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The role of social capital for farmers' climate change adaptation in Lancang River basin in China

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Abstract This paper distinguishes between bridging and bonding social capital to assess their roles for individual farmers' adaptation strategies taken through technology adoption. Based on primary data collected in Langcang River (LCR) basin area in southwestern China, the paper finds: (1) adaptation measures have been widely taken by surveyed households, but non-infrastructure-based measures are more prevalent than infrastructure-based measures and (2) surveyed households have strong social capital while having weak bridging social capital. Their bonding social capital has significantly positive relationship with their adaptation decisions, but bridging social capital does not have such statistically significant relationship. It recommends that the governments contemplate carefully how to help the poor to get a good combination of bonding and bridging social capital when designing policies to help the rural poor to improve their long-term adaptive capacity and achieve sustainable rural development.

Keywords Climate change · Lancang River · Adaptation · Social capital · Bonding and bridging

1 Introduction

Adaptation to climate change is broadly defined as adjustment in a system to respond to climatic stimuli, such as stresses, extreme events, and hazards (Smit et al. 2000; Smit and

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Wandel 2006). For many rural households in developing countries, they depend heavily on agricultural production for their livelihood and food security. As climate change can reduce major food crop yields (e.g., Fischer et al. 2002; Peng et al. 2004; Battisti and Naylor 2009) and impose notable effects on farm income (Wang et al. 2014), they are vulnerable to climate change. Nonetheless, successful adaptation can help to reduce the vulnerability to climate change impacts (Smit et al. 1996; Cooper et al. 2008; Zilberman et al. 2012). Thus, taking effective adaptation strategies is crucial for rural households in developing countries (Jayne et al. 2010; Dethier and Effenberger 2012).

Adaptation strategies may involve a wide range of approaches, such as the adoption of new technologies, practices, and institutions, technology transfer across different regions, and international trade (Batterbury and Forsyth 1999; Zilberman et al. 2012). Justifications for why technology adoption may serve as one adaptation strategy can be made at two different levels. At the aggregated level, individual adoption of technology accumulated over time can facilitate the technology diffusion in agricultural sector that will play a critical role for food security in a changing climate (Lybbert and Sumner 2010). At the individual level, changes in practices or technologies help rural households to respond to climate change and reduce certain risks associated with climate change (Zilberman et al. 2012).

In the past, although the adoption[1] of new technologies and practices has been studied extensively in economics and sociology, research on technology adoption through the lens of adaptation still needs more empirical evidence. Hence, this paper focuses on a specific adaptation strategy, i.e., farmers' adoption of technologies/farming practices. It is intended to assess roles of social capital for individual adaptation strategy taken through the adoption of technologies/farming practices.

Social capital is broadly defined as "the connections among individuals—social networks and the norms of reciprocity and trustworthiness that arise from them" (Putnam 2000, p. 19). It encompasses bonding and bridging social capital (Putnam 2000). Bonding social capital refers to connections within a group, while bridging social capital refers to connections external to the group (Gittell and Vidal 1998; Putnam 2000; Adler 2002; Adger 2003a).

Social capital may be important for climate change adaptation implemented both at community and individual levels. At the community level, social capital can facilitate community-level collective actions taken for climate change adaptation (e.g., Marshall 2013; Rodima-Taylor 2012; Adger 2003b; Tompkins and Adger 2004). At the individual level, individual households may take such adaptation strategies as the adoption of certain specific technologies (e.g., sprinkler irrigation) or farming practices (e.g., changing crop patterns) to cope with risks (Cooper et al. 2008; Deressa et al. 2009). While information sharing, social learning, and risk sharing may facilitate the technology adoption (Bloch et al. 2008; Cai et al. 2011; Zilberman et al. 2012),[2] social capital aids information flow and enforcement (Eswaran and Kotwal 1990; Morduch 1995; Bowles and Gintis 2002; Ioannides and Loury 2004; Anderson et al. 2009). Thus, social capital can be important for individual adaptation strategies.

Regarding roles of social capital for farmers' adaptation strategies, Chen et al. (2014), who have conducted one of few studies in China, find a significantly positive role. While they take

[1] Zilberman et al. (2012) defines adoption as a change in practice (e.g., farming practice) or technology (e.g., new crop varieties and drip irrigation technology) used by individuals or communities.

