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Cooperatives and irrigation in Vietnam

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To Katie,

whose value to me greatly exceeds that of this work.

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ABSTRACT

Cooperative agricultural activity has existed in Vietnam in various forms for many decades. Under central planning, cooperative institutions provided a means for the government to extract surplus from agriculture for the development of the industrial sector. Now, under policies promoting market liberalization in agriculture, household farming units are no longer obliged to transact with the cooperative. The focus of this dissertation is on the interaction between autonomous household production units and cooperative institutions.

Collective action around irrigation represents one economic motive for coop participation. Recent developments in club theory provide a conceptual framework within which analysis can be conducted. The (partially) non-rival and excludable characteristics of irrigation satisfy the requirement of the model while the presence of agricultural cooperatives suggests a possible means for organizing household production units for efficient utilization of irrigation. A household production model is employed to address the external affects of irrigation among households. The conditions of Pareto optimality for the hybrid model, which combines club theory and household production theory, are derived and compared with the corresponding conditions of conventional club models. The comparative statics of the model are exploited to derive labor market consequences of a shared partially non-rival good.

An empirical analysis is conducted using data from The Living Standards Measurement Survey- an elaborate household and community questionnaire which contains substantial data on household use of irrigation and participation in cooperatives. Evidence is reported for model predictions regarding coop formation, coop participation and labor market effects. The appropriateness of the model confirmed the viability of state cooperatives in a liberalized economy and confirmed the gains in labor productivity due to irrigation infrastructure.

CHAPTER I. COOPERATIVES IN VIETNAM

Introduction

Irrigation has been an important aspect of the economic growth of virtually all developing countries. Sociologists and economists have generated a large and substantive literature regarding irrigation in developing countries.[1] Much of this literature is devoted to the organization of communities around irrigation facilities.

To my knowledge, household production models which include irrigation interdependencies have not been applied to the analysis of farm-level decisions. Household production models have provided considerable insight regarding labor decisions. Adapting household production to include collective action regarding irrigation is one way to forge a link between irrigation and household production and consumption decisions, including labor decisions.

Club theory has been used to address issues related to collective action. Because club theory intends to "cover the whole spectrum of ownership-consumption possibilities, ranging from the purely private or individualized activity on the one hand to purely public or collectivized activity on the other" (Buchanan [1965], p. 1) it is particularly suited to address issues of an irrigating community in which the irrigation services available to the individuals in the community are neither purely private nor purely public. Specifically, club theory has been used to address issues related to finance, resource allocation and Pareto efficiency, all of which are relevant issues for irrigating

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[1]Martin (1989) provides a list of 748 region-specific irrigation studies covering Africa, Central America, South Asia, the Middle East, the Orient, the Pacific region and South America.

communities. To modify household production to include a club input allows analysis of the interaction between irrigation and household consumption and production.

In addition to exploring new theoretical junctures, the proposed research will contribute to the sparsely studied region of Vietnam. Still a communist country, Vietnam has taken significant steps away from a centrally planned economy and toward a market economy. Vietnam has a vast irrigation and drainage system that is crucial for growth in agricultural output and productivity. How irrigation is utilized is an important policy issue facing this emerging exporter of rice.

The dissertation is organized as follows. The rest of this chapter provides a more thorough discussion of cooperatives in Vietnam including a brief historical review. Chapter II reviews the club theory literature and simultaneously constructs a production model which includes a club input. Chapter III develops an extension of the model, which includes simultaneously determined consumption choices, connecting club theory with household production theory. Chapter IV constructs and estimates an empirical model which tests hypotheses related to the nature of irrigation and the value of coops. Chapter V constructs and evaluates an empirical model which tests hypotheses related to the impact on labor markets. Chapter VI presents a summary and conclusions.

Cooperatives in Vietnam

A brief historical review

In order to establish the importance of cooperatives it is necessary to understand the history of cooperatives in Vietnam. In the north, agriculture was collectivized from the late 1950's to 1990; in the south, collectivization was attempted only after reunification in 1975. In the north, the transition to a centrally planned economy (from colonialism) took approximately 15 years. Efforts to collectivize in the south, however, never succeeded. Even though in 1976 the Communist Party adopted a resolution that all party leaders in the south move toward collectivization, by 1986 only 6% of farmers in the Mekong delta were members of cooperatives compared to 99% of farmers in the Red River delta (Pingali and Xuan [1992]). This failure to collectivize was due in part to the brief time provided for the attempt. Four years after reunification, the household contract system was implemented which, at least partially, undermined the formation of collective production teams.

After reunification, two separate systems of incentives existed - a cooperative, centrally planned system in the north and a more liberalized system in the south. The two systems varied greatly in economic performance. Production levels were much higher in the south while production in the north stagnated, a fact which has led some to conclude that the production incentives in the south were superior to those in the north (e.g. Pingali and Xuan [1992]). Although in the north the government had a high degree of control over agricultural markets through cooperatives, in the south, experience with free markets had eroded that control and unleashed more powerful production incentives.

The government has recently admitted the failure of the centrally planned economy and the superiority of the production incentives in a market economy. Consistent with this reversal, more powerful production incentives were cemented for farmers in the form of the 1993 Land Law. This law broadened and made more permanent the land use rights established for farmers in 1988. Among the provisions in the law is the right to lease land for up to 50 years. If the effects of "the land to the tiller" program are any indication, the new law will increase farm-level investment and agricultural productivity (Callison [1983]). Consequently, apart from the presence of substantial gains from collective action, it is expected that farmer participation in cooperatives will continue to decline.

Activities of Vietnamese cooperatives

Tax Collecting

In some areas of Vietnam the scope of the cooperative's responsibilities includes sale of inputs, purchase of output and collection of land taxes (Chung and Weber [1994]). In the past, the cooperatives have functioned as tax collecting agencies of the state by offering prices for agricultural products which were typically much lower than the market price (White [1985]). The dependency on the cooperatives for inputs and employment has ensured high rates of participation in the cooperatives which, in turn, has reduced the costs of monitoring farmers with regard to their compliance with tax obligations. In fact, a recent study (Chung and Weber [1994]) shows that 5-10% of agricultural output is still procured by the cooperative. The study demonstrates the ease with which the State can confiscate output in the north. These cooperatives have been surprisingly compliant with taxation obligations. It is not clear whether such compliance will continue or whether farmers will estimate probabilities of enforcement or monitoring and opt to evade the taxation obligations.

Agricultural Input Distribution

Trade in agricultural inputs has been guided by the state to varying degrees throughout the country. For most of the country inputs have been distributed to cooperatives according to National Land Use Plans. In the past, the cooperatives distributed the inputs to production teams. In the Mekong Delta private markets for fertilizer and pesticides have been present since 1988 (Pingali and Xuan [1992]). Also, several Mekong provinces have imported urea and di-ammonia phosphate independently of the central government.

The trend of replacing cooperative trades with market trades is apparent in the north as well as the south. Chung and Weber (1994) found that 70% of pesticide and fertilizer were obtained from private traders. However, they also note that poor farmers rely more heavily on the cooperative for inputs than do wealthy farmers.

Irrigation Services Distribution

Cooperatives have also played an important role in distributing irrigation services and mobilizing resources for the operation and maintenance of water control facilities. Irrigation services are widely available in Vietnam and are utilized by many farmers. In the Chung and Weber sample of 201 households in the north, no farmer was without access to irrigation services. Khiem and Pingali (1994) report that over 80% of the 6 million hectares of rice sown area in 1990 was irrigated. Small, Bruns and Herklots (1993) state that the portion is only two thirds. The fact remains that a vast area of irrigated land exists in Vietnam and yet not all farmers are irrigating.

Small (1994a, 1994b) has noted that in Quang Nam-Da Nang province in Vietnam cooperatives have a direct role in distributing water to individual household fields and collecting irrigation fees. In other cases the cooperatives contract out the task of distribution to Village Administrative Boards (Ban Dan Chinh Thon). In other cases, the Village

Administrative Boards, not cooperatives, organize local communities. In general, the cooperatives function as intermediaries between households and the Irrigation Management Enterprise (Xi Nghiep Khai Thai Thuy Loi) which operates the main irrigation facilities.

The Economic Benefits of Irrigation

The ability to control water on rice fields represents an important factor in rice production. In areas where total rainfall is adequate for rice production, yield reductions may nevertheless occur due to untimely rainfall. Where this is the case water control may have substantial economic benefits. Chambers (1988, p. 25) cites data which shows that in 4 Indian states the unirrigated areas produced much less food grain (per hectare) than the irrigated areas. Also for India, Easter (1986) shows that application of water from either wells or tanks has a significant and positive effect on rice yields. In Northeast Thailand, net return from crop production was as much as eight times greater in irrigated areas than in non-irrigated areas (Apinantara and Sriswasdilek [1986]). For rice production irrigation influences yields substantially.

The Nature of Irrigation

It is important to note that the nature of the good provided by the cooperative may influence the incentive structure faced by the household. In particular, many have noted the feature of partial non-rivalry in irrigation services (see, for example, Small, Bruns and Herklots [1993]). That is, the consumption of a unit of irrigation services does not entirely reduce the consumption opportunities of the same unit of irrigation services of some other person.

Less clear perhaps is the feature of excludability. In the irrigation systems common to Southeast Asia the delivery of water to individual plots is carried out by relatively small groups of people from the local community. On this scale, monitoring and enforcement of individual farm household decisions is well within the realm of possibility. Although some have neglected this fact (Tang [1992]), others have noted the effectiveness of social organizations to enforce community-wide irrigation practices (see for example, the discussion of the Balinese subak in Hutapea, Dirjasanyata and Nordholt [1978]). The ease with which an irrigating community can enforce agreements regarding individual household production decision implies, at least in some general sense, excludability. With perfect excludability any farmer can be refused all benefits of irrigation if he does not meet the obligations commensurate with receiving benefits. Where both excludability and partial non-rivalry are features of irrigation then irrigation can be characterized as a club good which is impurely public.

By emphasizing the non-rival features of irrigation facilities such as primary canals, reservoirs or large pumping stations, irrigation services may appear to be purely public in nature. Small (1994b) adds to this list by suggesting that operation and maintenance (O&M) of the facilities constitutes a pure public good:

> Irrigation involves many externalities among the people farming within the irrigated area. Externalities and public goods aspects are also typical of the many irrigation services associated with the O&M of the irrigation facilities. Maintaining an irrigation channel free of weeds and silt facilitates the flow of water, and thus enhances the ability of the channel to deliver water to all the fields served by it. Channel maintenance is thus a public good, as

> all farmers served by the channel thus benefit from the fact that water flows quickly through it, regardless of whether or not they contributed to its maintenance. The situation with respect to irrigation operation is similar. Once arrangements have been established for the effective operation of the irrigation facilities, all the farmers served by the system will benefit, regardless of their contribution to the cost of these arrangements. (p. 3)

In addition, Small continues with an explanation of at least one way irrigation services may be partially non-rival: "If, for example, an upstream farmer diverts an excessive portion of the flow of water in a channel into his field, downstream farmers will suffer from a shortage of water." (p. 3)

Upstream overuse of water resources is a frequent source of conflict attributable to the non-rival features of irrigation.[2] One might also conceive of other more hypothetical situations in which non-rival features are operative. For example, the topography of the area adjacent to a channel's banks may require several farmers to irrigate from the same location on the channel. Thus, irrigation by one farmer may result in waiting costs for other irrigating farmers.

Apart from increased costs on some farmers due to increased use by others of the irrigation facilities there may be direct production consequences on some due to the increased use by others of the irrigation facilities. For instance, in a typical gravity scheme, irrigation water flows over an adjacent field before it reaches the end consumer. That is, there is an

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[2] A domestic case in point is the dispute between the U.S. states of Colorado and Kansas over water use rights of the Arkansas river. The widespread practice adopted by Colorado farmers of drilling irrigation wells prevented the Arkansas river from attaining usual flow levels, depriving downstream Kansas farmers of irrigation opportunities. (Kansas Alumni Magazine, August/September 1995)

excess amount of water which is drained from an adjacent field and is subsequently available for irrigation purposes. The portion of the irrigation services used by an individual that is recycled for use by others no longer has the same quality as the original units of irrigation services. Thus, when irrigation services are utilized by high elevation users the amount of the services available to low elevation others is reduced not only in amount but also in quality. The reduced quality directly affects production possibilities.

Collective Action around Irrigation

To the extent that external effects exist in irrigation, absence of a market for the rights to create those external effects prevents a competitive economy from attaining efficient levels of irrigation usage. Consequently, some degree of collective action is necessary at either the national government or the community level to coordinate or induce individual activity to conform to that which is consistent with the efficient outcome. It is in this capacity that agricultural cooperatives in Vietnam may find economic viability.

