Chapter 5. Inter-Village Cooperative Action and the Assessment of Multi-Functionality in Agriculture (第５章　農村間の協調行動と農業の多面的機能評価)

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和文要旨

オープン・アクセスの環境下で，多くの人が共有資源を乱獲し，その維持・管理を怠れば，資源の機能は低下しやがて枯渇する。これがハーディン（G. Hardin）によって指摘された「共有地の悲劇（tragedy of commons)」である。しかし，すべての共有地がそのような運命を辿っているわけではない。おもに途上国のフィールドからは，悲劇的な結末とともに多くの成功事例が報告されている。ハーディンの予測に反し，慣習的なルール，共同体の規範がオープン・アクセスを制限している。その結果，農村の共有資源は適正な状態に維持・管理されている。明らかにそこには，ハーディンが悲劇を回避する方法として提唱した私的所有権の確立,中央集権的な管理とはまったく別のメカニズムが作用している。

過去の実証研究によれば，経済的・社会的異質性（economic and social heterogeneity）がコミュニティー内に少なく，定住の歴史が長く，人口が稠密で資源制約がシビアで，市場経済の浸透度が弱く,人々の時間割引率が低く,資源を利用する集団の規模が小さいほど,共有資源は自治的な組織によってうまく管理されるという。また,このテーマについては,所有権の所在が俎上に上る一方で，途上国の貧困撲滅，家計内の所得分配・ジェンダー問題などの文脈で論じられることも多い。しかし,実証研究が曖昧なままに残している領域,あるいは直観的なロジックに依拠している部分も少なくない。たとえば，経済的な異質性とは具体的にどのような現象を指しており，なぜそれが協調行動に重大な影響を及ぼすのか。コモンズの管理に政府あるいは利用者以外の第三者が介入する余地が残されているのか。こうした問題については議論の余地があると思われる。

一方，コモンズを維持・管理するために，どのくらいのコストが必要で，それを誰が負担すべきか，というテーマはこの問題の核心部分を成す。受益者負担が原則であるとしても，そこには「ただ乗り」のインセンティブが常に働くから，実際に用いられているルールは，限界原理よりもむしろ単純なシェアリングである場合が多い。したがって，市場経済が農村に浸透し地元の農林水産業が衰退すれば，乱獲とは異なるメカニズムによって，共有資源は劣化・陳腐化する。仮に，農業およびそれを取り巻く農村の共有資源が，生産活動とは独立した価値（多面的機能）を有していれば，それを保全する別の方法を模索しなくてはならない。

ところで，各国・各地域の農村資源は location specific な特質を持ち，財の属性によって管理の方法も異なるから，一つの理論によってコモンズ問題のすべてを説明することはできない。同じ制度が効果的な場合もあれば，そうでない場合もあり，一つの比喩（モデル）

ですべてを語り尽くすことはできないのである。そこで本稿では，われわれの調査地である中国雲南省紅河蛤尼族彝（イ）族自治州元阳県の棚田を念頭に置きながら，モデル分析を試みた。分析の結論は以下のようにまとめられる。

(1) 当地の稲作は山頂の森林を水源とする単純な重力灌漑に依存している。上流農村が森林を管理する権利を有しているが，森林伐採に関する意志決定は，自村のみならず下流農村が利用する灌漑用水の供給量をも規定する。水利用に関しては，上流農村が下流農村に対して立地的な優位性を有しているといえる。反対に，標高差による気候および圃場条件の相違により，稲作の生産性は上流農村に比べて下流農村の方がはるかに高い。かかる状況下で，上流農村が利己的に行動すれば，この農村社会はいわゆる「囚人のジレンマ」に陥る。反面からいえば，米の総生産量を最大化し，森林を保全するためには，両村間での合意形成が不可欠である。

(2) 中国では退耕還林政策の下で，上流農村の森林伐採には厳しいペナルティーが科せられている。その結果，「囚人のジレンマ」は回避されるが，上・下流農村間の所得格差が拡大し，両村にとって better-off な状態は実現しない。上流農村の利他的な行動に対する下流農村の「裏切り」を処罰するような制度改革により，協調行動（上流農村における森林保全と上流農村への所得補償）が進化論的安定戦略（Evolutionary Stable Strategy）となり，もう一つのナッシュ均衡である「囚人のジレンマ」は排除される。その結果，最善の状態，すなわち米生産に関するパレート効率性の改善，森林保全，そして所得の平等分配が実現する。

(3) 市場経済の浸透あるいは閾値を超えた経済格差は，協調行動の経済的な誘因を奪い，下流農村から上流農村への所得移転（所得の平準化）は，それとは反対の結果をもたらす。このことは，信用ある制裁（credible punishment）を条件として，単純な受益者負担原則がコモンズの維持・管理にとって，有効な政策であることを示唆している。

最後に，本研究の政策的インプリケーションと残された課題を述べておこう。上流農村の森林伐採，それにともなう下流農村の水不足は外部不経済の典型であり，協調行動の失敗は上・下流農村間の協調行動が結果する所得格差を平準化することによって克服される。一方，上流農村における棚田の景観がプラスの外部効果（多面的機能）を持つならば，その内部化が不可欠なものとなる。具体的な方法としては直接支払いであり，これも所得平準化の一形態と見なし得る。ただし，経済的同質性の確保と協調行動の関係については，十分なコンセンサスが得られておらず，理論的にも未解決の部分が多い。

Keywords: Common pool resources; Cooperation; Prisoner's dilemma; Nash bargaining; Evolutionary stable strategy; Heterogeneity

1. Introduction

According to G. Hardin's (1968) pessimistic prediction, common pool resources (CPRs) are destined to malfunction and exhausted in the end if they are overused without proper maintenance activities in the circumstances where many people gain access to them openly. A preventive and curative measure proposed by Hardin for circumventing such tragic consequences is to establish either private ownership or centralized regulation. His epoch-making article spurred tens of thousands of interdisciplinary researches on this subject, but if not all at least some of them arrive at the conclusion that goes counter to his prediction (Feeny et al., 1990; Ostrom, 1990; Baland and Platteau, 2003).

As has been verified by numerous empirical studies, CPRs are more likely to be well harnessed when social homogeneity is secured among their users, communities have a longer history of sedentary agriculture in densely populated terrains, severer restriction is imposed on the resource utilization, development of market economy is far lagging behind, people have a longer time horizon, and user groups are smaller in scale (Hayami and Kikuchi, 1981; Olson, 1965; Ostrom, 1990 and 2000; Wilson and Thompson, 1993; Bardhan, 2000; Banerjee et al., 2001; Fujiie et al., 2005). These findings translate into the conjecture that the protective mechanism that is actually at work is neither market function nor state control, but community-base collective activities under which users organize themselves autonomously, and devise and modify indigenous rules in such a manner that CPRs are kept in better conditions (Ostrom, 1990, p. 20).(1)

It is true that a great deal of effort has been devoted to identifying significant factors that initiate cooperative action, but there are still further points that need to be clarified. For one thing, the hypotheses that are established and tested in the past empirical studies are imprecise, as has been claimed by Baland and Platteau (1996, p. 1). More specifically, it is still an open question as to under what conditions economic homogeneity/heterogeneity facilitates or impedes mutual cooperation, and in what manner penetration of market economy or an increasing exit option biased toward one party undermines the effective management of CPRs. It is no doubt this has much relevance to the question as to how much resource should be mobilized for CPR preservation, and who are supposed to bear the cost for that purpose. Hereupon, we have to bear in mind that much research has not gone as far as identifying the exact impact of economic inequality on the CPR management in spite of that heated debates have often taken place on this subject (Baland and Platteau, 1999; Dayton-Johnson and Bardhan, 2002).(2)

Second, the major concerns of some empirical works are confined to the extraction of ingredients that facilitate or impede cooperative action at the inter-household or intra-village level. Indeed, this leaves no room for criticism when CPRs have a small service area, but more wide-range collective action comes into question if they serve several people across villages

(Knox et al., 2002). According to the analysis below, two village economies that share service flows from a single CPR are more liable to be thrown into the game structure described as Prisoner's Dilemma when the inter-village productivity difference of agriculture becomes larger. Nevertheless, in the absence of regulated common property regimes, collaborative efforts for preventing such misery from occurring are less likely to be made in inter-village than in intra-village situations because the intensity of cooperation is believed to be negatively correlated with the user group sizes. (A variety of factors must be involved there including high information costs, lack of an adequate monitoring, hardship of rule enforcement, heterogeneity of social components.)

One final point that deserves to be mentioned is that most studies usually take up a single CPR for discussion as if its utilization were separable from that of other local commons. But in fact, there are a host of cases where identical user group exploits multiple CPRs in an interactive manner, and sometimes, their preservation may have an intricate trade-off relation with economic activities in the region. (See Mukhopadhyay, 2004 as to the similar argument.) To take a simple example, the extent of forest protection, water supply and paddy rice production are closely inter-linked in the sense that an expansion of arable land in pursuit of an increase in farm output is accompanied by deforestation, which gives rise to decreased discharge in dry season.

A modest attempt of this paper is to surmount the aforementioned limitations by using a model, and to give some theoretical foundation to hypotheses that are previously presented. It goes without saying, however, that building a model that intends to capture the whole picture in a comprehensive manner is almost impossible because village societies are diverse and CPRs have local specific attributes and characteristics. Thus, we work toward our objectives with focusing on paddy rice production and CPR management in Yuanyang County of Yunnan Province, China. The county is located near the national border with Vietnam and 200 kilometer away to the south from the provincial capital city of Kunming. Ethnic people such as Dai, Yi and Hani and others eke out a living of self-sufficiency with residing in the mountainous areas of this hinterland at altitudes of 200-2,000 meter. The irrigation systems in this region are dominated by a simple gravity flow technique and less elegant diversion and canal structures.

The remainder of this paper is organized as follows: Section 2 builds a model that describes paddy rice production subject to the limited water availability. Section 3 considers the determinant of rice production based on two distinct behavioral hypotheses, and by doing so, calls into question the feasibility of cooperative action for efficient water use and forest protection. We extend the basic model in Section 4 to examine how much resource should be mobilized for the conservation of local forest with paying attention to its imperfect reversibility. The first half of Section 5 discusses the impact of an exit option on collective action, while the last half explores the cost-sharing rule that enables CPR users to be mutually cooperative. Then, concluding remarks are given in Section 6.

2. Description of rice production technology

2.1. Statistical description of village economy

The rural areas of Yuanyang County can be categorized into two groups based on the topographical aspect: upstream villages (Village 1) and downstream villages (Village 2). Table 1 summarizes the statistical description of this economy. Eight villages are excluded from the following analysis due to the lack of data, with the result that the number of observations is equal to 124. Among them, 25 belong to downstream villages, while the rest of them belong to upstream villages. The table tells us that paddy rice production is the main industry in this region. It also shows that the share of farmers who are engaged in agricultural production is higher in upstream than in downstream villages although the difference is quite small. There is a significant difference in chemical fertilizer input intensity with far higher in Village 2 than in Village 1. The other indicators, including the number of draft animals on a per capita basis, both labor and land productivity, and per capita net income, are also higher in Village 1 than in Village 2. We cannot say from this table that to what extent urbanization has advanced in this region, but it is no doubt that Village 2 has much advantage in this respect.

