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Kathy Baylis
Yazhen Gong
Shun Wang

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ABSTRACT

Social capital can facilitate community governance, but not all social capital is alike. We distinguish bonding social capital (within a village) from bridging social capital (between villages), and we compare their effects on the management of a common pool resource. We develop a theoretical model and show that bonding social capital can improve common pool resource management, while the effect of bridging social capital is mixed. We test these findings using primary data from Yunnan, China on social capital and firewood collection on communal lands. We find that bonding social capital decreases the consumption of the common pool resource, and bridging social capital erodes the effect of bonding. Bridging social capital also decreases the use of the common pool resource by villagers who are near subsistence levels of consumption. Our results are robust to alternative measures of social capital and to treating social capital as endogenous.

Kathy Baylis
Department of Agricultural
and Consumer Economics
University of Illinois
Mumford Hall
Urbana, IL 61801
baylis@illinois.edu

Yazhen Gong
School of Environment and Natural Resources,
Renmin University of China
ygong.2005@gmail.com

Shun Wang
School of Public Policy and Management
Korea Development Institute (KDI)
85 Hoegiro, Dongdaemun Gu
Seoul, 130-868, Korea
swang@kdischool.ac.kr

1 Introduction

Firewood is the primary source of fuel for heating and cooking in many developing regions, and its use has caused deforestation. Forests in the Yunnan province of China have been deemed a 'biological hotspot' by Conservation International (2007), and are under threat from deforestation. Both firewood collection and illegal logging in Yunnan have destroyed habitat for endangered species such as the red panda (Xu and Wilkes 2004). Around the world, much community-held forest land is a common pool resource (CPR). Exclusion is difficult or impossible, and so overconsumption is common.

Social capital can help make village-level management of CPRs successful, however, since village members can better detect over-use of the resource and often can enforce consumption rules more effectively than state or federal government. Because social capital can aid information flow and enforcement, it can help communities overcome the tragedy of the commons often associated with CPRs (Hardin 1968; Acheson 2000; Bowles and Gintis 2002; Ostrom 1990 and 1999). Empirical evidence is more mixed, however, and social capital has not always led to better CPR management (Isham and Kahkonen 2002; Ishihara and Pascual 2009; Pretty and Ward 2001; Varughese and Ostrom 2001). In this paper, we consider how social capital affects firewood collection on community lands in the Yunnan province of China.

Social capital affects various aspects of the economy (for a good review, see Durlauf and Fafchamps 2005). While early research often groups all social capital together, Putnam (2000) distinguishes between bonding and bridging social capital. Bonding social capital refers to trust and social networks within a group, while bridging social capital refers to links between groups. Most studies only consider one of these two dimensions. Bonding social capital could be measured by ethnic homogeneity (Costa and Kahn 2003; Easterly and Levine 1997) or higher levels of trust (Helliwell 1996; Knack and Keefer 1997; La Porta *et al.* 1997). It can increase growth or public good provision, and it can improve co-management of CPRs. Bridging social capital as measured by trust or networks between communities can improve economic growth and opportunities

(Fafchamps and Minten 2002; Palloni *et al.* 2001; Narayan 1999). A few recent studies begin to distinguish between the effects of bonding and bridging social capital. Several studies find that bonding social capital has either no effect or a negative effect on economic outcomes, while bridging social capital can improve economic development, growth, and employment (Sabatini 2008; Zhang *et al*. 2011; Lancee 2010; Beugelsdijk and Smulders (2003, 2009) and Knudsen *et al*. 2010).

To our knowledge, our paper is the first to consider how both bridging and bonding social capital affect the management of a common pool resource. We first modify the CPR model of McCarthy *et al*. (2001) to allow for the effect of social capital on CPR consumption. We model bonding social capital as enabling risk-sharing within the village, so greater bonding social capital implies a greater penalty from being excluded. In effect, the vulnerability to social sanction facilitates enforcement of community norms.[2] Thus, villagers with more bonding social capital are less likely to overuse their CPR. In contrast, bridging social capital gives villagers an expansive social network outside the community, so it can reduce an individual's vulnerability to community social sanctions and limit the enforcement capability of the community. That said, bridging social capital can also reduce the stress put on CPR consumption from those villagers near the subsistence level. Therefore, while we find bonding social capital clearly aids CPR management, the effect of bridging social capital is mixed.

We then test our theoretical predictions using field experiments and primary survey data collected from 600 households in Yunnan. While social capital may be a village-wide asset, we measure each household's expected return from that asset [following Glaeser *et al*. (2002), Pugno and Verme (2012), Sabatini (2008), and Zhang *et al*. (2011)]. We then measure each household's consumption of firewood from communal land, and regress it against the household measures of social capital.

[2] Social sanction relies on the pre-existing social connections between individuals and is very important for the community enforcement of some informal rules, such as in the case of Rotating Savings and Credit Associations, or ROSCAS (Anderson *et al*. 2009, Besley *et al*. 1993). Social sanction can take different forms, such as creating a bad reputation, retaliating at the workplace, excluding individuals from a mutual insurance system, or even damage to personal property.

Yunnan's great biological diversity is threatened by firewood collection, so CPR management is crucial to conservation efforts. It is also ethnically diverse, so the level of social capital might vary from village to village.

We collect data directly from 10 randomly-selected households in each of 60 natural villages in rural Yunnan. Specifically, we interview each household about its income and expenditure, the amount of firewood it collects on communal land, and the quality and use of its own private land. Second, to measure trust, we engage villagers in a field experiment. Each player is given money and told that any funds sent to an anonymous village member will be doubled, and that the recipient can choose to return any portion of the financial gift to the sender. As an indicator of bridging social capital, we use the percent of days that household members spend outside the township.

We find that a household's expected return from bonding social capital reduces its firewood collection on communal lands. Its expected return from bridging social capital decreases consumption of the CPR at low levels of bonding social capital, but erodes the effect of bonding social capital at higher levels of trust. We also find evidence that bridging social capital makes villagers less sensitive to the quality of the CPR. Our results are robust to alternative measures of social capital and to whether we control for wealth, expenditure, or cash income. We also find similar results when we instrument for both types of social capital.

To be consistent with our model and to identify the effect of social capital in the presence of unobserved village-level characteristics, we focus on how individual differences in expected returns from social capital affect household CPR consumption. When we aggregate our social capital observations to the village level, we find that higher levels of community bridging social capital increase common pool resource consumption, and that a greater number of individuals with very low bonding social capital can worsen the tragedy of the commons.

Our paper makes several contributions. First, while previous theoretical literature is focused primarily on the effect of bonding social capital, we model and contrast the effect of both bonding and bridging social capital. Second, we explicitly model how social capital can affect vulnerability to social sanction, which helps determine the community's ability to enforce a cooperative level of CPR consumption. Third, we show the circumstances under which some types of social capital can erode the community's ability to manage CPRs. Fourth, while we follow Schechter (2007) in using a field experiment to measure trust within a village, we then empirically test whether this trust affects CPR management.

The rest of the paper is organized as follows. Section 2 briefly introduces the study area, Yunnan province. Section 3 builds a model and generates several testable hypotheses. Section 4 discusses the primary data for analysis, and section 5 shows the estimation strategy and empirical results. We conclude in section 6.

2 Background

Yunnan is a largely mountainous, rural province in southwest China. It is home to the headwaters of six major rivers including the Yangtze. The province hosts a high diversity of plant and animal life, containing 43 percent of China's protected plant species and 73 percent of China's priority protected wild animal species (Yang *et al*. 2004). Over 60 percent of the land is forested, and has traditionally been used for logging. Deforestation is blamed for habitat loss, landslides, and severe flooding in the late 1990s.

Developing successful community forest management in Yunnan has long been a problem. After the Household Responsibility System reallocated land to households in 1985, for example, villagers were found to log illegally at night to harvest timber before their neighbors depleted the forest (Su 2002). On the other hand, a number of villages such as Wenming and Mabuchong have good track records of successful community forest management. By exploring the nature of local social capital, we hope to be able to identify characteristics that can help explain why local resource management has been successful in some villages and failed in others.

Yunnan is one of the poorest provinces in China. Not counting the value of agricultural and forest goods produced for home use, median cash rural income in our data is under 6,000 Chinese Yuan Renminbi (CNY) per household per year (US$1,731 at an exchange rate of 3.466), or slightly over 2,000 CNY (US$577) per working individual.[3] This amount is only 12.5 percent of the Chinese national GDP per capita in 2006 (World Bank 2012). Young men from rural Yunnan often work in towns or cities and send money back to support the rest of the family still in the village. Around 12 percent of household income is from remittances. On average, our households have one child under the age of 16, contain slightly fewer than 3 adults, and are 46 percent female.

Even after the 2006 land tenure reform, all natural villages manage some of their own communal land.[4] The head of each natural village coordinates local land use decisions largely through village-level meetings. Any income from communal land is divided among members proportionally by household or by the number of hectares of private land each household holds. Most households have some privately-owned land after the 2006 tenure reform. A large majority of households in our sample (80 percent) have some land for forestry (averaging 1.3 hectares). All but three households have a small plot of land for agriculture (averaging 0.5 hectares), and all households in our sample produce some agricultural product. Our sample largely consists of subsistence farmers, with only one quarter of their agricultural produce sold on the market.

3 The Model

The setting for this paper is a village economy where the community manages common land for firewood collection. All members have access rights, implying that the community is not able to exclude members who consume more than the agreed-upon level of the resource. Each household has a certain level of social connection with the rest of the community and expects to receive returns from that network when it faces a negative shock such as an illness in the family. Similarly, each household expects to contribute to others when it experiences an unexpected boon such as an extra high

[3] The exchange rate is from the World Development Indicators published by the World Bank (2012), and is adjusted for purchasing power parity (PPP).

[4] The term 'natural village' refers to a naturally-formed community, which is a sub-unit of an administrative village. An administrative village is the smallest administrative unit in rural China.

agricultural yield from their individual plot.

Some families in the village also have ties outside the village, whether through a family member who sends back remittances, or through friends or relatives that have since moved to a larger urban center. Having these outside connections helps a family cope not only with an idiosyncratic shock but also with a village-level shock such as a bad crop year, because of access to outside employment income or to informal credit.

The intuition behind our model is relatively simple. Bonding social capital facilitates village-level insurance, which increases the cost to a villager of social sanction such as being removed from the insurance pool. In contrast, bridging social capital enables access to outside insurance, weakens an individual's vulnerability to social sanction, and thus mitigates against the effect of bonding social capital. Even if monitoring is costly, a village can sustain a cooperative level of CPR consumption by threatening non-cooperative villagers with social sanction. The level of supportable cooperative CPR consumption is then a function of the expected individual returns from each type of social capital. We also introduce a subsistence level of consumption to capture the idea that in years a negative income shock, villagers may be forced to consume more of the CPR than the cooperative level. In a survival situation, social sanction may not be a potent deterrent. On the other hand, having access to an outside insurance network in this case may reduce the pressure on the CPR, supporting cooperative CPR management. Thus, our model generates several predictions: that CPR consumption is decreasing in bonding social capital, and that this effect is mitigated by bridging social capital. However, bridging social capital can aid in CPR management if villagers are close to a subsistence level of consumption.

In the following section, we first illustrate how bridging and bonding social capital affect a villager's expected utility through their vulnerability to social sanction. In the next section, we develop a two stage game where communities choose an optimal level of enforceable consumption as a function of households' vulnerability to social sanction. In our first proposition, we demonstrate that community governance with costly monitoring will not achieve the first-best level of CPR consumption but can improve on the outcome from no community governance. Then we derive two propositions that suggest how bridging and bonding social capital will affect the level of CPR consumption that can be sustained by community governance.

3.1 Risk Sharing and Vulnerability to Social Sanction

Assume $N > 2$ community members share a common source of firewood. Villager i derives utility from consumption of firewood c_i and a numeraire good c_{0i}. In our model, villager i's consumption of the numeraire is subject to an idiosyncratic shock, μ_i, such as illness or injury.[5] For simplicity, we assume the shock is normally identically distributed with mean zero and variance σ_μ^2.

Rural communities often have risk-sharing networks (Bramoullé and Kranton 2005, 2007). Assume villager i shares a specific fraction of her total shocks $r_A \in (0,1)$ with the $N-1$ other individuals in the same village. Villager i also has M_i individuals in a bridging social network who are subject to a normally and identically distributed shock $\mu_{im}(m = 1, 2, \cdots, M_i)$ with mean zero and variance σ_μ^2. Each individual in this bridging social network shares a fraction of her total shocks $r_{iB} \in (0,1)$ with the other bridging members. Moreover, since fellow villagers also have outside connections, villager i can indirectly share a fraction $r_A r_{nB}(n \neq i)$ of her risks with the $\sum_{n\neq i}^{N} M_n$ "friends of friends." With these forms of risk-sharing, villager i's consumption of the numeraire good is then:

$$c_{0i} + \theta_i \mu_i + r_A \sum_{n\neq i}^{N} \mu_n + r_{iB} \sum_{m=1}^{M_i} \mu_{im} + \sum_{n\neq i}^{N} \left(r_A r_{nB} \sum_{m=1}^{M_n} \mu_{nm} \right). \tag{1}$$

[5] For simplicity we do not include a village-level shock in the model; adding a systemic shock would not affect our results.

where $\theta_i \equiv 1-(N-1)r_A - M_i r_{iB} - \sum_{n \neq i}^{N} M_n r_A r_{nB} \in (0,1)$ is the residual risk to villager *i*. Moreover, assume the degree of risk sharing is greater than zero but incomplete, implying that not all risk can be pooled. Thus, $\theta_i \geq r_A$ and $\theta_i \geq r_{iB}$.