Recall that in a former life the Vietnamese agricultural cooperative existed as a collective farm and as a means of the government to extract surplus from agriculture. Now, in a market-oriented economy the agricultural cooperative must provide economically viable services or else it simply will not exist. In fact, some predicted the demise of cooperatives shortly after the initial reforms (e.g. Hiebert [1988]). However, the distribution of irrigation services among community members is an important economic function that a coop can have in a market economy. Referring to communities in Quang Nam-Da Nang province in Vietnam, Small states:

> "Responsibility for organizing and financing the construction and O&M [of farmer-managed irrigation schemes] lies entirely with the agricultural cooperatives. Most of these farmer-managed schemes in Quang Nam-Da Nang use pumps to lift water from rivers or other bodies of surface water. Although these pump schemes are relatively expensive to operate (particularly in those cases where they must rely on charcoal-generated water gas to power the engines for pumping), the cooperatives are able to manage them effectively, resulting in economic benefits to the farmers large enough to justify their cost." (1994b, p. 4)

In this particular province (and probably in many others) the government maintains the primary and secondary canals of the irrigation system while the local agricultural cooperative maintains the tertiary and quaternary canals which deliver water to individual land holdings (Small, Bruns and Herklots [1993]) . This system establishes a role for the agricultural cooperative of organizing local farmers in order to distribute irrigation services as efficiently as possible.

The Context of Transition From a Centrally Planned Economy

Currently in Vietnam financing for large scale irrigation facilities is provided by the State as it is in market economies. Such was also the case prior to "economic renovation" (*doi moi*) which began in the early 1990s. However, public provision of operation and maintenance at the local level cannot reasonably be expected to continue under current plans to transition to a market economy. In the past, the government, because it owned either the land or the output or both, was able to extract agricultural surplus via the agricultural cooperative to pay for the public facilities down to the local level. By liberalizing the output markets the government can no longer generate public funds in this manner. The Vietnamese irrigating community in the 1990's must find a way to finance local operation and maintenance of the irrigation facilities or face reduced aggregate output resulting from deteriorated infrastructure or suboptimal aggregate irrigation use.

Implications on the Demand for Other Productive Inputs

Less transparent than the financing issue which faces Vietnamese irrigating communities is the issue of input substitution with irrigation. Insofar as irrigation and other inputs are substitutes for one another in the household's production function, the degree to which communities coordinate irrigation decisions affects the demand for other inputs.

The benefits of irrigation for Vietnamese rural communities may exist not only in the form of increased production but also in the form of increased labor productivity. Thus, where collective action around irrigation may not be justified on the grounds of increased income it may very well be justified on the grounds of preserving other inputs.

The labor-leisure decision provides a relevant example. Suppose that irrigation and labor are gross substitutes. As the price of irrigation increases, the demand for labor also increases and therefore leisure decreases. Either by strong substitutability between labor and irrigation or by strong tastes for leisure the incentives for acting collectively are strengthened. Where both of these effects are strong there is substantial incentive for collective action around irrigation.

The issue of substitutability of other inputs with irrigation is a central one in this dissertation. Hitherto unstudied, this issue may partly explain the disparity of participation rates in agricultural cooperatives between those in the north and those in the south. In order to examine this issue, it seems both necessary and desirous to construct a formal model. The next chapter intends to fulfill that desire.

CHAPTER II. LITERATURE REVIEW AND MODEL OF A CLUB INPUT

In this chapter, the notion of a club is developed. The treatment focuses on the nature of a club of producers as opposed to a club of consumers, the latter being the model that dominates the literature. The neglect of producer clubs may be due, in part, to the presumption that such clubs parallel consumer clubs. In a general equilibrium setting, this is not the case. In order to identify the distinctiveness of a producer club, a formal model must be developed, a task to which this chapter is devoted. The first section briefly reviews the basic concepts of a consumer club. The second section characterizes efficiency for a model of a club input, as opposed to a club good. The third section formalizes individual optimization for a member of the producer club.

Review of Basic Club Concepts

Club theory, as it is known in the field of economics, is based on concepts that are familiar to non-economists as well as economists. When sociologists speak of communities acting collectively toward a goal or for a cause that improves the entire community, they rely on concepts similar to those which underlie club theory. Both fields admit that certain incentives are necessary for such collective action to take place. Perhaps the sociologist would allow altruism to play a part in those incentives. Economists typically have not. In his seminal article, Buchanan (1965) formalized the economic incentives that could support collective action. In particular, he supposed that a partially non-rival good whose purchase price far exceeded the benefit to any one member of the community could be purchased collectively (the cost being shared by the members of the community) such that the benefit to each member was at least as great as that member's share of the cost. In this case, economic incentives are sufficient to forge collective action in the provision of the collective good. That the collective good is *partially* non-rival implies that the size of the club (collective) adversely affects the benefit of each and every member, at least over a specified range of sizes. In general, the optimal club size will not include the entire population. Consequently, exclusion is necessary to achieve optimal outcomes.

Buchanan (1965) spawned a vast literature on club theory that has produced a variety of useful models. These models have shed light on a host of normative issues including the efficient distribution of clubs in the economy and the efficient provision of club facilities and services. Thorough surveys are found in Sandler and Tschirhart (1980) and Blumel, Pethig and von dem Hagen (1986). A more modest attempt is made here to synthesize three decades of productive research. Berglas, Helpman and Pines (1982) and Cornes and Sandler (1986) provide categorizations of club models. Taken together, four distinguishing features of the models appear. Club models

1. are either fixed-use or variable-use models,
2. have a variable number of clubs or a predetermined number of clubs,
3. have the entire population or only part of the population in a club,
4. have homogeneous or heterogeneous memberships.

While there may be other ways to characterize the literature, these four characteristics of club models highlight several important issues raised by club models. By distinguishing between fixed-use and variable-use clubs, the models shed light on, respectively, pure local public goods- where it is usually assumed that the level of the public good is consumed by each member of the community- and public services that are made possible by the existence of public facilities- where it is usually assumed that individual consumption of the services can be less than but not greater than some level determined by the facilities. The variable-use models distinguish between services that are non-rival and the facilities that provide those services. By making this distinction, club models have been applied to a wide array of situations. To borrow the frequently used example of a swimming pool, the models make the important distinction between the individual visits to the swimming pool and the swimming pool itself. The former represents consumption of services while the latter represents the facilities that make possible the consumption of services. Examples of these models are found in Oakland (1972), Berglas and Pines (1981), Berglas (1976b), Berglas, Helpman and Pines (1982), Sandler and Tschirhart (1980), Sandler (1984), Scotchmer and Wooders (1987b) and more recently in Menezes and Silva (1995). Examples of fixed use clubs include Berglas (1976a), McGuire (1974), Berglas (1984) and more recently Henderson (1994) and McGuire (1991).

This subtle conceptual distinction highlighted the difference between membership fee and a "visitation" or use fee, the former being a fee structure that yields an efficient outcome in fixed-use models and the latter being a fee structure that yields an efficient outcome in variable-use models. In the latter case, a membership fee creates incentives such that club members use the facilities until their marginal benefit of doing so is zero. However, the distinction between fixed-use and variable-use clubs is not important for many of the basic conclusions of club theory, including the Tiebout hypothesis.

Tiebout (1956) showed that a consumer-voter will move to a different location, in part because the destination location offers a package of local public goods that most closely reflects the preference of the consumer-voter. To obtain this result Tiebout made several assumptions, including perfect mobility in the population, complete information about all locations, a sufficient number of locations to satisfy the tastes of every consumer-voter. As a consequence, communities tend to consist of individuals with the same tastes: homogeneous clubs.

Much of the literature has been devoted to normative issues. By allowing the number of clubs to vary the models have addressed the issue of optimal club size and, hence, the optimal number of clubs in the economy. Obviously, models which have a predetermined number of clubs cannot address club size optimality. But both models can address the optimal level of the club good and the optimal size of the club. The optimal level of the club good is determined by equating the marginal cost of producing the club good with the marginal benefit to consumers, summed over all the club members (i.e. the Samuelson condition for a public good). The form of the membership condition varies with the structure of the model. In general, membership is determined by equating the net benefit of the added individual of being included in the club with the marginal cost of adding the member to members, summed over all members. In variable-use models, a third condition is produced which determines the optimal level of use. This condition equates the marginal benefit of use for a single member with the total cost of the additional visit summed over all members, including the member whose marginal benefit is considered.

A competitive market mechanism can produce these optimal levels in both homogeneous clubs (see Berglas [1976b]) and heterogeneous clubs (see Sandler and Tschirhart [1984]). Consequently, these models have addressed the concern raised by Samuelson (1954) that "no decentralized pricing system can serve to determine optimally" (p. 388) the level of a pure public good. Thus, the models formalized the contention of Tiebout who pointed out that although Samuelson's statement was true for federal public expenditures, it need not be true of local public expenditures. Models that have contributed to an understanding of the optimality of clubs under a decentralized system include Berglas (1976a, 1976b, 1981), Ng (1973, 1974), Boadway (1980), Berglas and Pines (1980), Sandler and Tschirhart (1980, 1981, 1984), Scotchmer and Wooders (1987b), Schwab and Oates (1991), McGuire (1974, 1991).

Models, which impose a predetermined number of clubs, have had a significant influence on the regional science literature. These models assume that a planner or nature or some force outside the influence of the community determined the number of shared goods in the economy. This feature is prominent in the models relevant to regional science, including those found in Flatters, Hendersen and Mieskowski (1974), Henderson (1994), Helpman and Pines (1980) and Helpman (1978). In this vein of the literature, two clubs are typically assumed which represent two government jurisdictions like cities, counties or states. This assumption allows the model to shed light on the effects of local public goods on commodity and factor movements, and the distribution of the population.

The models that have only a portion of the population as members of clubs were perhaps the last to be understood. Misunderstandings about these models[1] persisted some time after many issues were resolved. The ensuing discourse revealed the necessity of a total economy perspective (one which includes the utility of the members who are excluded from the club) versus a within-club perspective (one which includes only the utility of club members in the objective function).

The models that partition the entire population into clubs contributed to our understanding of what has become known as the integer problem. These models, particularly Berglas (1976b), were used to demonstrate that competition among clubs supported an efficient outcome provided that the size of the optimal (homogeneous) club divided evenly into the total population. That is, the population needed to be an integer multiple of the optimal club size. If this condition did not hold, a member of the club of suboptimal size could bid his way into an optimally sized club, resulting in the expulsion of one member who could bid his way into another club in the same manner.

Basic Features and Implications of a Club Input

Much of what follows in this section mirrors the results of published work. However, in order to introduce and motivate the model in the next section several general results in the

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[1] See the comments in Helpman and Hillman (1977) about Ng (1973) and the comments in Sandler (1984) about Berglas, Helpman and Pines (1982).

literature will be rederived here in a production context. The production model which undergirds the proposed research includes a partially rival, excludable input (i.e. irrigation[2]) in precisely the same manner as some published consumption models have included a partially rival, excludable consumption good. The models, though, are not perfectly symmetrical. Rederivation of general results is necessary to determine precisely where the symmetry fails. This will be accomplished as a byproduct of the two primary objectives of this section: establish the analytical model of the dissertation and demonstrate the ways in which the model coincides with those in the literature. In order to accomplish both objectives the discussion that follows alternately addresses features of the model and connections with the literature.

Consider a production function that has private input x which might be considered labor, and another input r which might be considered irrigation services and which is excludable and at least partially non-rival. The non-rival features of the input are captured in a congestion function that depends positively on the total usage of the input r in a given region and negatively on the level of facilities which are uniquely associated with the provision of the input r. The congestion function can be written as $c(r+\tilde{r},Z)$ where Z is the level of facilities and $\tilde{r}$ is the aggregate level of usage of the input in the region less the amount r which is used by the producer. The theory developed so far requires that the partial derivative with respect

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[2] It should be emphasized that club models have not yet been applied to irrigation. An elaborately constructed model will not only reveal differences with the club good model but also bridge the conceptual gap between club theory and irrigation.

to the first argument $(r + \tilde{r})$ is positive $(c_r > 0)$ and the partial derivative with respect to the second argument is negative $(c_Z < 0)$.

Congestion functions have appeared elsewhere in the literature related to impure public goods. Models that embed a congestion function in a utility function can be found in Deserpa (1978), Oakland (1972) and Sandler and Tschirhart (1980). Models that embed a congestion function in a resource constraint can be found in Berglas and Pines (1981) and McGuire (1974). The seminal model by Buchanan (1965) contains congestion in both the utility function and the resource constraint. Although they analyzed only the Buchanan model, Adams and Royer (1977) derive generalizable results regarding the income and substitution effects of a change in the price of the club good on the amount of the club good and on the size of the club. Their results imply that the manner with which congestion enters the model carries with it implications on the income and substitution effects of variables affecting congestion. Thus, some care should be taken with the specification of congestion in the production model. In the current model it is assumed that the effects of congestion on production may be completely offset by increasing other inputs. This would not be the case if congestion entered the model as a fixed cost.

As others have noted (Blumel, Pethig and von dem Hagen [1986]), the form of the congestion function used here implies that the congestion effects are symmetric in the sense that the congestion created by a unit of use of the club input by one individual is indistinguishable from the congestion created by a unit of use of the club input by any other individual. Others regard these effects as anonymous rather than symmetric, drawing attention to the consequences on strategic behavior (Scotchmer and Wooders [1987b]).

In irrigation, congestion may occur via costs or production. In the previous section three stories were used to describe the possible ways congestion is associated with irrigation. These three and at least three additional stories can be told to elaborate on congestion in irrigation. First, the story was told of excessive upstream water use which reduced irrigation opportunities for downstream irrigators. In this story, congestion is represented by an additional cost to the producer due, for instance, to the increased amount of energy required to apply a given amount of water to the plot.

Second, the existence of a single point source for irrigation produces queuing by farmers for the irrigation services. In this story, congestion is represented by waiting costs or scheduling costs or inconvenience costs.

