources (Mendola 2008), we also included a set of household characteristics.

[2] We also tried to include mean annual temperature and mean annual precipitation for the previous five years as alternative measures. However, they were not jointly significant for migration decisions. Therefore, we decided to include only the weather variables in the previous year in our analyses without losing essential information.

The structural model is specified as follows:

$$Y_{it}=\beta_0+\beta_1 A_{it}+X_{it}+g_t+f_i+\varepsilon_{it} \qquad \text{Equation (2)}$$

and

$$A_{it}=\gamma_0+\gamma_1 Z_{it}+X_{it}+h_t+k_i+\mu_{it} \qquad \text{Equation (3)}$$

In Equations (2) and (3), Y_{it} denotes family i's migration decisions in the surveyed years. A_{it} is family i's crop yields in surveyed years. X_{it} is a set of variables associated with household characteristics.

Z_{it} is a set of weather variables associated with crop-growing seasons. Regarding the choices of weather variables to identify the impact of weather changes on crop yields, a number of econometric studies have demonstrated that there appears to be a strong causal relation between extreme temperature and crop yields (e.g., Roberts, Schlenker, and Eyer 2013; Welch et al. 2010). Therefore, if the data is allowed, variables associated with extreme weather conditions may be desired. However, the weather data available to us was gathered every 10 days, and recorded only mean temperature and precipitation. Thus, we did not have good information on extreme weather conditions (such as extreme temperatures). We then decided to use the mean temperature and the mean precipitation in the growing seasons of each crop, based on the cropping calendar of each crop. We included both linear and squared terms of weather variables to account for a nonlinear relationship between changes in weather conditions in growing seasons and changes in crop yields.

As in the reduced-form model, g_t and h_t are time dummies capturing the time effect common to all households. The variables f_i and k_i are time-invariant variables specific to households. ε_{it} and μ_{it} are error terms, which are independent of each other.

To estimate Equations (2) and (3), both the fixed-effect two-stage least square (FE-2SLS) method and the random-effect two-stage least square method (RE-2SLS) could be appropriate, depending on the assumptions made for the correlation between the error terms and the dependent variables included in the equations. We believed that the FE-2SLS method would be more appropriate to get consistent estimators, given the possible effect of time-invariant characteristics specific to households on migration decisions or crop yields. For example, in Equation (2), a number of time-invariant characteristics specific to households may affect household migration decisions, with similar arguments made for Equation (1) in Section 4.1. In Equation (3) some time-invariant characteristics (e.g., gradient of the land and the quality of family plots, distance from plots to rivers/canals) could affect crop yields. We conducted the Hausman test to verify whether the household FE-2SLS model or RE-2SLS model should be used for the analysis.

We also conducted overidentification tests for IVs and F-statistics for IVs used in the first stage. Additionally, we included province dummies and used village-level clustered standard errors, as we did in the reduced-form model.

We ran separate regressions for rice, wheat, and corn. In our data set, we had missing yield information for crops that were planted in 2000 but not in 2008. Therefore, we imputed the missing crop-yield information for the year 2008 before we ran the regressions. This missing crop-yield information in 2008 was because a number of households switched to other crops between 2000 and 2008. We used crop yield information in 2000 as a reference point to impute the data.

Specifically, we took two steps to impute the missing crop yield information. For example, take a given family who grew rice in 2000 but not in 2008. In the first step, we calculated the average rice yield of all families, including that specific family, within the village who planted rice in 2000; we then divided that family's rice yield in 2000 by the average rice yield in the village in 2000 to derive a ratio of that family's rice yield to the village average rice yield in 2000. In the second step, we calculated the average rice yield of other families within the same village who planted rice in 2008; we then multiplied the village average rice yield by the ratio calculated in the first step. We took the same steps to impute missing information on wheat (or corn) yield for those families who planted wheat (or corn) in 2000 but not in 2008.