Table 1. Summary of village economy

	Upstream (Village 1)	Downstream (Village 2)
Number of villages	99	25
Share of agricultural labor (%)	86	84
Share of rice production labor (%)	82	77
Chemical fertilizer per mu (kg)	19.4	65.4
Ratio of draft animal to agricultural workers (head/person)	0.27	0.39
Labor productivity of paddy rice (ton/person)	0.40	0.50
Land productivity of paddy rice (ton/mu)	0.42	0.58
Per capita net income (yuan)	677 (101)	847 (191)

Notes: (1) Every statistics is computed from the village survey 2004 (Yuanyang County Government). (2) The data of urban areas are not included in the original survey. (3) The mean values are based on the aggregate data of upstream and downstream, respectively. (4) The numbers in parentheses are standard deviations. (5) Mu is equal to 1/15 ha.

2.2. Model assumption

Our village survey conducted four times between 2004 and 2005 reveals the following facts:

(i) Village 2 has no water source of its own for paddy rice production and that the amount of irrigation water available to both Villages depends exclusively on torrential water flow whose sources are local forest in Village 1. This means that water availability is exclusively influenced by the degree to which Village 1 protects local forest in their territory.
(ii) Due to the difference of atmospheric temperature with lower in the higher altitudes, double-cropping of paddy rice is possible only in Village 2.
(iii) Village 2 is more likely to suffer from water shortage than Village 1.
(iv) Rural people have already halted slash-and-burn agriculture under the Land Afforestation Program,[(3)] but there remain some bald territories in Village 1 that are left unused for agriculture.

We can see from fact (i) that head-enders have a locational advantage over tail-enders in determining how much irrigation water is drawn and released among users. As has been referred to by some scholars who deal with irrigation water management (e.g., Bardhan, 1993; Ostrom and Gardner, 1993; Lam, 1996), this kind of locational asymmetry is not specific to paddy rice production in rural Yunnan, and may give rise to conflict scrambling for scarce resources. On the other hand, fact (ii) suggests that tail-enders have an agro-climatic advantage for rice production over head-enders.

Taking these facts into consideration, paddy rice production function is specified by the following Leontief type:

$$Q_i = b_i G(W_i,\ A_i,\ L_i) = b_i \phi(W_i)\min[A_i,\ L_i] \quad (i=1,\ 2), \tag{1}$$

where Q_i, W_i, A_i, and L_i denote the amount of rice produced annually, the amount of water used for paddy rice production, the area of paddy fields, and the number of labor engaged in rice production in Village i, respectively. The coefficient of b_i is included to capture the productivity difference between the two Villages that is entirely attributed to agro-climatic conditions, while $\phi(W_i)$ is included to capture the influence of irrigation water availability. The following assumptions are imposed on equation (1):
(a) $b_1 = 1 < b_2 = b$ is assumed from fact (ii).
(b) By referring to the unpublished data of the IRRI (Levine, 1980, Figure 3.2), $\phi(W_i)$ is specified as follows:

$$\phi(W_i) = \begin{cases} 1 & \text{if } W_i^d \le W_i^s \\ e\ (<1) & \text{otherwise} \end{cases}, \tag{2}$$

where W_i^d and W_i^s denote water demand and supply of Village i, respectively. When there exists an excess demand for water, $\phi(W_i)$ decreases by $100(1-e)\%$ in comparison with the situation of $W_i^d \le W_i^s$ because paddy rice is intolerant to drying and highly tolerant to excess water (Ostrom and Gardner, 1993).

(c) The territory of Village 1 is divided into paddy fields (A_1) and local forest R. The total area is equal to $\overline{R}$. Section 4 modifies this assumption because it contradicts fact (iv). All arable lands of Village 2 have been converted into paddy fields and their area is equal to $\overline{R}$.

(d) The endowment of workforce in both Villages is equal to $\overline{L}$ and that there is no dependent member. The paddy rice production technology is described as $\min[A_i,\ \overline{L}] = A_i$.

In the case where irrigation water is sufficiently supplied to Village 1, and it is not to Village 2, rice productivity of Village 2 relative to Village 1 is equal to be. The production function estimates in Appendix A provide empirical evidence that one-input production function can be justified.

3. Benefits from cooperative action and its feasibility

We have the following equation from assumption (c):

$$\overline{R} = R + A_1. \tag{3}$$

Equation (3) and assumption (d) suggest that Villagers 1 who live close to their subsistence level have a potential incentive to convert their local forest area into paddy fields in order to mitigate over-employment or population pressure brought to bear on farmland.

If demand for irrigation water is proportional to the area of paddy fields, we have the following function:

$$W_i^d = W_i^d(A_i) = mA_i \qquad (m > 0, i = 1,\ 2). \tag{4}$$

On the other hand, since provision of irrigation water in the long-run depends on to what extent local forest is preserved in Village 1, a water supply function is specified as:

$$W^s = W^s(R) = nR \qquad (n > 0). \tag{5}$$

Based on these setting, this section builds a theoretical model that determines water allocation between villages and the quantity of rice produced, and by doing so, examines the feasibility of cooperative action for efficient water use and forest protection.

3.1. Case 1

Case 1 assumes that Village 1 determines supply of irrigation water in such a manner that rice produced in the village may be maximized by taking advantage of its locational superiority.

This can be formally expressed by:

$$\max_{A_1, W_1, R} \quad Q_1 = \phi(W_1)A_1 \\ \text{s.t.} \quad (2),\ (3),\ (4), \text{and } (5). \tag{6}$$

The production function of Village 1 is reduced to the above form from assumption (d). Consider first the situation where water supply and demand of irrigation water in Village 1 are brought into balance. The equilibrium condition, $mA_1 = nR$, is reduced to:

$$A_1 = zR \ , \tag{7}$$

where $z = n/m$. Equation (7) combined with equation (3) yields the following equations:

$$R^{*} = \frac{\overline{R}}{1+z}, \tag{8}$$

$$A_1^{*} = \frac{z\overline{R}}{1+z}. \tag{9}$$

Secondly, consider the situation where Village 1 over-supplies irrigation water by keeping the area of local forest more than R^{*}. Water supply that is beyond demand does not affect $\phi(W_i)$ from assumption (b), only to decrease the amount of rice produced compared with the situation of $W_1^d = W^s$ through a decrease in the arable land. Therefore, $W_1^d < W^s$ is less likely to happen.

Thirdly, consider the possibility that irrigation water is under-supplied. If let A_1^{+} denote the area of paddy fields in this circumstance, we have $A_1^{+} > A_1^{*}$. Indeed, an increase in the arable land may contribute to an increase in rice production, but such a positive effect may be cancelled out by the fact that irrigation water cannot cover the whole area of paddy fields. If the former effect prevails entirely over the latter, the amount of rice produced (Q_1^{+}) would be maximized when forest in Village 1 is entirely depleted, that is, $A_1^{+} = \overline{R}$. Although the difference between $Q_1^{+} = e\overline{R}$ and Q_1^{*} is ambiguously determined, we have $e\overline{R} \le Q_1^{*}$ if the following equation is met:

$$e \le \frac{z}{1+z}. \tag{10}$$

Equation (10) is more likely to be met when e has a smaller number (a severe production loss from water shortage).[4] If this is the case, Village 1 has no incentive to under-supply irrigation water.

Under the situation of $W_1^d = W^s$, the amounts of rice produced in Villages 1 and 2 are shown in the first column of Table 2. If the following equation is met, we have $Q_1^* \le Q_2^*$:

$$b \ge \frac{z}{e(1+z)}. \tag{11}$$

Table 2. Summary of rice output

	Case 1	Case 2	
Village 1	$Q_1^* = \frac{z\bar{R}}{1+z}$	$Q_1^{**} = \frac{(z-1)\bar{R}}{1+z}$	$\tilde{Q}_1^{**} = \left[\frac{z}{1+z} - \frac{1}{1+\beta^* z}\right]\bar{R}$
Village 2	$Q_2^* = eb\bar{R}$	$Q_2^{**} = b\bar{R}$	$\tilde{Q}_2^{**} = b\bar{R}$
Total	$Q^* = \left[\frac{z}{1+z} + eb\right]\bar{R}$	$Q^{**} = \left[\frac{z-1}{1+z} + b\right]\bar{R}$	$\tilde{Q}^{**} = \left[\frac{z}{1+z} - \frac{1}{1+\beta^* z} + b\right]\bar{R}$

Note: Q_i^* and Q_i^{**} $(i = 1,2)$ are solutions of equation (6) and (13), respectively.

3.2. Case 2

Case 2 assumes that Village 1 determines supply of irrigation water in such a manner that the total amount of rice produced in Villages 1 and 2 may be maximized. Now, consider the situation where water supply and demand of irrigation water are brought into balance as a whole. The equilibrium condition is written as:

$$m(A_1 + \bar{R}) = nR. \tag{12}$$

Besides the volume, timing is also a crucial facet of water distribution. Since water demand of paddy rice production has in general a periodic peak with the highest in puddling and earning seasons, inter-village timed rotation or recycling use of Village 1's drainage water would help to moderate water shortage in Village 2. The upstream farmers in this region, however, make it a rule to keep irrigation water to the full in their paddy fields even after harvest. This is partly because by doing so seepage and percolation of paddy fields are effectively controlled and partly because plowing paddy fields that are submerged does not need much manual work in the next spring. The rejuvenation of soil quality and no necessity of field conversion for other-crop-growing may be another reason why they flood their paddy fields throughout the year. These facts combined with the lack of water source other than torrential water flow make the equilibrium condition be given by equation (12).

The optimization problem faced by Village 1 is expressed as:

$$\max_{A_1,W_1,W_2,R} \quad Q=\sum_{i=1}^{2} b_i\phi(W_i)A_i=\sum_{i=1}^{2} b_iA_i \tag{13}$$
$$\text{s.t.} \qquad (2),(3),(4), \text{ and } (12).$$

From equations (3) and (12), we have

$$R^{**}=\frac{2\overline{R}}{1+z} \quad , \tag{14}$$

$$A_1^{**}=\frac{(z-1)\overline{R}}{1+z} \quad . \tag{15}$$

As is evident from equations (8), (9), (14), and (15), we have $R^{*}<R^{**}$ and $A_1^{*}>A_1^{**}$ unconditionally. In order for equation (15) to make sense, the following equation has to be met:

$$z\geq 1. \tag{16}$$

It should be noted that over-supply of irrigation water is less likely to happen for the same reason as in Case 1. When equation (10) is met, the necessary condition by which the total amount of rice produced in Case 2 exceeds that in Case 1 $(Q^{*}\leq Q^{**})$ is written by:

$$b\geq\frac{1}{(1-e)(1+z)} \quad . \tag{17}$$

Equation (17) is more likely to be met when e has a smaller number and b has a larger number, and it constitutes a necessary condition by which irrigation water is never under-supplied in Case 2 because water shortage for Village 2 in Case 2 is nested in Case 1.