Third, by recycling lower quality irrigation services into the public irrigation source producers face lower output levels with increased public use. In this story, congestion is represented by an input into the production function.

Fourth, the broader notion of water control which includes but is not limited to water application to the plot appears in the irrigation literature as the factor which increases agricultural production (Trung [1978], Wickham and Valera [1978]). Increased water control increases the probability of achieving the target yield. Although the farmer may utilize the same amount of irrigation services, yields may, nevertheless, decrease if he cannot drain his field in a timely manner because, say, other farmers flood the drainage ditch.

Fifth, use by others of the irrigation system increases the number of stress days, a term used by Wickham and Valera (1978) to denote the number of continuous days greater than 3 in which the plot had no standing water. Prolonged dryness which is associated with stress days results in soil cracking which increases the minimum water requirement for rice (Tabbal and Wickham [1978]). Thus, use by others of the irrigation system diminishes on average the productivity of the water applied to the plot.

Sixth, and related to the fourth and fifth, plot-to-plot drainage systems, which are common in Southeast Asia, not only reduce water control for lower elevation farmers but also provide lower quality water for lower elevation farmers. Regarding the former effect, Wickham and Valera (1978) found that in three Philippine provinces the number of stress days increased at an average rate of 1.4 days per 100 meters of distance from the turnout (irrigation source). The average distance from the turnout was nearly 250 meters so that the average additional stress days was 3.5 which is associated with a reduction in rice yields of 0.1 to 0.3 tons per hectare (Wickham and Valera [1978], p. 65).

A convenient way to model each of these irrigation stories is to include congestion in the production function. By doing so, congestion will have both income and substitution implications. Alternatively, allowing congestion to augment only the resource constraint eliminates the substitution possibilities between congestion and other inputs. Thus irrigation is modeled most generally when congestion enters both the production function and the resource constraint.

Note that the inherent asymmetrical effects on congestion by the agents in the preceding stories is assumed away in the congestion function of the form $c(r+\tilde{r},Z)$. A more general form is $c_k(r_1,r_2,r_3,\ldots,r_{s-1},r_s,Z)$ where k denotes the kth farm household in the set of s farm households. Although not as general, the symmetric form seems imminently appropriate for irrigation use since the production effects of congestion arise mainly as a result of the amount of irrigation usage and not the use for which irrigation is demanded. Whether the irrigating household is large or small, livestock producing or grain producing, rich or poor has no effect on congestion apart from the derived demand for irrigation services. Consequently, the symmetrical form is assumed throughout the analysis.

Let the production function be written as $f(x, r, c(r + \tilde{r}, Z))$ where f(.) is assumed to be strictly quasiconcave in x, r and -c. Therefore, $f_x > 0 > f_{xx}$ and $f_r > 0 > f_{rr}$ but $f_c < 0$. Applying what we know about the congestion function, we theorize that $\partial f/\partial \tilde{r} = f_c\, c_r < 0$ and $\partial f/\partial Z = f_c\, c_Z > 0$. That r (irrigation) enters into the production function is consistent with the rival features of r. The fact that the congestion function depends on the aggregate usage of r is consistent with non-rival features of r. Thus, the input r is said to be partially non-rival (or partially rival). It is important to note that a particular producer's usage of a unit of r reduces the production possibilities of other producers. Combined with excludability this feature defines a particular type of club input.

Analogous features define club goods. Sandler and Tschirhart (1980) define a club as "a voluntary group deriving mutual benefit from sharing one or more of the following: production costs, the members' characteristics, or a good characterized by excludable benefits" (p. 1482). Thus, in their definition excludability, more than non-rivalry, characterizes club goods. On the other hand Pauly (1970) defines a club as "a group of persons who share in the consumption of a good which is not purely private, not wholly divisible among persons" (p. 53,54), emphasizing the non-rival features of the club good although excludability is implied in many of his proofs. Also, Buchanan (1965) in the seminal article on club theory considered goods which are neither purely public nor purely private. Thus, the Buchanan model may also be viewed as one which allows both excludability and non-rivalry as features of the club good. The current production model maintains both features of excludability and non-rivalry, making it consistent with many of the models that appear in the literature.

Excludability provides that the users of the input r can be restricted to a subset of the population with little or no cost. The congestion that occurs from usage of r is experienced only by those who have not refused or been excluded from access to r. The population of producers is comprised of two mutually exclusive sets: one group (referred to hereafter as "the club" or as "the club producers") uses r and also observes a reduction in production due to congestion, the other group does not use r and observes no reduction in production due to congestion.

With this framework, it is possible to examine conditions of production efficiency that apply to the entire population of producers. That is, I will take a total economy perspective that is similar in spirit to Oakland (1972), Ng (1973) and Sandler and Tschirhart (1980). Moreover, I will assume that a single club exists in the community and that the population is divided between a set of club members belonging to the same club and non-club members. This scenario is identical to that of Buchanan (1965), Oakland (1972), Sandler and Tschirhart (1980) and Cornes and Sandler (1986).

The following additional assumptions are necessary to simplify the analysis. First, let the production technologies of each of the producers be identical. Second, let s denote the number of club producers and let $\bar{s}$ be the total number of producers in the economy so that $\bar{s} - s$ is the number of producers for whom the input r has been refused. Third, let the trade-offs in the economy between the private input x and the facilities that provide the input r be captured in the transformation function G(X,Z,s) = 0 where X is the total amount of private input available to producers and Z is the level of the facilities through which the club input r is provided.

The transformation function used here follows other models in which the transformation function G(X,Z) is augmented by the club size, s.[3] In this way, maintenance costs are accounted for which are due to an increased burden on the club facilities. Such costs might include additional labor to distribute the benefits of the coop or to service irrigation outlets that deteriorate from heavy use. On the other hand, for the case of irrigation in Vietnam where large portions of the population irrigate, one might also conceive of ways in which labor is freed up by a larger club size. Specifically, the costs of excluding non-members from irrigation diminishes dramatically as the club size approaches the size of the population. Consequently, there may be a reduction in maintenance costs for a larger coop. Thus, it is not clear how maintenance costs are affected by club size in the case of Vietnamese irrigation cooperatives. By assuming that maintenance costs can be passed on to the member by a lump sum transfer of either cash or labor, there is no need at all to allow s to affect G(X,Z).

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[3] See Sandler and Tschirhart (1984), Berglas (1976a), Berglas, Helpman and Pines (1982) and Cornes and Sandler (1986), pages 165, 171 and 188.

Presumably, a similar argument underlies models that neglect the affect of s.[4] Nevertheless, for the sake of generality, I will account for both resource costs and individual congestion costs that result from increased membership size.

Under these assumptions the optimal allocation of x across producers, the optimal level of r for the club producers, the optimal level of Z and the optimal club size, s, can be determined by solving the following problem

$$\max_{x,r,Z,s,\hat{x},X} \quad sf(x,r,c(sr,Z)) \quad \text{s.t.} \begin{cases} (\lambda) & (\bar{s}-s)[f(\hat{x},0,0)-\hat{Q}]=0 \\ (\mu) & X - sx - (\bar{s}-s)\hat{x} = 0 \\ (\gamma) & G(X,Z,s)=0 \end{cases}$$

where the Greek letters in parentheses represent the Lagrangean multipliers for each of the constraints. The derivatives of the Lagrangean with respect to the choice variables imply the following (assuming an interior solution):

$$x: \quad sf_x - s\mu = 0$$
$$\hat{x}: \quad (\bar{s}-s)\lambda\hat{f}_x - (\bar{s}-s)\mu = 0$$
$$X: \quad \mu - \gamma G_X = 0$$
$$r: \quad sf_r + s^2 f_c c_r = 0$$
$$Z: \quad sf_c c_Z - \gamma G_Z = 0$$
$$s: \quad f + sf_c c_r r - \lambda\hat{f} - \mu(x-\hat{x}) - \gamma G_s = 0$$

where $\hat{f}$ and $\hat{f}_x$ refer to the non-club producer's level of production and marginal product of the private input, respectively, evaluated at the optimal levels. These equations imply the following efficiency conditions[5]:

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[4] See Oakland (1974), Berglas, Helpman and Pines (1982), Sandler (1984) and Cornes and Sandler (1986), pages 177 and 180.

(1) $sc_Z MRTS_{cX} = MRT_{ZX}$ [provision]

(2) $MRTS_{rX} = MRTS_{cX}(-c_r s)$ [toll]

(3) $\frac{f}{f_X} - \frac{\hat{f}}{\hat{f}_X} + (\hat{x} - x) = -src_r MRTS_{cX} + MRT_{sX}$ [membership size]

where $MRTS_{cx}$ is the marginal rate of technical substitution of production congestion for the private input. Because congestion affects production negatively this marginal rate of technical substitution is a negative value as is c_Z so that the left side of (1) is positive. MRT_{ZX} is the marginal rate of transformation of the club input facilities for the private input. In other words, MRT_{ZX} is the marginal cost of the club input facilities in units of the private input. Thus, in equation (1) the left hand side is the marginal benefit to all of society of the facilities which provide the club input and the right side is the marginal cost to society of constructing facilities which provide the club input. When the right side is equal to the left side the level of the facilities is at the optimal level (if (2) and (3) are also satisfied). Equation (1) is properly interpreted as the Samuelson condition and is similar to the condition derived by Sandmo (1972).

Similarly, in (2) the right side is the sum of the marginal costs of employing the club input on the rest of society and the left side is the marginal benefit for the individual club producer of employing the club input. When these two sides are equal to one another the level of employment of the club input is at its optimal level (if (1) and (3) are also satisfied). Note that in both (1) and (2) the marginal cost of congestion in production ($MRTS_{cx}$) is

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[5] Analogs of these conditions for a consumption model can be found in Cornes and Sandler (1986, p. 177), Sandler and Tschirhart (1980, p. 1489) and Sandler (1984, p. 63).

multiplied by the number of producers in the club, s. This is analogous to the Samuelson condition of a public good in which the efficient level of provision of a public good is reached when the marginal cost of providing the good is equated with the sum, over all agents deriving some benefit from the public good, of the marginal benefits.

Equation (3) is rather innocuous and one needs to have in mind the marginal producer who is indifferent between joining the club of producers and not joining the club. Because all production technologies are identical in this model, the only thing that distinguishes the marginal producer from the rest is the state of the economic environment when the participation decision is made. The marginal producer balances the costs and benefits of participating in a club whose membership is s. The left side of (3) is the net increase in output that results from participation in the club, evaluated in terms of the marginal productivity of the private input, plus the net reduction of the private input that results from participation in the club. Recall that participation in the club provides access to the excludable input r which contributes positively to production. The degree of substitutability between x and r will affect the net gains of participation for the marginal producer represented by the two terms on the left side of equation (3). The first term on the right side is the cost of increased congestion imposed on all the other members of the club from the acceptance of one more member (who uses r units of the club input) into the club. The second term on the right side is the cost of distributing the services to one more member. Consequently, the benefits for one individual are balanced against the costs of distribution of the services plus the costs imposed on all the other members in the club when the decision of accepting an additional member is evaluated. The optimal size of the club is obtained when the social cost of an additional member equals the benefit of joining for that member.

Combining (1) and (2) we get

$$(4)\quad MRTS_{rx} = -c_r(sMRTS_{cx}) = -c_r(\frac{MRT_{ZX}}{c_Z}) = \left(\frac{-c_r}{c_Z}\right)MRT_{ZX}$$

In a competitive economy in which r (and not just x) is a private good the following is the analogous efficiency condition.

$$(5)\quad MRTS_{rx} = MRT_{ZX}$$

Thus, policy makers who incorrectly perceive r to be an excludable and entirely rival input will make the mistake of adopting lassez-faire policies. That is, the result of lassez-faire policies (equation (5)) does not match the condition of efficiency. This unpleasant consequence occurs whenever a market does not exist for a valued good or input. In this case, irrigation has external effects on other farmers which are not reflected in the prices resulting from a competitive market for irrigation. In other words, with an input that is merely partially rival a market failure results, justifying market intervention to achieve production efficiency. Note that the degree of intervention depends on the technology of congestion (i.e. the values of the partial derivatives, c_r and c_Z) as is evident from equation (4). Note also that where the partials are equal, a competitive outcome is efficient because the marginal effects of facilities and aggregate irrigation are offsetting; congestion is minimized.

Equation (4) establishes the fact that in this economy a liberalized market for the input r cannot, in general, support an efficient outcome and that an institution other than a market institution may be desirable. Of course, failure of any of equations (1) to (3) will also produce inefficiencies.