5.0 EMPIRICAL RESULTS AND DISCUSSIONS

5.1 Results and Discussions of the Reduced-Form Model

Table 4 presents the results of the reduced-form model.

Table 4. Effects of weather variables on migration (reduced-form model)

Dependant variable: proportion of migrants in total family labors		
Parameters	FE-model	RE-model
Annual mean temperature in previous year	0.2247 (0.1715)	0.6239*** (0.1927)
Annual mean temperature in past year squared	– 0.0073 (0.0052)	–0.0180*** (0.0061)
Annual mean precipitation in past year	– 0.0041 (0.0050)	0.0010 (0.0048)
Annual mean precipitation in past year squared	0.0001 (0.0001)	0.0000 (0.0001)
Annual mean temperature	–0.2029 (0.1428)	–0.5258*** (0.1681)
Annual mean temperature squared	0.0066 (0.0045)	0.0150*** (0.0054)
Annual mean precipitation	– 0.0151** (0.0063)	0.0110* (0.0058)
Annual mean precipitation squared	0.0002* (0.0001)	–0.0002** (0.0001)
Dependant ratio	– 0.0016*** (0.0003)	–0.0013*** (0.0002)
Year dummy (1 = 2008; 0 = 2000)	0.0920*** (0.0197)	0.0518*** (0.0166)
Constant	0.2621 (0.3579)	–0.8366*** (0.2456)
No. of observations	2036	2036
Province dummies	YES	NO
Joint significance of weather variables	0.0000	0.0000
Hausman test statistic (p-value): FE vs. RE		62.81 (0.0000)

Notes: (1) Standard errors in parentheses are robust standard errors clustered at village level; (2) *, **, and *** represent significance levels of 10%, 5%, and 1%, respectively

Weather changes appear to have had a significant effect on household migration decisions during the years we surveyed. As shown by the Hausman test in Table 4, the household FE model should be appropriate for the analyses. In the household FE model, the F-statistic showed that the weather variables were jointly significant for household migration decisions at the 1% significance level, after the province fixed effect, the time effect, and household characteristics were controlled for (column 2 of Table 4). In particular, changes in precipitation seem to have had a significant effect on migration decisions, compared with temperature changes. Further F-tests showed that weather conditions in previous years had an insignificant effect on household migration decisions. Regarding the effect of household characteristics on migration decisions,[3] a family's dependant ratio had a significantly negative effect on family members' migration decisions. One explanation for this could be that with a higher dependant ratio, more family

[3] We also tried to control for head of household education and age, but they were not significant in the model. Thus, we did not include them in the final regressions.

laborers have to stay at home to take care of children and the elderly. An alternative explanation could be that with a higher dependant ratio, a family has fewer family laborers available to migrate to urban areas and earn off-farm income.

The time dummy had a significant and positive effect on household migration decisions, indicating a significant time effect. This finding largely conformed to the fact that rural households' migration decisions between 2000 and 2008 were partially affected by changes in macroeconomic conditions over this period. For example, rapid urbanization may have attracted more rural laborers to move to urban areas to seek economic and social benefits.

5.2 Results and Discussions of the Structural Model

Table 5 presents the results of the second-stage regression of the structural model.

Table 5. Effects of weather shocks on household migration (second-stage results)

Dependant variable: proportion of migrants in total family labors			
Parameters	FE-2SLS	FE-2SLS	FE-2SLS
Rice yield	$-3.4E-05^{*}$ (1.84E-05)		
Wheat yield		–5.04E-06 (1.46E-05)	
Corn yield			$-1.5E-05^{***}$ (5.68e-0)
Dependant ratio	-0.0022^{***} (0.0004)	-0.0022^{***} (0.0004)	-0.0018^{***} (0.0004)
Year dummy (1 = 2008; 0 = 2000)	0.1001^{***} (0.0221)	0.0654^{*} (0.0361)	0.1276^{***} (0.0303)
No. of observations	1064	860	1094
Province dummies	YES	YES	YES
Hausman test statistic (p-value)	37.19(0.0000)	2.98(0.2254)	47.81(0.0000)
F-statistics for IVs (p-value)	4.09 (0.0018)	2.41(0.0211)	11.99 (0.0000)
Hansen J statistic (p-value)	5.646(0.5816)	16.558(0.349)	8.284(0.3082)