The amount of rice produced in Case 2 is shown in the second column of Table 2. As long as equation (17) is met, inter-village cooperation would help to increase the total amount of paddy rice produced, and the same time, it would be conducive to the protection of local forest. In addition, the ratio of Q^{**}/Q^{*} is an increasing function of b, suggesting that the larger the productivity difference between Villages 1 and 2, the greater production increase obtained from cooperative action for efficient water use. Nevertheless, Village 1's selfish behavior ends up with a production loss resulting from water shortage in Village 2. In order for Village 2 to keep the condition of $\phi(W_2)=1$, Village 1 has to refrain from converting their forest areas into paddy fields to some extent. This, however, brings about an adverse effect on Village 1's paddy rice production through a decrease in the arable land.

The shadow area of Figure 1 represents the range of (e,b) that satisfies equations (10) and (17) under the situation of $z = 3$. The area is divided into two parts: one satisfies equation (11), and another does not. When the value of z increases, Line (10) shifts rightward, and Line (17) shifts right-downward, with the result that the shadow area expands. An increase in z shifts Line (11) upwards. The three Lines of (10), (11) and (17) cross at $b = 1$, irrespective of the value of z. To the extent that (e, b) is within this shadow area, there is room for Villages 1 and 2 to be cooperative by which the total amount of rice produced is larger than in Case 1. According to the production function estimates in Appendix A, the productivity difference between the two villages ranges from 1.29 to 1.48. Thus, on the assumption that $e = 0.70$, for instance, $1.29 \le be \le 1.48$ is reduced to $1.84 \le b \le 2.11$. As Figure 1 illustrates, this range of (e, b) denoted by aa' is within the shadow area. On the other hand, in the case of $e > 0.75$ meaning that the degree of a production loss due to water shortage is less than 25 percent, they have no incentive to be cooperative, even if b has a large number.

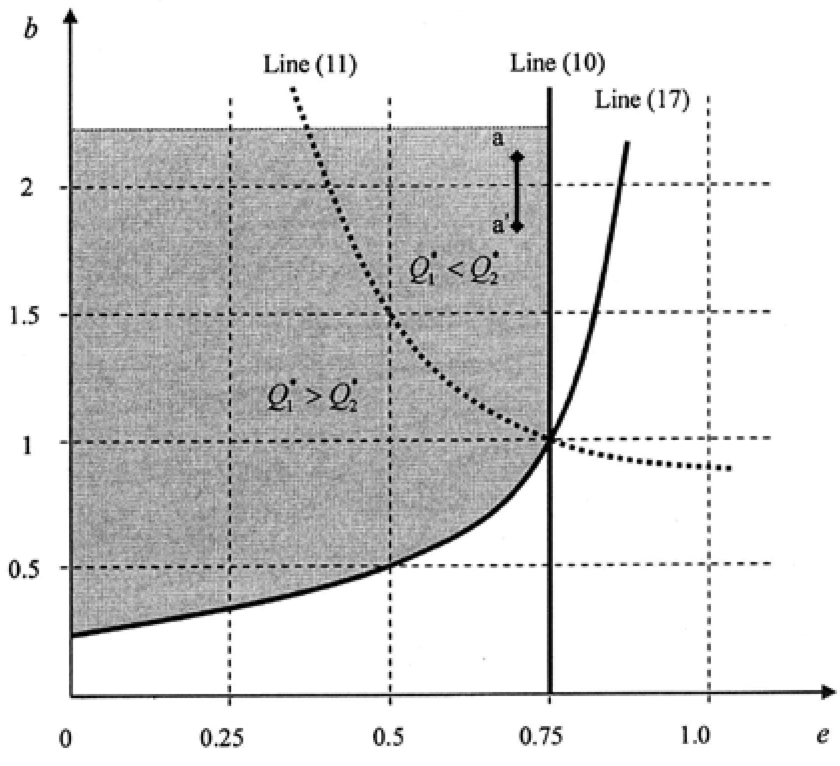


Fig. 1. Cooperation possibility set

Notes: (1) Lines (10), (11), and (17) represent the loci when equations (10), (11), and (17) are satisfied by equalities. (2) z is set at 3.

3.3. Absence of inter-village landholding arrangement

The situation where an optimal forest area is determined by equation (14) can be referred to as the long-run equilibrium. Apart from Village 1's indifference toward Village 2's water shortage, there is another institutional factor that deters the equilibrium from being realized. Now, we shall consider two distinct ways irrigation water is released among user groups; equity rule: water is so distributed that a production loss due to water shortage may be minimized; efficiency rule: water is so distributed that the loss may be shared between them.

Figure 2 illustrates the total amount of rice produced in Villages 1 and 2 that depend on how water is distributed. When water supply is less than nR^{**}, both villages suffer from water shortage under the equity rule. Thus, the total quantity of rice produced is equal to $Q = eA_1 + eb\overline{R}$ that is denoted by aa'''. When water supply is equal to or more than nR^{**}, no village suffers from water shortage under the rule. Thus, the total quantity of rice produced is equal to $Q = A_1 + b\overline{R}$ that is denoted by dd'. The reason for Q being a decreasing function of W^s for each range is that an increase in water supply is accompanied by a decrease in the arable land of Village 1.

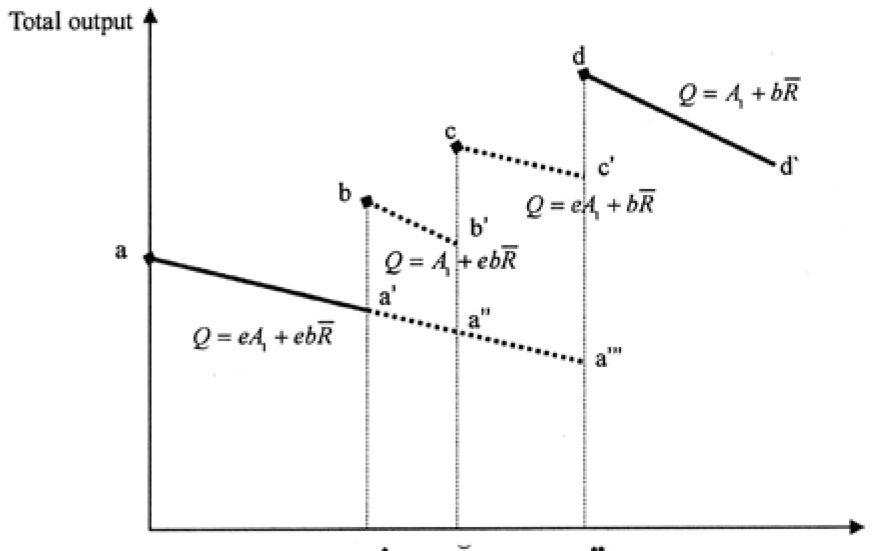


Fig. 2. Water supply and rice production

Note: To the extent that equations (10) and (17) are met, we have $Q_a \le Q_b \le Q_c \le Q_d$, where Q_j denotes the output level corresponding to point j in this figure.

Next, we shall consider rice production under the efficiency rule. $\breve{R}$ in Figure 2 denotes the forest area of Village 1 that brings supply and demand of Village 2's irrigation water into balance with no irrigation water available to Village 1. Since the equilibrium condition is written by $m\overline{R} = n\breve{R}$, we have $R^* < \breve{R} = \overline{R}/z < R^{**}$. For $W^s < nR^*$ or $W^s \geq nR^{**}$, the total amount of rice produced is equivalent to that under the equity rule. On the other hand, when water supply is within the range of $nR^* \leq W^s < n\breve{R}$, water should be provided preferentially to paddy fields of Village 1 for rice production to be maximized, while it should be to paddy fields of Village 2 when $n\breve{R} \leq W^s < nR^{**}$. That is, in order for output per unit of water to be maximized, irrigation water should be selectively released and conveyed instead of being spread over the entire field.

As is evident from this figure, the output level varies depending on how irrigation water is distributed when $nR^* \leq W^s < nR^{**}$, which is reflected on the divergence between bb' and a'a", and cc' and a"a"'. In so far as this divergence gives rise to conflicts, inter-village cooperation should be organized, while it is unnecessary when water is severely deficient or excessively supplied. These considerations are in conformity with empirical findings that the scarcity of resources is related with the degree of cooperative efforts with an inversed U-shape (Uphoff, 1986; Wade, 1988b; Meinzen-Dick et al., 2002; Fujiie et al., 2005). Namely, water users have a strong incentive to cope with conflict with each other when water shortage is moderately problematic, but such an action is less likely to be taken when water is sufficiently supplied or severely in the short supply. More important is the fact that the loss-sharing arrangement based on egalitarian rules erodes production efficiency especially when water shortage is moderately problematic.

One possible measure to reconcile equity and efficiency in production is to divide the entire paddy fields of Villages 1 and 2 into a number of scattered sections, and entitle farmers to cultivate a portion of each section (Wade, 1988a, p. 185; Quiggin, 1993). This kind of arrangement allows them to allocate irrigation water based on the efficiency rule without conducing to income inequality with the result that the optimal forest area can be realized. However, the implementation of scattered landholding across villages in rural China is almost impossible because such arrangements are confined to inside villages alone under the current land contract system.(5) After all, it follows that a negative externality created by head-enders' overexploitation of resources is unable to be well controlled to the extent that they are concerned only with their self-interests and the inter-village landholding arrangement is absent. As a consequence, R^* instead of R^{**} is a likely equilibrium.

3.4. Long-run cooperation and its feasibility

We shall return to an argument regarding an alternative situation of Case 1 or Case 2. Figure 3 is depicted on the presumption that equations (10) and (17) are met. The horizontal and vertical axes measure the amount of rice produced by Village 1 and Village 2, respectively. The points a and b in this figure correspond to the production combination in Case 1 and Case 2, respectively. Since the two Villages have the same population from assumption (d), the aggregate production for each Village can be seen as an indirect measure of per capita rice consumption if there is no income transfer. The highlight of this analysis lies in the fact the inter-village inequality measured by rice production would be endogenously generated as a consequence of cooperation. Note that this provides us with a new perspective on the way inequality bears upon cooperation because most studies on this subject look upon economic heterogeneity among CPR user groups as being exogenously given by some factors such as differential access to credit, asset (land) holding, technology and so on, and then explore the impact they have on collective action (e.g. Aggarwal and Narayan, 2004; Cardenas, 2003; Dayton-Johnson and Bardhan, 2002; Jones, 2004; Molinas, 1998; Mukhopadhyay, 2004). On the other hand, the rice production disparity appeared in Figure 3 has nothing to do with the predetermined inter-village difference of asset possessions and endowments. In effect, economic heterogeneity originating in the imbalanced distribution of wealth is not critical in rural China because egalitarianism associated with the legacy of socialist regime is still prevalent under collective landholding, limited immigration, and no existence of the landless.