[2] Empirical evidence has shown that social networks have positive impact on adoption of weather index insurance (Cai et al. 2011) and an inverse-U-shaped relationship exists between social network and adoption of a new crop (Bandiera and Rasul 2006).

social capital together, we intend to extend their work by distinguishing between bonding and bridging social capital in terms of their respective roles in farmers' adaptation strategies.

We postulate that bonding social capital may encourage rural households to take adaptation strategies through their adoption of technologies, while bridging social capital may have ambiguous roles. Bonding social capital may play positive roles through two possible channels. First, while the adoption of technologies requires certain awareness and knowledge (Zilberman et al. 2012), bonding social capital such as connections within communities can facilitate information sharing and mutual learning. Second, rural poor often have credit constraints (Cetorelli and Gambera 1999; Morduch 1999) in their individual adoption of technologies that requires initial cost (e.g., purchasing inputs or constructing wells). Thus, they often have to rely on mutual help through lending, borrowing, and exchange of family labor needed for adoption. In such circumstances, bonding social capital such as trust and norms of reciprocity underlying mutual help may facilitate their adoption. The ambiguous role of bridging social capital may be attributed to two counter effects. On one hand, better connections to the outside world allows farmers to have better access to external resources (e.g., funding and information), which increases their ability to adopt. On the other hand, better external connections help farmers to get outside help to cope with weather-related shocks (e.g., crop failures). This may reduce their vulnerability to climate change and thus decrease their incentives for adoption.

The rest of the paper is organized as follows: the next section briefs on regional background and our survey area; Sect. 3 introduces the methodology of this study; Sect. 4 present the results and discussions, followed by conclusions in Sect. 5.

2 Brief background of the study area

To empirically assess the roles of bonding/bridging social capital for individual farmers' adaptation strategies, we choose Lancang River (LCR) basin area[3] in southwestern China as our study area and collect our primary data there. LCR is the upper stream of Mekong River, which gets its headwater in China and flows through Cambodia, Myanmar, Laos, Thailand, and Vietnam in southeast Asia. In China, LCR flows through Qinghai-Tibet Plateau and Yunnan Province (Fig. 1).

LCR basin in Yunnan Province alone approximately drains a total area of 164,000 km^2, larger than Nepal (147,181 km^2) but slightly smaller than Cambodia (181,035 km^2). It is located in western Yunnan, where deep valleys and high mountains are interwoven with each other. It covers 7 of a total number of 16 prefectures in Yunnan.

The LCR basin area in Yunnan is characterized with high poverty incidence and ethnic diversity. Among 73 national-level poverty-stricken counties in Yunnan[4], 35 counties (48% of 73) are from this region. It is the home to a number of ethnic minority groups, including Tibetan, Yi, Bai, Dai, Hani, Lagu, Wa, Lili, and among others. The ethnic minority people often have poor education and language barriers, which, along with their isolation from outside

[3] LCR basin lies between latitudes 10° and 34° N and longitudes 94° and 107° E. It is divided into two parts, one in Qinghai-Tibet Plateau and the other in Yunnan Province. In Qinghai-Tibet part of LCR basin, the population is very sparse, so this paper does not survey Qinghai-Tibet part of LCR basin.

[4] Yunnan Province, like other regions in Mekong River basin, is the home to many rural poor. It hosts 73 counties (12%) of 592 national economically deprived counties (also called national-level poverty-stricken counties) listed by the Leading Group Office of Poverty Relief and Development under China's State Council.

Fig. 1 A location map for Langcang River basin in China

market due to high mountains and deep valleys, are major factors limiting their capacity to seek outside options (e.g., migrating to urban areas to earn off-farm income).

Climate change appears to have been intensified in the LCR basin area in Yunnan over past several decades (Liu and Xiao 2010; Li et al. 2011a, b). Associated with climate change, heavy rainfalls have occurred more frequently, leading to more floods and landslides (Li et al. 2011a), while droughts are projected to be more frequent in future (Yu et al. 2014). More frequent natural disasters such as floods, landslides, and droughts inevitably impose threats on the livelihood of local communities, especially those poor ones.