We follow the idea that the extent of risk sharing is positively related to the individual's level of social capital (Carter and Maluccio 2003; De Weerdt and Dercon 2006). Thus, we assume r_A is an increasing function of bonding social capital, $A_i\left(i=1,2,\cdots,N\right)$, that is, $r_A = f\left(A_1, A_2, \cdots, A_N\right)$ and $\frac{\partial r_A}{\partial A_i} > 0\left(i=1,2,\cdots,N\right)$. Also, r_{iB} is an increasing function of villager *i*'s bridging social capital, B_i, or the intensity of ties within this bridging social network.[6] That is, $r_{iB} = f\left(B_i\right)$ and $\frac{\partial r_{iB}}{\partial B_i} > 0$.

Assume each villager's numeraire consumption has a CARA utility function of the form $v(x) = -\exp(-\gamma x)$, where γ is the Arrow-Pratt coefficient of absolute risk aversion. Villager *i*'s expected utility with both of these risk-sharing networks is defined as EU_{1i}, while her expected utility with only her bridging risk-sharing network is denoted as EU_{2i}. If the villager has access to both bonding and bridging risk-sharing networks, her expected utility is a function of the variance of consumption,

$$EU_{1i} = u\left(c_i\right) + v\left(c_{0i}\right) - \frac{1}{2}\gamma\sigma_{1i}^2,$$

where the residual variance, σ_{1i}^2 is a function of the degree of risk-sharing both inside and outside the village. If villager *i* is excluded from the village risk-sharing network, she can only share risks with those M_i individuals outside the village in her bridging social network. Her expected utility, denoted as EU_{2i} is then a function of the

[6] Think of A_i as the individual's expected return from the village-level bonding social capital, and B_i as her expected return from her bridging network's social capital stock. Each might vary with the individual's prior contributions to that type of social capital, or to her exogenous position within the social network.

variance of consumption with the more limited risk-pooling through only her bridging network, defined as σ_{2i}^2. Her consumption of the numeraire good with shocks is then:

$$c_{0i} + \left(1 - M_i r_{iB}\right)\mu_i + r_{iB}\sum_{m=1}^{M_i}\mu_{im},$$

and her expected utility is:

$$EU_{2i} = u\left(c_i\right) + v\left(c_{0i}\right) - \frac{1}{2}\gamma\sigma_{2i}^2,$$

Additional mutual insurance reduces the variance of consumption ($\sigma_{2i}^2 > \sigma_{1i}^2$) and increases expected utility ($EU_{1i} > EU_{2i}$). In other words, villagers benefit from pooling their risks with more villagers. We formally show this result in the proof in *Appendix 1*.

We model social sanction as the exclusion of a villager from the risk-sharing network in the village. Assume that individuals who deviate from the village consensus face probability η of being excluded, and define the villager's vulnerability to social sanction as $\varphi_i = \eta\left(EU_{1i} - EU_{2i}\right)$. Substituting EU_{1i} and EU_{2i} into the definition of vulnerability, we solve for how vulnerability changes with bonding and bridging social capital. Villager *i*'s vulnerability to social sanction is increasing with bonding social capital and decreasing with bridging social capital. Moreover, the marginal effect of bonding social capital is decreasing with bridging social capital:

$$\frac{\partial\varphi_i}{\partial A_i} > 0, \quad \frac{\partial\varphi_i}{\partial B_i} < 0, \text{ and } \quad \frac{\partial^2\varphi_i}{\partial A_i \partial B_i} < 0. \qquad (2)$$

Proof: The full derivation is in *Appendix 1*.

3.2 Social Capital and Community Governance of CPRs

We now consider how social capital affects the cooperative level of resource consumption. We know that individuals have the incentive to extract more CPR than the socially-optimal level, since each person only internalizes direct costs of consumption (ignoring the externality imposed on neighbors). Thus, to achieve the cooperative level of consumption, a community must have some means of enforcement. Here, we consider community monitoring and social sanction as an enforcement mechanism. Without external regulation, the community conducts costly monitoring and imposes sanctions on those who do not follow community rules. The monitoring cost is shared, and an individual's probability of being caught consuming more than the cooperative level of the CPR is an increasing function of the community's monitoring effort.

Resource consumption is modeled as a two-stage game: In the first stage, the community sets a cooperative level of consumption and monitoring to enforce this level based on social sanction. In the second stage, members of the community can choose to consume the agreed-on level of CPR under the proposed degree of monitoring or can deviate and face social sanction. Once the optimal level of monitoring is determined in the community's profit maximization problem, we assume that the level of monitoring is pre-committed by individuals, following McCarthy *et al*. (2001). Monitoring could be pre-committed in the form of an in-kind or monetary contribution to a joint fund, or by signing up to help patrol the forest.

Whether individuals deviate from the consumption level set in the first stage depends on two conditions: first, whether expected utility from using the cooperative level of CPR is greater than under deviation given the probability of sanction, and second, whether *ex post* consumption is greater than subsistence level. If an individual with few resources who lives near subsistence level realizes a large negative income shock, she might consume more CPR to survive regardless of the threat of social sanction.

The game can be solved by backward induction. In the second stage of the game, each player has two strategies: one is to cooperate and extract the CPR at the level determined by a joint utility maximization, and the other is not to cooperate, and to extract the CPR to maximize individual utility from consuming the CPR. Each player must expend constant marginal cost d to extract and consume each unit of the CPR, such as the cost of fishing or firewood harvesting. Following McCarthy *et al*. (2001), we specify the utility from consuming the CPR as:

$$u\left(c_i\right)=c_i\left(a-b\sum_{n=1}^{N}c_n\right)-dc_i\ ,\tag{3}$$

where a is the resource capacity, and b is its sensitivity to extraction.

In the case without a village agreement on CPR consumption, the optimal consumption of player i is solved by setting $\partial u\left(c_i,c_{-i}\right)/\partial c_i=0$. We then obtain player i's reaction function:

$$c_i\left(c_{-i}\right)=\frac{a-d}{2b}-\frac{1}{2}\sum_{n\neq i}^{N}c_n\ .\tag{4}$$

Assume all villagers face identical marginal costs of CPR consumption, d. If there is no community rule to limit CPR consumption, we can combine the reaction functions to obtain the non-cooperative equilibrium consumption for each player ($\tilde{c}$) and for the group ($\tilde{C}$):

$$\tilde{c}=\frac{1}{N+1}\frac{a-d}{b},\qquad \tilde{C}=\frac{N}{N+1}\frac{a-d}{b}.\tag{5}$$

Next, we define the level of enforceable cooperative consumption as $\hat{c}_i\ \left(i=1,2,\cdots,N\right)$ and solve for villager i's level of consumption if she deviates. We then solve for the expected penalty and the required level of monitoring effort needed to keep player i from deviating.

Ignoring penalties for the moment, if all other villagers cooperate, villager i's consumption under deviation is:

$$c_i\left(\hat{c}_{-i}\right)=\frac{a-d}{2b}-\frac{1}{2}\sum_{n\neq i}^{N}\hat{c}_n\ .\tag{7}$$

Villager i's utility from deviation is:

$$u\left(c_i\left(\hat{c}_{-i}\right),\hat{c}_{-i}\right)=c_i\left(\hat{c}_{-i}\right)\left(a-b\left(c_i\left(\hat{c}_{-i}\right)+\sum_{n\neq i}^{N}\hat{c}_n\right)\right)-dc_i\left(\hat{c}_{-i}\right)=\frac{1}{4b}\left(a-d-b\sum_{n\neq i}^{N}\hat{c}_n\right)^2,\tag{8}$$

compared to her utility from cooperation:

$$u_i\left(\hat{c}_i,\hat{c}_{-i}\right)=\hat{c}_i\left(a-b\sum_{n=1}^{N}\hat{c}_n\right)-d\hat{c}_i=\hat{c}_i\left(a-d-b\sum_{n=1}^{N}\hat{c}_n\right).\tag{9}$$

Assume that each villager i contributes s_{in} in monitoring cost to monitor the CPR consumption of villager n. The total monitoring cost paid by any villager i, $s \equiv \sum_{n=1}^{N} s_{in}$, is the same for all villagers.[7] If a villager i consumes more than the agreed-upon level of the CPR, the probability of being caught, π_i, is an increasing function of total effort spent monitoring villager i, $S_i \equiv \sum_{n=1}^{N} s_{ni}$. At the community level, the sum of the amount of monitoring effort contributed equals the sum of amounts monitored, so $\sum_{i=1}^{N}(s) = Ns = \sum_{i=1}^{N}(S_i)$. Specifically, we choose a simple form of monitoring technique, following McCarthy *et al*. (2001):

$$\pi_i(S_i) = \frac{\alpha S_i}{1+\alpha S_i},$$

where $\alpha > 0$ denotes the efficiency of monitoring. Villager i will not deviate from the cooperative level of consumption if and only if: 1) the expected penalty is at least as large as the extra utility from deviation, where her penalty is her vulnerability to social sanction times the probability she gets caught; and 2) *ex post* consumption is not lower than subsistence level. Thus, we have the two following conditions for cooperation:

$$\pi_i(S_i) m_i \geq \left(1-\pi_i(S_i)\right)\left(u\left(c_i(\hat{c}_{-i}), \hat{c}_{-i}\right) - u\left(\hat{c}_i, \hat{c}_{-i}\right)\right), \tag{10}$$

and

$$\beta \hat{c}_i + c_{0i} + \theta_i \vec{\mu}_i + r_A \sum_{n \neq i}^{N} \vec{\mu}_n + r_{iB} \sum_{m=1}^{M-1} \vec{\mu}_{im} + \sum_{n \neq i}^{N} \left(r_A r_{nB} \sum_{m=1}^{M-1} \vec{\mu}_{nm} \right) \geq \underline{c}, \tag{11}$$

where β is the marginal rate of substitution between firewood and numeraire goods, $\underline{c}$ is the subsistence level of consumption, and $\vec{\mu}_i$ and $\vec{\mu}_{im}$ denote the realized shocks.

First we consider the case where the subsistence constraint (11) is not binding and

[7] We allow for villagers to contribute to a central monitoring fund, where one's contribution might partially go toward self-monitoring. We could equally assume villagers do not contribute to self-monitoring, implying $s_{ii} = 0$.

focus on the penalty constraint (10). To force player i to cooperate, the monitoring effort by villagers must be equal to or greater than some minimum effort that just equals the increase in utility from deviation divided by i's vulnerability to social sanction:

$$S_i \geq \hat{S}_i = \frac{u\left(c_i\left(\hat{c}_{-i}\right), \hat{c}_{-i}\right) - u\left(\hat{c}_i, \hat{c}_{-i}\right)}{\alpha m_i}. \tag{12}$$

The community will have two outcomes. Each villager either (a) extracts the cooperative level, $\hat{c}_i$ and pays the monitoring cost, s; or (b) extracts the non-cooperative level of $c_i\left(c_{-i}\right) = \frac{a-d}{2b} - \frac{1}{2}\sum_{n \neq i}^{N} c_n$ without paying any monitoring cost. For the cooperative equilibrium to exist, all villagers must cooperate, which implies they each must have larger payoffs under cooperation than under deviation. We return to the first stage of the game, where the community chooses the cooperative consumption levels to maximize total welfare and solve for the sustainable cooperative level of CPR consumption. We also derive the explicit conditions needed for the cooperative equilibrium to exist in *Appendix* 2. Comparing the sustainable cooperative consumption of CPRs ($\hat{C}$) with the first best level of consumption ($\bar{C}$) and the non-cooperative consumption ($\tilde{C}$) leads us to the following proposition.

Proposition 1*: The sustainable cooperative consumption of CPRs with social capital and costly monitoring (*$\hat{C}$*) lies between the first best level of consumption with no monitoring cost (*$\bar{C}$*) and the non-cooperative consumption (*$\tilde{C}$*), i.e.* $\bar{C} < \hat{C} \leq \tilde{C}$. *In other words, community governance may mitigate the overconsumption of CPRs, but cannot completely eliminate it.*

Proof: The full derivation is in *Appendix 3*.

The main implication of this proposition for empirical work below is that any finding of reduced actual consumption of firewood ($\hat{C}$) must mean a step closer to the first-best level *(*$\bar{C}$*)*, which therefore implies better community management.

When the conditions allowing the cooperative equilibrium to exist are satisfied, the enforceable cooperative level of consumption will be a function of villagers' bonding and bridging social capital. The relationship between player *i's* consumption and the two types of social capital is given by the following proposition.

Proposition 2. *If the subsistence constraint is not binding, player i's consumption of CPR under the cooperative strategy is decreasing with her bonding social capital and increasing with her bridging social capital. Moreover, the marginal effect of bonding social capital is decreasing with bridging social capital, that is,*

$$\frac{\partial \hat{c}_i}{\partial A_i} < 0, \quad \frac{\partial \hat{c}_i}{\partial B_i} > 0, \text{ and } \frac{\partial^2 \hat{c}_i}{\partial A_i \partial B_i} > 0. \tag{13}$$

Proof: The full derivation is in *Appendix 4*.