Optimizing Behavior of Households

In this section, the incentive structure of household production units will be examined. The analysis requires various assumptions on the costs and benefits of production. For now, consider the assumptions that are consistent with competitive market conditions. Specifically, assume that the household takes as given the output price, P, the private input price, W, and the club input price, T. Regarding the latter, one should note that market power in the hands of the collective decision-making unit does not necessarily confer market power to individual decision-making units. By assuming excludability in the club input r, the framework of a single club permits monopolization of r. The price, T, of the club input is then a price that the club assesses on its own members which reflects the club's market power. It is assumed here that the individual member cannot affect the level of this price either through voting or purchasing the club input. This assumption is quite reasonable for large clubs that have little tolerance for an uneven distribution of power, as is typical in cooperatives in Vietnam. In addition, both the level of club facilities, Z, and the aggregate level of club input usage by all the other club producers, $\tilde{r}$, is invariant to decisions by the household. That Z is exogenous corresponds with an important aspect of irrigation which was discussed previously. Specifically, it was noted that households and even rural communities in Vietnam had no part in the decision involving the production of the irrigation infrastructure. The model below attempts to capture the distribution of the available irrigation services to individual households and the behavior of individual households when their incentives are properly modeled. The household solves the following optimization problem.

$$\pi(P,W,T;Z,\tilde{r}) \equiv \max_{x,r} Pf(x,r,c(r+\tilde{r},Z)) - Wx - Tr$$

where the prices - P, W, and T - as well as the variables Z and $\tilde{r}$ are exogenous to the producer. The first order conditions for the club producer are:

$$x:\quad Pf_x - W = 0 \quad\Rightarrow\quad \text{(F1)}\quad Pf_x = W$$
$$r:\quad P(f_r + f_c c_r) - T = 0 \quad\Rightarrow\quad \text{(F2)}\quad P(f_r + f_c c_r) = T$$

Consequently, it is possible to solve for the actual demands for both the club input and the private input as functions of $\tilde{r}$. In particular,

$$r = r(P, W, T; Z, \tilde{r})$$
$$x = x(P, W, T; Z, \tilde{r})$$

The individual's optimal usage of the club input is determined without considering the congestion imposed on the other members of the club. This is representative of Nash behavior in that the individual producer takes the decisions of others as given and invariant with respect to his own decisions. However, the individual producer takes into account the increased congestion on his own production that results from his own input decisions.

Recall that T represents a "visitation" or user charge. Suppose that a membership charge (say, the cost share, C(Z,s)/s, where C(Z,s) is the cost of providing the irrigation services given facility size Z and membership size s) replaced this fee so that irrigation expenditure (Tr) was replaced with a fixed cost in the household's profit function. In this case, (F2) is replaced with

$$\text{(F2')}\quad P(f_r + f_c c_r) = 0.$$

The household irrigates until its marginal benefit in doing so is zero. This situation is sometimes called the tragedy of the commons since it results in the overexploitation of the resource- irrigation, in this case. Thus, efficiency requires that a per-use fee be assessed on households.

For completeness, consider the non-club producer. Let the non-club producer solve the following maximization problem.

$$\hat{\pi}(P,W) \equiv \max_{\hat{x}} Pf(\hat{x},0,0) - W\hat{x}$$

which has the first order necessary condition

$$\hat{x}:\ \ P\hat{f}_x - W = 0 \qquad \Rightarrow \ \ (F3)\ \ P\hat{f}_x = W$$

Again, the non-club producer takes as given the prices P and W.

It should be emphasized that the costs of producing the club facilities, Z, are not born by the club member. The members take as given the level of facilities which provide them the club input. This feature is particularly appropriate in the present context of irrigation since not only households, but whole communities take as given the level and type of irrigation infrastructure that services the community (see, for example, Small, Bruns and Herklots [1993]). Furthermore, the costs of the irrigation system are not born in any direct manner by the communities.

CHAPTER III. CONSUMPTION PATTERNS IN MEMBER-OWNED PRODUCER CLUBS

Until now the model has only treated production aspects of the club producers. In this section consumption possibilities are included so that the model can address issues relevant to a household which produces a marketable commodity utilizing its own endowment of a productive resource and buys on the market a consumable good.

Extending the model in this way makes it similar in many respects to the basic labor supply model of agricultural households (see, for example, Huffman (1980), Rosenzweig (1980), Huffman and Lange (1989), Huffman (1991), Huffman and Tokle (1994) and Tokle and Huffman (1991)). These models typically treat the inputs to agricultural production as entirely private, i.e. fully rival and excludable. Because the model developed in the previous section incorporates a partially non-rival input, the model extension will raise issues not previously examined in the literature related to labor supply decisions of farm households.

These issues are divided into two groups: normative issues related to efficient allocation of resources and positive issues related to comparative statics. The normative analysis extends the general equilibrium model in Chapter II to address top level efficiency as well as production efficiency. The positive analysis is organized as a set of propositions.

Normative Analysis

Including consumption adds considerable complexity to the efficiency problem. Typically, efficiency is described in three parts. 1) Production efficiency occurs when the productive resources in the economy are allocated among productive processes in such a way that no change in the allocation can take place without decreasing the output of one of the production units. 2) Exchange efficiency occurs when the goods produced in the economy are allocated among consumers in such a way that no change in the allocation can take place without making one of the consumers worse off. 3) Top level efficiency occurs when the efficient allocation of productive resources results in marginal tradeoffs that exactly coincide with the marginal tradeoffs of the efficient allocation of the output of those resources among consumers.

In the typical Walrasian model (see, for example, the treatment in Varian [1992, chapter 18] or the more mathematical treatment in Arrow and Hahn [1971]), resource owners are free to choose among several production techniques to which they may sell their resources. This is not the case in the present model of a club input. That is, the production technique for club producers is not the same as that for the non-club producers, nor is it available to the non-club producers. Consequently, the population is divided with respect to consumption as well as resource allocation and production. In the following model, y is a homogeneous consumable good produced either by club producers or by non-club producers. Also, x_l represents leisure, the amount of the private input which is not used in production. The total endowment of the private input in the economy is given by X. The distribution of X across individuals is determined endogenously in this model.

Regional efficiency

As before, the model assumes identical preferences and technologies making it an extension of the model of a homogeneous club. In this context, the central planner desires to maximize the total utility of the economy. Consistent with the presence of a club, there are in this economy club members and non-members. Because members and non-members have the same utility and production functions they differ in utility and production levels only because of differences in consumption and input bundles. To make this difference explicit, non-member variables will be denoted with a hat ($\hat{x}$, for example) while member choice variables will not have any additional mark (i.e. x). In this economy, two uses of time (x) are possible. First, time may be allocated to a production process which results in the creation of a consumable good, y. This use is denoted as x. Second, time may be consumed directly as leisure, denoted as x_l. As before, the total number of agents in the economy is $\bar{s}$, the total endowment of time available to the economy is X, and the transformation function which maps X to a level of irrigation facilities, Z, is given as G(X,Z,s), where the dependence on maintenance costs has been made explicit. The top level efficiency conditions are determined from the following optimization problem.

$$\max_{\substack{x,x_l,\hat{x},\hat{x}_l,y,\\ \hat{y},r,Z,s,X}} \quad sU(y,x_l)+(\bar{s}-s)U(\hat{y},\hat{x}_l) \quad \text{s.t.} \begin{cases} (\lambda) & sf(x,r,c(sr,Z))+(\bar{s}-s)f(\hat{x},0,0) \\ & \quad -sy-(\bar{s}-s)\hat{y}=0 \\ (\mu) & X-s(x+x_l)-(\bar{s}-s)(\hat{x}+\hat{x}_l)=0 \\ (\gamma) & G(X,Z,s)=0 \end{cases}$$

which has the following first order conditions

$$y: \quad sU_y - s\lambda = 0$$
$$\hat{y}: \quad (\bar{s}-s)\hat{U}_y - (\bar{s}-s)\lambda = 0$$
$$x: \quad s\lambda f_x - s\mu = 0$$
$$\hat{x}: \quad (\bar{s}-s)\lambda\hat{f}_x - (\bar{s}-s)\mu = 0$$
$$x_l: \quad sU_l - s\mu = 0$$

$$\hat{x}_l: \quad (\bar{s}-s)\hat{U}_l - (\bar{s}-s)\mu = 0$$
$$X: \quad \mu - \gamma G_x = 0$$

r: $\lambda(sf_r + s^2 f_c c_r) = 0$

Z: $\lambda s f_c c_Z - \gamma G_Z = 0$

s: $U - \hat{U} + \lambda(f + sf_c c_r r - \hat{f} - y + \hat{y}) - \mu(x - \hat{x} + x_I - \hat{x}_I) - \gamma G_s = 0$

From these conditions one obtains equations (1) and (2), the provision and toll conditions of productive efficiency. In addition, the following conditions are obtained. Equations (1) and (2) are reproduced for completeness.

(1) $sc_Z MRTS_{cx} = MRT_{ZX}$

(2) $MRTS_{rx} = MRTS_{cx}(-c_r s)$

(12.1) $MRS = \hat{MRS}$

(12.2) $\frac{U}{U_y} - \frac{\hat{U}}{\hat{U}_y} - (y - \hat{y}) + f_x[\frac{f}{f_x} - \frac{\hat{f}}{\hat{f}_x} + src_r MRTS_{cx} - MRT_{sX} - (x - \hat{x}) - (x_I - \hat{x}_I)] = 0$

Similar to the Walrasian model, exchange efficiency occurs in this model indicated by (12.1). Note that (12.2) replaces (3) as the membership condition. The condition (12.2) expresses optimal membership in terms of the private consumption good, y. Comparing (12.2) and (3), it is apparent that (3) is neither necessary nor sufficient for top-level efficiency in this model. In general, the optimal club size for production efficiency is not the same as the optimal club size for top-level efficiency when the club is one which shares a public input. Membership involves costs and benefits to club members that go beyond production considerations. There are consumption considerations as well which affect the optimal membership size. The direct affect of club membership on production may be viewed as only the first level of consequences on the Pareto optimal conditions. These production consequences have ramifications on the optimal consumption bundle as well, establishing a more complicated interdependency among optimal consumption bundles, optimal production bundles and optimal club size. This is an important result that demonstrates the precise way in which producer clubs differ from consumer clubs.

Recall that (3) is perfectly symmetric with the corresponding efficiency condition for a consumer club. That is, the top-level efficiency conditions, which arise when a consumption good is shared, look identical to the production efficiency conditions, which arise when an input is shared. But this is where the similarities end. When an input is shared (i.e. in a producer club) other efficiency conditions must be accounted for. In particular, exchange efficiency (equation 12.1) and top-level efficiency must also occur. The deviation of (12.2) from published results confirms the intuition that in a general equilibrium, the symmetry between a club good and a club input is lost.

To reiterate, top level efficiency with a club good is symmetric only with production efficiency of a club input. Top level efficiency conditions with a club input cannot be replicated with a club good. Thus, it matters a great deal whether the shared good affects consumption directly or indirectly through a production relation.

Equation (12.2) can be rewritten in terms of the private input as

$$(12.3)\quad \frac{1}{f_x}\left[\frac{U}{U_y}-\frac{\hat{U}}{\hat{U}_y}\right]+\frac{1}{f_x}\left[(f-y)-(\hat{f}-\hat{y})\right]+(\hat{x}+\hat{x}_l)-(x+x_l)=-src_r MRTS_{cx}+MRT_{sX}$$

To interpret this expression one needs to have in mind the marginal member who faces an environment such that the private benefits of joining the club are exactly offset by the marginal production costs incurred on all the other members by including another individual in the club plus the marginal resource costs of club size. The first term (in brackets) represents the gain in utility (in terms of marginal utility) for the marginal member of joining the club. The second term (in brackets) represents the gain in surplus of household production that results from joining the club. The last two terms represent the reallocation of labor between club members and non-members that is necessary to equate the marginal product of labor and the marginal benefit of leisure between the two groups.

Note that the first two terms are weighted by the unit labor requirement (i.e. the inverse of the marginal product of labor). These two bracketed terms are the analogs of terms that would appear in the membership condition of a consumer club. As in a model of a club good, the net benefit of the marginal club member has a utility component and a "compensating variation" component[1] which is denominated in terms of the good that is directly consumed.

The last two terms represent a complicated mixture of balancing effects. Note that the marginal product of labor is equalized between club producers and non-club producers. This must be the case for an efficient allocation of labor. If $f_{xc} > 0$, then increased membership in the club boosts labor productivity such that a transfer of labor is necessary from non-members to members in order to equate the marginal product of labor between included and excluded households. So, $x - \hat{x} > 0$. This effect may be aided or abated by congestion effects. That is, if $f_{xc} < 0$ and membership in the club carries with it the adverse imposition of congestion on

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[1] Hillman and Swan (1983) interpret $y - \hat{y}$ as compensating variation since in their model it is the amount of the reduction in the club members consumption of the private good that reduces utility to the level of a non-member. While Cornes and Sandler (1986, p. 178) question the consistency of the model, I use the term "compensating variation" only to provide a conceptual handle for the readers who are familiar with the term.

production, then the amount of labor transferred is less than it would be if the club had no congestion.

The transfer of labor is associated with a differential in production between club and non-club members. In addition, note that the private input (labor) is directly consumed as leisure and the privately produced good is also directly consumed. Efficiency requires that the marginal rates of substitution be equal across both club members and non-members. Consequently, both y and x_l may also be different between club and non- club members in order to sustain the equality of the marginal rates of substitution.[2] To reiterate: when a member joins the club, maintenance of the efficiency conditions (specifically (12.1) and $f_x = \hat{f}_x$) requires a reallocation of resources which can be expressed in real terms as part of the net benefit that accrues to the added member.

Note also that in (12.3) the unit labor requirement translates the terms expressed in units of the private good (y) into units of the private input (x) which then can be directly interpreted as the net benefit for the marginal member. In this way, labor productivity plays a direct role in the determination of the optimal club size as it augments the net benefit of membership, vis-à-vis non-membership, for the directly consumed good. Thus, for high labor productivity, the reallocation of labor may represent the entire net benefit for the marginal member.