Notes: (1) Standard errors in parentheses are robust standard errors clustered at village level; (2) *, **, and *** represent significance levels of 10%, 5%, and 1%; (3) F-statistic is for instruments used in first-stage equation; (4) Hansen J statistic is for overidentification test for instrumental variables.

The Hausman test showed that FE-2SLS models should be used to get consistent estimators for equations of rice yield and corn yield (Table 5). For the equation of the wheat yield, the Hausman test indicated that the RE-2SLS model could be used to get more efficient estimates. However, as discussed in Section 4.2, some time-invariant household-specific characteristics could affect wheat yield, which may also be associated with the household dependant ratio, indicating that the RE-2SLS model may not give consistent estimates for the wheat equation. Therefore, we used the FE-2SLS model for the wheat equation in order to get consistent estimates. P-values of overidentification tests showed that the null hypotheses of overidentification of IVs failed to be rejected, suggesting that the IVs were properly identified.

Table 5 shows that reduced crop yields increased the intensity of household migration, although the significance level varied across crops. A reduced rice or corn yield significantly increased household migration, but a reduced wheat yield did not. The significant effect of rice or corn yield may be explained as follows: as discussed in Section 3.3, in our sample, rice and corn are partly rain fed and partly irrigated and their yields are relatively susceptible to rainfall. By contrast, wheat is grown on irrigated land, and therefore its yield may be less sensitive to rainfall.

The dependant ratio had significantly negative effects on the intensity of household migration. The same arguments as those in the reduced-form model held for the significant effect of the dependant ratio. As in the reduced-form model, the time dummy had a significant and positive effect on household migration decisions, indicating significant time effect. The same explanations given in the reduced-form model could be made.

The first-stage estimation results (Appendix Table 1) provided some useful information for understanding the impact of changes in weather conditions on crop yields and for exploring proper model specifications. The F-test showed that weather variables were jointly significant for rice yield at 1% significance level, wheat yield at 5% significance level, and corn yield at 1% significance level.

For the rice-yield equation, no single weather variable (e.g., mean summer temperature or mean fall precipitation) appeared to have a significant effect. This may be because we used growing seasons' mean temperature and precipitation rather than extremes, due to the lack of available daily data. In fact, studies have shown that rice yield in tropical/subtropical Asia appears to be highly sensitive to extreme temperatures (Welch et al. 2010). Our results provide complementary evidence that it may be more important to use extreme temperatures in growing seasons rather than mean temperatures to better capture the causal-effect of climate change on crop yields.

For the wheat-yield equation, mean fall temperature in the previous year (when it is time to plant the winter wheat) had a significant and negative effect on wheat yield at a significance level of 10%. As shown in column 3 of Appendix Table 1, a higher temperature in the fall season of the previous year significantly reduced the wheat yield, but this negative effect was reduced after the temperature reached a certain point. Temperatures during other seasons—including mean winter temperature in the previous year, mean spring temperature, and mean summer temperature—did not appear to have significant effects on wheat yields. However, after the mean seasonal temperature reached a certain point, the temperature did appear to have a significant effect (column 3 of Appendix Table 1). The significance of quadratic terms of the mean seasonal temperature highlighted the following point: to model the impact of weather shocks on crop yield, even over a relatively short period (e.g., the eight years of our study), it is not only important to describe a nonlinear relationship between weather shocks and crop yields, but also important to pay careful attention to a potential strong effect of extreme temperature on crop yields.