Proposition 2 implies that higher individual bonding social capital induces a more restrictive cooperative level of consumption for that villager, given a fixed level of bridging social capital. Further, higher bridging social capital reduces enforceability, implying a larger feasible cooperative level of CPR consumption. The result also implies that the combination of high bonding and high bridging social capital might generate the same level of CPR consumption as a combination of low bonding and low bridging social capital. These results may help explain conflicting findings in empirical research, that demonstrate high bonding social capital cannot always induce lower consumption of CPRs. If authors neglect the offsetting effect of bridging social capital on the effectiveness of bonding social capital, they might well observe different effects of social capital on CPR consumption. Two communities endowed with similar resource characteristics and bonding social capital but different enough bridging social capital will have different levels of consumption of CPRs in equilibrium.

Now we consider the subsistence constraint in (11). Let $\vec{\mu}_i$ denotes the realized shock on villager *i*. Assuming that shocks are independently distributed with a mean of zero, the sum of villagers' realized shock and the sum of realized shocks of each villagers' bridging network are both equal to zero, that is $\sum_{n=1}^{N}\vec{\mu}_n = 0$ and $\sum_{m=1}^{M_i}\vec{\mu}_{nm} = 0 \ \mathit{for}\ \forall n = 1,2,\cdots,N$. If villager i's shock $\vec{\mu}_i$ is negative and big enough such that player i's *ex post* consumption under the cooperative strategy is below the subsistence level, i.e. $\beta\hat{c}_i + c_{0i} + (\theta_i - r_A)\vec{\mu}_i < \underline{c}$, user i will then over-consume the CPR at the level $\widehat{c}_i > \hat{c}_i$. Her total consumption will then equal the subsistence level:

$$\widehat{c}_i = \frac{1}{\beta}\left(\underline{c} - c_{0i} - (\theta_i - r_A)\vec{\mu}_i\right). \tag{14}$$

Then we have the following proposition on the relationship between consumption and social capital.

Proposition 3: *If the subsistence constraint is binding, player i's consumption of CPR is decreasing with both bonding social capital and bridging social capital. Moreover, the marginal effect of bonding social capital does not change with bridging social capital, that is,*

$$\frac{\partial \widehat{c}_i}{\partial A_i} < 0,\ \frac{\partial \widehat{c}_i}{\partial B_i} < 0, \text{ and } \frac{\partial^2 \widehat{c}_i}{\partial A_i \partial B_i} = 0.$$

Proof: The full derivation is in *Appendix 5*.

In the case of a large negative shock, a villager with high level of bridging social capital is more capable of getting financial aid from outside the community, so the incentive to over-consume the CPR to maintain a subsistence level of consumption is not as high as for a villager with low bridging social capital. Therefore, for individuals close to the subsistence level of consumption, bridging social capital can be good for maintaining cooperation in the community governance of the CPR.

3.3 Hypotheses

From our propositions, we get the following testable hypotheses:

(H1) Bonding social capital increases vulnerability to social sanction, and therefore decreases consumption of the CPR.

(H2) Bridging social capital decreases vulnerability and thus may erode the effect of bonding social capital, increasing consumption of the CPR.

(H3) For households near a subsistence level of consumption, bridging social capital can provide access to outside risk sharing and thus help conserve the CPR.

4 Data

We survey 600 families in 60 natural villages in Yunnan Province, covering a total of 2,818 people. We select 5 counties in northwestern and southwestern Yunnan Province.[8] Then we randomly select 30 administrative villages, with two natural villages per administrative village, and we randomly select 10 households from each natural village. In our survey, we ask extensive questions about land use, income, household characteristics, and purchasing behaviour. In particular, we are interested in the consumption of fuel. We also ask about the amount of time household members spend outside the village, and village-level characteristics such as the distance to the nearest road. We use these measures of connection with the outside world as indicators of bridging social capital.

4.1 Trust Game: Bonding Social Capital

To determine the level of bonding social capital, we follow Schechter (2007) and conduct a field experiment to measure villager's trust of each other.[9] We randomly select household heads from each village and pair them with another anonymous village member. To ensure each partner's identity remains hidden, we conduct the interviews in the home rather than meeting in a central hall.

In the game, each player is randomly chosen to be a sender or a recipient. We give all players 20 CNY at the beginning of the game, about the equivalent of one day's wages. Then the sender is given a choice of sending 0, 5, 10, 15 or 20 CNY to the anonymous

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[8] The counties covered are Yongping, Jianchuan, E'shan, Pingbian and Jinggu.

[9] The field experiments were conducted for this paper; documentation on the details of the game and results are available in the dissertation by Gong (2010).

recipient, who they know lives in the same village. They are told that the recipient will receive double the amount sent, and will then have a choice of how much to send back. Because fairness is a powerful motivating force in Chinese culture, the sender is also informed that the recipient also receives 20 CNY, to eliminate equity concerns as a motivation for sending money. The sender then decides the amount she wishes to send and puts it into an envelope for the interviewer. The sender is then asked how much money she expects to receive back.

We double the amount in the envelope before talking to the recipient. This recipient is first asked how much she expects to receive. Then, after opening the envelope, she is asked how much he wishes to return. That amount is then given to the sender.

Although we observe the amount sent by each, we want a comparable measure across senders and recipients. Thus, we use the amount the sender and recipient expect to receive as a measure of bonding social capital. This amount reflects the degree to which people trust their fellow villagers to behave in a trustworthy manner. As one might expect, this figure is highly correlated with the amount sent by the sender (correlation coefficient of 0.87), while it is less correlated with the amount sent by the recipient.

As found in other trust games, the majority of our sample sent money and expected to receive money. The average amount sent was about 9 CNY, and it is only one CNY less than the average amount returned. Of people who sent a positive amount, the average amount sent was approximately 11 CNY (more than half of their starting amount). On average, the recipients returned 60 percent of the funds sent. The summary of the findings of the game appear in Table 1.[10]

[10] We hope to develop a close friendship with the two recipients who returned 150% of the money they received.

Table 1: Results of trust game

	Obs.	Mean	Std. Dev.	Min	Max
Player 1					
Money expected	297	8.91	7.67	0	40
Money sent	300	8.38	6.39	0	20
Money received	300	10.01	8.66	0	35
% who sent money	230	76.7			
% of money sent that is returned	230	119.8	41.1	0	300
Player 2					
Money expected to be sent (half the amount expected to be received)	300	8.85	5.40	0	20
Money received	300	16.77	12.77	0	40
Money returned	300	10.01	8.66	0	35
% who sent money (of those who received money)	223	97.0			
% of returned of money received	230	59.5	19.6	0	150

Although we trained players in the nature of the game using tokens, before asking them to send money, we were still concerned that those players with higher education may have better understood the game, which may affect the amount they expect to receive. We do not have any explicit reason to believe that education improves trust, and education itself might affect both the amount expected and firewood management. Therefore, we are concerned that direct use of the amount players expect to receive might contaminate our results. So, to generate our measure of bonding, we first regress the amount expected against education of the household head and a dummy for whether the person is the sender or the receiver. We then use the residuals as our measure of bonding social capital. We also use the amount expected in a robustness test. Results for this initial regression are given in *Appendix 6,* Table A1. Whether the player is a sender or a recipient does not appear to affect the amount expected, while the coefficient on education is positive and highly significant.

4.2 Bridging Social Capital

To capture bridging social capital, we use the percentage of days that the household's adult members worked outside of the township. We assume that a household member spending more time outside the township means a greater connection with the outside world, and therefore a greater potential insurance against village-wide shocks.

One might be concerned that our bridging measure could affect firewood demand simply by reducing the cooking requirements of the household. To test for this concern, we include the number of household members living at home in the regression for firewood. Further, one might worry that our measure of bridging social capital is largely picking up household wealth, expenditure, or cash income. In separate specifications, we include measures for each of these factors to see the effects on results.

Further, one might be concerned that our measure of bridging social capital is arbitrary. As alternative measures, we use the number of household members working outside the township, the percent of members working outside the township, and the amount of remittances received. Following Jensen and Oster (2009), we also use cable TV ownership and phone to proxy for connections with the outside world. We also later explore the potential endogeneity of both of our social capital variables.

4.3 Measure of the CPR

We are interested in observing how the two types of social capital affect the management firewood collection on communal lands. While we would ideally like to know how much land is publically held per natural village, we only observe the amount of communal land per administrative village. Thus, to measure firewood collection, we use the logged amount of firewood collected on public lands divided by the amount of forestland in the administrative village to get a measure of firewood collected per forest. We are missing information on forestland on one administrative village, which drops our sample size to 580. Summary statistics are presented in Table 2.

Table 2: Summary statistics

Variable	Obs.	Mean	Std. Dev.
ln(firewood collected per mu)	580	-6.399	3.653
Bonding SC	597	7.201	6.541
Bridging SC	600	28.241	29.805
Natural village's forest yield (kg/mu)	60	4.136	2.845
HH resource capacity (100 kg)	599	0.584	1.694
Firewood per mu collected by others	600	92.483	538.680
Dummy if family owns pigs	600	0.448	0.498
Number of HH members at home	600	4.035	1.548
Average slope of HH forest plots (high number = low slope)	599	1.155	0.786
Average distance of HH forest plots to road	599	1.797	2.642
Household expenditure less energy (1,000 CNY)	600	8.415	6.921
ln (cash income) (CNY)	600	7.499	3.443
ln(productive assets) (CNY)	600	6.698	2.786
ln (total household assets) (CNY)	600	9.724	1.845

A "mu" is a measure of land, equal to 1/15th a hectare or 0.165 acres.

5 Estimation Strategy and Empirical Results

We follow our theoretical model and estimate household consumption on public lands as a function of social capital and factors that affect the cost and benefit of collecting firewood on private land.[11] Like Pugno and Verme (2012), Sabatini (2008) and Zhang *et al*. (2011) who treat bonding and bridging social capital as an individual characteristic, we model social capital as the individual's expected return from the village social network or community bonding stock. We then compare the effect of bridging versus bonding social capital on the management of a CPR. We have both theoretical and practical identification reasons for this approach.

First, we believe that households will make decisions based on their individual expected returns from social capital, not just based on the common village-level stock. A household may not know the level of the social capital stock, implying that their

[11] We also tried including the amount of grain harvested, under the assumption that grain stalks might be used as fuel. However, we were informed that this practice is not common in Yunnan, which corresponds with the insignificance of its estimated coefficient.

perception of that level, not the level itself, will affect their vulnerability and thus their CPR use. Further, each household may benefit differentially from social capital, and these differences will affect household behavior. We feel the expected amount of money in the trust game is consistent with the concept of individual vulnerability to social sanction used in our theoretical model.

Second, on a practical note, we can better control for the many village-level unobservables if we compare villagers' actions to each other. For example, if high levels of social capital result in good CPR management and therefore high resource quality, one might observe high levels of consumption that do not indicate poor management but are in fact sustainable. We find as much within-village variation in our measure of expected returns from bonding social capital measure as we observe between villages. We also observe substantial variation in firewood collected on community land within a village. Thus, we use individual expected return to village social capital to explain the household decision of how much firewood to collect on communal lands relative to the consumption of others in the village. We modify the reaction function in equation (4) and divide own consumption through by the total per *mu* natural-village level consumption.[12] Thus, we estimate the following relation:

$$c_{iv} = \delta_I + \delta_A A_{iv} + \delta_B B_{iv} + \delta_{AB} A_{iv} B_{iv} + \delta_p p_{iv} + \delta_x x_{iv} + \varepsilon_{iv} \quad (15)$$

where *i* refers to villager and *v* refers to village. Then *c* is the (log) quantity of firewood consumed per *mu* divided by total village consumption per *mu*, δ_I is an intercept term, which includes village fixed effects, A is bonding social capital, and B is bridging social capital. The variable *p* is the cost of consuming firewood on the household's private land, which includes the slope of the land and the quality and quantity of the household forest resource, and *x* is a vector of household characteristics to control for fuel demand. Because we have two natural villages with no collection of firewood on public lands, our sample size falls to 526.

While we do not explicitly observe the cost of villagers collecting firewood on public

[12] *Mu* is a measurement unit for land area widely used in China. One *mu* is approximately equal to 0.165 acre.

lands, we do have measures of the cost to the household of consuming their private resources. Thus, we include the household forest resources (defined as forest plot area times yield), the area-weighted average slope of the household forest plots, and their area-weighted average distance from road. These variables capture both the benefit and cost of firewood collection on private lands (Deng *et al.* 2011).

Anecdotally, we heard that firewood demand is affected by whether the family owns pigs or not, since food for the livestock is often cooked. Thus, we include an indicator variable for pig ownership. We cluster errors by last name within each natural village, to capture possible joint decisions made by a multiple-household family unit. Note that many unrelated households have the same last name, so this clustering might slightly overstate our standard errors. We first estimate a simple reduced form relation between bonding and bridging social capital and the dependent variable (firewood collected on public lands per *mu* relative to the village total). We next estimate the model with the controls suggested by our theoretical model. The results of the simple model are presented in Table 3, and the results with controls are presented in Table 4.