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[2] In order to make $y = \hat{y}$ and $x_l = \hat{x}_l$, one may wish to assume $U = \hat{U}$. Although Berglas, Helpman and Pines (1982) showed that in a club good model this assumption implies that there is no exclusion in the efficient allocation, it is doubtful that their proof can be applied to the model presented here.

The individual household's problem

Having compared the efficiency conditions with those derived in Chapter II, I will also compare the utility maximizing conditions of a household with those of the profit maximization problem discussed in Chapter II. Many features of the previous model of individual optimization are retained including the exogeneity of Z and $\tilde{r}$, the exogeneity of prices (including the price for the club input), the form of the production function and the role of cost-sharing. There are, however, several new features introduced in this model, including a utility function, a labor market, two-tier pricing of the club input, and a differentiation between the produced good and the consumed good. The result is a model that links club theory with household production theory.

Recall that, in the previous model of individual optimization, the household takes as given the level of the irrigation facilities (Z) and the rate of usage of all of the other club members ($\tilde{r}$). This assumption acknowledged the fact that the decision to provide the facilities and the decisions of other producers are beyond the influence of the individual household. For much the same reason, the size of the club (s) is exogenous. Also, the household is a price taker as before in all markets, including the market for the club input. The production function has the same features as before, including strict quasiconcavity. The cost sharing motive, which has already been repeatedly discussed, appears in this model.

In contrast to the previous model of individual optimization, a strictly quasiconcave utility function is included, the maximization of which represents the household's objective. Recall that in the previous model the household was only concerned with the maximization of money income. As it will be shown later, utility maximization in this model encompasses profit maximization. The household derives utility from the consumption of a private good (denoted y) which is purchased in a competitive market for price V. Also, the household derives utility from leisure which is secured out of the household's endowment of labor, or time, as the two are conceptually indistinct in this model.

The model expressly admits a competitive labor market from which the household may obtain wage income at the market wage (denoted W). The household must determine the optimal allocation of the labor endowment (X) across three distinct uses: household production (or on-farm labor, denoted x), wage income (or off-farm labor, denoted x_m), and leisure (denoted x_l). The presence of a competitive labor market has important consequences on the theoretical form of the optimal solution. In particular, the solution becomes non-recursive in a sense that will be formalized later.

For the sake of generality, it is supposed that the coop utilizes a fee structure that includes a fine component and a coarse component. The fine component is a fee (denoted T) that is assessed on a per-unit or per-visit basis. Specifically, households are assessed the charge, T, for every day (or hour or cubic meter) of use of the irrigation services. The coarse component is a fee assessed on a seasonal basis. Specifically, households are assessed the charge (denoted C(Z,s)/s) for every season they wish to receive irrigation services. As was demonstrated earlier, the fine component is necessary in order to obtain efficiency. The coarse component may be relied upon to cover the fixed costs of the producer club.

The nature of the private consumable good (y) deserves special comment. This model follows others in the macroeconomics literature, in which aggregate consumption is depicted as a single good. In this way, y is an index of all consumption goods. Similarly, the price of y (denoted V) is a price index of consumption goods. It is natural, then, to think of the household produced good as distinct from the private consumable good. Consequently, the price of the household produced good (denoted P) differs from V. In some cases, it may be desirable to model explicitly household consumption out of production, which can be accomplished in this model by restricting the price of the consumable good to equal the price of the produced good. Thus, the model presented contains a model of marketed surplus as a special case.

Under these assumptions the agent solves the following maximization problem.

$$\max_{y,x,r,x_m,x_l} U(y,x_l) \quad \text{s.t.} \quad \begin{array}{c} X = x + x_l + x_m \\ Pf(x,r,c(r+\tilde{r},Z)) - Tr - \dfrac{C(Z,s)}{s} + Wx_m = Vy \end{array}$$

After substituting for y and x_l the first order conditions are:

$$x:\quad U_y\left(\frac{P}{V}f_x\right) - U_l = 0 \quad \Rightarrow \quad \text{(M1)} \quad \frac{P}{V}f_x = \frac{U_l}{U_y} = MRS_{ly}$$

$$r:\quad U_y\left[\frac{P}{V}(f_r + f_c c_r) - \frac{T}{V}\right] = 0 \quad \Rightarrow \quad \text{(M2)} \quad P(f_r + c_r f_c) = T$$

$$x_m:\quad U_y\left(\frac{W}{V}\right) - U_l = 0 \quad \Rightarrow \quad \text{(M3)} \quad \frac{W}{V} = \frac{U_l}{U_y} = MRS_{ly}$$

Note that (M1) and (M3) imply (F1) and that (M2) is identical to (F2). The production decisions are identical to those in the model where consumption was not included. Thus, optimization of production as was presented in Chapter II is implied by the consumption model. Utility maximization implies profit maximization in this model.

Now note that in the consumption model under market conditions the consumption pattern of the household depends only on the real wage. Assuming an interior solution, condition (M3) equates the real wage (W/V) with the marginal rate of substitution of leisure with the consumable good. Also, condition (M1) equates the real wage with the real value of the marginal product of labor. So long as the real wage is exogenous, which is consistent with an interior solution ($x_m > 0$), the optimal consumption pattern which is determined by (M3) will be independent of the optimal production pattern which is determined by (M1). Consequently, (M1) to (M3) need not be solved simultaneously. However, (M1) and (M2) must still be solved simultaneously to obtain the optimal levels of the production variables. In general, production decisions and consumption decisions are non-joint whenever a labor market exists.

The problem for the non-club producer is less complicated and can be written formally as

$$\max_{y,x,x_m,x_l} \quad U(y,x_l) \quad \text{s.t.} \quad \begin{array}{c} X = x + x_l + x_m \\ A + Pf(x,0,0) + Wx_m = Vy \end{array}$$

The first order conditions for this problem are (F3) and (M4).

Figure 3.1 is the picture normally associated with the agricultural household production models found in the literature. The locus of points which include B and B' represents the production possibility frontier for the household. Specifically, an amount of on-farm labor (measured from the right, i.e. from O) has a one-to-one correspondence with an amount of the consumable good. The assumption of strict quasiconcavity in the production function implies that household production monotonically increases in on-farm labor with diminishing marginal returns. Units of household production may be expressed in units of the consumable good by multiplying by

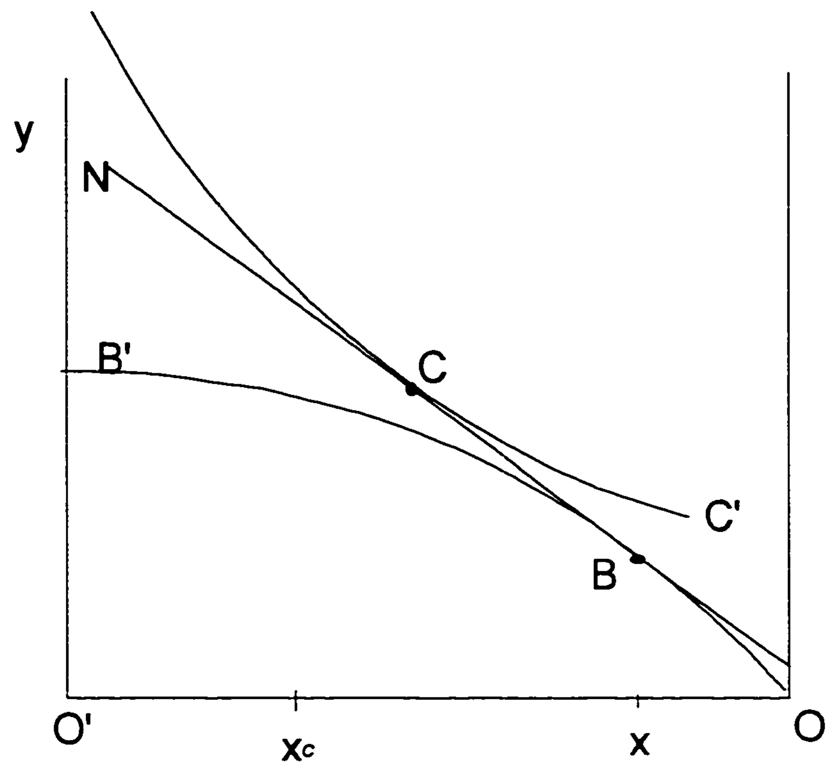

Figure 3.1. Optimal consumption and production patterns

the (exogenous) relative price so that the shape of the mapping between on-farm labor and the consumable good is the same as the shape of the production function.

The locus of points which include C and C' represents a set of consumption points among which the household is indifferent. Recall that utility depends only on consumption of the private good, y, and leisure, x_l. With the assumption of strict quasiconcavity in the utility function, the marginal rate of substitution monotonically decreases along an indifference curve that is drawn in the first quadrant. Thus, Figure 3.1 depicts an indifference curve (CC') that is consistent with measurement of leisure from the left (i.e. from O').

The horizontal axis marks off measures of labor (or time). The length of the line segment O′O represents the total endowment of labor for the household. Moving from O′ to the right is the direction of increasing leisure. Moving from O to the left is the direction of increasing on-farm labor.

The line that connects N and B and passes through C represents the consumption possibility frontier. In this model consumption possibilities are expanded due to the labor market. That is, the household need not be constrained by the production possibilities set. Given that the household can earn the wage W by selling labor to the market, another means of earning income is available which expands the consumption set. The optimal allocation of on-farm and off-farm labor is determined by equating the returns on each. The return for off-farm labor is simply the real wage so that on-farm labor will be provided until the marginal product of the on-farm labor equals the real wage. Thus, the slope of NB corresponds to the real wage. Optimality requires that NB be tangent to the production possibility frontier, B′B.

Given the consumption set defined by NB, the household chooses a combination of (y, x_l) within this set such that household utility is maximized. This occurs when the slope of the indifference curve (i.e. the marginal rate of substitution) equals the slope of the consumption possibility frontier (i.e. the real wage). Thus, point C represents the optimal consumption bundle for the household given the consumption possibility set which depends on household production and the real wage.

Positive Analysis

The input decisions of households are sensitive to changes in the production possibility frontier. In particular, if the production function shifts up for all levels of production due, for instance, to an increase in the marginal productivity of the private input then B would shift to a point associated with a higher level of x. The budget constraint would shift out, the consumption possibility set would expand and the household would arrive at a higher utility level.

Note that Figure 3.1 can also be employed with a club input. The shape of the production function is unchanged due to decreasing marginal productivity. In the household's production function $[f(x,r,c(r+\tilde{r},Z))]$ several factors can affect the marginal product of the private input. In order to sign the effects it is necessary to impose a little more structure to the model. Specifically, assume that condition C1 holds.

Condition C1: $f_{xc} < 0$

Under C1 congestion adversely affects the marginal product of the private input, not just the level of output. It is not hard to imagine cases in which this condition holds. For example, when truckers encounter interstate congestion the consequent diminished speeds not only increase the amount of time necessary to deliver the load but also decrease fuel efficiency. More importantly, with regard to irrigation it has been noted in chapter 1 that congestion diminishes the productivity of irrigation. The logic extends in a natural way. Recall that use by others increases the number of stress days which increase the minimum water requirement to obtain target yields. In addition, stress days increase the labor required to apply the minimum water requirement. By diminishing returns to labor, labor productivity declines.

In order to focus attention on the leisure-labor consequences of a club input we assume for the moment that r is fixed for some period, say, by a contractual arrangement. Adopting this assumption leaves only one decision for the household: the proper allocation of labor between the market and household production and leisure. Under these conditions the following proposition is obtained.

Proposition 1 -

If C1 holds then a) the amount of private input employed in household production increases (decreases) with increased (decreased) facilities and b) if, in addition, the (consumable) private input is a normal good, then the amount of the private input supplied to the market decreases (increases) with increased (decreased) facilities.

Proof:

To prove the proposition it will be useful to write the optimization problem in more familiar terms. This is accomplished by substituting for x_m instead of for x_l and not making any substitution for y. The individual optimization problem can then be written as

$$\max_{y,x,x_l} \quad U(y, x_l) \quad \text{s.t.} \quad F(x; r, \tilde{r}, Z, T, W, s, X) = Vy + Wx_l$$

where $F(x,r, \tilde{r}, Z,T,W,s,X) = Pf(x,r,c(r+\tilde{r}, Z)) - Tr - \dfrac{C(Z,s)}{s} + W(X-x)$, the full income of the household. The first order conditions are

$$\text{(P.1)} \quad \lambda F_x = \lambda(Pf_x - W) = 0$$
$$\text{(P.2)} \quad U_y - \lambda V = 0$$

(P.3) $U_l - \lambda W = 0$

(P.4) $F(x, r, \tilde{r}, Z, T, W, s, X) = Vy + Wx_l$

The optimal values of the choice variables can be written as

$x(W/P, r, \tilde{r}, Z)$

$x_l(P, V, F(x(W/P, r, \tilde{r}, Z), r, \tilde{r}, Z, T, W, s, X))$

$y(P, V, F(x(W/P, r, \tilde{r}, Z), r, \tilde{r}, Z, T, W, s, X))$

Note that (P.1) does not contain the other choice variables y and x_l and that (P.2) and (P.3) do not contain the choice variable x. The system can be solved in blocks. Solving (P.1) yields $x(W/P, r, \tilde{r}, Z)$ as the optimal value of employment of the private input in household production. The change in the optimal value of x given a change in any of the exogenous variables is obtained by totally differentiating (P.1).