Changning and Jinggu counties were purposively chosen as our survey area in terms of heterogeneity in their locations in the basin area[5] and socio-economic characteristics. As shown in the Fig. 1, Changning County is located on the riverside in the upper north part of LCR basin in Yunnan part while Jinggu County is located off the riverside in the south downstream. Between the two, Changning is economically poorer while Jinggu is more ethnically diversified. Changning, a national-level poverty-stricken county, is the home to eight ethnic minority groups. In 2013, its population size reached 349,600 persons and it had a population density of 90 persons/km^2. Jinggu inhibits 14 ethnic minority groups, whose population accounts for 48% of Jinggu's total population. In 2014, Jinggu had a population size of 295,900 persons and a population density of 39 persons/km^2. In both counties, agriculture is important for local economy. In 2013, agricultural income accounted for 39 and 43% of the total income in Changning and Jinggu, respectively.

3 Methodology

3.1 Data collection

Questionnaire surveys were conducted both at village and household levels in summer of 2014. Personal interviewers were conducted with village heads and household heads, respectively.

To select survey respondents, purposive and random sampling methods were combined.[6] The purposive sampling method was applied to choose counties and townships: within each county, two townships were purposively chosen, one close to the river and the other farther away from the river. The random sampling method was deployed to select villages and households: within each township, two villages were randomly chosen; within each village, 12 households were randomly selected from the village's rosters. Eventually, 96 households from 8 villages[7] were selected.

3.2 Village surveys

Information on village physical and social-economic characteristics and natural disaster occurred in recent years were collected through village surveys (Appendix Table 1 summarizes key information). Generally speaking, the eight surveyed villages, half of which are national- or provincial-level poverty-stricken villages, are economically poor. In 2013, their average annual income per capita was about US$561 (RMB 3870 yuan).[8] For those four poverty-stricken villages in particular, their average annual income per capita in 2013, ranging from US$152 (equivalent to US$0.42 a day per person) to US$338 (equivalent to US$0.93a day per person), was below the World Bank's poverty line (US$1 a day per person).

[5] Counties near the River and off the River might have different levels of vulnerability to climate change impacts. For example, counties near to the River may be more vulnerable to floods while those off the River and up to the mountains may be vulnerable to droughts. They may also have quite different livelihood means. Thus, we purposively choose two counties at the different locations, one near the River and the other away from the River.
[6] See Neyman (1934) for method comparison and Ritchie et al. (2003) for the sampling design.
[7] The eight villages are Mangzhuan, Pingzhang, Qiande, Taiping, Sijiaotian, Yanjiang, and Gongyu.
[8] We use an exchange rate of US$1 = RMB 6.91 yuan, the exchange rate in December of 2016.

The villages are isolated from major transportation systems or local markets and residents in these villages live quite away from each other. On average, their distance to the nearest paved roads is about 6 km and to the nearest townships, which are usually the local markets in rural China, is about 17 km. On average, the villages have 712 families, distributed in an average number of 12 natural villages.[9] The natural villages are quite away from each other: the average distance between two natural villages at the two farthest ends is about 15 km. The villages have an average population density of about 129 persons/km^2. However, their population density is quite varied, ranging from 21 persons/km^2 in the least populous village to 400 persons/km^2 in the most populous village.[10]

Agriculture plays important roles for villagers' livelihood but is heavily affected by weather-related disasters. In 2013, about 71% of the total income in villages was earned through agricultural production. The villages were reported to have experienced eight weather-related disasters on average in the past 10 years. The main type of natural disasters is drought, followed by frost and pest breakout. The frequent occurrence of weather-related disasters may have imposed threats on villagers' livelihood.

3.3 Household surveys

Information related to households' demographic characteristics, their adaptation decisions, and social capital was collected through household surveys. To collect information on household adaptation strategies, a detailed list of technologies/farming practices was designed (Appendix Table 2 and Appendix Table 3) by primarily referring to Adger et al. (2007) and Chen et al. (2014). During surveys, the respondents were presented with the detailed list of technologies/farming practices, and for each listed technology, they were asked to check whether or not their families had adopted it.