Table 3: Effect of social capital on firewood collected (dependent variable is firewood collected on public lands per *mu* relative to the village total)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Bonding SC	-0.037*		-0.037*	-0.080***	-0.052**		-0.052**	-0.109***
	(0.021)		(0.021)	(0.030)	(0.023)		(0.023)	(0.032)
Bridging SC		-0.0101**	-0.0104**	-0.021***		-0.016***	-0.016***	-0.031***
		(0.005)	(0.005)	(0.007)		(0.005)	(0.005)	(0.008)
Bonding SC ×				0.001*				0.002**
Bridging SC				(0.0007)				(0.0007)
Village dummy	no	no	no	no	yes	yes	yes	yes
Observations	527	530	527	527	527	530	527	527
R-squared	0.006	0.009	0.016	0.023	0.153	0.162	0.171	0.183

Notes: The measure of bonding social capital is the amount of money sender and recipient expect to receive from their anonymous partner in the trust game net of the effect of education. The measure of bridging social capital is the percentage of days members of the household worked outside of the township. Standard errors in parenthesis are robust and adjusted for clustering within groups of the same last name within a natural village. *, **, and *** indicate significance at the 10, 5, and 1% levels respectively.

Table 4: Effect of social capital on firewood collected with controls

	(1)	(2)	(3)	(4)	(5)	(6)
Bonding SC	-0.081***	-0.085***	-0.086***	-0.107***	-0.110***	-0.109***
	(0.0295)	(0.0305)	(0.0304)	(0.0319)	(0.0328)	(0.0328)
Bridging SC	-0.021***	-0.022***	-0.022***	-0.030***	-0.031***	-0.030***
	(0.007)	(0.007)	(0.007)	(0.008)	(0.008)	(0.008)
Bonding SC × Bridging SC	0.001*	0.001*	0.001*	0.002**	0.002**	0.002**
	(0.0007)	(0.0007)	(0.0007)	(0.0007)	(0.0007)	(0.0007)
HH resource capacity	-0.227***		-0.199***	-0.181**		-0.185**
	(0.043)		(0.037)	(0.076)		(0.074)
Average slope of HH forest plots		-0.608***	-0.566***		-0.244	-0.236
		(0.188)	(0.188)		(0.209)	(0.209)
Average distance of HH forest plots to road		0.172***	0.169***		0.030	0.022
		(0.038)	(0.038)		(0.060)	(0.062)
Dummy, =1 if family owns pigs			-0.023			0.518
			(0.269)			(0.375)
Village Fixed Effects	no	no	no	yes	yes	yes
Observations	526	526	526	526	526	526
R-squared	0.039	0.064	0.076	0.187	0.184	0.193

Notes: standard errors in parenthesis are robust and adjusted for clustering within groups of the same last name within a natural village. *, **, and *** indicate significance at the 10, 5, and 1% levels respectively.

In the first 4 columns of Table 3, we run the regression with bonding SC (model 1), then bridging SC (model 2), then both together (model 3), and then with an interaction term (model 4), all without fixed effects. The next four columns repeat the same four models with natural-village fixed effects. Independently and together, the two types of social capital are shown to reduce the quantity of CPR consumed. Without natural-village-level fixed effects, in models (1) and (3), bonding reduces firewood consumption on public lands, but this term is only significantly different from zero at the 90 percent level. In models (2) and (3), bridging SC also reduces firewood consumption, and this effect is significantly different from zero at a 95 percent confidence level. While the effect of bonding social capital is consistent with our model, the coefficient on bridging social capital alone is opposite from that expected if households are not constrained by subsistence. We explore this subsistence effect in detail later.

In model (4), we see that the interaction term between bridging and bonding SC is positive, implying that each type of social capital erodes the effect of the other. This result is consistent with our theoretical model, which suggests that bridging social capital may erode the vulnerability to social sanction provided by bonding social capital. Results are consistent when we include village fixed effects, with a slight increase in the coefficient magnitudes and significance.

In Table 4, we introduce controls for: the household's resource capacity, the cost of harvesting wood on their private land, and factors that might affect demand for fuel. As in Table 3, the models presented in the first columns do not include village-level fixed effects, whereas the models in the last columns do. The signs on the effect of bonding and bridging SC are the same as in Table 3, although the magnitudes of the coefficients increase with the additional controls. The signs on the control variables are as expected. A lower household resource capacity implies more firewood collected on public lands. The cost of private collection also increases public-land collection: higher slope and less accessible land imply more firewood collected on public lands.

In Table 5, we present marginal effects for the models presented in Table 5, where we calculate the effect of bonding and bridging social capital, each at different levels of the other. When one level of social capital is relatively low, in the 25th percentile, the other type of social capital significantly reduces consumption of firewood. Using results with village fixed effects, consider the 25 percent of households with no measured bridging social capital. A one CNY increase in their bonding social capital generates an 11 percent decrease in their collection of firewood relative to the village total. For those approximately 18 percent of households who, in the trust game, did not expect any money to be sent or returned (no bonding social capital), a one percent increase in the number of days household members are away (more bridging social capital) decreases the amount of firewood collected by approximately 3 percent. When calculated at the median amount of bridging and bonding social capital, the effect of bonding social capital remains significant, reducing firewood consumption by 6 percent, while the effect of bridging social capital reduces to one percent. At the 75th percentile of the other type of social capital, the marginal effect of an increase in bonding or bridging social capital is not statistically different from zero.

Table 5: Marginal effects of bonding and bridging social capital

	With no other social capital	25%	50%	75%
Model (3) without Fixed Effects				
Marginal effect of Bonding SC, at	-0.086***	-0.086***	-0.059***	-0.019
percentiles of Bridging SC	(0.030)	(0.030)	(0.022)	(0.025)
Marginal effect of Bridging SC, at	-0.022***	-0.019***	-0.012**	-0.009*
percentiles of Bonding SC	(0.007)	(0.006)	(0.005)	(0.005)
Model (6) with village Fixed Effects				
Marginal effect of Bonding SC, at	-0.109***	-0.097***	-0.063***	-0.016
percentiles of Bridging SC	(0.033)	(0.030)	(0.023)	(0.025)
Marginal effect of Bridging SC, at	-0.030***	-0.021***	-0.013***	-0.009
percentiles of Bonding SC	(0.008)	(0.005)	(0.005)	(0.005)

Notes: standard errors in parenthesis are robust and adjusted for clustering within groups of the same last name within a natural village. *, **, and *** indicate significance at the 10, 5, and 1% levels respectively.

5.1 Robustness Tests

While our measure of bonding social capital is a result of the trust game, we use a proxy measure for bridging social capital: the percent of days adult household members worked outside the township. One may worry that our measured effect of bridging SC is thus either a result of the specific way we measure time outside the village or is capturing other effects of a household with a migrant member. To test the robustness of these results, we use a number of other related measures as proxies for bridging SC. These results are presented in Table 6.

Table 6: Alternate measures of social capital

	(1)	(2)	(3)	(4)	(5)	(6)
Bonding SC	-0.084***	-0.089***	-0.063**	-0.084***	-0.077*	-0.102***
	(0.028)	(0.028)	(0.026)	(0.024)	(0.041)	(0.032)
Bridging SC	-0.570**	-0.027**	-0.039***	-2.042***	-0.695	-0.032***
	(0.247)	(0.018)	(0.010)	(0.645)	(0.543)	(0.009)
Bonding SC × Bridging	0.051*	0.003**	0.002	0.105**	0.037	0.002**
SC	(0.0278)	(0.001)	(0.001)	(0.052)	(0.050)	(0.001)
HH resource capacity	-0.199**	-0.202***	-0.196***	-0.180**	-0.179**	-0.184**
	(0.079)	(0.076)	(0.074)	(0.072)	(0.078)	(0.075)
Dummy =1 if family	0.561	0.560	0.564	0.687*	0.664*	0.525
owns pigs	(0.381)	(0.379)	(0.371)	(0.382)	(0.379)	(0.376)
Average slope of HH	-0.241	-0.257	-0.273	-0.232	-0.217	-0.225
forest plots	(0.218)	(0.217)	(0.211)	(0.210)	(0.211)	(0.209)
Average distance of HH	0.0313	0.029	0.026	0.023	0.025	0.0217
forest plots to road	(0.062)	(0.062)	(0.060)	(0.062)	(0.061)	(0.062)
ln (cash income)			-0.067			
			(0.047)			
ln (total household				-0.149*	-0.158*	
assets)				(0.086)	(0.094)	
Village Fixed Effects	yes	yes	yes	yes	yes	yes
Observations	526	526	526	526	526	526
R-squared	0.174	0.176	0.184	0.192	0.179	0.190

Notes: The measure of bridging social capital in model (1) to (5) is number of household members working away, percent of household members working away, the amount of remittances (1,000 yuan), ownership of a television, and ownership of a phone. The measure of bonding social capital in model (6) is the amount of money sender and recipient expect to receive from their anonymous partner in the trust game and the measure of bridging social capital is the one used in the main model. Standard errors in parenthesis are robust and adjusted for clustering within groups of the same last name within a natural village. *, **, and *** indicate significance at the 10, 5, and 1% levels, respectively.

Whereas our main specification above uses the percent of days worked outside the township as our measure of bridging social capital, the first model in Table 9 uses the number of household members working outside the township as our measure of bridging social capital. In model (2), we use the percent of household members working outside the township. While the exact coefficients on bridging change along with the magnitudes of our bridging measures, the signs and significance remain the same for both social capital measures, and the magnitudes of the other coefficients remain relatively unchanged. In model (3) we use the amount of remittances sent by household members to capture a measure of the degree of connectedness to outside communities. In this model we separately control for the amount of cash income earned by the household to ensure we do not inadvertently capture an effect of having extra cash in the household. Again, we observe consistent results, where both bridging and bonding social capital reduce firewood collection on public lands, while an increase in one type of social capital reduces the effect of the other. This latter effect is not significantly different from zero.

In models (4) and (5), we use access to communications media as a proxy for connections to the outside world. Specifically, we ask whether ownership of a television or a phone affects the amount of firewood collected, while controlling for total household assets to ensure we are not merely capturing the effect of wealth. We find that ownership of a television or a phone reduces consumption of firewood on public lands, and that owning a television reduces the effect of bonding social capital. We see a similar trend in the case of phone ownership, but the coefficient is not significantly different from zero.

Last, in model (6), we test an alternative to the main specification above, where our measure of bonding social capital used residuals from a regression on the amount expected regressed against education. In model (6), we simply use the amount players expected to be returned in the trust game, and find our results substantively unchanged.

To check whether our results are robust to model specification, we test several other models as reported in *Appendix 6*, Table A2. First, one might be concerned that a household with a larger number of members at home will demand more fuel and, by definition, have fewer members working outside the township (lower measure of bridging social capital). In our first alternative model, we include the number of household members in residence. We find the results do not change and that the effect of the number of household members is not significant. This lack of significance persists over numerous other specifications, so we leave the number of household members out of our primary specifications. Second, since the amount of fuel is determined alongside household expenditure, we include total household expenditure less expenditure on energy (model 2 in Table A2). We also instrument for total expenditure using household assets and log of total household assets, and we find little change in our results (model 3). We also both include the number of households in the village and cluster our standard errors by natural village and find no qualitative change in our results.

To address the concern that our results may be driven by the specific form of our dependent variable, we use consider household firewood collection on its own and per mu as opposed using the amount collected relative to the total consumption per mu of others in the natural village. We present these results in *Appendix 6*, Table A3. In all cases, the effects of the two types of social capital remain unchanged.

5.2 Interaction Effects

In all of the cases above, we find that expected returns to bridging social capital decrease CPR consumption, which is contrary to the prediction in Proposition 2 but consistent with Proposition 3 if the household faces a subsistence constraint. Thus, we want to test whether the estimated effect of bridging social capital is capturing the fact that many of our households are near subsistence levels of consumption. By facilitating insurance against negative shocks, bridging social capital may give households outside options to meet their subsistence needs (rather than over-use the CPR).

Our model implies that bridging social capital makes households less vulnerable to social sanction for overconsumption. We may expect to see the effect of the decrease in vulnerability most strongly when the resource is depleted and sanction for overconsumption is high. Thus, bridging social capital may reduce households' sensitivity to the CPR resource quality, making it more difficult to sustain a cooperative outcome when the resource is already depleted.

We interact the bridging and bonding measures with CPR quality and household productive assets, to observe if the overall resource quality or being near subsistence changes the effect of either social capital on CPR use. Results are presented in Table 7. We do not observe the quality of the CPR itself, so we use the forest yield of the land in the natural village as a proxy. We use productive assets to measure how close a household is to subsistence. Productive assets may be better than total assets to reflect a household's ability to respond to a negative income shock, because total assets not be fungible and may not increase income (Liverpool-Tasie and Winter-Nelson 2011).

In Table 7, we first present the results of the interaction terms with bonding social capital (model 1), with bridging social capital (model 2) and then both (model 3). Models (4) through (6) repeat models (1) through (3) but include natural village fixed effects. First, we see that neither bonding interaction term is significantly different from zero. By contrast, bridging social capital reduces firewood collection if people are asset-poor, but also reduces people's sensitivity to resource capacity. Households appear to be relatively insensitive to resource quality (p-stat of 0.259 at average levels of bridging). While at high levels of bridging social capital, villagers actually collect more firewood when communal forests are depleted in a rush to consume the resource before it is gone. Thus, high levels of bridging social capital may facilitate the tragedy of the commons.