(P.5) $f_{xx}dx + f_{xr}dr + f_{xc}c_r(dr + d\tilde{r}) + f_{xc}c_z dZ = dw \quad ; \quad \text{where } w = \dfrac{W}{P}$

Consequently, the partial derivative of the optimal level of employment of the private input in household production with respect to Z is

$$\frac{\partial x}{\partial Z} = -\frac{f_{xc}c_z}{f_{xx}} > 0$$

where condition C1 establishes the sign.

The change in the optimal values of y and x_l given a change in any of the exogenous variables is obtained by totally differentiating (P.2) and (P.3). However, a more straightforward approach to obtain the effect on x_l due to changes in s and Z is to consider the Marshallian demand of x_l derived from the optimization problem. The partial derivative of the Marshallian demand of x_l with respect to Z is

$$\frac{\partial x_l}{\partial Z} = \frac{\partial x_l}{\partial F}\frac{\partial F}{\partial Z} = \frac{\partial x_l}{\partial F}\left(Pf_x \frac{\partial x}{\partial Z} + \left[Pf_c c_Z - \frac{\frac{\partial C(Z,s)}{\partial Z}}{s} \right] \right) > 0$$

To obtain a sign for the expression, first assume that the club's provision of the club good is at an efficient level. That is, suppose that the Samuelson condition holds so that $sc_Z MRTS_{cx} = MRT_{ZX}$. This is equation (2). If the total costs of the club are denoted TC(Z,s) then $sc_Z Pf_c = \partial TC(Z,s)/\partial Z$. A two-tier fee structure, which is included in this model, provides two means by which the total costs of the club may be covered. Consequently, it is supposed that the shared club costs (C(Z,s)), which are covered by a membership fee, represent only a portion of the total club costs (i.e. TC(Z,s) > C(Z,s)) and that $\partial TC(Z,s)/\partial Z > \partial C(Z,s)/\partial Z$. The assumption that the Samuelson condition holds implies that $sc_Z Pf_c > \partial C(Z,s)/\partial Z$. Thus, starting from an initial point where even Z is at an optimum (from the club's perspective) the term in the square brackets is positive as is the other term in the round brackets. The sign is established by the assumption that x_l, leisure, is a normal good.[3] The effect on the marketed amount of the private input, x_m, is then determined by the resource constraint associated with labor, the total derivative of which is

(P.6) $0 = dx + dx_m + dx_l$

This relation yields

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[3] Some empirical analyses support this assumption (see Gronau (1977)).

$$\frac{\partial x_m}{\partial Z} = -\left(\frac{\partial x}{\partial Z} + \frac{\partial x_l}{\partial Z}\right) < 0$$

The proof is complete. Note that we have made use of four important assumptions to obtain this clean result: 1) a labor market, 2) $f_{xz} < 0$, 3) efficiency as a starting point, and 4) leisure is a normal good.

These effects are presented graphically in Figure 3.2. Regarding the production effects, an increase in labor productivity shifts the B′B locus to a higher level. Facing a fixed wage (W), the household will increase its allocation of on-farm labor from X to X′. The

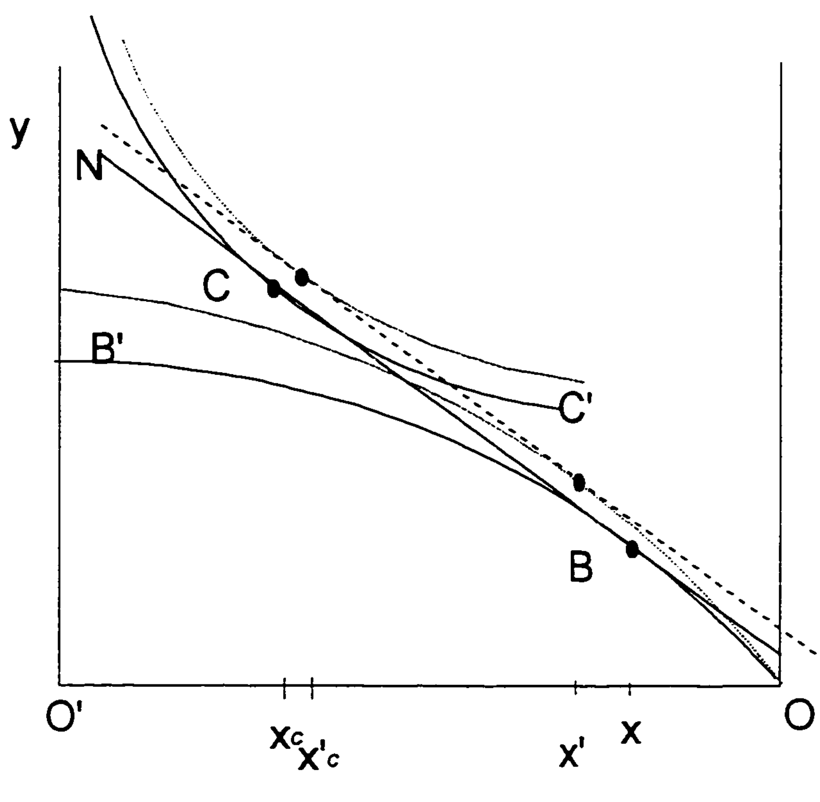

Figure 3.2. Optimal patterns given a change in Z

resulting increase in household income will allow the household to move to a higher level of utility. If leisure is a normal good, as is indicated in Figure 3.2, leisure will increase from OX_c to OX_c'. The remaining allocation of labor, market labor, will decrease. The reduction is represented by the narrower gap between X' and X_c'.

Proposition 2 -

a) The amount of private input employed in household production increases (decreases) as the size of the club decreases (increases).

b) If the club size is larger than the size for which average shared costs are minimized and if, in addition, the (consumable) private input is a normal good, then the amount of the private input supplied to the market increases (decreases) with increased (decreased) club size.

Proof:

Note that $x(W/P, r, \tilde{r}, Z)$ is not explicitly a function of s. However, it should be recognized that the exogenous variable $\tilde{r}$ is related to the exogenous variable s. That is, it is supposed that the aggregate level of irrigation use by the other club members is positively related to the number of club members. Consequently, we can employ the relation $\tilde{r}(s)$ where it is assumed that the derivative is positive. In this way, the optimal amount of on-farm labor depends indirectly on the club size via congestion. Using P.5 we can write

$$\frac{\partial x}{\partial \tilde{r}} = -\frac{f_{xc}c_r}{f_{xx}} < 0$$

which allows us to sign the club size effect on on-farm labor

$$\frac{\partial x}{\partial s} = \frac{\partial x}{\partial \tilde{r}}\frac{\partial \tilde{r}}{\partial s} < 0$$

Now consider the club size effect on the household's optimal consumption of leisure. As before, club size only affects income so that we can write

$$\frac{\partial x_l}{\partial s}=\frac{\partial x_l}{\partial F}\frac{dF}{ds}=\frac{\partial x_l}{\partial F}\left(\frac{\partial F}{\partial x}\frac{\partial x}{\partial s}+\frac{\partial F}{\partial \tau}\frac{\partial \tau}{\partial s}+\frac{\partial F}{\partial s}\right)=\frac{\partial x_l}{\partial F}\left[0+Pc_r f_c\frac{\partial \tau}{\partial s}-\frac{1}{s}\left(\frac{\partial C(Z,s)}{\partial s}-\frac{C(Z,s)}{s}\right)\right]<0$$

The first term in the square brackets is zero by the first order conditions of the household optimization problem. The second term is negative, reflecting the adverse congestion consequences of a change in the club size. The third term, which is the expression in the round brackets, reflects the structure of the costs which are explicitly shared among the club members. The marginal membership effect of this function is compared to the average membership effect. Specifically, where the average shared cost is minimized, the expression is zero and optimal leisure is not affected by exogenous changes in the size of the club. If the club is larger than the size which minimizes the average shared costs of the club, the expression in the round brackets is positive. Taken together, these effects produce an inverse relationship between the optimal level of leisure and the size of the club.

The effect of club size on off-farm labor is obtained via (P.6) which shows that

$$\frac{\partial x_m}{\partial s}=-\left(\frac{\partial x}{\partial s}+\frac{\partial x_l}{\partial s}\right)>0$$

The proof is complete.

Proposition 2 forges a link between shared costs and labor supply. An increase in the size of the club has a direct effect on the aggregate level of congestion faced by the household which has adverse consequences on both the level of output and the marginal product of labor. However, an increase in s has favorable cost-sharing implications provided that the cost of adding another individual to the club (i.e. the marginal cost of membership) does not exceed that individual's share of the cost. In this case, there are only adverse consequences for the individual household of increasing membership. The optimizing household would allocate more labor to off-farm work.

Proposition 3 -

If C1 holds and $f_{xr} < 0$, *then*

a) the amount of private input employed in household production decreases (increases) with increased (decreased) use of the club input and

b) if, in addition, the (consumable) private input is normal and the club input is overutilized then the amount of the private input supplied to the market increases (decreases) with increased (decreased) use of the club input.

Proof:

By (P.5)

$$\frac{\partial x}{\partial r} = -\frac{1}{f_{xx}}\left(f_{xr} + f_{xc}c_r\right) < 0$$

Also,

$$\frac{\partial x_l}{\partial r} = \frac{\partial x_l}{\partial F}\frac{dF}{dr} = \frac{\partial x_l}{\partial F}\left(F_x\frac{\partial x}{\partial r} + \frac{\partial F}{\partial r}\right) = \frac{\partial x_l}{\partial F}\left(0 + \left[Pf_r + Pf_c c_r - T\right]\right) < 0$$

Note that the first term in the round brackets is zero by the first order conditions of the individual optimization problem. If the use of the club input is at the optimal level prior to making an infinitesimal change then the second term (in the square brackets) is also zero and there are no effects on leisure for an exogenous change in the club input. When the club input is overutilized, the expression in square brackets is negative and an infinitesimal change in the club input results in a change in the opposite direction of the optimal level of leisure.

By (P.6)

$$\frac{\partial x_m}{\partial r} = -\left(\frac{\partial x}{\partial r} + \frac{\partial x_l}{\partial r}\right) > 0$$

The proof is complete.

Two aspects of this proposition should be noted. First, r is a fixed factor in this treatment and is of relevance only insofar as it increases output and labor productivity. Second, aggregate usage of the club input by the remaining club members is unchanged. The clean result of Proposition 3 cannot be maintained without these assumptions.

Propositions 1 to 3 highlighted the labor-leisure consequences of a producer club, drawing exclusively on the club input features of the model while imposing the special assumption that r is a fixed factor. Specifically, comparative static results with respect to Z, s, and r - variables unique to a producer club- have been derived as propositions. Other comparative static results on labor supply have been derived for a number of real variables, including real farm price (P/V), and real labor wage (W/V) (Lange [1979]). These results as well as those represented by Propositions 1 to 3 are summarized in Table 3.1.

Table 3.1 Summary of comparative static results

An increase in . . .	. . . produces the following change in . . .		
	household labor	leisure[1]	market labor
Z[2]	(+)	(+)	(-)
s[3]	(-)	(-)	(+)
r[4]	(-)	(-)	(+)
P/V	(+)	(+)	(-)
W/V	(-)	?	?

[1]Assumption: Leisure is a normal good.
[2]Assumption: f_{zr} 0, and r is fixed
[3]Assumption: club profits positive, and r is fixed
[4]Assumption: f_{rr} 0, f_{rz} < 0, r is fixed

Having demonstrated the qualitative implications for household labor supply of collective action around irrigation in a simplified structure, it is now appropriate to be more general. Specifically, let usage of the club input be endogenous rather than exogenous. That is, let the period over which the household makes decisions be such that the club input decision is also made during the period. The household's optimization problem is unchanged. The solution values for the problem are given by (M1) to (M3). The equations that determine production can be written as

$$\text{(M1}'\text{)} \quad f_x = \frac{W}{P} = w$$

$$\text{(M2}'\text{)} \quad f_r + c_r f_c = \frac{T}{P} = t$$

where w and t represent the real wage and the real visitation toll, respectively.

To determine how the optimal levels of the inputs change with the real prices, w and t, it is necessary to totally differentiate equations (M1′) and (M2′). This operation yields

$$f_{xx}dx + f_{xr}dr + f_{xc}c_r(dr + d\tilde{r}) + f_{xc}c_z dZ = dw$$

$$\begin{pmatrix} f_{rx}dx + f_{rr}dr + f_{rc}c_r(dr + d\tilde{r}) + f_{rc}c_z dZ + \\ c_r(f_{cx}dx + f_{cr}dr + f_{cc}c_r(dr + d\tilde{r}) + f_{cc}c_z dZ) + f_c(c_{rr}(dr + d\tilde{r}) + c_{rz}dZ) \end{pmatrix} = dt$$

which can be written in matrix form as

$$\begin{bmatrix} f_{xx} & f_{xr} + f_{xc}c_r \\ f_{rx} + f_{xc}c_r & f_{rr} + 2f_{rc}c_r + f_{cc}c_r^2 + f_c c_{rr} \end{bmatrix} \begin{bmatrix} dx \\ dr \end{bmatrix} =$$

$$\begin{bmatrix} 1 & 0 & -f_{xc}c_r & -f_{xc}c_z \\ 0 & 1 & -(f_{rc}c_r + f_{cc}c_r^2 + f_c c_{rr}) & -(f_{rc}c_z + f_{cc}c_r c_z + f_c c_{rz}) \end{bmatrix} \begin{bmatrix} dw \\ dt \\ d\tilde{r} \\ dZ \end{bmatrix}$$

$$\begin{bmatrix} f_{xx} & \varphi_1 \\ \varphi_1 & f_{rr} + f_{rc}c_r + f\varphi_2 \end{bmatrix}\begin{bmatrix} dx \\ dr \end{bmatrix} =$$

$$\begin{bmatrix} 1 & 0 & -f_{xc}c_r & -f_{xc}c_z \\ 0 & 1 & -\varphi_2 & -(f_{rc}c_z + f_{cc}c_r c_z + f_c c_{rz}) \end{bmatrix}\begin{bmatrix} dw \\ dt \\ d\tilde{r} \\ dZ \end{bmatrix}$$

where $\varphi_1 = f_{rx} + c_r f_{cx}$ and $\varphi_2 = f_{rc}\, c_r + f_{cc}\, c_r^2 + f_c\, c_{rr}$.