For each surveyed household, an "adaptation intensity index" is constructed by counting the total number of technologies/farming practices adopted. It is used to capture the household's adaptation decisions in terms of "how many technologies/farming practices are adopted," rather than a binary choice of "whether or not to adopt it."[11]

Our approach of constructing the "adaptation intensity index" essentially implies "the intensity of technology adoption." The term, "intensity," used in our study has slightly different meanings from existing literature.[12] In agricultural economics literature, "intensity" often refers to "the degree to which a household is immersed in the technology," while in public health literature, it refers to the number of treatments (e.g., number of tests ordered, number of prescribed medications) (Glied and Zivin 2002). Our approach of constructing "adaptation intensity index" may refer to the revealing comments in Feder et al. (1985): "… for many types of innovations, the interesting question may be related to the intensity of use (e.g., how much fertilizer is used per hectare or how much land is planted to HYVs). Future

[9] Villages surveyed are administrative villages. In the context of rural China, one administrative village usually involve several sub-units, called natural villages.

[10] The population density in the surveyed villages is quite consistent with the spatial distribution of population density in Lancang-Mekong River basin area studied by You et al. (2010).

[11] Technology adoption can be measured with discrete adoption choice of a particular technology (or class of technology) or an incremental value (such as the extent of adoption) (Zilberman et al. 2012).

[12] We thank our anonymous reviewer to point out the importance of making some discussions and clarifications on this point.

studies can rectify this problem by properly accounting for a more varied range of responses and by employing statistical techniques suitable for the variables considered" (pp. 287–88).

To measure bonding social capital, we primarily refer to a World Bank Study conducted by Grootaert et al. (2004),[13] who introduce six dimensions of social capital. We only focus on two dimensions: (1) information and communication among villagers within the same community and (2) mutual trust and solitariness within the community, since information sharing and mutual help supported by norms of reciprocity and trust could be main channels influencing individual adaptation decisions. In particular, we develop two alternative proxies for bonding social capital: (1) the number of fellow villagers' phone numbers kept in the respondents' telephone directories and (2) the frequency with which they lent farming tools to fellow villagers in the past. Our first proxy is intended to capture respondents' available means or a probability of information sharing and mutual learning in the adoption process. In a mountainous region such as LCR basin area, villagers in different natural villages usually live far away from each other,[14] so door-to-door visit may only be common among villagers living in the same natural village or those nearby. For villagers living in different natural villages, they may have to rely on phone calls[15] for information sharing and mutual learning. The number of fellow villagers' phone numbers saved may also imply a probability of contacting their fellow villagers again to establish a relationship that requires certain level of trust. Our second proxy largely captures the level of trust in fellow villagers. In rural China, lending farming tools to fellow villagers requires a certain level of trust and implies expected reciprocal behaviors (reciprocity) from their fellow villagers.

Based on survey information on two alternative proxies for bonding social capital, we create two dummy variables: (1) "social interaction," taking a value of one, representing that more than half of respondents' fellow villagers' phone numbers kept in their phone directories, and a value of zero, representing less than half; (2) "trust," taking a value of one, indicating the respondents' families had frequently lent farming tools to fellow villagers in the past, and a value of zero, indicating otherwise.

To measure bridging social capital, we mainly follow Chen et al. (2014) and others (Xin and Pearce 1996; Lin and Si 2010), who measure social capital by "Guangxi." We use Guangxi as our proxy for bridging social capital. We define Guangxi as (the number of the respondents' relatives working in the government at township or a higher level." In Chinese culture, having a relationship with government officers is important for resource accessibility and problem solving (Hwang 1987; Yang 1994; Park and Luo 2001). Thus, Guangxi in our study reflects a family's connections/networks outside its own community.[16] It indicates a family's capacity to get access to information and possible funding support outside its community to help it to take adaptation measures. It also indicates the family's ability to pool resources from outside when it faces sudden shocks such as crop failures.