Table 7: Interaction effects

	(1)	(2)	(3)	(4)	(5)	(6)
Bonding SC	-0.151*	-0.081***	-0.161*	-0.153*	-0.104***	-0.159*
	(0.080)	(0.031)	(0.082)	(0.082)	(0.033)	(0.084)
Bridging SC	-0.023***	-0.032***	-0.033***	-0.030***	-0.033***	-0.034***
	(0.007)	(0.011)	(0.011)	(0.008)	(0.013)	(0.013)
Bonding SC × Bridging	0.001**	0.001*	0.001*	0.002***	0.002**	0.002**
SC	(0.0007)	(0.0007)	(0.0008)	(0.0007)	(0.0007)	(0.0008)
Bonding SC × Natural	0.002		0.003	0.002		0.002
village's forest yield	(0.007)		(0.007)	(0.007)		(0.007)
Bonding SC × Productive	0.007		0.009	0.005		0.006
assets	(0.010)		(0.010)	(0.010)		(0.010)
Bridging × Natural		-0.003**	-0.003*		-0.004**	-0.004**
village's forest yield		(0.001)	(0.001)		(0.001)	(0.001)
Bridging SC × Productive		0.004***	0.004***		0.003**	0.003**
assets		(0.001)	(0.001)		(0.001)	(0.001)
HH resource capacity	-0.192***	-0.190***	-0.190***	-0.186**	-0.184**	-0.187**
	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.078)
Dummy if family owns	-0.034	0.002	0.005	0.532	0.465	0.463
pigs	(0.269)	(0.264)	(0.264)	(0.376)	(0.372)	(0.372)
Average slope of HH	-0.566***	-0.580***	-0.593***	-0.245	-0.264	-0.277
forest plots	(0.189)	(0.187)	(0.188)	(0.207)	(0.205)	(0.204)
Average distance of HH	0.156***	0.151***	0.151***	0.019	0.0191	0.0170
forest plots to road	(0.040)	(0.040)	(0.041)	(0.062)	(0.061)	(0.062)
ln (productive assets)	-0.068	-0.133*	-0.199*	-0.061	-0.134*	-0.180
	(0.079)	(0.068)	(0.103)	(0.087)	(0.078)	(0.110)
Natural village's forest	-0.053	0.045	0.022			
yield	(0.066)	(0.062)	(0.079)			
Village Fixed Effects	no	no	no	yes	yes	yes
Observations	526	526	526	526	526	526
R-squared	0.078	0.092	0.094	0.194	0.209	0.210

Notes: standard errors in parenthesis are robust and adjusted for clustering within groups of the same last name within a natural village. *, **, and *** indicate significance at the 10, 5, and 1% levels, respectively.

As our model predicts, bridging social capital reduces the consumption of firewood from public lands when the household is asset-poor. At the average level of productive assets in our sample, and at average levels of resource capacity and bonding social capital, bridging social capital still significantly reduces consumption of the CPR. At the 75th percentile of productive assets, bridging social capital no longer has a significant effect on CPR consumption; at the upper end of productive assets, bridging social capital actually increases consumption of the CPR, although this effect is not significantly different from zero. Given that our communities are in some of the poorest regions of China, the majority of our sample may live close to the subsistence level and has little ability to absorb negative income shocks.

In short, while bridging social significantly reduces consumption of the CPR on average, when forests are depleted or when the household is poor, bridging social capital no longer limits CPR consumption. By contrast, the effect of bonding social capital is not affected by resource quality or asset poverty. As before, however, the effect of bonding social capital it is limited by higher levels of bridging social capital.

5.3 Endogeneity of Social Capital

One might well be concerned that bridging and bonding social capital, along with forest management, are outcomes of underlying individual and community characteristics and are therefore co-determined. To address this concern about endogeneity, we instrument for bridging and bonding social capital.

Finding variables that influence trust but do not affect forest management except through trust is difficult. We target potential instruments that may facilitate village communication or assistance, or ones that capture household exposure to other, non-forestry forms of collective action. While all of our instruments pass the exclusion restriction, none is unassailable. Therefore, we present results using five different sets of instruments for bonding social capital – two at the individual level, two using both individual and village-level instruments, and one set strictly at the administrative village level. For these last two sets of instruments, we use township-level fixed effects in both the first and second stages. We believe our instruments for bridging social capital are less controversial, and so we stick to a single set of instruments.

We instrument for bonding social capital first by noting that if a household experiences a shock that engenders assistance from fellow villagers, the household may increase its trust. Thus, we use whether a household had a member who was ill in the previous year. Second, we heard during field work that women often have stronger village connections than the working men in the household who are often away on the farm, so we use the number of women in the household to instrument for bonding. Last, we use the amount of money spent on gifts as an instrument. For this latter variable to be a valid instrument, gifts must be driven in part by exogenous shocks, such as gifts induced by weddings or festivals.

Conceptually, gifts may themselves be driven by goodwill induced by successful resource management, so our second two sets of instruments for bonding social capital rely on village-level information. We first include the standard deviation of housing assets across the village to capture a measure of observable income inequality. We chose housing assets, which are visible to fellow villagers. The assumption here is that larger differences in conspicuous wealth may erode trust within a village. Second, we use whether the village has a fishpond. A village with a fish pond will have more incentive to develop rules regulating its use, which in turn might build management capacity and trust. In the first model with village-level instruments, we include the number of members struck with illness that year, to capture some household-level variation. Third, we use the number of households in the village engaged in the exchange of agricultural labor. In the one model with only village-level instruments, we aggregate our individual instruments to the village level in hopes of reducing potential endogeneity; thus we include the total village expenditure on gifts and the total number of women in the village.

The percent of days members of a household spend working outside the township is likely a function of accessibility and whether the household has surplus labor. Thus, our instruments for bridging social capital include the number of household members who are registered under the Chinese national registration (hukou system) as non-agricultural, making migration easier.[13] Second, we include the number of children at home under the age of 6, assuming that young children increase the need for labor at home. Third,

[13] The hukou system prevents households registered as agricultural from benefiting from public services such as education or social security in urban centers.

we include household size to capture the amount of labor available. In all instrumented regressions, we control for the number of individuals in the household in the second stage. Because the percent of days spent outside the township is censored at zero, we estimate the first stage using a tobit and use both the predicted levels and predicted probability of observing a non-zero outcome as instruments. We then include these predictions as instruments in a three-staged least squares regression. Results from the first stages are given in Tables 8 and 9.

Table 8: First stage of IV regressions for bonding social capital

	(1)	(2)	(3)	(4)	(5)
Whether HH has a member who was ill in the previous year	1.045	0.112	0.0247		0.595
	(1.273)	(1.270)	(1.300)		(1.330)
Number of women	0.222				
	(0.302)				
Amount of money spent on gifts (1,000 yuan)	0.599***	0.465**			
	(0.188)	(0.185)			
Standard deviation of housing assets in the village			-1.527*	-2.256**	-2.155**
			(0.880)	(0.954)	(0.906)
Fishpond dummy			0.069*	0.049	0.051
			(0.038)	(0.039)	(0.039)
Number of households engaged in the exchange of agricultural labour				0.533**	0.542**
				(0.234)	(0.234)
Total number of women in the village				-0.029	
				(0.094)	
Total village expenditure on gifts (10,000 yuan)				0.837	0.826
				(0.445)	(0.444)
Controls	yes	yes	yes	yes	yes
Fixed Effects	village	village	township	township	township
Observations	526	526	526	526	526
R-squared	0.150	0.148	0.058	0.073	0.073

Notes: standard errors in parenthesis are robust and adjusted for clustering within groups of the same last name within a village. *, **, and *** indicate significance at the 10, 5, and 1% levels respectively.

Table 9: First Stage of IV regressions for bridging social capital

	(1)	(2)
Number of household members who are registered as non-agricultural	6.420***	3.585
	(1.943)	(2.397)
Number of children under 6 years old	-8.082***	-1.567
	(2.615)	(2.750)
HH size	5.694***	16.32***
	(1.112)	(1.802)
Controls	yes	yes
Fixed Effects	village	township
Observations	599	599

Notes: standard errors in parenthesis are robust and adjusted for clustering within groups of the same last name within a village. *, **, and *** indicate significance at the 10, 5, and 1% levels respectively.

As can be seen in Table 8, the level of trust is positively affected by the number of sick people in the household and the number of women in the household. Higher trust is also related to expenditure on gifts. A higher standard deviation on house values is correlated with lower trust, and having a fishpond in the village was correlated with higher trust. We also observe that trust increases with the number of households engaged in agricultural labor exchanges, an alternative form of cooperation. In Table 9, it can be seen that both the household hukou and the number of children under the age of six affect the percent of days worked outside the village. Given that the error terms for the various first stage regressions are likely correlated to eachother, we use three-stage least squares for our regression. Table 10 presents our results for firewood consumption with instrumented social capital.[14]

[14] Because the regression formulation here is slightly different from those presented in Table 4, we also run these equations as a seemingly unrelated regression for comparison. We get results qualitatively similar to those in Table 10.

Table 10: Instrumenting for social capital, 3SLS regressions

	(1)	(2)	(3)	(4)	(5)
Bonding SC	-0.540***	-0.636***	-0.580**	-0.234	-0.269
	(0.194)	(0.204)	(0.268)	(0.169)	(0.168)
Bridging SC	-0.079*	-0.101**	-0.090**	-0.060*	-0.071**
	(0.042)	(0.048)	(0.044)	(0.031)	(0.031)
Bonding SC × Bridging SC	0.009	0.012*	0.015**	0.010**	0.012***
	(0.006)	(0.006)	(0.006)	(0.004)	(0.004)
Number of household members working at	0.100	0.121	0.135	0.037	0.049
home	(0.116)	(0.118)	(0.137)	(0.120)	(0.121)
HH resource capacity	-0.164	-0.157	-0.136	-0.163	-0.155
	(0.105)	(0.106)	(0.108)	(0.100)	(0.100)
Dummy =1 if family owns pigs	0.583	0.596	0.690*	0.787**	0.802**
	(0.383)	(0.390)	(0.387)	(0.361)	(0.366)
Average slope of HH forest plots	-0.409*	-0.430*	-0.489**	-0.351*	-0.353*
	(0.216)	(0.220)	(0.229)	(0.206)	(0.208)
Average distance of HH forest plots to road	-0.016	-0.029	0.041	0.043	0.036
	(0.083)	(0.086)	(0.066)	(0.061)	(0.062)
Exogeneity: Bonding SC	4.77**	4.21**	0.37	1.64	1.45
Exogeneity: Bridging SC	0.0001	0.0002	0.80	0.80	0.80
IV relevance: Bonding SC	11.01**	10.69***	7.38*	15.41***	15.48***
IV relevance: Bridging SC	120.24***	120.24***	20.55***	20.55***	20.55***
Over-identification test: Bonding SC	0.33	0.08	2.28	4.66	4.50
Over-identification test: Bridging SC	1.88	1.89	0.34	0.35	0.36
Fixed Effects	village	village	township	township	township
Observations	526	526	526	526	526

Notes: standard errors in parenthesis are robust and adjusted for clustering within groups of the same last name within a natural village. *, **, and *** indicate significance at the 10, 5, and 1% levels respectively.

As can be seen in Table 10, these results are qualitatively very similar to those above in Table 4, with the instrumented bonding and bridging social capital reducing firewood collection on public lands, but with each type of social capital offsetting the effect of the other. Yet the instrumented social capital terms have larger coefficients than in the earlier OLS results. The large coefficient on each type of social capital in Table 10 is offset by an equally larger coefficient on the interaction term, with the marginal effects at the median relatively similar in magnitude to those reported in Table 5. All coefficients on the other variables have similar magnitudes but larger standard errors, as one might expect. In all cases, the instruments appear both to be strong and to satisfy the exclusion criterion. Further, we see some evidence that bonding social capital is endogenous when we use individual-level instruments and natural village fixed effects. When we use village-level instruments, and in all cases for bridging social capital, we find no statistical evidence that social capital is endogenous.

5.4 Village Social Capital Stock

One last concern that readers may have with our approach is that instead of directly measuring the village-level stock of social capital, we use the household-specific expected returns from social capital to identify the effect of social capital on resource consumption. One might first be concerned that the expected returns are not necessarily a good measure of the stock of social capital, in that they will be a function of (1) the actual stock, (2) individual-specific abilities to capture benefits from that stock and (3) individual perceptions of possible returns. Thus, whether the household head is inherently optimistic or a misanthrope will affect the measure of individual returns from social capital. Second, much of the literature on social capital focuses on social capital as essentially a form of community public good, common to all community members. Thus, if the individual measures are truly capturing the effect of village level social capital, then we might see village-level bonding and bridging also affecting CPR management.

As noted above, the reason we use the individual-level measures of returns from social capital is first that this measure is consistent with our model, where we allow individuals to benefit heterogeneously from the village-level social capital stock. We are also concerned with unobservables at the village level that might bias our results. That said, we are interested in observing how household consumption is affected by village levels of bridging and bonding social capital. We first use the sum of the expected returns from bonding and bridging social capital to proxy for total social capital stock.[15]

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[15] While bonding social capital is often thought of as a village-level stock, each household may have different levels of bridging social capital stock. That said, one might expect that the village average of bridging social capital might affect household firewood consumption. In particular, one household's level

Because of our limited number of natural villages (60), we do not interact bridging and bonding in this aggregate case. These results are presented in columns 1 and 2 of Table 11. As can be seen, the village-level sum of bonding social capital has no discernible effect on consumption. We may not observe a clear result because of the identification problems listed above. However, we see a consistent positive effect of aggregate levels of bridging social capital on household CPR consumption. We see this effect despite strong evidence that individual level bridging decreases household CPR consumption. Thus, having more households with access to outside income sources appears to erode a community's ability to sustain CPR management, while allowing each household with those contacts to reduce their own consumption.