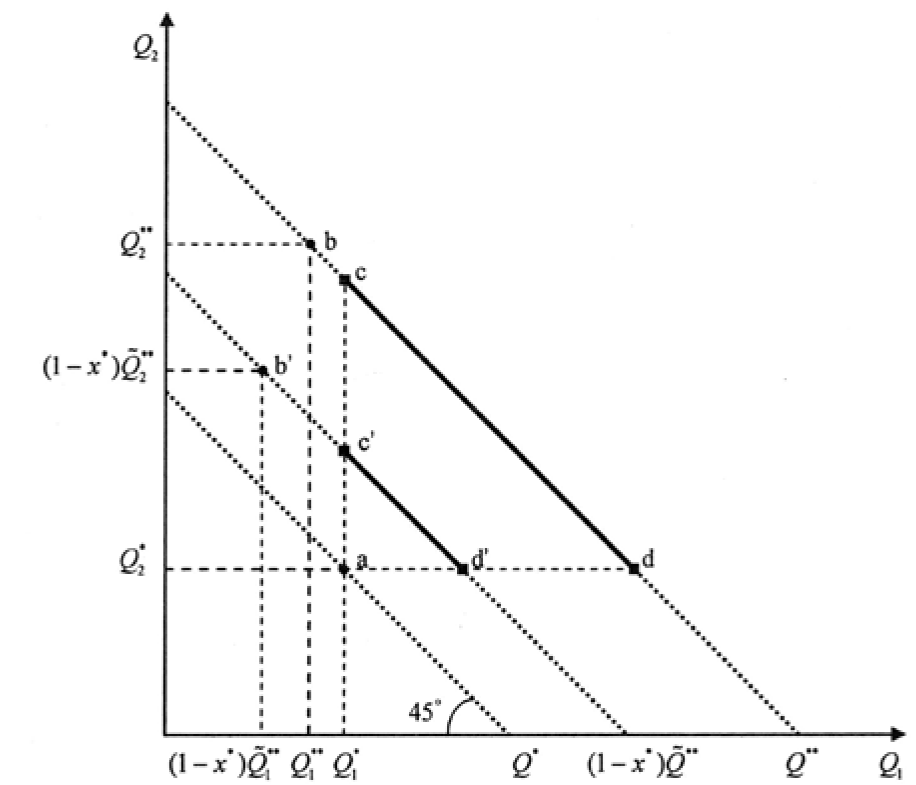


Fig. 3. Inter-village cooperation and Pareto-improving contract

If equation (17) is met, Case 1 is not only inefficient in terms of paddy rice production but also harmful to local forest preservation. With a view to circumventing the advent of such misery, some mechanisms should be devised so that Village 1 may prefer Case 2 to Case1. Now, suppose that some amount of rice produced in Village 2 is gifted to Village 1 in return for Village 1's altruistic behavior, by which irrigation water is supplied to Village 2 to the point where equation (12) is met.(6) Starting from point a in Figure 3, in order for all people concerned to have Pareto-improving outcomes, the rice consumption pattern must lie somewhere along the contract line of cd.(7) If Village 2 has a strong bargaining power for some reason, the amount of rice consumed by Village 1 (C_1) is equal to Q_1^*; that is, Village 1's participation condition for this bargaining game is met as an equality. By contrast, if Village 1 has a strong bargaining power, they have $C_2 = Q_2^*$, where C_2 denotes the amount of rice consumed by Village 2. In short, the determination of consumption pattern is conditioned by the existing power structure.

Table 3. Nash equilibrium

Game I		Village 2: C	Village 2: S
Village 1	C	(C_1, C_2)	(Q_1^{**}, Q_2^{**})
	S	(Q_1^*, Q_2^*)	(Q_1^*, Q_2^*)

Game II		Village 2: C	Village 2: S
Village 1	C	(C_1, C_2)	(Q_1^{**}, Q_2^{**})
	S	$(Q_1^* - P_1, Q_2^*)$	$(Q_1^* - P_1, Q_2^*)$

Game III		Village 2: C (y_2)	Village 2: S $(1-y_2)$
Village 1	C (y_1)	(C_1, C_2)	$(Q_1^{**}, Q_2^{**} - P_2)$
	S $(1-y_1)$	(Q_1^*, Q_2^*)	(Q_1^*, Q_2^*)

Notes: (1) C: cooperation, S: non-cooperation. (2) It is assumed that equations (10) and (17) are met.

Although Case 2 outperforms Case 1 in terms of rice production efficiency and the conservation of local forest, such outcomes are not necessarily guaranteed to emerge. The normal-form representation of this game (Game I) illustrated in Table 3 tells us that the game ends with the Nash Equilibrium of (S, S), the Prisoner's Dilemma. Infinitely repeated game might lead to mutual cooperation by avoiding such a dilemma if both players adopt a trigger strategy with the reasonable discount rate in their mind.(8) Inter-linkage between the irrigation game and the community social exchange game is another remedy for staying away from the Prisoner's Dilemma (Aoki, 2001, p. 47).(9)

As far as paddy rice production in Yuanyang County is concerned, there are a couple of factors that impede inter-village cooperation. For one thing, it is demographic heterogeneity. Ethnic people in this region reside in the mountainous areas in segregated manners in accordance with the altitude, with Dai people in lower, Yi people in middle, and Hani people in higher altitude. If correct is the hypothesis that social heterogeneity makes up one of the significant causes that deter cooperative action (Bardhan, 1993 and 2000), inter-village cooperation is less likely to be forthcoming. For another thing, the degree to which potential gains from collective action are reliably assured is of great importance for farmers' concerted efforts to be mobilized (Ostrom, 1990; Gaspart et al., 1998; White and Runge, 1994). Our interview to the farmers in this region reveals that few of them are aware of fruitful outcomes of incremental rice consumption realized by mutual cooperation although almost all of them correctively perceive the importance of local forest protection. The fact that there is few reservoir or pond that facilitates efficient water use is thought to be the major cause of making potential gains unpredictable.

Among a large array of possible method for mitigating water shortage, the penalty system that punishes people who deforest has been implemented across China under the Land Afforestation Program. And in fact, the forest coverage in Yunnan Province has been increasing over the past years since the enactment of this Program.(10) This is in line with the thought that local forest management under common property regime would contribute to an overall efficiency improvement by internalizing externalities over a large geographical unit (de Janvry et al., 2001, p. 11). But, this Program poses a serious problem of income distribution. Game II in Table 3 shows payoff of Villages 1 and 2 under the Program. It is assumed that Village 1 pays a fine of P_1 that satisfies $P_1 > Q_1^{*} - Q_1^{**}$ to the government when they choose non-cooperation. This game ends with (C, S) because $C_2 < Q_2^{**}$. Although the total amount of rice produced increases as compared with Case 1 (see Figure 3), the rice consumption pattern is a far cry from the Pareto-improving outcomes because the distribution is highly skewed in favor of Village 2.

To solve this problem, we shall consider how the program should be reformed. Game III in Table 3 illustrates that Village 2 pays a fine of P_2 when it chooses non-cooperation in response to Village 1's cooperative behavior. It is assumed that P_2 satisfies:

$$P_2 > Q_2^{**} - C_2 \ . \tag{18}$$

Note that since $C_1 \geq Q_1^{*}$ is always met, Village 1 needs not be punished for its betrayal in response to Village 2's cooperation. As is easily understood, this game has two Nash Equilibriums, (C, C) and (S, S). According to Baland and Platteau (1996, chapter 2) that exemplify the situation where two Nash equilibriums coexist, the selection of inferior equilibrium (S, S) is due to a coordination failure under the unregulated common property regime. An evolutionary thinking, however, might preclude (S, S) without players' coordination efforts.

Now, let y_i $(i=1,2)$ and $1-y_i$ be the ratio of people in Village i who choose C and S, respectively. The average payoff of Village 1 and 2 is given respectively by:

$$ave\ u_1 = y_1[y_2C_1 + (1-y_2)Q_1^{**}] + (1-y_1)Q_1^{*},$$

$$ave\ u_2 = y_1y_2C_2 + y_1(1-y_2)[Q_2^{**} - P_2] + (1-y_1)Q_2^{*}.$$

Thus, replicator equations are given by (Maynard-Smith, 1982; Weibull, 1995):

$$\frac{dy_1}{dt} = y_1[u_1(\mathrm{C}) - ave\ u_1] = y_1(1-y_1)[y_2C_1 + (1-y_2)Q_1^{**} - Q_1^{*}] \equiv y_1(1-y_1)A, \tag{19}$$

$$\frac{dy_2}{dt} = y_2[u_2(C) - ave\ u_2] = y_2(1-y_2)y_1[C_2 - Q_2^{**} + P_2] \equiv y_2(1-y_2)B, \tag{20}$$

where $u_i(\mathrm{C})$ $(i=1,2)$ denotes the expected payoff of C behavior.

To the extent that equation (18) is met, B is positive. Thus, we have $dy_2/dt \geq 0$, suggesting that the number of Villagers 2 who choose C increases over time. On the other hand, A is positive only when y_2 satisfies the following equation:

$$y_2 > \frac{Q_1^{*} - Q_1^{**}}{C_1 - Q_1^{**}} \equiv y_2^{*}. \tag{21}$$

When equation (21) is met, we have $dy_1/dt \geq 0$, suggesting that the percentage of Villagers 1 who choose C increases. By contrast, when $y_2 < y_2^{*}$, we have $dy_1/dt \leq 0$. The phase diagram depicted in Figure 4 illustrates that the Nash Equilibrium of (C, C) is the only evolutionary stable strategy (ESS) of Game III.(11)

The strategy set of (C, S) corresponding to $(y_1, y_2) = (1, 0)$ is the Nash Equilibrium of Game II. Therefore, if the penalty system is altered from Game II to Game III, the number of Villagers 2 who change their strategy from S to C increases throughout the time, while that of Villagers 1 who choose C decreases first, and then increases. Equations (21) tells us that when $C_1 = Q_1^{*}$, we have $y_2^{*} = 1$. This signifies that when the participation constraint of Village 1 for the bargaining is met as an equality, the number of Villagers 1 who choose S behavior increases throughout the time. By contrast, even if the participation constraint of Village 2 is met as an equality, Villagers 2 prefer C to S behavior because C is a dominant strategy for them in Game III. At any rate, we can understand from equations (19) to (21) that the way in which rice is distributed between the villages plays a significant role in determining the dynamic aspect of cooperation.(12) Section 5 discusses on this issue in a great detail.