[13] Grootaert et al. (2004) introduces some integrated tools for measuring social capital in developing countries.
[14] In our case for example, the average distance of two natural villages at the two farthest ends is about 15 km.
[15] Some may argue that the number of fellow villagers' phone numbers kept in the respondent's phone directories does not necessarily mean that they have actual communication in the adoption process. However, a higher number of fellow villagers' phone numbers kept in the respondent's phone directories at least indicates a higher probability of communicating with their fellow villagers. So it is a reasonable proxy for measuring connections among fellow villagers within the same community.
[16] "Guanxi" refers to the personal network in Chinese culture. It is used as substitutes for formal institutional support. Numerous case studies document that Chinese firms can benefit through their personal connections with government officials to solve the broad range of the problems (e.g., Yan 1996; Park and Luo 2001). It also plays an important role on farmers' market participation (Lu et al. 2010).

A dummy variable is also generated based on survey information of our measure of bridging social capital. It takes a value of one, meaning the surveyed families have relatives working in the government at township or a higher level, and a value of zero, indicating otherwise.

3.4 Data analysis

3.4.1 Main model specifications in econometric analyses

Besides descriptive statistical analyses to summarize key information for surveyed villages and households, we also conduct econometric analyses to analyze the relationship between social capital and adaptation decisions taken by the surveyed households. For our main models in the econometric analyses, we use our adaptation intensity index, i.e., the total number of technologies adopted by the surveyed households, as the dependant variable.

We employ two alternative model specifications: one is a Poisson model specification, a non-linear model specification using a count variable as its dependent variable; the other is a linear model specification used to check the robustness of the non-linear model specification.

The Poisson model is specified as follows:

$$p(Y_i = y_i) = p(y_i) = \frac{\mu_i^{y_i} e^{-\mu_i}}{y_i!} \quad i = 1, 2, 3, \ldots n \tag{1}$$

where

$$\mu_i = E(Y_i) = e^{\mathbf{x}_i' \beta} \quad i = 1, 2, \ldots, n \tag{2}$$

The linear model is specified as follows:

$$y_i = \mathbf{x}_i' \alpha + u_i \tag{3}$$

In Eqs. (1)–(3), α and β are vectors of unknown parameters to be estimated. $i = 1, 2, 3, \ldots n$ is the number of households surveyed. y_i in Eqs. (1) and (3) is the total number of technologies/farming practices adopted by household i while Y_i in Eqs. (1) and (2) is a random variable representing the number of technologies/farming practices adopted by the household i. Thus, y_i is the actual observation (i.e., the realization) of the random variable Y_i.

In all equations, $\mathbf{x}_i$ is a vector of independent variables, including household demographic characteristics and social capital. Village dummies are also included to account for heterogeneity across villages. To estimate both types of models, robust standard errors are used to account for heterogeneity in error terms.

The marginal effect in the Poisson model is expressed as $\frac{\partial E(y|\mathbf{x})}{\partial x_j} = \beta_j e^{\mathbf{x}_i' \beta}$, which depends on the parameter β_j and a particular value of $\mathbf{x}$ at which the marginal effect is evaluated. To estimate the marginal effect of $\mathbf{x}_i$ on y_i, we calculate an average marginal effect (AME), which is evaluated at the mean values of $\mathbf{x}$.

3.4.2 Robustness checks

We conducted two robustness checks. First, we speculate social capital may play different roles in the adoption of two different types of technologies, i.e., infrastructure-based vs. non-infrastructure-based adaptation measures, since they require different levels of capital investment or knowledge. For some technologies, they require capital investment in developing micro-scale infrastructure, such as drilling wells and digging ponds. Adaptation measures taken through the adoption of such type of technologies fall into the category of infrastructure-based measures. For other technologies, they predominantly require knowledge and information such as changes in farming practices or crop insurance. Adaptation measures taken through the adoption of this type of technologies fall into the category of non-infrastructure-based measures. To check our speculation, we run two separate sets of regressions using infrastructure-based vs. non-infrastructure-based adaptation measures, respectively, as dependant variables.

Second, we posit households with different economic standings may possess different levels of social capital, which may play different roles for households' adaptation decisions. To check this, we conduct the second robustness check using two different subsamples, one with family income below the median income of the surveyed households and the other above the medium.[17] As the Poisson model and the OLS model produce consistent results in our main model, for simplicity, we only run regressions with Poisson model specifications.[18]

4 Results and discussions

4.1 Description of the surveyed households

About 96% of the surveyed households in our sample had taken adaptation measures through adopting certain types of technologies, while only 4% of them did not take any single adaptation measure. In terms of adaptation intensity, they had taken nine different adaptation measures on average, including seven non-infrastructure-based measures and two non-infrastructure-based measures (Table 1 (Adaptation measures)). The above shows that non-infrastructure-based measures appear to be more prevalent than the infrastructure based.