It is not clear how to appropriately aggregate the individual expected returns to generate a measure of the village-level stock of social capital. Merely summing individual expected returns may not be appropriate, because having all individuals with similar levels of expected returns to bonding social capital may reflect a higher stock of social capital than having half of the individuals with zero social capital and others with twice the average. Thus, as an alternate aggregation, we measure the stock of bonding social capital as the number of households in the natural village who have positive bonding social capital, measured as the number of households who expected more than zero dollars returned in the trust game. Similarly, we measure aggregate bridging as the number of households who have a member who spends at least part of the year working outside the township (columns 3 and 4 in Table 11). Using these measures, we continue to see aggregate bridging social capital increase CPR consumption, while this measure of aggregate bonding social capital decreases consumption of the CPR.

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of bridging social capital might affect the sustainable cooperative level of CPR consumption of all other households in the same village. Thus, we also test the effect of the aggregate level of bridging social capital on household CPR use.

Table 11: Effect of village-level social capital

Variable	(1)	(2)	(3)	(4)
Village sum of Bonding SC	0.008	0.006		
	(0.012)	(0.012)		
Village sum of Bridging SC	0.006**	0.006**		
	(0.002)	(0.002)		
Number of HH with Bonding SC > 0			-0.281***	-0.264**
			(0.101)	(0.101)
Number of HH with Bridging SC > 0			0.290**	0.275**
			(0.117)	(0.114)
HH resource capacity		-0.196***		-0.198***
		(0.055)		(0.055)
Dummy if family owns pigs		0.387		0.429
		(0.366)		(0.362)
Average slope of HH forest plots		-0.184		-0.171
		(0.184)		(0.186)
Average distance of HH forest plots to road		0.083		0.052
		(0.066)		(0.068)
Admin Village Fixed Effects	yes	yes	yes	yes
Observations	580	579	580	579
R-squared	0.343	0.352	0.341	0.349

Notes: standard errors in parenthesis are robust and adjusted for clustering within groups of the same last name within a natural village. *, **, and *** indicate significance at the 10, 5, and 1% levels respectively.

One can think of this bonding measure as essentially capturing the effect of having a limited number of misanthropes in the village. If households do not expect to gain anything from the stock of social capital, they may be more inclined to extract the CPR at non-cooperative levels because they are not subject to social sanction. If a large number of villagers want to extract the CPR at non-cooperative levels, enforcing a cooperative level of total extraction will be difficult, if not impossible. Management may devolve into the archetypical tragedy of the commons.

6 Discussion and Conclusions

We find that bonding and bridging social capital appear to act as substitutes, where either type of social capital reduces consumption of firewood in the absence of the other, but where high levels of both do not generate CPR conservation. We first develop a model where social capital facilitates risk-pooling, and we demonstrate how bridging social capital might erode the effect of vulnerability to social sanction induced by higher bonding social capital.

We next empirically test this relationship between bonding and bridging social capital by comparing household collection of firewood on public lands to our measures of individual bridging and bonding social capital. As in our theoretical model, we find that bonding social capital reduces consumption, while bridging social capital erodes the effect of bonding. As in a special case of our model, we observe that individual expected returns from bridging social capital reduce CPR consumption. We explore this relation by interacting both types of social capital with the productive assets of the household, intended to measure whether the household is near subsistence levels of consumption. We also interact social capital with resource quality. We find that at high levels of assets and low levels of CPR resource quality, a marginal increase in bridging social capital has no effect on CPR consumption. Since we do not find that households are particularly sensitive to resource capacity, it is particularly concerning that connections with outsiders further induces consumption of low-yielding resources. We believe this may reflect a tragedy of the commons argument, where households hurry to consume a weakened resource fearing that otherwise their neighbors will rush to consume it first.

Our findings are consistent with the results of Dayton-Johnson (2000), who finds that a higher wage, and therefore higher opportunity cost, decreases a community's ability to cooperate in maintaining an irrigation system. We posit another explanation in this context, where high wages imply a greater ability to make money from outside the village, thus reducing the vulnerability to social sanction. Cases collected in Berkes and Folke (1998) show that strong kinship-based relationships are essential for promoting and enforcing collective action. They also find that relatively isolated systems, thus those with low bridging social capital, perform better.

Last, because we might be concerned that both types of social capital are jointly determined alongside community resource management, we instrument for bridging and bonding using various household and village characteristics intended to capture communication and aid within the village, inequality, or experience with other forms of collective action. We find no evidence that these factors directly affect firewood collection. We also find no evidence that bridging social capital is endogenous, while we see some evidence that bonding might be.

When we use these instruments, we find similar qualitative results as before, in that each type of social capital reduces collection of firewood on public lands in the absence of the other social capital, but that the two types of social capital together appear to act as substitutes, each decreasing the effect of the other when social capital is high.

In conclusion, we find that when considering a village's ability to manage a common pool resource successfully, one may need to consider levels of both bonding and bridging social capital. In the choice of community management versus government regulation to manage a CPR, it is important to understand the effects of the different types of social capital on the ability of a community to avoid the tragedy of the commons.

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Appendices

Appendix 1

We first show that $EU_{1i} > EU_{2i}$. Substituting the expressions for EU_{1i} and EU_{2i} into $EU_{1i} - EU_{2i}$ yields:

$$
\begin{aligned}
& EU_{1i} - EU_{2i} \\
&= \gamma\sigma_\mu^2\left(1 - M_i r_{iB}\right)\left(\left(N-1\right) + \sum_{n\neq i}^{N} M_n r_{nB}\right) r_A \\
&\quad - \frac{1}{2}\gamma\sigma_\mu^2\left(\left(N-1\right) + \sum_{n\neq i}^{N} M_n \left(r_{nB}\right)^2 + \left(\left(N-1\right) + \sum_{n\neq i}^{N} M_n r_{nB}\right)^2\right)\left(r_A\right)^2 \\
&> \gamma\sigma_\mu^2\left(1 - M_i r_{iB}\right)\left(\left(N-1\right) + \sum_{n\neq i}^{N} M_n r_{nB}\right) r_A - \gamma\sigma_\mu^2\left(\left(N-1\right) + \sum_{n\neq i}^{N} M_n r_{nB}\right)^2 \left(r_A\right)^2 \\
&= \gamma\sigma_\mu^2\left(\left(N-1\right) + \sum_{n\neq i}^{N} M_n r_{nB}\right)\left(1 - \left(N-1\right) r_A - M_i r_{iB} - \sum_{n\neq i}^{N} M_n r_A r_{nB}\right) r_A \\
&= \gamma\theta_i\left(\left(N-1\right) + \sum_{n\neq i}^{N} M_n r_{nB}\right)\sigma_\mu^2 \\
&> 0.
\end{aligned}
$$

Therefore we have $\varphi_i = \eta\left(EU_{1i} - EU_{2i}\right) > 0$.

The first derivative of φ_i in (1) with respect to A_i is:

$$\begin{aligned}
\frac{\partial\varphi_i}{\partial A_i} &= \gamma\eta\sigma_\mu^2\left(1-M_i r_{iB}\right)\left(\left(N-1\right)+\sum_{n\neq i}^{N} M_n r_{nB}\right)\frac{\partial r_A}{\partial A_i} \\
&\quad -\gamma\eta\sigma_\mu^2\left(\left(N-1\right)+\sum_{n\neq i}^{N} M_n\left(r_{nB}\right)^2+\left(\left(N-1\right)+\sum_{n\neq i}^{N} M_n r_{nB}\right)^2\right) r_A\frac{\partial r_A}{\partial A_i} \\
&> \gamma\eta\sigma_\mu^2\left(1-M_i r_{iB}\right)\left(\left(N-1\right)+\sum_{n\neq i}^{N} M_n r_{nB}\right)\frac{\partial r_A}{\partial A_i} \\
&\quad -\gamma\eta\sigma_\mu^2\left(\left(N-1\right)+\sum_{n\neq i}^{N} M_n r_{nB}\right)\left(1+\left(N-1\right)+\sum_{n\neq i}^{N} M_n r_{nB}\right) r_A\frac{\partial r_A}{\partial A_i} \\
&= \gamma\eta\sigma_\mu^2\left(\left(N-1\right)+\sum_{n\neq i}^{N} M_n r_{nB}\right)\left(1-M_i r_{iB}-N r_A-\sum_{n\neq i}^{N} M_n r_A r_{nB}\right)\frac{\partial r_A}{\partial A_i} \\
&= \gamma\eta\sigma_\mu^2\left(\left(N-1\right)+\sum_{n\neq i}^{N} M_n r_{nB}\right)\left(\theta_i-r_A\right)\frac{\partial r_A}{\partial A_i}.
\end{aligned}$$

(A1)

Since $\frac{\partial r_A}{\partial A_i}>0$ and $\theta_i \geq r_A$, we then have $\frac{\partial\varphi_i}{\partial A_i}>0$.

The first derivative of φ_i with respect to B_i is:

$$\frac{\partial\varphi_i}{\partial B_i} = -\gamma\eta\sigma_\mu^2 M_i\left\{\left(N-1\right)+\sum_{n\neq i}^{N} M_n r_{nB}\right\} r_A\frac{\partial r_{iB}}{\partial B_i}.$$

(A2)

Since $\frac{\partial r_{iB}}{\partial B_i}>0$, we then have $\frac{\partial\varphi_i}{\partial B_i}<0$.

Taking the first derivative of $\frac{\partial\varphi_i}{\partial A_i}$ with respect to B_i yields:

$$\frac{\partial^2\varphi_i}{\partial A_i\partial B_i} = -\gamma\eta\sigma_\mu^2 M_i\left\{\left(N-1\right)+\sum_{n\neq i}^{N} M_n r_{nB}\right\}\frac{\partial r_A}{\partial A_i}\frac{\partial r_{iB}}{\partial B_i}.$$

(A3)

Since $\frac{\partial r_A}{\partial A_i}>0$ and $\frac{\partial r_{iB}}{\partial B_i}>0$, we thus have $\frac{\partial^2\varphi_i}{\partial A_i\partial B_i}<0$.

Appendix 2: Derivation of the cooperative level of consumption and its existence conditions

The community's problem is to maximize joint utility less the required enforcement costs:[16]

$$\max_{\{c_1,c_2,\cdots,c_N\}} \sum_{i=1}^{N}\left(u\left(c_i,c_{-i}\right)-s\right)$$

s.t.

$$c_i=\begin{cases}\hat{c}_i & if\ S_i\geq\hat{S}_i\\ c_i\left(c_{-i}\right) & else\end{cases}\qquad for\ any\ i=1,2,\cdots,N.$$

If the subsistence constraint in (11) is not binding, then solving the community's problem yields the enforceable consumption of the CPR for player $i\left(\forall i=1,2,\cdots,N\right)$:

$$\hat{c}_i=\begin{cases}\dfrac{2\alpha\left(\sum_{n=1}^{N}\varphi_n-\left(N-1\right)\varphi_i\right)+\left(N+1\right)}{4\alpha\sum_{n=1}^{N}\varphi_n+\left(N+1\right)^2}\dfrac{a-d}{b} & if\ \max_{\{j=1,2,\cdots,N\}}\left(\varphi_j\right)\leq f\left(\bar{\varphi}\right),\\ \tilde{c}_i=\dfrac{1}{N+1}\dfrac{a-d}{b} & else,\end{cases}\tag{A4}$$

where $\bar{\varphi}$ denotes the average vulnerability of the users' group and $f\left(\bar{\varphi}\right)=\dfrac{N\left(N+3\right)}{\left(N+1\right)^2}\bar{\varphi}+\dfrac{\left(N-1\right)^2\bar{\varphi}}{2\left(N+1\right)\left(2N\alpha\bar{\varphi}+\left(N+1\right)\right)}$. This condition implies that the cooperative consumption under costly monitoring exists if and only if each user's vulnerability to social sanction is close to the average vulnerability. The intuition is that for each user *i*, a larger vulnerability to social sanction means lower cooperative consumption of the CPR and thus lower utility. If user *i*'s vulnerability is bigger than a specific critical value, she will deviate from the cooperative consumption, and all the users will end up with non-cooperative consumption.