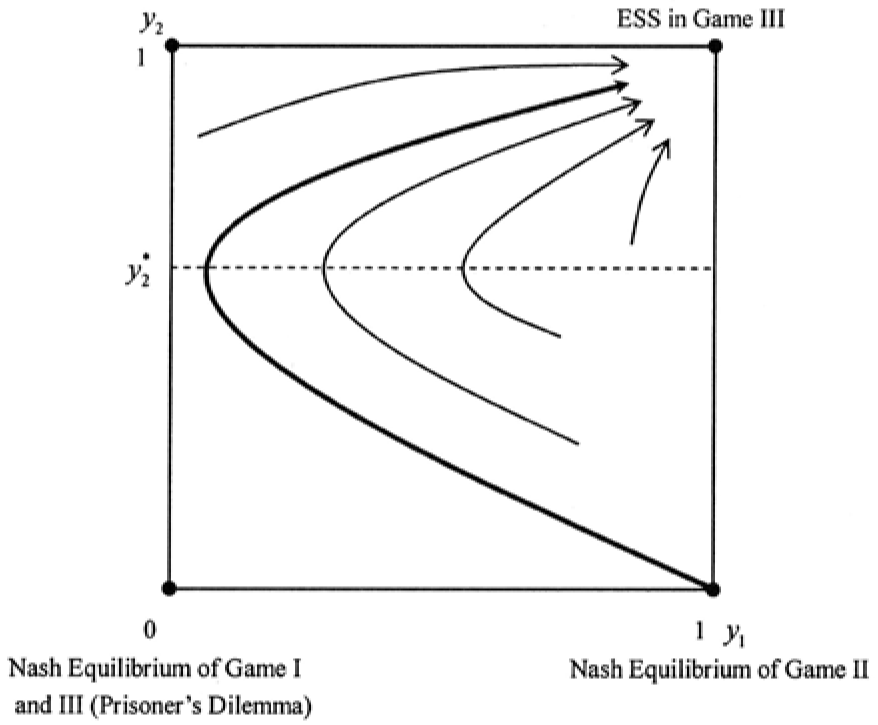


Fig. 4. Phase diagram (I)

4. Imperfect reversibility of natural resources and costs of reforestation

We have so far discussed private benefits accrue to collective action. Another important thing that should be questioned is costs CPR users have to pay for its preservation. This is directly related to the fact that the movement from Case 1 to Case 2 (reforestation) requires more strenuous activities than the reversal one. Thus, with a view to examining the impact of the imperfect reversibility of natural resources on inter-village cooperation, we rewrite equation (3) as:

$$R = \begin{cases} R^* - \beta(A_1 - A_1^*) \quad (0 \le \beta \le 1) & \text{if } R \ge R^* \ (A_1 \le A_1^*) \\ \bar{R} - A_1 & \text{otherwise} \end{cases}, \tag{22}$$

Equation (22) captures the situation where forest in Village 1 does not restore its original condition when reforestation starts from $A_1 = A_1^*$ in Case 1. In the case of $R \ge R^*$, the area that is neither paddy fields nor local forest is equal to $\bar{R} - R - A_1 > 0$, which exactly corresponds to fact (iv) that some bald territories in Village 1 are left unused for agriculture. The degree of reversibility is measured by a coefficient of β; the smaller the value, the larger the degree of irreversibility.

Under these general circumstances, the condition by which supply and demand of irrigation water are brought into balance for both Villages 1 and 2 is rewritten as:

$$n[R^* - \beta(A_1 - A_1^*)] = m(A_1 + \bar{R}).$$

Substituting equations (8) and (9) into this equation, we have:

$$\tilde{A}_1^* = \left[\frac{\beta z^2 - 1}{(1+z)(1+\beta z)}\right]\bar{R}. \tag{23}$$

where $\tilde{A}_1^*$ denotes the area of paddy fields of Village 1. In order for equation (23) to make sense, the following equation has to be met:

$$\beta \ge 1/z^2. \tag{24}$$

Naturally, equations (23) and (24) are reduced to equations (15) and (16) when $\beta = 1$, respectively. The third column of Table 2 presents the amount rice produced in this situation.

Based on these presumptions, we consider in what follows how much resource should be set aside for the purpose of reforestation and who are supposed to bear the cost. Since the determination of cost based on the marginal cost principle is expected to be troubled with problems engendered by free-riding, it is reasonable to levy $100x$ % tax of rice production on every irrigation water user.(13) Under this rule, x is so determined that $(1-x)\tilde{Q}^{**}$ may be maximized, where $\tilde{Q}^{**}$ denotes the total amount of rice produced when the paddy field area of Village 1 is given by equation (23). In general, $\beta = \beta(x)$ and $\beta'(x) > 0$ is expected; to what extent degraded land restores its capacities to supply irrigation water depends crucially on resources that are mobilized for that purpose. Since we conduct calibration analyses in Section 5, $\beta(x)$ is specified as the following linear form:

$$\beta = ax \quad (a > 0), \tag{25}$$

where a denotes a constant term. The optimal x (x^*) is defined as:

$$x^* = \arg\max\ (1-x)\tilde{Q}^{**} = \arg\max\ (1-x)\left[\frac{z}{1+z} - \frac{1}{1+axz} + b\right]\bar{R}.$$

By solving this, we have:

$$x^* = \frac{1}{az}\left[\sqrt{\frac{(1+z)(1+az)}{z+b(1+z)}} - 1\right]. \tag{26}$$

It is confirmed that the second order condition is broadly satisfied.(14) When the cost of reforestation is taken into consideration, the necessary condition by which cooperation is forthcoming is given by:

$$(1-x^*)\tilde{Q}^{**} - Q^* \geq 0. \tag{27}$$

Due to the fact that net rice production decreases as compared to the case where forest is perfectly reversible, the contract line shrinks from cd to c'd', as illustrated in Figure 3. That is to say, the imperfect reversibility of natural resource does a serious harm to collective action by narrowing its feasibility set. The remaining question as to the cost-sharing between Villages 1 and 2 will be discussed in the next section.

5. Cooperation and economic homogeneity/heterogeneity

As has been stressed in Section 3, the distribution of rice for consumption constitutes one of the most significant elements that shape the dynamic aspect of cooperation. Thus, we first intend to determine the consumption pattern with the aid of Nash Bargaining Solution (NBS), which can be formally expressed by:

$$\max_{C_1, C_2} \quad \varphi = (C_1 - X_1)(C_2 - X_2)$$
$$\text{s.t.} \quad C_1 + C_2 = (1 - x^*)\tilde{Q}^{**},$$

where X_i $(i = 1, 2)$ represents an exit option of this bargaining game for Village i; that is, failure of the bargaining ends up with $C_i = X_i$ $(i = 1, 2)$. Otherwise, the solution is given by:

$$C_1^* = \frac{(1 - x^*)\tilde{Q}^{**} + X_1 - X_2}{2},$$
$$C_2^* = \frac{(1 - x^*)\tilde{Q}^{**} - X_1 + X_2}{2}.$$

Inasmuch as equation (27) is met, we have always $C_i^* \geq Q_i^*$ $(i = 1, 2)$.

We can define the situation where $X_i > (1 - x^*)\tilde{Q}^{**} - Q_j^* \equiv X_{i\max}$ $(i = 1, 2 : i \neq j)$ is met, which is generated by high alternative income from non-farm sectors or job opportunities outside the village. No doubt this causes to break down the bargaining, and thereby dissolves inter-village cooperation. In short, "market integration erodes the ability of rural communities to manage their CPRs successfully" (Baland and Platteau, 1996, p. 270). By contrast, as long as Villages 1 and 2 have no exit option other than producing paddy rice, they have $X_i = Q_i^*$ $(i = 1, 2)$. Therefore, when equation (11) is met, $C_1^* \leq C_2^*$ is obtained, and vice versa. But in fact, $X_2 > Q_2^*$ is likely because Village 2 located in downstream is thought to have a geographical advantage over Village 1 in terms of market proximity. Accordingly, people in Village 2 are able to exert a strong bargaining power against Village 1. Furthermore, in the case of $X_2 > X_{2\max}$, Village 2 will lose interest in paddy rice production, and therefore deviate from the bargaining. These considerations provide us with a good understanding of why mutual cooperation is doomed to collapse when market economy penetrates across regions and/or economic heterogeneity among CPR users goes beyond a certain threshold point.(15)

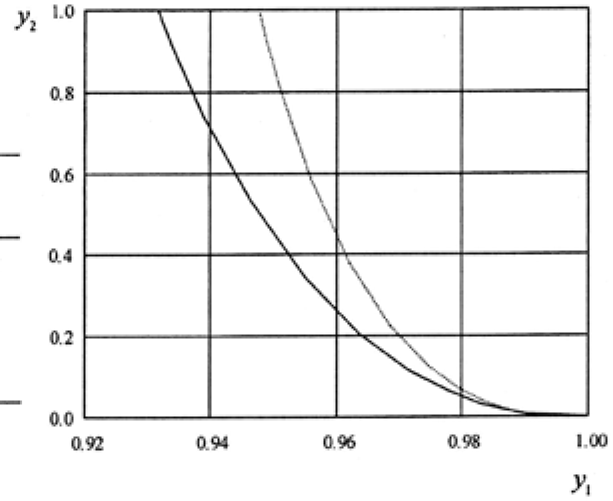
The question that should be addressed next is to see how the dynamic process of cooperation evolves when nobody has an incentive to deviate from the bargaining. More specifically, we would like to spotlight how the responses of Villages 1 and 2 in accordance with the reform of penalty system are affected depending on the cost-sharing or the resultant distribution of rice for consumption. For this purpose, calibration analyses are conducted. See Appendix B as to quantifying the relevant parameters.

In calculating equations (19) and (20), it is assumed that one percent population in each Village mutates and deviates from the Nash Equilibrium in Game II. On the assumption of $(a, b, e, z) = (9, 2.0, 0.7, 4)$, we have rice production in Case 1 and Case 2 as $(Q_1^*, Q_2^*) = (0.80\overline{R}, 1.40\overline{R})$, and $(\tilde{Q}_1^{**}, \tilde{Q}_2^{**}) = (0.52\overline{R}, 2.00\overline{R})$, respectively. Inter-village cooperation results in the exacerbated inequality, as has been seen in Figure 3, with an additional benefit exclusively accruing to Village 2 at the expense of Village 1. Since x^* is computed as around 0.073 from equation (26), the cost of reforestation, $x^*\tilde{Q}^{**}$, is equal to $0.18\overline{R}$. Sharing the cost between Villages 1 and 2 proportional to the amount of rice they produce is impossible because $(1-x^*)\tilde{Q}_1^{**} > Q_1^*$ is not met (Village 1 has no temptation to enter into the contract). On the other hand, the cost-sharing rule on a basis of the command area they cultivate is all the more unrealistic for the cost burdened by Village 1 increases more.(16)