If we set dw, $d\tilde{r}$ and dZ equal to 0 and premultiply both sides of the equation by the inverse of the 2x2 matrix then we obtain the partial derivatives with respect to the toll level. Similarly the partial derivatives with respect to the real labor wage are determined by setting dt, $d\tilde{r}$ and dZ equal to 0. The matrix of these partial derivatives is the substitution matrix:

$$(12.a.4) \quad \begin{bmatrix} \frac{\partial x}{\partial w} & \frac{\partial x}{\partial t} \\ \frac{\partial r}{\partial w} & \frac{\partial r}{\partial t} \end{bmatrix} = \frac{1}{\Delta}\begin{bmatrix} f_{rr} + f_{rc}c_r + \varphi_2 & -\varphi_1 \\ -\varphi_1 & f_{xx} \end{bmatrix}$$

where Δ is the determinant of the 2x2 Hessian matrix and is positive by the second order conditions of the maximization problem. As expected, the own price effect of the club input is negative$\left(\frac{f_{xx}}{\Delta} < 0\right)$ as is the own price effect of the private input x by the requirement that the Hessian is negative definite (i.e. the second order sufficient conditions of the maximization problem). The cross price effect of the private input is generally ambiguous even under condition C1. Nevertheless, there may be cases where a negative cross partial derivative (f_{rx}) may be assumed which would ensure that, under C1, $\varphi_1 < 0$ and the optimal level of the private input increases with increasing tolls due largely to the strong substitutability among the inputs. These price effects are summarized in the following proposition.

Proposition 4-

A. Employment of the club input increases (decreases) with decreasing (increasing) unit cost.

B. If C1 holds and $f_{x\tau} < 0$, employment of the private input increases (decreases) with increasing (decreasing) unit cost of the club input.

Proof:

The proof for part A is apparent from (12.a.4). Regarding part B, it was demonstrated in the previous paragraph that if $f_{x\tau} < 0$ and condition C1 holds then $\varphi_1 < 0$ so that $\frac{\partial x}{\partial t} = \frac{-\varphi_1}{\Delta} > 0$.

The proof is complete.

Suppose no toll was imposed on the household with respect to employment of the club input. For example, irrigation payments may be packaged with land payments such that the cost of irrigation to the household is a fixed cost not a marginal cost. In fact, transition to a market economy in Vietnam included the redistribution of government land holdings which were formerly operated by the collective to individual households. Households make payments to the cooperative for land more frequently than for irrigation although much of the land is irrigated. Consequently, the household has incentive to irrigate until the marginal benefit of doing so is zero. That is, the marginal product of irrigation would be equated with the marginal effect of own household irrigation decisions on production through congestion. Levels of irrigation use would increase substantially beyond that which is consistent with a socially efficient outcome. In this situation, (Nash) decisions of club members are suboptimal and the potential efficiency gains for the club are not realized. Moreover, the welfare-enhancement role of a coordinating institution is lost. That is, the situation is akin in results to a seasonal tax on the irrigators. This arrangement does not need a coop and, therefore, apart from other motivations for collective action, a coop is not sustainable. If the real price that households pay for irrigation services is given by (M2′) then the potential efficiency gains are realized. The coop has a welfare-enhancement role and is, therefore, sustainable. These points are summarized in the following remarks about sustainability.

Remark 1: As t goes to 0 the incentive for defection from the efficient level of club input usage increases, the efficiency gains are not realized and the club is generally not sustainable.

Remark 2: As t increases to T/P full efficiency is realized. The cooperative is generally sustainable.

The foregoing analysis depicted on Nash behavior on the part of the household. For completeness the following analysis examines Pareto behavior which may be exhibited in the community. That is, under certain conditions a fully operational club may be observed despite the absence of a toll. Factors which may explain such an observation include societal pressure to conform production decisions to that which is deemed by the community as acceptable. In these cases, economic incentives may be insufficient to explain behavior. Those households which demonstrate cooperation in the absence of economic decisions to do so are referred to as Pareto-minded individuals.

To be more formal let Pareto-minded households solve the Pareto problem characterized by (1), (2), (12.1), and (12.2) for reasons which are neither quantifiable nor economic. The first order conditions for the Pareto-minded producers are

(12.b.1) $f_x = w$

(12.b.2) $f_r + sc_r f_c = 0$

It should be emphasized that these households are voluntarily acting in the collective best interest, not in self-interest. In particular, the benefit of an extra unit of the club input is balanced against the cost incurred on ALL (s) of the other households. This feature defines a Pareto-minded household.

Equation 12.b.2 can be rewritten as

$$f_r + c_r f_c = -(s-1)c_r f_c \quad \Rightarrow \quad f_r + c_r f_c = t(x, r)$$

which bears some resemblance to 12.a.2. Here, the toll is not an exogenous parameter, a fact which is emphasized by the functional dependence on the choice variables, r and x. However, substituting the solution values of the Nash problem into this function and solving gives the value of the toll which would compel Nash-minded households to conform to the Pareto outcome. That is, let t^n solve

$$t = t(r^n(t), x^n(t)) \equiv -(s-1)c_r(sr^n(t), Z)f_c(x^n(t), r^n(t), c(sr^n(t), Z))$$

where $x^n(t)$ and $r^n(t)$ are the solutions to equations 12.a.1 to 12.a.3. (The exogenous variables - w, $\tilde{r}$, and Z - have been suppressed.) Also, t^n denotes the level of the toll which compels Nash-minded households to conform to the Pareto outcome. In other words,

$$x^p = x^n(t^n)$$
$$r^p = r^n(t^n)$$

Appealing to the relations obtained in 12.a.4 the following proposition obtains.

Proposition 5-

If no toll is assessed on households for employment of the club input then

a) Pareto-minded producers employ less of the club input than do Nash-minded producers.

b) If f_{xr} < 0 then Pareto-minded producers employ more of the private input than do Nash-minded producers. Furthermore, if the private input is a normal consumer good, Pareto-minded producers supply more of the private input to the market than do Nash-minded producers.

Proof:

Note that 12.a.4 shows that the substitution matrix equals the inverse of the Hessian matrix of the production function. For a strict maximum resulting in the optimal values x(t,w) and r(t,w) the Hessian must be negative definite, implying global quasiconcavity. Thus, the price effects depicted in the substitution matrix characterize the global properties of the optimal values. In particular, x(t,w) and r(t,w) monotonically decrease in their own prices.

By definition, t^n is positive and is the value that compels Nash-minded producers to produce at the optimal level which is obtained for Pareto-minded producers when they face t=0. A reduction from t^n to zero in the toll faced by Nash producers increases their demand for the club input according to the effects in the substitution matrix. Similarly, if $f_{xr} < 0$ then a reduction in the toll from t^n to zero increases their demand for labor in household production. Also, demand for leisure increases (due to the income effect since leisure is normal). Consequently, labor supplied to the market decreases. The proof is complete.

CHAPTER IV. EMPIRICAL EVIDENCE OF COOP FORMATION AND UTILIZATION

Since widespread market reforms began in earnest in the early 1990's the relationship between the government of Vietnam and rural institutions has changed dramatically. Most notably, collective farms in Vietnam which formerly served as a government mechanism to transfer surplus from the agricultural sector to the industrial sector could no longer serve this function. The emergence of markets for agricultural products and inputs severed the connection between the collective farm and the government.

There still remains the important question about the efficiency and viability of agricultural cooperatives in Vietnam. The collective farm, formerly a government-mandated institution, was transformed by market reforms into an institution which may perform a welfare enhancing role in a competitive economy. In particular, the efficiency losses which are known to exist in competitive economies with externalities, may be regained through the collective action that is embodied in an institution like an agricultural cooperative. This seems to be the case for irrigation, a partially non-rival agricultural input for which decisions by one farmer affect usage possibilities of other farmers. This paper reports evidence that irrigation not only possesses properties of publicness but also enhances the viability of agricultural cooperatives in Vietnam in the presence of widespread market reforms.

The Theoretical Model

Participation in an agricultural cooperative

Having developed a model of labor supply in the presence of a club input (Chapter III), a more simple model will be developed here that captures the incentives for participation in a cooperative. Recall that the agricultural cooperative is hypothesized to be the appropriate institution for coordinating household decisions in the presence of a club input. In addition, it was hypothesized that irrigation in Vietnam has features of publicness such that irrigation is properly characterized as a club input. A simple model would, at a minimum, have features that include a public input and include an institution that may or may not provide the public input. Such a model is described in this section.

Firm profits for households

Drawing from the model of the individual household developed in Chapter III, it is assumed that the households that participate in the cooperative operate like a single-product firm. Recall that in the model developed in Chapter III there were two components of household income- wage income and farm income. Using the same notation as before, we can write household farm income as,

$$\pi^{P} = Pf(x, r, c(r + \tilde{r}, Z), \tau) - Tr - Wx - \frac{C(Z, s)}{s}$$

where Wx is the opportunity cost of farm work. Maximal profits where only x and r are decision variables can be written as

$\pi^p(P, W, T, Z, s, r + \tilde{r}, \tau)$

where P is the price received for the agricultural product which is produced with inputs, x and r, cooperative facilities, Z, and has technology parameter, τ. Note that, just as in Chapter II, congestion (c(.)) enters the production function and depends on the extent of irrigation possibilities (Z) and aggregate irrigation use (r + $\tilde{r}$). The number of participating firms decreases shared costs, if any. The participating firm pays the cooperative T for the irrigation services received from the cooperative and purchases x at price W.

Assuming that households that do not participate in the cooperative are similarly single-product firms, farm income for these households can be written as

$\pi^{np} = Pf(x, 0, 0, \tau) - Wx$

Again, maximal profits, obtained when x is a decision variable, can be written as

$\pi^{np}(P, W, \tau)$

where P is the price received for the agricultural product which is produced with inputs, x, and has technology parameter, τ. As above, the opportunity cost of farming is captured in the term Wx and is included in the determination of farm profits.

Utility of households

Recall that the model developed in Chapter III shed important light on the impact of a labor market. In particular, it was shown that the presence of a labor market separated the household production decisions from household consumption decisions. In the same spirit, it is assumed here that household decisions are made in two stages. In the first stage, production decisions are made, including those related to the provision of labor to household production. In the second stage, after the realization of profits (net of the opportunity cost), the household makes consumption decisions over leisure and a consumable good which may be the same good as that produced by the household. Using the notation of Chapter III, the household's optimization problem in the second stage can be written as:

$$\max_{y,x_l} \quad U(y,x_l,\phi) \quad \text{s.t.} \quad Vy + Wx_l = \pi + WX$$

Note that in the second stage, income derived from selling the household product (i.e. firm profits for the household) and household output is exogenous. To reiterate, this feature is a result of a well-functioning labor market so that the decisions regarding household farm labor (x) and leisure (x_l) are non-joint. Appealing to a less technical explanation, the situation may be considered a seasonal one in which the household farm labor decision is made during planting season and the off-farm labor decision is made thereafter.

Maximal utility can be written as

$$V(V,W,\pi,X,\phi)$$

where X is the total endowment of time possessed by the household and ϕ is a parameter of taste.

Participation in the agricultural cooperative occurs where

$$H_p(V,P,W,Z,s,r+\tilde{r},T,\tau,X,\phi) \equiv$$
$$V(V,W,\pi^p(P,W,Z,s,r+\tilde{r},T,\tau),X,\phi) - V(V,W,\pi^{np}(P,W,\tau),X,\phi) > 0$$

Note that maximal utility is affected by the decision to participate in the coop through farm income (either π^p or π^{np}).

A number of important comparative static properties characterize participation in agricultural cooperatives. The club variables are a good starting point. Recall that congestion adversely affects production and, hence, farm profits for cooperative irrigators. Consequently, Z and $r + \tilde{r}$ affect farm profits and, hence, participation positively and negatively, respectively. Similarly, T reduces farm profits (ceteris paribus) and s increases farm profits by reducing the household's share of the fixed costs. Thus, T and s affect participation negatively and positively, respectively.

Now suppose that marginal utility of income is constant for the households. In this case, coop participation is determined on the basis of enhanced farm profits alone when variations in farm prices are considered. With respect to changes in the output price (P), changes in the participation function depend explicitly on the output supply differential. To the extent that cooperative irrigators produce larger amounts than non-cooperative irrigators, it is expected that participation varies positively with output price. With respect to changes in the labor wage (W), changes in the participation function depend positively on the marketed labor differential. To the extent that cooperative irrigation is labor-saving, it is expected that participation varies positively with the labor wage.