For corn yield, the temperature in growing seasons (i.e., spring and summer) had jointly significant effects. The marginal effect, evaluated at mean spring and summer temperatures over the whole sample, was 16,866.922, indicating that a warming temperature during the corn-growing seasons appeared to be beneficial to yields. The significance of quadratic terms of mean temperature during the corn-growing seasons further confirms the previous point regarding the importance of paying careful attention to a nonlinear relationship between weather shocks and the effects of extreme temperatures on crop yields to specify econometric models.

Overall, our finding that a warming temperature is beneficial to wheat or corn but harmful to rice is consistent with some existing studies (Xu et al. 1999), which also analyzed the impact of climate change on crop yields over a relatively short-term period (e.g., 1990–1999). Our findings were opposite to those of some existing studies (Tao et al. 2006; Zhang and Huang 2012), which examined the impact of climate change over a relatively long time (1981–2000, 1980–2008 respectively). The difference between findings over short-term vs. long-term periods in our study and existing studies may be explained by the fact that over the relatively longer-term, individuals may be able to invest in adopting adaptation technologies or building up the infrastructure necessary to adapt to change.

6.0 ROBUSTNESS CHECKS AND THEIR RESULTS

We conducted three robustness checks. First, we used different measures of weather variables. Second, we used different measures of migration decisions both for the reduced-form model and the structural model. Finally, we used a variable indicating a family's dependence on agricultural production.

Robustness check 1. We used mean temperature and mean precipitation in the growing seasons of crops (i.e., fall and winter seasons in the previous year; spring, summer, and fall seasons in the current year) as alternative weather variables for inclusion in the reduced-form model. First, as with the main model specification, we used the proportion of migrants in total family labors as a dependant variable in order to check whether the results in the main model specification remained essentially unchanged when alternative measures of weather variables were used. We then used two alternative measures for migration decisions: (1) the total number of migrants and (2) the total working months of migrants. For these two alternative measures, we also used weather variables associated with the growing seasons of crops. We included the family labors as an additional explanatory variable when the two alternative migration measures were used. We continued to use the household fixed-effect model to analyze the data.

Robustness check 2. We used two alternative migration measures to those used in robustness check 1 in order to check whether the results in the structural model would remain robust. We also included family labors as an additional explanatory variable.

Robustness check 3. We considered that during shortfalls in agricultural production, those families who relied more heavily on agricultural production might intensify their migration. In the structural model, we were interested in checking whether or not migration decisions could be associated with a family's dependence on agricultural production. We used the percentage value of agricultural production in a family's total income as a proxy to measure the contribution of agricultural production to a family's total income. For migration decisions, we used three alternative migration measures, namely, (1) the proportion of migrants in total family labors, (2) the total number of migrants, and (3) the total working months of the migrants. Except for the variable associated with the proportion of migrants, we used family labor as an additional explanatory variable. We used 2SLS-FE models to analyze the data.

The results of robustness check 1 are presented in Appendix Table 2. As in the main model specification for the reduced-form model, weather variables were jointly significant when alternative measures of weather variables and those of migration decisions were used. These may indicate that weather shocks had a significant effect on household migration decisions.

Table 6 presents the results of the second-stage of robustness check 2. The results of the first stage were exactly the same as those in the main model specifications for the structural model (see Appendix Table 1), as we essentially used the same set of instrumental variables and the same mode specification.