Thus, the following three cost-sharing rules are presumed under the restrictions of $(1-x^*)\tilde{Q}^{**} = C_1^* + C_2^*$, and $C_i^* \geq Q_i^*$ $(i = 1, 2)$, and $P_2 = 1.2\overline{R}$.(17) First, we determine the sharing rule so that C_1^* may be minimized (or equivalently, $X_2 = X_{2\max}$), from which the cost borne by Villages 1 and 2 is equal to $(s_1^*, s_2^*) = (-0.28\overline{R}, 0.46\overline{R})$. This means that Village 2 not only bears the entire cost of reforestation but also hands over some portions of their rice production to Village 1. In spite of this, the dynamic process does not converge to mutual cooperation because they have $y_2^* = 1$ under $C_1^* = Q_1^*$. The phase diagram depicted in Figure 5-1 shows this situation. Second, we determine $(s_1^*, s_2^*) = (-0.35\overline{R}, 0.53\overline{R})$ and $(C_1^*, C_2^*) = (0.87\overline{R}, 1.47\overline{R})$, which corresponds to the consumption pattern in the case of $X_i = Q_i^*$. As Figure 5-2 illustrates, this cost-sharing rule guarantees the dynamic process to arrive at the ESS. Third, income transfer is further increased to the point where C_2^* is minimized (or equivalently, $X_1 = X_{1\max}$), meaning that the participation constraint of Village 2 is met as an equality. In this setting, we have $(s_1^*, s_2^*) = (-0.42\overline{R}, 0.60\overline{R})$

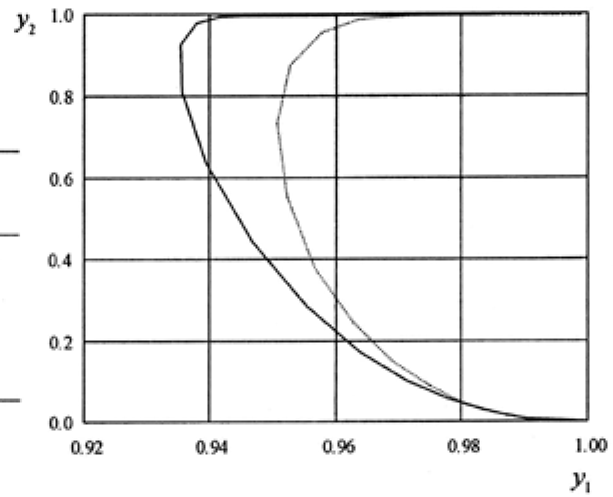
	Total output in Case 2	
	$(1-x^*)\tilde{Q}^{**}$	$\tilde{Q}^{**}$
(C_1^*, C_2^*)	$(0.80\bar{R}, 1.54\bar{R})$	$(0.80\bar{R}, 1.72\bar{R})$
C_1^*/C_2^*	0.52	0.46
(s_1^*, s_2^*)	$(-0.28\bar{R}, 0.46\bar{R})$	(0, 0)
T^*	∞	∞

Fig. 5-1



	Total output in Case 2	
	$(1-x^*)\tilde{Q}^{**}$	$\tilde{Q}^{**}$
(C_1^*, C_2^*)	$(0.87\bar{R}, 1.47\bar{R})$	$(0.96\bar{R}, 1.56\bar{R})$
C_1^*/C_2^*	0.59	0.62
(s_1^*, s_2^*)	$(-0.35\bar{R}, 0.53\bar{R})$	(0, 0)
T^*	112	51

Fig. 5-2



	Total output in Case 2	
	$(1-x^*)\tilde{Q}^{**}$	$\tilde{Q}^{**}$
(C_1^*, C_2^*)	$(0.94\bar{R}, 1.40\bar{R})$	$(1.12\bar{R}, 1.40\bar{R})$
C_1^*/C_2^*	0.67	0.80
(s_1^*, s_2^*)	$(-0.42\bar{R}, 0.60\bar{R})$	(0, 0)
T^*	60	32

Fig. 5-3

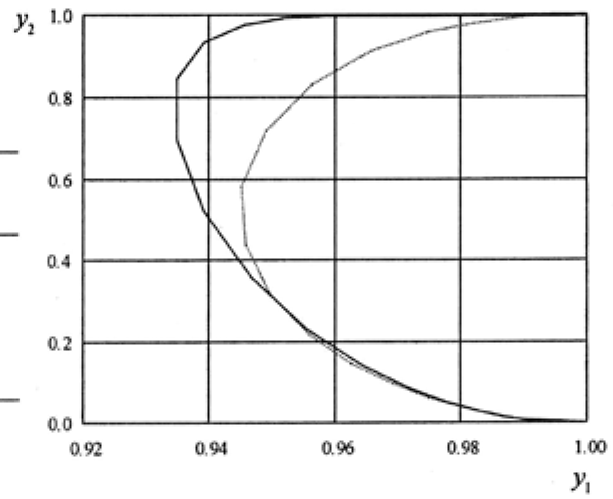
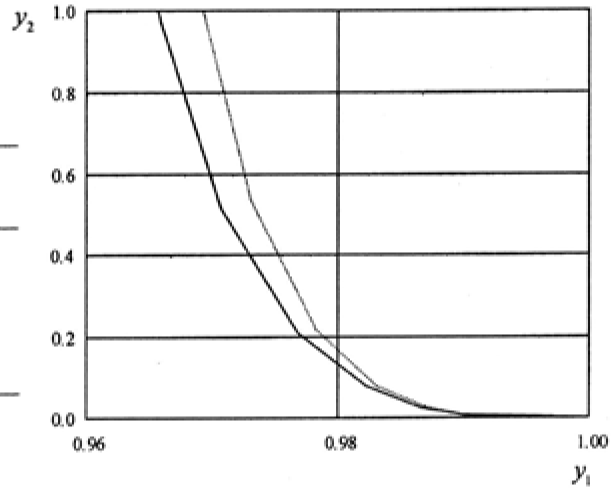


Fig. 5. Phase diagram (II)

Note: The solid and dotted lines correspond to DRC $= (1-x^*)\tilde{Q}^{**}$, and DRC $= \tilde{Q}^{**}$, respectively.

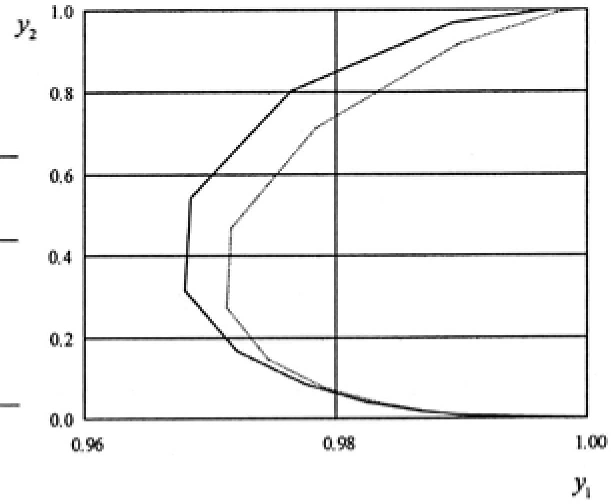
	Total output in Case 2	
	$(1-x^*)\tilde{Q}^{**}$	$\tilde{Q}^{**}$
(C_1^*, C_2^*)	$(0.80\overline{R}, 2.24\overline{R})$	$(0.80\overline{R}, 2.44\overline{R})$
C_1^*/C_2^*	0.36	0.33
(s_1^*, s_2^*)	$(-0.31\overline{R}, 0.51\overline{R})$	(0, 0)
T^*	∞	∞

Fig. 6-1



	Total output in Case 2	
	$(1-x^*)\tilde{Q}^{**}$	$\tilde{Q}^{**}$
(C_1^*, C_2^*)	$(1.58\overline{R}, 1.46\overline{R})$	$(1.68\overline{R}, 1.56\overline{R})$
C_1^*/C_2^*	1.08	1.07
(s_1^*, s_2^*)	$(-1.09\overline{R}, 1.29\overline{R})$	(0, 0)
T^*	13	12

Fig. 6-2



	Total output in Case 2	
	$(1-x^*)\tilde{Q}^{**}$	$\tilde{Q}^{**}$
(C_1^*, C_2^*)	$(2.35\overline{R}, 0.69\overline{R})$	$(2.55\overline{R}, 0.69\overline{R})$
C_1^*/C_2^*	3.42	3.71
(s_1^*, s_2^*)	$(-1.86\overline{R}, 2.06\overline{R})$	(0, 0)
T^*	47	118

Fig. 6-3

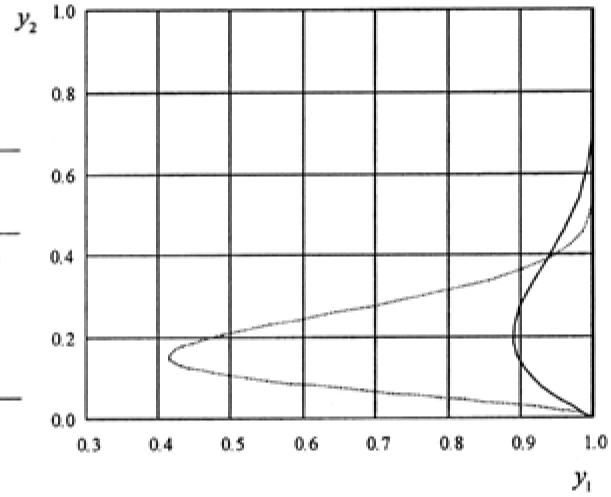


Fig. 6. Phase diagram (III)

Note: see Fig. 5.

and $(C_1^*, C_2^*) = (0.94\bar{R}, 1.40\bar{R})$, and the phase diagram is shown in Figure 5-3. (Recall that Villagers 2 choose C even in this situation because cooperation is a dominant strategy for them in Game III.) Although the configurations are quite similar between Figures 5-2 and 5-3, time required for reaching the ESS (T^*) differs considerably. The dotted in Figure 5 denote the convergence loci in the case where either forest is perfectly reversible without any cost ($\beta = 1$) or the entire cost of reforestation is shouldered by someone else. Roughly speaking, the loci shift rightward as a result of the disposable rice for consumption (DRC) increased by $x^*\tilde{Q}^{**}$.

Figure 6 is illustrated by assuming $(a, b, e, z) = (9, 2.0, 0.25, 4)$, by which the rice production in Case 1 and Case 2 is computed as $(Q_1^*, Q_2^*) = (0.80\bar{R}, 0.69\bar{R})$, and $(\tilde{Q}_1^{**}, \tilde{Q}_2^{**}) = (0.49\bar{R}, 2.75\bar{R})$, respectively. The difference from the previous case lies in the fact e is decreased with other parameters being unchanged, with the result that they have $Q_1^* > Q_2^*$. (As is shown in Figure 1, $Q_1^* > Q_2^*$ is a likely result for a smaller e.) Likewise, three cost-sharing rules are presumed under the restrictions of $(1 - x^*)\tilde{Q}^{**} = C_1^* + C_2^*$, $C_i^* \geq Q_i^*$ $(i = 1, 2)$, and $P_2 = 2.2\bar{R}$.[18] First, the sharing rule is so determined so that C_1^* may be minimized. By the same token as the previous case, no convergence to mutual cooperation occurs as shown in Figure 6-1. As the second and third const-sharing patterns, $X_i = Q_i^*$ and $X_1 = X_{1\max}$ are assumed, which generates $(s_1^*, s_2^*) = (-1.09\bar{R}, 1.29\bar{R})$, and $(s_1^*, s_2^*) = (-1.86\bar{R}, 2.06\bar{R})$, respectively. Figures 6-2 and 6-3 illustrate that although the convergence is possible in both cases, time required for reaching mutual cooperation differs between them.