The surveyed households are small landholders, whose family income relies heavily on farming activities. In 2013, their average sown area per capita was only about 0.25 ha/person and less than half (42%) of their family income was from off-farm activities (Table 1 (Household demographic and socio-economic characteristics)). The average size of their families, mostly headed by males (86%), is five persons, and their family heads had completed primary school education on average. Most of them (77%) belong to ethnic minority groups.

[17] Ideally, we could have divided our samples into four subsamples using 25th, 50th, and 75th percentiles of income as cut-off lines. However, given a total sample size of 96, we use the median (50th percentile) income as the cut-off line to divide our sample into two subsamples.

[18] Readers who are interested in taking a look at OLS results, the results are available upon the request. For the Poisson model specification, we only run the regression with the full set of social capital variables, i.e., two alternative measures of the bonding social capital and one proxy of the bridging social capital.

Table 1 Adaptation measures, household characteristics, and social capital (2013)

	Mean	Standard deviation
Adaptation measures		
Total number of infrastructure and non-infrastructure adaptation measures	9.10	6.17
Total number of infrastructure-based adaptation measures	2.29	2.15
Total number of non-infrastructure-based adaptation measures	6.81	4.60
Household demographic and socio-economic characteristics		
Mean crop sown area per capital (ha/person)	0.25	2.25
Household size (persons)	5.00	1.44
Household head gender (1 = male, 0 = female)	0.86	0.34
Household head education level (years)	6.32	3.51
If family belonging to ethnic minority group (1 = yes, 0 = no)	0.77	0.42
If family has village leader or party members (1 = yes, 0 = no)	0.17	0.37
If any of family members received trainings in past 3 years (1 = yes, 0 = no)	0.34	0.48
Share of off-farm income in family total income	0.42	0.35
Distance to the township (km)	12.39	12.96
If the family has phones (1 = yes, 0 = no)	0.92	0.28
Household-level social capital		
% of families keeping more than half of peer villagers' phone numbers	42	50
% of families frequently lending farming tools to peer villagers in the past	63	49
% of families having relatives working in the government at township or higher levels	16	36
No of observations	96	

About 17% of them have a member being a village leader or a Chinese Communist Party (CCP) member. In the past 3 years (i.e., 2011–2013), slightly more than one third of them had received certain trainings related to agricultural production or combating natural disasters. They live relatively far away from local market (on average about 12 km to the nearest market). Nonetheless, they have good access to modern communication facilities since 92% of them own telephones.

The surveyed households have strong bonding social capital but weak bridging social capital. About 42% of them have saved more than half of fellow villagers' phone numbers in their phone directories and about 63% of them have frequently lent farming tools to their fellow villagers before (Table 1 (Household-level social capital)). In terms of their connections outside communities, namely "Guangxi," they on average only have fewer than one relative working in township government or above (Table 1 (Household-level social capital)). Of all 96 surveyed households, only 15 (16% of 96) families have relatives working in township government or above, while the rest do not have any.

4.2 Results of econometric analyses

Results from main model specifications regarding roles played by bonding and bridging social capital for adaptation intensity, measured by the total number of adaptation measures taken by surveyed households, are quite consistent across different model specifications (Table 2). In all model specifications, the two alternative measures of bonding social capital, i.e., social interactions and trust, are significantly and positively correlated with adaptation intensity, while the bridging social capital, measured by Guangxi, has positive but insignificant coefficients. Moreover, the magnitude of coefficients associated with bonding social capital is quite consistent between Poisson models (columns (1)–(3) of Table 2) and OLS models (columns

Table 2 Marginal effects of social capital on household adaptation decisions

Dependant variable: adaptation intensity (total number of adaptation measures)