Table 6. Results of robustness check 2 (second stage results)

Parameters	(1) No. of migrants	(2) Working months of migrants	(3) No. of migrants	(4) Working months of migrants	(5) No. of migrants	(6) Working months of migrants
Rice yield	−0.0001 (0.0001)	−0.0005 (0.0005)				
Wheat yield			−5.66e-06 (3.62e-05)	0.0001 (0.0004)		
Corn yield					−3.2e-05* (0.0000)	−0.0004** (0.0002)
Dependant ratio	−0.0027** (0.0013)	−0.0272* (0.0147)	−0.0040*** (0.0015)	−0.0363** (0.0156)	−0.0031** (0.0013)	−0.0313** (0.0145)
No. of family laborers	0.2910*** (0.0389)	2.8602*** (0.4549)	0.2752*** (0.0555)	2.7196*** (0.5899)	0.2557*** (0.0440)	2.5295*** (0.4970)
Year dummy (1 = 2008; 0 = 2000)	0.3125*** (0.0654)	3.2821*** (0.5336)	0.2067** (0.0865)	2.1667** (0.9761)	0.3493*** (0.0833)	3.8801*** (0.7517)
No. of observations	1064	1064	860	860	1094	1094
Province dummies	YES	YES	YES	YES	YES	YES
F-statistics for IVs (p-values)		4.09 (0.0018)		2.41 (0.0211)		11.99 (0.0000)
Hansen J statistic (p-values)		5.646 (0.5816)		16.558 (0.349)		8.284 (0.3082)

Notes: (1) Standard errors in parentheses are robust standard errors clustered at village level; (2) *, ** and *** represent significance levels of 10%, 5%, and 1%; (3) F-statistic is for instruments used in the first-stage equation; (4) Hansen J statistic is for overidentification test for instrumental variables.

When alternative measures of migration decisions were used in the structural model, corn yield continued to have a significant and negative effect on migration decisions (columns 5 and 6 of Table 6), while the negative effects of rice yield became insignificant (columns 1 and 2 of Table 6). As in the main model specification, wheat yield continued to have a negative but insignificant effect on migration decisions (columns 3 and 4 of Table 6). These results indicated that weather shocks could have some effect on migration through their effect on crop yields.

As in the main model specification, a family's dependant ratio had significant and negative effects on a family's migration decisions, while a family's labor supply had a significant and positive effect. As previously mentioned, this could be explained by the fact that when a family has a higher number of family laborers, it is faced with fewer constraints in labor supply for migration. The time dummies continued to be significant for migration decisions.

The second-stage results of robustness check 3 are presented in Table 7.

Table 7. Results of robustness check 3 (second stage results)

Parameters	Proportion of migrants	No. of migrants	Working months of migrants
% of total value of agricultural products sold in the market and consumed at home in total family income	–0.1879 (0.1181)	–0.4184 (0.3050)	–6.0646** (2.9716)
Dependant ratio	–0.0013*** (0.0003)	–0.0015** (0.0007)	–0.0127 (0.0083)
No. of family laborers		0.2636*** (0.0413)	2.4117*** (0.4306)
Year dummy (1 = 2008; 0 = 2000)	0.0326* (0.0188)	0.1471*** (0.0559)	1.4601** (0.6110)
No. of observations	1,954	1,954	1,954
Province dummies	YES	YES	YES
F-statistics for IVs (p-values)	4.20 (0.0000)	5.02(0.0000)	5.02 (0.0000)
Hansen J statistic (p-values)	17.479(0.4224)	14.072(0.6620)	14.145(0.6568)

Notes: (1) Standard errors in parentheses are robust standard errors clustered at village level; (2) *, ** and *** represent significance levels of 10%, 5% and 1%; (3) F-statistic is for instruments used in first-stage equation; (4) Hansen J statistic is for overidentification test for instrumental variables.

As shown in Table 7, a family with a higher share of agricultural revenue in its total income had a higher level of migration, although the significance level varies across alternative measures of migration decisions. This indicates that households whose income relies more on agricultural production could face more income shortfalls caused by weather shocks, and could be more likely to resort to migration to cope with risks and to smooth their income.

As in the main models, a family's dependant ratio still had a negative effect on migration. However, the significance level of the dependant ratio was also sensitive to the measurement of the migration variable. The significant effect of the family labor supply to migration was robust to all model specifications. This stressed the importance of constraints in labor supply for migration decisions.