Moreover, if $\max_{\{j=1,2,\cdots,N\}}\left(\varphi_j\right)\leq f\left(\bar{\varphi}\right)$, user *i*'s enforceable consumption is decreasing with her vulnerability at a decreasing rate. That is,

[16] The utility from consuming the numeraire goods is not included in the objective function since it is not related with the consumption of the CPR.

$$\frac{\partial \hat{c}_i}{\partial \varphi_i} < 0 \quad \text{and} \quad \frac{\partial^2 \hat{c}_i}{\partial (\varphi_i)^2} > 0 \quad .$$

(A5)

To derive equations A4 and A5, note that since $\sum_{i=1}^{N}(s) = \sum_{i=1}^{N}(S_i)$, the community's objective function can be re-written as:

$$\max_{\{c_1, c_2, \cdots, c_N\}} \sum_{i=1}^{N}\left(u\left(c_i, c_{-i}\right) - S_i\right)$$

Substituting the minimum level of monitoring effort needed to sustain the cooperative equilibrium, $\hat{S}_i$ in (12), into the community's problem, the group's cooperative level of consumption is thus given by:

$$\hat{c}_i = \underset{\{\hat{c}_1, \hat{c}_2, \cdots, \hat{c}_N\}}{\arg\max} \sum_{i=1}^{N}\left(\left(1 + \frac{1}{\alpha\varphi_i}\right)u\left(\hat{c}_i, \hat{c}_{-i}\right) - \frac{1}{\alpha\varphi_i}u\left(c_i\left(\hat{c}_{-i}\right), \hat{c}_{-i}\right)\right)$$

. (A6)

For the cooperative equilibrium to be enforceable, we also need the condition that the utility for each player from cooperative consumption and monitoring must be greater than the utility from no monitoring together with deviation[17], i.e.:

$$\hat{U}_i \equiv u\left(\hat{c}_i, \hat{c}_{-i}\right) - \hat{s} \geq \tilde{U}_i \equiv u\left(\tilde{c}_i, \tilde{c}_{-i}\right) \quad for\ \forall i = 1, 2, \cdots, N \quad ,$$

(A7)

where $\hat{s} = \frac{1}{N}\sum_{i=1}^{N}\hat{S}_i$ is each user's minimum devotion to monitoring to sustain the cooperative equilibrium.

Therefore the enforceable consumption for user *i* is given by (A6) if the condition in (A7) is satisfied, otherwise the enforceable consumption is equal to the non-cooperative equilibrium consumption given in (5).

Substituting $u\left(c_i\left(\hat{c}_{-i}\right), \hat{c}_{-i}\right)$ from equation (8) and $u_i\left(\hat{c}_i, \hat{c}_{-i}\right)$ from equation (9) into the group objective function, we then have:

[17] Assume in the non-cooperative equilibrium, no social sanction is imposed and the mutual insurance still exists.

$$\max_{\{\hat{c}_1,\hat{c}_2,\cdots,\hat{c}_N\}} \sum_{i=1}^{N}\left(\left(1+\frac{1}{\alpha\varphi_i}\right)u\left(\hat{c}_i,\hat{c}_{-i}\right)-\frac{1}{\alpha\varphi_i}u\left(c_i\left(\hat{c}_{-i}\right),\hat{c}_{-i}\right)\right)$$

$$=\max_{\{\hat{c}_1,\hat{c}_2,\cdots,\hat{c}_N\}} b\sum_{i=1}^{N}\left(\left(1+\frac{1}{\alpha\varphi_i}\right)\hat{c}_i\left(\frac{a-d}{b}-\sum_{n=1}^{N}\hat{c}_n\right)-\frac{1}{4\alpha\varphi_i}\left(\frac{a-d}{b}-\sum_{n\neq i}^{N}\hat{c}_n\right)^2\right).$$

The first order condition for user $i=1,2,\cdots,N$ is given by:

$$\left(1+\frac{1}{2\alpha\varphi_i}+\frac{1}{2\alpha}\sum_{n=1}^{N}\frac{1}{\varphi_n}\right)\left(\frac{a-d}{b}-\sum_{n=1}^{N}\hat{c}_n\right)-\frac{1}{2\alpha}\sum_{n=1}^{N}\frac{\hat{c}_n}{\varphi_n}-\sum_{n=1}^{N}\hat{c}_n-\frac{1}{2\alpha}\frac{\hat{c}_i}{\varphi_i}=0 \quad .$$

(A8)

Summing all the users' first order condition yields:

$$\frac{1}{2\alpha}\sum_{n=1}^{N}\frac{\hat{c}_n}{\varphi_n}=-\left(\frac{2N}{N+1}+\frac{1}{2\alpha}\sum_{n=1}^{N}\frac{1}{\varphi_n}\right)\sum_{n=1}^{N}\hat{c}_n+\left(\frac{N}{N+1}+\frac{1}{2\alpha}\sum_{n=1}^{N}\frac{1}{\varphi_n}\right)\left(\frac{a-d}{b}\right) \quad .$$

(A9)

Substituting (A7) into (A6) to eliminate $\sum_{k=1}^{N}\frac{\hat{c}_k}{m_k}$ and rearranging yields:

$$\hat{c}_i=-\left(\frac{4\alpha}{(N+1)}\varphi_i+1\right)\sum_{n=1}^{N}\hat{c}_n+\left(\frac{2\alpha}{(N+1)}\varphi_i+1\right)\frac{a-d}{b} \quad .$$

(A10)

Summing over i on both sides and rearranging solves the total cooperative consumption:

$$\sum_{n=1}^{N}\hat{c}_n=\frac{2\alpha\sum_{n=1}^{N}\varphi_n+N(N+1)}{4\alpha\sum_{n=1}^{N}\varphi_n+(N+1)^2}\frac{a-d}{b} \quad .$$

(A11)

Substituting (A11) into (A10) solves user i's optimal consumption under cooperation:

$$\hat{c}_i = \frac{2\alpha\left(\sum_{n=1}^{N}\varphi_n - (N-1)\varphi_i\right) + (N+1)}{4\alpha\sum_{n=1}^{N}\varphi_n + (N+1)^2}\frac{a-d}{b}$$

(A12)

Now we need to show whether the condition in (A5) is satisfied. Since each villager's total contribution to monitoring is the same, therefore villager *i*'s contribution is denoted by:

$$\hat{s} = \frac{1}{N}\sum_{i=1}^{N}\hat{S}_i = \frac{1}{N}\sum_{j=1}^{N}\frac{u\left(c_j\left(\hat{c}_{-j}\right),\hat{c}_{-j}\right) - u\left(\hat{c}_j,\hat{c}_{-j}\right)}{\alpha\varphi_j}$$

(A13)

Substituting (A13) into (A7), we have user *i*'s utility of consuming the CPR under the cooperative strategy

$$\hat{U}_i = u\left(\hat{c}_i,\hat{c}_{-i}\right) - \frac{1}{N}\sum_{j=1}^{N}\frac{u\left(c_j\left(\hat{c}_{-j}\right),\hat{c}_{-j}\right) - u\left(\hat{c}_j,\hat{c}_{-j}\right)}{\alpha\varphi_j}.$$

Substituting $u\left(c_i\left(\hat{c}_{-i}\right),\hat{c}_{-i}\right)$ from (8) and $u_i\left(\hat{c}_i,\hat{c}_{-i}\right)$ from (9) into the utility function above yields:

$$\hat{U}_i = \hat{c}_i\left(a - d - b\sum_{n=1}^{N}\hat{c}_n\right) - \frac{1}{N}\sum_{j=1}^{N}\frac{1}{4b\alpha\varphi_j}\left(a - d - b\sum_{n\neq j}^{N}\hat{c}_n\right)^2.$$

Substituting $\sum_{n=1}^{N}\hat{c}_n$ from (A9) and $\hat{c}_i$ from (A10) into the utility function above and rearranging yields the user *i*'s utility of consuming the CPR under the cooperative strategy:

$$\hat{U}_i = \frac{N\left(2\alpha\sum_{n=1}^{N}\varphi_n + (N+1) - 2\alpha(N-1)\varphi_i\right)\left(2\alpha\sum_{n=1}^{N}\varphi_n + (N+1)\right) - \alpha(N-1)^2\sum_{n=1}^{N}\varphi_n}{N\left(4\alpha\sum_{n=1}^{N}\varphi_n + (N+1)^2\right)^2}\frac{(a-d)^2}{b}. \qquad \text{(A14)}$$

User *i*'s utility of consuming the CPR under a non-cooperative strategy is given by (3) and (5):

$$\tilde{U}_i = \frac{1}{(N+1)^2}\frac{(a-d)^2}{b}.$$

(A15)

To make the cooperative equilibrium enforceable, we must have $\hat{U}_i \geq \tilde{U}_i$ for each $i = 1, 2, \cdots, N$. That is, for all villagers, the utility from cooperation must be at least as large as the utility from non-cooperation. Using the expressions for utility in (A14) and (A15) we can solve for the vulnerability needed to sustain cooperation:

$$\varphi_i \leq \frac{N(N+3)}{(N+1)^2}\bar{\varphi} + \frac{(N-1)^2\bar{\varphi}}{2(N+1)\left(2N\alpha\bar{\varphi} + (N+1)\right)} \quad \textit{for } \forall\, i = 1, 2, \cdots, N ,$$

(A16)

where $\bar{\varphi} \equiv \frac{1}{N}\sum_{n=1}^{N}\varphi_n$. Equation (A14) can be re-written as:

$$\max_{\{j=1,2,\cdots,N\}}\left(\varphi_j\right) \leq f(\bar{\varphi}) ,$$

(A17)

in which $f(\bar{\varphi}) \equiv \frac{N(N+3)}{(N+1)^2}\bar{\varphi} + \frac{(N-1)^2\bar{\varphi}}{2(N+1)\left(2N\alpha\bar{\varphi} + (N+1)\right)}$.

If the condition (A17) is not satisfied, we then have $\hat{U}_i < \tilde{U}_i$, and the cooperative equilibrium is not sustainable. The consumption level is then the same as:

$$\tilde{c}_i = \frac{1}{N+1}\frac{a-d}{b}.$$

Now we explore the relationship between the optimal consumption under cooperation and the vulnerability to social sanction. Using the expression for $\hat{c}_i$ in (A13), we can derive the first derivative of $\hat{c}_i$ with respect to φ_i:

$$\frac{\partial \hat{c}_i}{\partial \varphi_i} = -\frac{2(N-1)\alpha\left(4\alpha\sum_{n\neq i}^{N}\varphi_n + N(N+1)\right)}{\left(4\alpha\sum_{n=1}^{N}\varphi_n + (N+1)^2\right)^2}\frac{a-d}{b} < 0.$$

(A18)

The second derivative of $\hat{c}_i$ with respect to m_i is:

$$\frac{\partial^2 \hat{c}_i}{\partial(\varphi_i)^2} = \frac{16(N-1)\alpha^2\left(4\alpha\sum_{n\neq i}^{N}\varphi_n + N(N+1)\right)}{\left(4\alpha\sum_{n=1}^{N}\varphi_n + (N+1)^2\right)^3}\frac{a-d}{b} > 0 .$$

(A19)

Summation of (A4) over *i* gives the group's total consumption under costly monitoring,

$$\hat{C} = \begin{cases} \sum_{n=1}^{N}\hat{c}_n = \dfrac{2\sum_{n=1}^{N}\varphi_n + N(N+1)}{4\sum_{n=1}^{N}\varphi_n + (N+1)^2}\dfrac{a-d}{b} & \text{if } \max_{\{j=1,2,\cdots,N\}}(\varphi_j) \leq f(\bar{\varphi}), \\ \sum_{n=1}^{N}\tilde{c}_n = \dfrac{N}{N+1}\dfrac{a-d}{b} & \text{else.} \end{cases}$$

Appendix 3: Proof of Proposition 1

We first derive the first best level of consumption with no monitoring cost ($\bar{c}_i$). Assume a social planner can costlessly enforce the optimal level of cooperative CPR consumption. In this case, the optimal consumption level is the amount that maximizes the sum of all households' utility:

$$(\bar{c}_1, \bar{c}_2, \cdots, \bar{c}_N) = \underset{\{c_1, c_2, \cdots, c_N\}}{\arg\max} \sum_{i=1}^{N} u(c_i, c_{-i}) .$$

Substituting the specific functional form of utility inform equation (2) and solving the maximization problem gives the cooperative levels of consumption for each villager and for the group:

$$\bar{c}_i = \frac{1}{2N}\frac{a-d}{b}, \qquad \bar{C} = \frac{1}{2}\frac{a-d}{b} .$$

Now we compare the sustainable cooperative consumption of CPRs ($\hat{C}$) with the first best level of consumption ($\bar{C}$) and the non-cooperative consumption ($\tilde{C}$). We consider the two cases for $\hat{C}$ respectively.

Case 1. If the condition $\max_{\{j=1,2,\cdots,N\}}\left(\varphi_j\right) \le f\left(\bar{\varphi}\right)$ in A(17) is satisfied,

$$\hat{C} = \frac{2\sum_{n=1}^{N}\varphi_n + N\left(N+1\right)}{4\sum_{n=1}^{N}\varphi_n + \left(N+1\right)^2}\frac{a-d}{b}.$$

Substituting the expression of $\hat{C}$ and $\bar{C}$ into $\hat{C}-\bar{C}$ and rearranging yields:

$$\hat{C}-\bar{C} = \frac{2\sum_{n=1}^{N}\varphi_n + N\left(N+1\right)}{4\sum_{n=1}^{N}\varphi_n + \left(N+1\right)^2}\frac{a-d}{b} - \frac{1}{2}\frac{a-d}{b} = \frac{\left(N+1\right)\left(N-1\right)}{2\left(4\sum_{n=1}^{N}\varphi_n + \left(N+1\right)^2\right)}\frac{a-d}{b} > 0.$$

Similarly, substituting the expression of $\hat{C}$ and $\tilde{C}$ in $\hat{C}-\tilde{C}$ and rearranging yields:

$$\hat{C}-\tilde{C} = \frac{2\sum_{n=1}^{N}\varphi_n + N\left(N+1\right)}{4\sum_{n=1}^{N}\varphi_n + \left(N+1\right)^2}\frac{a-d}{b} - \frac{N}{N+1}\frac{a-d}{b} = \frac{-2\left(N-1\right)\sum_{n=1}^{N}\varphi_n}{\left(N+1\right)\left(4\sum_{n=1}^{N}\varphi_n + \left(N+1\right)^2\right)}\frac{a-d}{b} < 0.$$

In this case, we have $\bar{C} < \hat{C} < \tilde{C}$.