We can see from Figures 5-2, 5-3, and 6-2 that an increase in DRC from $(1 - x^*)\tilde{Q}^{**}$ to $\tilde{Q}^{**}$ shortens the convergence process to reach the ESS, but this does not hold true for Figure 6-3 with T^* more than twice when DRC is equal to $\tilde{Q}^{**}$ as compared with when it is equal

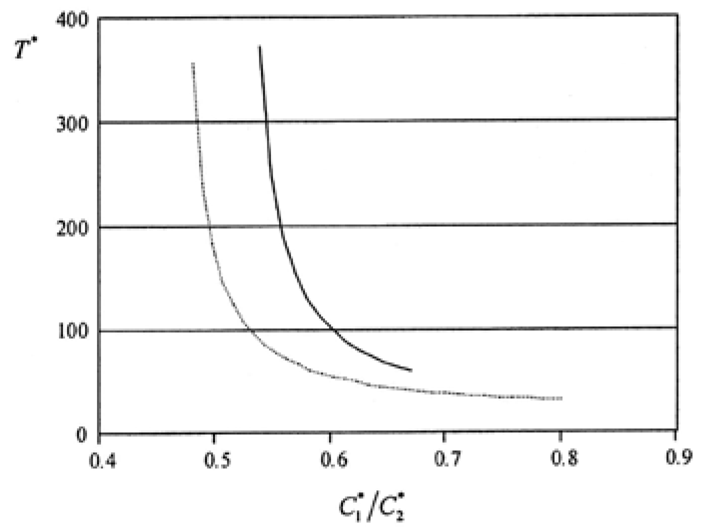


Fig. 7. Rice consumption pattern and time for convergence ($Q_1^* < Q_2^*$)

Note: see Fig. 5.

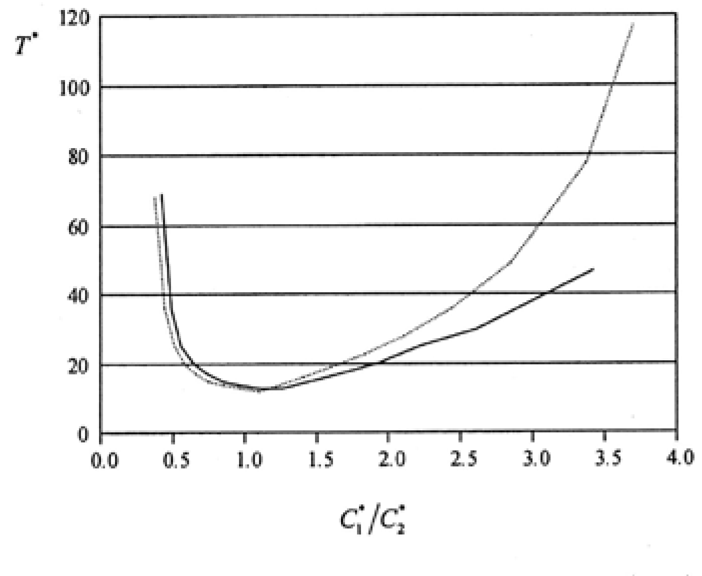


Fig. 8. Rice consumption pattern and time for convergence ($Q_1^* > Q_2^*$)

Note: see Fig. 5.

to $(1-x^*)\tilde{Q}^{**}$. Accordingly, it follows that there is another factor other than the magnitude of an additional DRC obtained from cooperation that dictates the convergence velocity.

Figures 7 and 8 illustrate the relationship between C_1^*/C_2^* and T^* (the solid and dotted lines correspond to DRC that is equal to $(1-x^{*})\tilde{Q}^{**}$ and $\tilde{Q}^{**}$, respectively).(19) Since we have no choice but to change C_i^{*} under the restriction of $C_i^{*} \geq Q_1^{*}$ $(i=1,2)$, $C_1^{*}/C_2^{*}=1$ is impossible when $Q_1^{*} < Q_2^{*}$. Indeed, DRC is one of the determinants that shape the convergence, but the way rice is distributed is much more influential. More precisely, with an increasing similarity of the consumption pattern between Villages 1 and 2, the dynamic process moves swiftly from the Nash Equilibrium in Game II to Pareto-superior outcomes in Game III. To put it another way, in order to get the penalty system on the right direction through which mutual cooperation is realized as the ESS, its reform program has to entail income transfer from downstream villages that would acquire a large additional gain from cooperation to upstream villages that would suffer serious income loss by decreasing the paddy field area. Olson (1965, p. 34), Wade (1988a, p. 190), and among others contend that cooperation would be forthcoming to the extent that those who have a disproportionate great interest in the effective regulation of local commons are motivated to pay a major share of the costs involved.(20) Not only consistent is our analysis with their claim in the sense that Village 2 bears more than the entire cost of reforestation, but also contributes to the relevant literature by saying that income transfer and "resultant" economic homogeneity are of great importance for Pareto-superior outcomes to appear swiftly in an evolutionary manner.

6. Conclusions

Paddy rice production and irrigation water use in Yuanyang County of Yunnan Province in China is characterized by the situation where head-enders have a locational advantage over tail-enders in determining how much water is drawn and distributed among rice producers in the territory. By contrast, downstream villages have an agro-climatic advantage for rice production over upstream villages in that double-cropping is possible only in lower altitude. In addition, rice production in this region is subject to the inter-linked management of local forest, supply of irrigation water, and an expansion of paddy fields. Our consideration reveals that the locational asymmetry is liable to throw this economy into the game structure described as Prisoner's Dilemma.

One of the major objectives of this paper is to develop a theoretical model that mirrors these phenomena, and thereby, to identify the conditions and institutional frameworks by which inter-village cooperative action would bring about welfare-enhancing outcomes to local stakeholders. The analysis elucidates that the feasible set in which they become better off as a result of cooperative action shrinks when the risk of irreversible depletion of CPRs is increased. By contrast, the wider the productivity difference of rice production between upstream and downstream villages, the larger benefits expected from mutual cooperation. The model also tells us that Pareto superior outcomes in this economy are not only efficient in terms of rice production but also preventive to deforestation. Nevertheless, such outcomes are beyond their reach as long as farmers behave themselves to their own interest and the inter-village landholding arrangement is absent.

The government of China has adopted the penalty system under the Land Afforestation Program in order to prevent such tragic consequences associated with Prisoner's Dilemma from occurring. Indeed, the system is in fact conducive to circumventing the advent of Prisoner's Dilemma by internalizing externalities, but it causes a serious problem of income distribution with highly skewed in favor of downstream villagers. With a view to mitigating this kind of distributional problem, the ongoing penalty systems should be reformed in such a way that farmers who betray in response to others' altruistic behavior should be punished. This policy reform makes it possible for every stakeholder to have Pareto superior outcomes as the evolutionary stable strategy (ESS).

Another important implication drawn from the analytical combination of Nash Bargaining Solution with the evolutionary game theory is as follows: an overall penetration of market economy or inequality beyond a certain threshold point is to the detriment of inter-village cooperation, and as opposed to it, transfers as a means of equalizing income help to regulate CPRs effectively. Implicit in this argument is that a simple beneficiary-pay principle in the presence of credible punishment is conducive to mutual cooperation irrespective of the degree of *ex ante* group heterogeneity. Finally, external regulators in charge of identifying the beneficiaries and implementing the transfer and penalty mechanisms feel less troublesome partly because it is neither hidden information nor hidden behavior but locational asymmetry that constitutes the proximate cause of inter-village inequality and partly because group heterogeneity is generated endogenously as a result of cooperation.

Appendix A. Production function estimates

With the aim of testing the validity of production function specification and measuring the productivity difference between Villages 1 and 2, we estimate the paddy rice production function using the 2004 village data that were collected by this author in Yuanyang County. To begin with, the production function is specified by the following Generalized Leotief (GL) type (Chambers, 1988):

$$Q = \sum_{m,n=L,A,F,K} \sum \gamma_{mn} \sqrt{mn}, \quad \gamma_{mn} = \gamma_{nm} \text{ and } \gamma_{mn} \geq 0 \ , \qquad \text{(A1)}$$

where F and K denote chemical fertilizer and draft animals, respectively. For the estimation, every variable is standardized by the mean value in order to make the estimated parameters unit-free. The first column of Table A-1 represents the OLS estimation result. There is a potential endogeneity problem in equation (A1) if an opposite causality from output to labor input exists. For the purpose of dealing with this problem, equation (A1) is estimated with the instrumental variable (IV) methods using rural population as the IV, and the result is shown in the second column. As the p-value indicates, the Hausman test does not reject the null hypothesis with respect to the parameter consistency at any conventional level of significance. Thus, labor input is allowed to be treated as exogenous. This result is not surprising because labor market development in this region is far lagging behind. A parameter that is statistically significant at a 1% level is γ_{AA} alone. Although γ_{AK} is significant at a 5% level, its negative sign violates a regularity condition required for the production function to be well-behaved. Parameters of γ_{LF} and γ_{LK} are statistically significant at a 5% level, while γ_{LL} is negative. Therefore, one-input production function is estimated by imposing the restriction of every parameter except γ_{AA} is equal to zero, and the result is shown in the third column. A slope dummy is included to capture the productivity difference between Villages 1 and 2 (downstream = 1, otherwise = 0). The result suggests that two coefficients are highly significant and that productivity is $100*0.279/0.958=29$ percent higher in downstream than in upstream villages.

The production function is re-estimated by specifying it as the Cobb=Douglass form. The fourth column represents the OLS, while the fifth column represents the IV estimates. The Hausman test does not also reject the null hypothesis with respect to the parameter consistency. The fitness of regressions equation improves as compared with the GL form. As is consistent with fact (ii) and assumption (a), the cropping intensity (the ratio of sown areas to land areas) is positively associated with production. Due to the data restriction, it is impossible to determine the impact of water availability on production. A positive sign of downstream dummy, however, indicates that an advantage possessed by downstream villages prevails over their locational disadvantage in terms of water availability. The elasticity of production with respect to labor, fertilizer, and draft animals is quite small, relative to land elasticity, and some of which are statistically insignificant, which does not contradict the estimation result of the GL function. The last column shows the estimation result when every factor input except land and the cropping intensity are dropped from the original specification. The productivity difference between upstream and downstream villages calculated from this one-input production function specification is equal to $\exp(0.394-0.474)/\exp(-0.474)=1.48$ (48 percent higher in downstream villages) that is larger than in the case of Leontief specification.