The unobserved factors associated with time dummies had a significant effect on migration over time, further confirming that migration could continue to be driven by factors other than climate change over time.

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7.0 CONCLUSIONS

This paper used a unique household-level survey data set combined with a weather data set to explore the effects of weather shocks on rural-urban migration in China.

Weather shocks had a significant overall effect on household migration decisions, as shown by the results of the reduced-form models. Weather shocks appeared to have significant indirect effect on migration through their strong effect on agricultural production, as shown by the results of the structural models. Nonetheless, the significance of the effect was sensitive to alternative measures of agricultural production or those of migration decisions, as shown by the results of robustness checks on the structural model.

Therefore, from a methodological point of view, there must be more scrutiny of appropriate estimation methods to identify the relationship between weather shocks and migration in future research. Moreover, in order to provide conclusive evidence on the effect of weather shocks on migration in future empirical research, it will be crucial to pay careful attention to alternative measures of weather shocks and migration decisions.

Our research also indicated that weather shocks appeared to have a significant effect on crop yields. To model the effect of weather shocks on crop yields, it may be important to pay attention to extreme weather conditions (particularly extreme temperatures), rather than mean temperature/precipitation during growing seasons.

Furthermore, unobserved factors associated with time, such as changes in economic conditions between rural and urban areas and other socioeconomic factors, have all played (and will continue to play) significant roles in household migration decisions.

The findings of this paper suggest that weather-driven migration is an important policy issue in China, as weather shocks in combination with other driving forces (such as disparities between economic development across regions and levels of urbanization) were found to be important determinants of migration decisions in rural households. With rapid urbanization and economic development disparities across China, some areas (especially coastal regions) might face increasing pressure from intensified migration flows. Therefore, policy makers in China should consider the effects of other driving forces along with the effects of weather shocks when designing policies to better address issues related to rural-urban migration.

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APPENDIX

Appendix Table 1. Effects of weather shocks on household migration (first-stage results)

Parameter	Rice yield	Wheat yield	Corn yield
Mean fall temperature in previous year		–22,556.89** (9,314.642)	
Mean fall temperature in previous year squared		668.2648** (320.7395)	
Mean fall precipitation in previous year		–966.37 (1,230.036)	
Mean fall precipitation in previous year squared		13.2282 (20.8728)	
Mean winter temperature in previous year		3,216.837 (2,127.858)	
Mean winter temperature in previous year squared		–383.5973* (191.3302)	
Mean winter precipitation in previous year		1,312.451 (2,828.946)	
Mean winter precipitation in previous year squared		–152.0377 (281.3457)	
Spring temperature		–764.5035 (4,788.656)	–576.4004* (327.6875)
Spring temperature squared		104.1772** (50.4322)	41.8074*** (7.6245)
Spring precipitation		43.3242 (55.8820)	657.9864*** (241.0524)
Spring precipitation squared		–25.5243 (55.8820)	–8.7525* (5.1883)
Summer temperature	205.1322 (1,224.761)	15,058.96 (9,415.347)	2,393.05** (929.7913)
Summer temperature squared	–8.2594 (26.9873)	–313.3844** (147.1838)	–70.0541*** (21.9472)
Summer precipitation	18.6115 (86.5524)	241.6601 (422.1860)	–48.5561 (113.0877)
Summer precipitation squared	–0.2630 (0.5339)	–0.2894 (3.5078)	–0.5280 (1.2851)
Fall temperature	–6.5e+02 (649.2938)		
Fall temperature squared	21.8608 (19.1967)		
Fall precipitation	169.2394 (123.6924)		
Fall precipitation squared	–2.0842 (1.2429)		
Dependant ratio	–4.8236 (4.5224)	–3.4735 (3.2289)	–1.4014 (4.5083)
Year dummy (1 = 2008; 0 = 2000)	–2.3e+03 (4.0e+03)	19,997.55 (4.3e+04)	2.6e+03 (3.3e+03)
Constant	1.4e+04 (1.9e+04)	415.3988 (7.0e+04)	–1.1e+04 (1.1e+04)
No. of observations	1,076	871	1,148
Province dummies	YES	YES	YES
F-statistic for joint significance of weather variables (p-values)	4.08 (0.0018)	2.41 (0.0212)	11.99 (0.0000)

Notes: (1) Standard errors in parentheses are robust standard errors clustered at village level; (2) *, ** and *** represent significance levels of 10%, 5%, and 1%.