Case 2. If the condition $\max_{\{j=1,2,\cdots,N\}}\left(\varphi_j\right) \le f\left(\bar{\varphi}\right)$ in A(17) is not satisfied, we have

$$\hat{C} = \frac{N}{N+1}\frac{a-d}{b}.$$

Simply we have $\hat{C} = \tilde{C} > \bar{C}$.

Combining the results in case 1 and 2, we show $\bar{C} < \hat{C} \le \tilde{C}$.

Appendix 4: Proof of Proposition 2

Applying the chain rule, we have the derivative:

$$\frac{\partial \hat{c}_i}{\partial A_i} = \frac{\partial \hat{c}_i}{\partial \varphi_i}\frac{\partial \varphi_i}{\partial A_i}.$$

Combining $\frac{\partial \hat{c}_i}{\partial \varphi_i} < 0$ and $\frac{\partial \varphi_i}{\partial A_i} > 0$ from equation (2), we have $\frac{\partial \hat{c}_i}{\partial A_i} < 0$.

Similarly, $\frac{\partial \hat{c}_i}{\partial B_i} = \frac{\partial \hat{c}_i}{\partial \varphi_i}\frac{\partial \varphi_i}{\partial B_i}$. Combining with the results $\frac{\partial \hat{c}_i}{\partial \varphi_i} < 0$ and $\frac{\partial \varphi_i}{\partial B_i} < 0$ in equation (2), we obtain $\frac{\partial \hat{c}_i}{\partial B_i} > 0$.

Taking the partial derivative of $\frac{\partial \hat{c}_i}{\partial A_i}$ with respect to B_i yields:

$$\frac{\partial^2 \hat{c}_i}{\partial A_i \partial B_i} = \frac{\partial^2 \hat{c}_i}{\partial (\varphi_i)^2}\frac{\partial \varphi_i}{\partial B_i}\frac{\partial \varphi_i}{\partial A_i} + \frac{\partial \hat{c}_i}{\partial \varphi_i}\frac{\partial^2 \varphi_i}{\partial A_i \partial B_i}.$$

(A20)

Substituting the expressions for $\frac{\partial^2 \hat{c}_i}{\partial (\varphi_i)^2}$ from (A19), $\frac{\partial \varphi_i}{\partial B_i}$ from (A2), $\frac{\partial \varphi_i}{\partial A_i}$ from (A1), $\frac{\partial \hat{c}_i}{\partial \varphi_i}$ from (A18), and $\frac{\partial^2 \varphi_i}{\partial A_i \partial B_i}$ from (A3) into (A20) and rearranging yields:

$$
\begin{aligned}
\frac{\partial^2 \hat{c}_i}{\partial A_i \partial B_i} &= 4\alpha\rho_i \sum_{n=1}^{N}\varphi_n + \rho_i\left(N+1\right)^2 \\
&\quad - 8\alpha\rho_i\gamma\eta\sigma_\mu^2 r_A \left\{ \begin{array}{l} \left(1-M_i r_{iB}\right)\left(\left(N-1\right)+\sum_{n\neq i}^{N} M_n r_{nB}\right) \\ -\left(\left(N-1\right)+\sum_{n\neq i}^{N} M_n\left(r_{nB}\right)^2+\left(\left(N-1\right)+\sum_{n\neq i}^{N} M_n r_{nB}\right)^2\right) r_A \end{array} \right\} \\
&= 4\alpha\rho_i \sum_{n=1}^{N}\varphi_n + \rho_i\left(N+1\right)^2 \\
&\quad - 8\alpha\rho_i \left\{ \varphi_i - \frac{1}{2}\gamma\eta\sigma_\mu^2 r_A^2 \left(\left(N-1\right)+\sum_{n\neq i}^{N} M_n\left(r_{nB}\right)^2+\left(\left(N-1\right)+\sum_{n\neq i}^{N} M_n r_{nB}\right)^2\right)\right\} \\
&= 4\alpha\rho_i\left(\sum_{n=1}^{N}\varphi_n - 2\varphi_i\right) + \rho_i\left(N+1\right)^2 \\
&\quad + 4\alpha\rho_i\gamma\eta\sigma_\mu^2\left(r_A\right)^2\left(\left(N-1\right)+\sum_{n\neq i}^{N} M_n\left(r_{nB}\right)^2+\left(\left(N-1\right)+\sum_{n\neq i}^{N} M_n r_{nB}\right)^2\right)
\end{aligned}
$$

where

$$
\rho_i \equiv \frac{2\alpha\gamma\eta\sigma_\mu^2\left(N-1\right)M_i\left(\sum_{n\neq i}^{N} M_n r_{nB}+\left(N-1\right)\right)\left(4\sum_{n\neq i}^{N}\varphi_n + N\left(N+1\right)\right)\frac{a-d}{b}\frac{\partial r_A}{\partial A_i}\frac{\partial r_{iB}}{\partial B_i}}{\left(4\sum_{n=1}^{N}\varphi_n + \left(N+1\right)^2\right)^3} > 0 .
$$

Therefore we have $\frac{\partial^2 \hat{c}_i}{\partial A_i \partial B_i} > 0$.

Appendix 5: Proof of Proposition 3

Taking the partial derivative of $\widehat{c}_i$ in (14) with respect to A_i yields:

$$
\frac{\partial \widehat{c}_i}{\partial A_i} = \frac{1}{\beta}\left(\left(M-1\right)\sum_{n\neq i}^{N} r_{nB} + N\right)\vec{\mu}_i \frac{\partial r_A}{\partial A_i} .
$$

By assumption we have $\vec{\mu}_i < 0$ and $\frac{\partial r_A}{\partial A_i} > 0$, the above equation thus implies $\frac{\partial \widehat{c}_i}{\partial A_i} < 0$.

Taking the partial derivative of $\widehat{c}_i$ in (20) with respect to B_i yields:

$$\frac{\partial \widehat{c}_i}{\partial B_i} = \frac{1}{\beta}\left(M-1\right)\vec{\mu}_i \frac{\partial r_{iB}}{\partial B_i}.$$

By assumption we have $\vec{\mu}_i < 0$ and $\frac{\partial r_{iB}}{\partial B_i} > 0$, the above equation implies $\frac{\partial \widehat{c}_i}{\partial B_i} < 0$.

Taking the partial derivative of $\frac{\partial \widehat{c}_i}{\partial A_i}$ with respect to B_i yields $\frac{\partial^2 \widehat{c}_i}{\partial A_i \partial B_i} = 0$.

Appendix 6: Trust Game Regression and Robustness Tests

Table A1: Amount expected regressed on education and player number

Amount Expected	Coef.	Std. Err.	P>|t|
Education of HH head	0.316***	0.080	0.000
Recipient (=1 , while sender = 0)	-0.210	0.538	0.696
Constant	7.201***	0.577	0.000
Observations	597		
R-squared	0.0254		

Notes: Standard errors are robust and adjusted for clustering within groups of the same last name within a village.

Table A2: Alternative specifications

	(1)	(2)	(3)	(4)	(5)
Bonding SC	-0.108***	-0.099***	-0.104***	-0.095***	-0.109***
	(0.033)	(0.033)	(0.034)	(0.030)	(0.030)
Bridging SC	-0.030***	-0.022***	-0.026***	-0.029***	-0.030***
	(0.008)	(0.008)	(0.009)	(0.007)	(0.007)
Bonding SC × Bridging SC	0.002**	0.002**	0.002**	0.002**	0.002**
	(0.0007)	(0.0007)	(0.0007)	(0.0007)	(0.0007)
HH resource capacity	-0.183**	-0.168**	-0.176**	-0.169***	-0.185**
	(0.076)	(0.074)	(0.074)	(0.051)	(0.074)
Dummy =1 if family owns pigs	0.525	0.654*	0.594	0.579*	0.518
	(0.377)	(0.374)	(0.375)	(0.333)	(0.406)
Average slope of HH forest plots	-0.236	-0.249	-0.243	-0.302	-0.236
	(0.209)	(0.204)	(0.206)	(0.189)	(0.215)
Average distance of HH forest plots to	0.020	0.028	0.025	0.091**	0.023
road	(0.063)	(0.061)	(0.062)	(0.041)	(0.074)
Number of HH members working at	-0.032				
home	(0.091)				
Total HH expenditure less expenditure		-0.073***	-0.040		
on energy		(0.021)	(0.033)		
Number of households in the				0.004	
administrative village				(0.002)	
Square of number of households in the				-0.022	
administrative village (/10,000)				(0.018)	
Fixed Effects	village	village	village	district	village
IV for HH expenditure less expenditure			0.69		
on energy					
IV relevance			164.64***		
IV over-identification			1.77		
Observations	526	526	526	526	526
R-squared	0.193	0.209	0.205	0.127	0.193

Notes: Model (1) controls number of people at home; model (2) controls total expenditure; model (3) instruments total expenditure using total assets and ln (total assets); model (4) controls the number of households in the administrative village; model (5) clusters errors at natural village level. Standard errors in model (1) - (4) are robust and adjusted for clustering within groups of the same last name within a natural village. *, **, and *** indicate significance at the 10, 5, and 1% levels respectively.

As seen in column 3 of Table A2 household assets and log of household assets both pass the strength of instruments and the exclusion criteria. Further, we see little evidence that total household expenditure is endogenous. In both cases, total expenditure is associated with a decrease in firewood collection on public lands, implying firewood may be an inferior good, but the effect of bridging and bonding SC remain unchanged.

In model (4), we include the number of households in the administrative village and its squared term (divided by 10,000), noting that coordination is likely more difficult over a larger group.[18] As expected, firewood collection by a household first increases and then decreases in the number of household members. That said, these results are only statistically significant at the 89 percent level. Last, we test to see if our standard errors are substantially affected by our choice of unit for clustering (where we have chosen to cluster by groups of the same last name within a village). In model (5), we cluster by natural village only, and find very similar effects as before. As other robustness tests, we include household cash income, total household size, productive assets, and household head demographics separately. We find no qualitative change in our results.

While in our main results, we consider the amount of firewood collected by the household relative to the village total, the first two columns of table A3, we present results using the total firewood collected on public lands as the dependent variable. In columns 3 to 5, we use the amount of firewood collected per mu of public lands as the dependent variable, controlling for consumption per *mu* by others in the natural village. In the last model (column 6, Table A3) we follow a procedure informed by a spatial lag model to instrument for the total of others' consumption using village characteristics. Again, the results remain qualitatively the same as those presented in Table 4.

[18] Regrettably, we do not have the number of households in each natural village.

Table A3: Alternative measures of firewood collected

	(1)	(2)	(3)	(4)	(5)	(6)
Bonding SC	-0.043	-0.091***	-0.076**	-0.097***	-0.079**	-0.087**
	(0.030)	(0.029)	(0.033)	(0.030)	(0.033)	(0.035)
Bridging SC	-0.018***	-0.025***	-0.014**	-0.026***	-0.018***	-0.033***
	(0.006)	(0.007)	(0.007)	(0.007)	(0.007)	(0.012)
Bonding SC × Bridging	0.001	0.002**	0.001*	0.002**	0.002**	0.002*
SC	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
HH resource capacity	-0.235***	-0.113	-0.421***	-0.182**	-0.410***	-0.367***
	(0.060)	(0.085)	(0.079)	(0.073)	(0.076)	(0.066)
Dummy =1 if family owns	0.029	0.566	-0.517	0.532	-0.388	0.123
pigs	(0.296)	(0.357)	(0.323)	(0.364)	(0.315)	(0.349)
Average slope of HH	-0.652***	-0.282	-0.915***	-0.232	-0.883***	-0.757**
forest plots	(0.200)	(0.185)	(0.219)	(0.183)	(0.212)	(0.309)
Average distance of HH	0.300***	0.053	0.193***	0.021	0.215***	0.303***
forest plots to road	(0.047)	(0.0613)	(0.059)	(0.061)	(0.056)	(0.053)
Average firewood					0.022***	0.108**
consumption by other						
villagers					(0.002)	(0.045)
Village Fixed Effects	no	yes	no	yes	no	no
Observations	596	596	576	576	576	576
R-squared	0.094	0.372	0.115	0.463	0.162	

Notes: The dependent variable in models (1) and (2) is logged amount of firewood collected on public lands. The dependent variable in models (3) through (6) is logged amount of firewood collected on public lands per area of public land. Other people's consumption of firewood is controlled in model (5) and (6), and other people's consumption is instrumented by in model (6) using village characteristics such as village resource capacity, total number of pigs, average slope, and distance to road from forest land. Standard errors in parenthesis are robust and adjusted for clustering within groups of the same last name within a village. *, **, and *** indicate significance at the 10, 5, and 1% levels, respectively.