Table A-1. Estimation results of production function

	GL		GL with instruments		Leontief	
Labor (L)	-0.565	(-1.42)	-1.231	(-1.25)	–	–
Land (A)	1.477***	(3.07)	0.930	(0.84)	0.958***	(53.51)
Fertilizer (F)	0.006	(0.07)	-0.037	(-0.38)	–	–
Draft animal (K)	0.161	(1.54)	0.148	(1.39)	–	–
$2\sqrt{LA}$	-0.077	(-0.19)	0.508	(0.50)	–	–
$2\sqrt{LF}$	0.313*	(1.85)	0.469*	(1.84)	–	–
$2\sqrt{LK}$	0.373*	(1.93)	0.285	(0.95)	–	–
$2\sqrt{AF}$	-0.058	(-0.39)	-0.171	(-0.82)	–	–
$2\sqrt{AK}$	-0.463**	(-2.47)	-0.368	(-1.30)	–	–
$2\sqrt{FK}$	-0.116	(-1.06)	-0.102	(-0.89)	–	–
Downstream slope dummy	–	–	–	–	0.279***	(5.53)
χ^2	–		1.538		–	
p-value	–		0.999		–	
Adjusted R^2	0.861		0.856		0.842	
Observations	124		124		124	

Table A-1. Continued

	CD		CD with instruments		CD	
Const.	-1.501***	(-5.01)	-1.597***	(-4.65)	-0.474**	(-2.03)
$\ln L$	0.055	(1.20)	0.091	(1.17)	–	–
$\ln A$	0.928***	(20.93)	0.907***	(15.70)	0.939***	(28.63)
$\ln F$	0.044*	(1.77)	0.040	(1.54)	–	–
$\ln K$	0.018	(0.75)	0.019	(0.77)	–	–
Cropping intensity	0.476***	(4.63)	0.474***	(4.60)	–	–
Downstream intercept dummy	0.156***	(2.88)	0.161***	(2.93)	0.394***	(9.28)
χ^2	–		0.328		–	
p-value	–		1.000		–	
Adjusted R^2	0.901		0.901		0.870	
Observations	124		124		124	

Note: Figures in parentheses indicate t-value. *, **, and **** represent 10%, 5%, and 1% significance level, respectively.

Appendix B. Parameters

For the calibration analyses in Section 5, we fix b at 2.0. Although there is no information available for us to determine the value of a, it has to satisfy $a \geq 1/xz^2$ from equations (24) and (25). Substituting equation (26) into this, we have $a \geq (z+b+2bz+bz^2)/z^3$. Since the right hand side of this equation is a decreasing function of z, a has the maximum value when $z=1$. In the case of $b=2.0$, we have $a=9$ for $z=1$. Besides, since the value of z is not indeterminate, we check the sensitivity by assuming $1 \leq z \leq 7$.

The computation results of the relevant variables are presented in Table A-2. In the above half, $e=0.7$ is assumed by which we have $Q_1^* < Q_2^*$, while in the below half, $e=0.25$ is assumed by which we have $Q_1^* > Q_2^*$. The shadow area represents the range of $z=n/m$ that satisfies equations (10), (24), and (27). Cooperative action between Villages 1 and 2 makes sense only in this area. Since $z/(1+z)-e$, $\beta-1/z^2$, and $(1-x^*)\tilde{Q}^{**}-Q^*$ are an increasing function of z, the above three equations are more likely to be satisfied for a lager z. The value of x^* is less than 0.1, suggesting that the resources required for maximizing net rice production is less than 10 percent of the total amount of rice produced. β^* computed from equation (25) is equal to around 0.5-0.7. As is consistent with our argument in Section 3, y_2^* is always equal to unity when $X_2 = X_{\max}$, suggesting that the players' strategy does not reach $(y_1, y_2)=(1,1)$ in Game III.

Table A-2. Calibration results

$a=9$, $b=2.0$ and $e=0.7$	$z=1$	2	3	4	5	6	7
Equation (10)	N	N	Y	Y	Y	Y	Y
Equation (24)	Y	Y	Y	Y	Y	Y	Y
Equation (27)	N	N	Y	Y	Y	Y	Y
$Q_1^*/\bar{R}$	0.70	0.70	0.75	0.80	0.83	0.86	0.88
$Q_2^*/\bar{R}$	1.40	1.40	1.40	1.40	1.40	1.40	1.40
$(1-x^*)\tilde{Q}_1^{**}/\bar{R}$			0.40	0.49	0.55	0.59	0.62
$(1-x^*)\tilde{Q}_2^{**}/\bar{R}$			1.84	1.85	1.87	1.87	1.88
x^*			0.08	0.07	0.07	0.06	0.06
β^*			0.73	0.66	0.61	0.56	0.53
y_2^* when $X_i = Q_i^*$ $(i=1,2)$			0.89	0.82	0.76	0.72	0.69
y_2^* when $X_2 = X_{max}$			1.00	1.00	1.00	1.00	1.00
$a=9$, $b=2.0$ and $e=0.25$	$z=1$	2	3	4	5	6	7
Equation (10)	Y	Y	Y	Y	Y	Y	Y
Equation (24)	N	Y	Y	Y	Y	Y	Y
Equation (27)	Y	Y	Y	Y	Y	Y	Y
$Q_1^*/\bar{R}$	0.50	0.67	0.75	0.80	0.83	0.86	0.88
$Q_2^*/\bar{R}$	0.69	0.69	0.69	0.69	0.69	0.69	0.69
$(1-x^*)\tilde{Q}_1^{**}/\bar{R}$		0.22	0.37	0.46	0.52	0.57	0.60
$(1-x^*)\tilde{Q}_2^{**}/\bar{R}$		2.54	2.56	2.58	2.59	2.60	2.61
x^*		0.08	0.07	0.06	0.06	0.05	0.05
β^*		0.68	0.61	0.56	0.52	0.48	0.46
y_2^* when $X_i = Q_i^*$ $(i=1,2)$		0.39	0.34	0.30	0.28	0.26	0.25
y_2^* when $X_2 = X_{max}$		1.00	1.00	1.00	1.00	1.00	1.00

Notes: (1) Y: an equation is met; N: it is not met. (2) Cooperative action provoked by private motives will take place in the shadowed areas. (3) This table uses the minimum penalty defined by equation (18) for computing y_2^*.

〔Notes〕

(1) But in fact, community-base management is promising in some circumstances, while it is problematic in others, suggesting that rich mixture of private and public institutional arrangements is required for maintaining CPRs in good conditions (Wade, 1988b; Ostrom, 1990; Grafton, 2000).

(2) Baland and Platteau (1996 and 1999), and Jones (2004) provide us with a comprehensive literature review regarding the relation between economic heterogeneity and cooperative efforts. Baland and Platteau (1999, p. 785) say that "increasing inequality, because it redistributes incentives in different directions, thus has ambiguous effect on the ability of users to take steps toward conserving their resources and even toward setting up the required mechanisms".

(3) The Chinese Government enacted this Program in 1998 in order to strike a balance between economic growth and environmental protection. The right to protect and manage local forest is recently devolved to village governments from the state, province or county government in China. However, logging in collectively owned forests is still subject to state quotas and control (Yeh, 2000, p. 269).

(4) High yielding varieties (HYVs) have already been introduced in this region. As is well known, yields of HYVs are very sensitive to the water availability. Therefore, the productivity difference between rain-fed and irrigated paddy is thought to be quite large.

(5) This kind of landholding arrangements is widely observed not only inside villages of Yuanyang County but also in rural communities across the world. The land contract system in China is traced back to land use in the era of the People's Commune System.

(6) There is another method other than income transfer that facilitates inter-village cooperation. Headenders are more likely to agree to the water claims of tailenders when tailenders contribute their labor to the maintenance of local forest and/or the canal headwork in upstream villages (Lam, 1996).

(7) We don not need to think about revenues from timber-felling from fact (iv).

(8) According to Bardhan's study (2000, p. 854) that deals with irrigation systems in South India, the realization of cooperation may be self-reinforcing or habit-forming in a village that has a long history of cooperation.

(9) An empirical study by White and Runge (1994) concludes that multiply imposed penalty systems and reciprocal ethic that are a common foundation for rural societies provides a basis for participations in the collective action for watershed management in Haiti. On the other hand, Tachibana et al. (2001) writes that an existence of social exchange game has no significant influence on the preservation of local forest in Nepal.

(10) As of 2003, the reforested area of Yuanyang County under this Program amounts to 41,116 mu against the total cultivated area of 298,101 mu in the beginning of the year.

(11) Although (S, C) is a stable equilibrium of the best response dynamics when $C_1 = Q_1^*$, it is not the ESS (Matsui, 1992).

(12) In order for the penalty system to be at work as a credible thereat, every S behavior has to be detected without fail and such a behavior has to be punished without any exception. Wade (1988b) says that in the most Third World countries the authority government is not vested with full formal power to penalize noncompliance.

Baland and Platteau (1996, chapter 111) refer to various causes that provoke CPR management failure by government as lack of information and enforcement abilities, corruption, and lack of genuine involvement or participation of user communities. Some of these problems can be solved in Game III. Firstly, knowing the level of penalty accurately is not necessary because any penalty that is equal to or greater than P_2 is effective. Second, the legacy of socialist regime of China makes it possible for the provincial and county governments to exert a strong enforcement power and absolute supremacy over the village committees. Third, the fact that there is no landless class and labor migration is limited makes peer monitoring system much more operational as compared to other developing countries.

(13) See Svendsen (1993) and Dayton-Johnson (2000) as to a theoretical consideration of the CPR cost-sharing rule.

(14) Twice derivative of $(1-x)\bar{Q}^{**}$ with respect to x is equal to $-2az(1+az)/(1+azx)^3$.

(15) According to Baland and Platteau (1996, p. 282), despite some qualifications, there is wide consensus that market penetration has a negative impact on the preservation of CPRs.

(16) This is because land productivity is lower in Village 1 than in Village 2 from assumption (a) under the circumstance of $\phi(W_i)=1$ $(i=1,2)$.

(17) The minimum penalty that is derived from equation (18) is shown in Table A-2. $P_2=1.2$ is larger than the minimum value.

(18) Since $P_2=1.2$ does not satisfy equation (18), it is increased to 2.2 that is larger than the minimum penalty in Game III.

(19) As is intuitively understood from equations (19) and (20), an increase in P_2 would help to decrease T^*.

Besides this, if leaders are able to persuade the half population of Village 2 to select C behavior from the beginning, for instance, by which the convergence process starts from $(y_1, y_2)=(0.99, 0.5)$, time required for reaching the ESS will be certainly shortened. These considerations tell us that there remains a great deal of room for local governments or political elite to take the initiative in leading to successful results.

(20) A similar argument can be seen in Gaspart et al. (1998). In this relation, Baland and Platteau (1996, pp. 344-345) argue that "the privileged users can assume a leadership role and provide the authority structure required for proper enforcement of regulatory rules". On the other hand, they refer to the possibility that "the elite hold a strategic position in the CPRs that enables them to dispense with a corporate organization and with the labor contributions of the rest of the resource users." Although opinions vary as to the role of group heterogeneity in collective action, it sounds quite reasonable from the standpoint of fairness and sustainability of institutional management to design the cost-sharing rule so that people beat the cost proportional to the benefits they receive (Shukla et al., 2002, p. 226).

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