Appendix Table 2. Results for robustness check 1 (reduced-form models)

Parameter	Proportion of migrants	No. of migrants	Total working months of migrants
Mean fall temperature in previous year	–0.2666** (0.1226)	–0.4619 (0.3451)	–0.4619 (0.3451)
Mean fall temperature in previous year squared	0.0057 (0.0036)	0.0081 (0.0101)	0.0081 (0.0101)
Mean fall precipitation in previous year	–0.0071* (0.0039)	–0.0062 (0.0128)	–0.0062 (0.0128)
Mean fall precipitation in previous year squared	0.0001 (0.0001)	0.0000 (0.0002)	0.0000 (0.0002)
Mean winter temperature in previous year	0.0397 (0.0345)	0.1321 (0.0951)	0.1321 (0.0951)
Mean winter temperature in previous year squared	–0.0024 (0.0021)	–0.0078 (0.0057)	–0.0078 (0.0057)
Mean winter precipitation in previous year	0.0131 (0.0111)	0.0418 (0.0299)	0.0418 (0.0299)
Mean winter precipitation in previous year squared	–0.0005 (0.0004)	–0.0012 (0.0009)	–0.0012 (0.0009)
Spring temperature	0.0575** (0.0280)	0.0503 (0.0786)	0.0503 (0.0786)
Spring temperature squared	0.0001 (0.0010)	0.0033 (0.0030)	0.0033 (0.0030)
Spring precipitation	0.0025 (0.0060)	0.0231 (0.0185)	0.0231 (0.0185)
Spring precipitation squared	–0.0001 (0.0001)	–0.0004 (0.0003)	–0.0004 (0.0003)
Summer temperature	0.1096 (0.0936)	0.2736 (0.2774)	0.2736 (0.2774)
Summer temperature squared	–0.0031 (0.0019)	–0.0072 (0.0058)	–0.0072 (0.0058)
Summer precipitation	–0.0014 (0.0027)	–0.0127 (0.0080)	–0.0127 (0.0080)
Summer precipitation squared	0.0000 (0.0000)	0.0000 (0.0001)	0.0000 (0.0001)
Fall temperature	0.0794 (0.0483)	0.0136 (0.1443)	0.0136 (0.1443)
Fall temperature squared	–0.0016 (0.0014)	0.0001 (0.0041)	0.0001 (0.0041)
Fall precipitation	–0.0052 (0.0047)	–0.0204 (0.0145)	–0.0204 (0.0145)
Fall precipitation squared	0.0001 (0.0000)	0.0002 (0.0001)	0.0002 (0.0001)
Dependant ratio	–0.0017*** (0.0003)	–0.0019** (0.0008)	–0.0019** (0.0008)
No. of family laborers		0.2821*** (0.0333)	0.2821*** (0.0333)
Year dummy (1 = 2008; 0 = 2000)	0.3233 (0.3109)	0.8531 (0.9342)	0.8531 (0.9342)
Constant	0.5637 (0.8099)	1.1786 (2.4749)	1.1786 (2.4749)
No. of observations	2036	2036	2036
Province dummies	YES	YES	YES
P-value of joint significance of weather variables	0.0000	0.0000	0.0000

Notes: (1) Standard errors in parentheses are robust standard errors clustered at village level; (2) *, ** and *** represent significance levels of 10%, 5%, and 1%.

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