	Poisson (AME)				OLS			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Social Interaction	2.94*** (1.12)	–	2.57** (1.01)	–	3.04** (1.20)	–	2.75** (1.10)	–
Trust	–	4.17*** (1.03)	3.94*** (1.01)	–	–	4.27*** (1.12)	4.06*** (1.10)	–
Guanxi	0.85 (1.60)	1.92 (1.69)	1.74 (1.73)	0.93 (1.54)	0.59 (1.83)	1.42 (1.78)	1.27 (1.82)	0.72 (1.79)
Individual FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Village FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
No of observations	96	96	96	96	96	96	96	96
Log-likelihood (R^2)	−319.54	−309.86	−302.73	−328.90	0.36	0.40	0.45	0.31

Note: Robust standard errors are presented in parentheses; household characteristics and village-fixed effects are included. Household characteristics included in the models are gender and education of the family head, village leadership of family members, family ethnicity, family size, family's distance to local market, and agricultural income ratio

*10%, **5%, and ***1%—significance levels

(5)–(7) of Table 3). It shows: (1) families who keep more than half of fellow villagers' phone numbers take about three more adaptation measures than those keeping less than half of their fellow villagers' phone numbers and (2) families who frequently lent farming tools to their fellow villagers take four more adaptation measures than those who had seldom lent farming tools.[19]

For bridging social capital, our measure of Guangxi has a positive but insignificant relation with adaptation intensity. Our finding of the insignificant relation may be explained as follows: (1) the surveyed households have weak bridging social capital: only 16% of surveyed households have Guangxi outside their communities; on average, they had fewer than one relative working in the government at township level or at a higher level and (2) the two counter effects of the bridging social capital, as discussed earlier, may have mitigated each another.

Table 3 presents results from the robustness check 1 for infrastructure- and non-infrastructure-based adaptation measures. For both categories of adaptation measures, the

[19] One reviewer points out that our measure of trust, i.e., whether or not the respondents had frequently lent their farming tools to their fellow villagers in the past, may be determined by their possession of the farming tools. Based on our survey measure that may reflect the respondents' possession of farming tools, i.e., the family's expenditure on purchasing farming tools in the year before our surveys (2013), we check whether our measure of trust is strongly correlated with the family's expenditure on purchasing farming tools in the previous year and find no significant correlation between the two variables. We also conduct two-sample *t* test and Wilcoxon rank-sum (Mann-Whitney) test, respectively, to check whether the family's expenditure on purchasing farming tools in the previous year is significantly different between the group who lent the farming tools and that who did not lend the farming tools. Both tests show no statistically significant difference between the two groups. Nonetheless, we still have to admit that our survey measure of trust may not be perfect.

Table 3 Results of robustness check 1

	Poisson (AME)			OLS		
	(1)	(2)	(3)	(4)	(5)	(6)
Infrastructure-based adaptation measures						
Social interaction	0.96** (0.38)	–	0.92** (0.37)	1.06** (0.44)	–	0.98** (0.42)
Trust	–	0.98*** (0.35)	0.93*** (0.35)	–	1.13*** (0.40)	1.05** (0.40)
Guanxi	0.10 (0.52)	0.35 (0.53)	0.23 (0.54)	0.02 (0.62)	0.25 (0.63)	0.20 (0.62)
Individual FE	Yes	Yes	Yes	Yes	Yes	Yes
Village FE	Yes	Yes	Yes	Yes	Yes	Yes
Log-likelihood (R^2)	− 171.01	− 171.01	− 167.3	0.34	0.34	0.40
Non-infrastructure-based adaptation measures						
Social interaction	2.00** (0.84)	–	1.68** (0.75)	1.98** (0.90)	–	1.77** (0.82)
Trust	–	3.14*** (0.83)	2.97*** (0.82)	–	3.14*** (0.89)	3.01*** (0.88)
Guangxi	0.77 (1.20)	1.61 (1.31)	1.52 (1.33)	0.57 (1.36)	1.17 (1.32)	1.07 (1.35)
Individual FE	Yes	Yes	Yes	Yes	Yes	Yes
Village FE	Yes	Yes	Yes	Yes	Yes	Yes
Log-likelihood (R^2)	−281.36	−272.68	−268.67	0.33	0.38	0.41
No of observations	96	96	96	96	96	96

Note: Robust standard errors are presented in parentheses; household characteristics and village-fixed effects are included. Household characteristics included in the models are gender and education of the family head, village leadership of family members, family ethnicity, family size, family's distance to local market, and agricultural income ratio

*10%, **5%, and ***1%—significance levels

bonding social capital has positive and significant coefficients in all model specifications while bridging social capital has positive but insignificant coefficients.

In terms of the magnitude of coefficients, the Poisson models and the OLS models in Table 3 show that bonding social capital has a stronger relationship with non-infrastructure-based adaptation measures than infrastructure-based ones. In a poor region such as the LCR basin area, borrowing and lending money among villagers may be less common than information sharing and mutual learning. As a result, bonding social capital may facilitate households to take non-infrastructure-based adaptation measures more effectively than infrastructure-based ones as non-infrastructure-based measures primarily depend on information sharing and social learning while infrastructure-based adaptation measures require more capital investment.

Results from the robustness check 2 show a difference both in the significance and the magnitude of social capital for households belonging to different income strata (Appendix Table 4). Specifically, bonding social capital plays a more significant role for households with higher-economic standings, while coefficients of bridging social capital are insignificant for households belonging to both income strata (Appendix Table 4 (Family income above the medium)). Households having higher economic standings may have more daily interactions with their fellow villagers such as lending farming tools to or talking on the phones with their fellow villages. As a result, they may have built up higher trust in their fellow villagers and tend to have a higher expectation for reciprocate behaviors from their fellow villages in their adoption process.

5 Conclusions

Adoption of new technologies forms an important component of adaptation strategies taken by rural households to cope with climate change impacts. Previous studies, primarily by taking a perspective in collective actions, have demonstrated some essential roles of social capital for climate change adaptation. Empirical research taking a perspective in individual adaptation decisions is still limited.

This paper is one of few empirical papers in China to link social capital to farmers' individual adaptation decisions by adding values to previous studies in two ways. First, it applies the concept of social capital to individual, other than collective, decisions on climate change adaptation through the adoption lens. Second, instead of taking social capital together, it distinguishes between bonding and bridging social capital. Using primary data collected in LCR basin area in Southwest China, the paper has the following main findings:

Despite the poor economic conditions in the LCR basin area, almost all of surveyed households have taken adaptation measures to some degree. Moreover, the adoption of non-infrastructure-based measures is more prevalent than that of the infrastructure-based measures. This makes sense in poor regions, where rural households often have credit constraints for capital investments: since non-infrastructure-based measures are less capital intensive than infrastructure-based measures, they are relatively easier for the credit-constrained farm households to take.

For surveyed households, their bonding social capital is positively and significantly related to their adaptation decisions, while their bridging social capital has an insignificant relationship with their adaptation decisions. The positively significant role of bonding social capital may be because their strong social capital accumulated within their own communities may have aided their information sharing, mutual help, and social learning with their fellow villagers that may have facilitated their adaptation decisions. The limited role of bridging social capital may be because of (1) weak bridging social capital, measured by their Guangxi in our study, possessed by our surveyed households or (2) two underlying opposite forces of bridging social capital mitigate each other in households' adaptation decisions.

Based on the above findings, we make the following two policy recommendations regarding how governments may help the poor, particularly those in poverty-stricken and drought-prone regions, to improve their individual household adaptive capacity. First, governments need to provide some enabling policies and institutional environment to improve the poor's capability of adopting technologies that require some initial capital investment. Developing some basic infrastructure such as micro-scale infrastructure for irrigation or water storage is one example. Improving input supply systems and strengthening extension system at the local level are another.

Second, when designing policies to improve the poor's long-term adaptive capacity, the governments should contemplate carefully how to help the poor to have a good combination of bonding and bridging social capital. The poor often have strong bonding social capital but weak bridging social capital (Woolcock and Narayan 2000), just like what we find in our study. This may limit their capacity to move ahead in a changing climate: while bonding social capital can serve as one primary resource for the poor to manage risks and vulnerability and help them to "get by," bridging social capital often helps them to "get ahead." To foster the poor's bridging social capital, improving the poor's accessibility to formal financial institutions, providing them necessary trainings such as those on disaster management, and improving extension services for technology adoption may be taken by the governments as entry points.

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