Regarding the effect of household size on participation, constant marginal utility of income removes any incentive the household may have to become a labor-saving cooperative irrigator. That is, the free labor that is available from an additional household member creates additional income strictly through the labor market which is accessible to the household regardless of participation in the cooperative. When the marginal utility of income is the same between participation and non-participation the household size has no effect on the participation decision. But for decreasing marginal utility of income, the household that faces an increase in income due to an increase in household members favors the alternative associated with a higher marginal utility of income, which is also associated with a lower income. To the extent that cooperative irrigation is associated with higher incomes, participation varies negatively with household size.

With regard to the price of the consumption good, both income and substitution effects are relevant, making the changes in participation dependent upon the relative strength of the income and substitution effects and prior beliefs about the different magnitudes of those effects between cooperative participants and non-participants. In general, it is not possible to sign the effect of a change in the price of the consumption good on the change in participation.

To summarize, the effects of changes in the exogeneous variables on coop participation depend, for some variables, on prior beliefs about the status of participants vis-à-vis non-participants. With the appropriate set of priors, the sign of the effect on participation of Z, $r + \tilde{r}$, T, s, P, W, and X, are +, -, -, +, +. +, and -, respectively.

Formation of agricultural cooperatives

Having established the incentives for participation in an institution (a coop) that coordinates decisions regarding the use of a public good, it is now important to characterize the incentives surrounding the formation of such institutions. To do so, we rely on characterizations of the costs and benefits of coop formation. In this paper, club formation refers to the economic feasibility of the existence of a club of the type described in the previous chapter. Where total costs of providing the club input exceed total benefits from the club input, the club is economically infeasible and will not form. Of main concern here is the total costs and benefits aggregated over all club members, rather than the individual costs and benefits faced by households.

Total costs and benefits for the provision of irrigation

Let Z be the level of the irrigation facilities and let the cost of providing those facilities be increasing in Z. We can write the cost to the coalition of households which collectively provide (and consume) the facilities as C(Z). We assume that the total benefits for the coalition depend on the level of the facilities, the number of members of the coalition and the level of aggregate use of the facilities so that we can write the benefits as $B(Z,s,\ r + \tilde{r}\,)$. By assuming that benefits to the coalition are increasing in the number of members, s, it is implicitly assumed that the shared facility has some public features associated with it. That is, the benefits derived from the usage of one member do not entirely reduce the benefits obtained by another member using the same facilities. Conversely, if the collective good is private in nature, benefits would decrease with an increase in s. That irrigation has public properties is a hypothesis that can and will be tested in this essay.

Cost-benefit analysis and coop feasibility

When the benefits to the coalition exceed the costs to the coalition then it is economically feasible for a collective to form. However, the way in which the net benefits are distributed among the members is crucial to the sustainability of the collective. The club input model that was analyzed in Chapter II had the appealing feature of accommodating diverse production functions in the club so long as a per unit fee was assessed on irrigation services.[1] That is, producers with differing demands for irrigation services could attain Pareto optimality by acting collectively if those with higher demands for the irrigation services made larger contributions to the collective. A per unit fee accomplishes this precisely because the net benefits of collective action are distributed "fairly" among the members. However, a per unit fee is considerably more difficult to implement than a flat membership fee. Consequently, it would be easier to form a homogeneous, variable use club than a heterogeneous variable use club since a flat membership fee (one that is not affected by repeated uses of the irrigation facilities) is part of an optimal solution in a variable use club only if members are very similar in their demand for the irrigation services. In this case, everyone pays his share which is exactly the same as everyone else's share.

Consider a mathematical formulation of coop formation. Let the coop formation variable be denoted as z^*, so that

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[1] Although mixed clubs (i.e. heterogeneous memberships) were not expressly discussed, the model of individual optimization presented here is consistent with a variable use club which can support heterogeneous memberships. (See Sandler and Tschirhart [1984].) Fixed use clubs cannot. (See Berglas [1976a].)

$$z^* = G(B(Z, s, r + \tilde{r}) - C(Z), E, \chi)$$

where E denotes the degree of homogeneity among members such that a low value of E corresponds to a high degree of homogeneity among members and where there is some function G(.) that determines the level of the coop formation variable and where χ represents community characteristics. A coop will form in an area where the coop formation variable is above some threshold level, say, $\bar{z}^*$. Thus, coop formation is associated with positive values of some function $H_f(.)$ where

$$H_f(Z, s, r + \tilde{r}, E, \chi) \equiv G(B(Z, s, r + \tilde{r}) - C(Z), E, \chi) - \bar{z}^* \quad \text{and} \quad \frac{\partial H_f}{\partial s} > 0, \frac{\partial H_f}{\partial E} < 0, \frac{\partial H_f}{\partial (r + \tilde{r})} < 0$$

The Empirical Model

Having developed a model that captures the incentives faced by individuals that utilize an impurely public input and by groups that attempt to provide the public input, it is now desirable to disentangle these two sets of incentives. These two sets of incentives can be characterized as coop participation incentives and coop formation incentives, respectively. In a fully liberalized economy, the two sets are linked. That is, the reason(s) that independent economic units act collectively is (are) frequently associated with the reason(s) independent economic units continue to participate in the cooperative because the formation and participation decisions are made by the same set of agents. However, in a command economy this may not be the case. Although a central planner may have economic reasons for dictating the formation of a cooperative, those reasons may not coincide with the reasons individual agents choose to participate in the cooperative. Given the history of central planning in

Vietnam which excluded the commune from the formation decision of cooperative institutions, independence will be maintained between coop formation and coop participation.

The type of data available for analysis dictates to some extent the type of technique used for the analysis. The variables of interest are coop formation and coop participation, neither of which is directly observable. However, whether or not a coop exists in the commune is available in the data and represents a binary variable that corresponds to the latent variable, coop formation. Similarly, whether or not a household obtains irrigation services from the coop is available in the data and represents a binary variable that corresponds to the latent variable, coop participation. Consequently, probit equations are the appropriate empirical models for these situations in which binary variables are available for latent variables.

Equation (1) formalizes the empirical model by denoting the latent variable with an asterisk and the vector of explanatory variables with $\mathbf{x}$. The error term, u, is distributed standard normal, for which the cumulative distribution function is denoted as $\Phi(.)$.

$$(1)\quad y_{1i}^{*} = \beta_1'\mathbf{x}_{1i} + u_{1i}; \qquad i = 1,\ldots,n$$

$$y_{1i} = 1 \quad \text{if } y_{1i}^{*} > \bar{y}_1{}^{*} = 0$$

$$y_{1i} = 0 \quad \text{if } y_{1i}^{*} \leq \bar{y}_1{}^{*} = 0$$

$$P_1 = \mathrm{Prob}(y_{1i} = 1) = 1 - \Phi(-\beta_1'\mathbf{x}_{1i}) = \Phi(\beta_1'\mathbf{x}_{1i}); \qquad i = 1,\ldots,n$$

$$P_2 = \mathrm{Prob}(y_{1i} = 0) = \Phi(-\beta_1'\mathbf{x}_{1i}); \qquad i = 1,\ldots,n$$

The likelihood function can be written as:

$$L = \prod_i P_1^{y_{1i}} P_2^{(1-y_{1i})}$$

Taking logarithms and using a variable transformation[2] yields

$$\ln L = \sum_i \ln \Phi(\beta_1' \mathbf{x}_{1i} q_{1i})$$

Maximum likelihood methods require first order differentiation of this expression (to obtain the gradient) and second order differentiation of this expression (to obtain the Hessian). The gradient and the Hessian can be written, respectively, as

$$\frac{\partial \ln L}{\partial \beta_1} = \sum_i \left[\frac{\phi(\beta_1' \mathbf{x}_{1i} q_{1i})}{\Phi(\beta_1' \mathbf{x}_{1i} q_{1i})} \right] (q_{1i} \mathbf{x}_{1i})$$

$$\frac{\partial \ln L}{\partial \beta_1 \partial \beta_1'} = -\sum_i \left[\beta_1' \mathbf{x}_{1i} q_{1i} + \frac{\phi(\beta_1' \mathbf{x}_{1i} q_{1i})}{\Phi(\beta_1' \mathbf{x}_{1i} q_{1i})} \right] \frac{\phi(\beta_1' \mathbf{x}_{1i} q_{1i})}{\Phi(\beta_1' \mathbf{x}_{1i} q_{1i})} (q_{1i} \mathbf{x}_{1i})(q_{1i} \mathbf{x}_{1i})'$$

Based on these equations, maximum likelihood techniques can be used to obtain parameters for the probit equations associated with coop formation and participation.

The Data and Variables

This simple model of institutional participation has a prescribed set of variables associated with it. The model dictates that variables be used which can be characterized as prices, demand shifters, technology shifters, cooperative goods or services, coop membership, and taste parameters. In addition, the level of aggregation differs such that coop formation requires commune level variables while coop participation requires household level variables. The main source for the data is the Viet Nam Living Standards Survey which consists of three separate questionnaires- the household questionnaire, the community questionnaire and the

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[2] See Appendix 2 for all the mathematical details and derivations.

price questionnaire. Rainfall data from the Legates global climatology was also used. A thorough description of these data sets is provided in Appendix 1. In addition, secondary data from the Ministry of Water Resources, Socialist Republic of Vietnam, obtained from Svendsen (1995) is utilized.

There are several issues regarding the data and variables that deserve discussion including sample size, geographic distribution and precise definitions of particular variables. With regard to sample size, 3114 households of the 4800 total households surveyed in the Viet Nam Living Standards were used. Because commune data was used, for which only rural communes were surveyed, the urban households (30*32=960) were excluded from the analysis. In addition, there were 5 of the 120 rural communes that did not report the market wage for field preparation, eliminating 160 households from the analysis. Missing data for individual households required that 547 more observations be eliminated. The data requirements for the model are satisfied for households which cultivate rice, have rights to land and who live in rural communes. Finally, 15 of the remaining observations indicated that they received irrigation inputs from the coop even though the coop did not exist in the commune. These observations were discarded.

Table 4.1 presents relevant commune level variables that will be used to estimate the coop formation equation. An examination of the geographic location of communes which have cooperatives reveals that none exist in the most southern regions of Vietnam. In fact, the southernmost commune with a cooperative is 150 km northeast of Ho Chi Minh City. Consequently, any explanatory variable that also possesses this geographic bias will have a

Table 4.1. Descriptions and statistics of relevant commune variables

Variable	Description
IRLNDCOM	binary (0,1)- 1 where the commune has some irrigated land
COOPS	binary (0,1)- 1 where the commune has a cooperative
AREAIRGR	estimate for the number of irrigators in the commune
DRYRAIN	total amount (mm) of rainfall during the dry season (November through April)
TRADIRR	the percent of irrigation methods that are not government schemes
FEECOLL	amount of paddy (kg/ha) collected as water use fees
GINI	gini coefficient of net agricultural income for the commune (0 is perfect income equality)
COMIEST	instrument for the level of aggregate irrigation use in the commune
LNYIELD	the natural log of [rice output (kg) / irrigated land (sq. m.)] for the sample irrigators
LNOUT	the natural log of rice output (kg) for the sample irrigators
LNLAND	the natural log of irrigated land (sq. m.) for the sample irrigators
LNINSC	the natural log of total insecticide expenditure (thou. dong) for the sample irrigators
LNEQUI	the natural log of the value of farm equipment (thou. dong) for the sample irrigators
LNWKR	the natural log of the number of agricultural workers for the sample irrigators

Table 4.1. (continued)

	n=115		n=88	
Variable	Mean	Std Dev	Mean	Std Dev
IRLNDCOM	0.7652	0.4257	1.0000	0.0000
COOPS	0.6435	0.4811	0.7046	0.4589
AREAIRGR	1038.2647	911.2255	1350.1534	816.6430
DRYRAIN	341.2522	206.1683	339.3864	206.6285
TRADIRR	34.3330	18.8519	33.3421	18.6365
FEECOLL	51.6957	37.4518	60.8296	36.9887
GINI	0.0485	0.0286	0.0486	0.0218
COMIEST	6.2589	3.4852	8.1793	0.1698
LNYIELD			8.1336	0.3242
LNOUT			18.9095	0.9869
LNLAND			10.7759	0.8169
LNINSC			7.2089	1.3288
LNEQUI			8.6540	1.1491
LNWKR			4.2112	0.5185

relatively large t-statistic in the probit equation for coop formation. This is the case for many of the variables used in the probit equation, including FEECOLL, GINI and TRADIRR.

That many variables in Vietnam have this geographical bias demonstrates that social disparities still exist between the north and the south. With respect to participation in cooperatives the disparity is again apparent. (See Pingali and Xuan [1992].) Rather than use a North/South dummy variable, the analysis in this paper attempts to shed light on the economic incentives which may vary greatly between the north and the south with regard to participation in cooperatives.

It should be noted that the variables used from Svendsen (1995), which include TRADIRR and FEECOLL, do not have much variation. These are regional variables where a single region can encompass as many as 36 sample communes. Vietnam is divided into 8 of these regions.

For most of the variables in Table 4.1, the descriptions provided sufficiently characterize the variables. However, the variable for aggregate irrigation use (COMIEST) needs a more thorough description. Because no data exists on actual irrigation practices among households in Vietnam and because irrigation use plays an important part in the theoretical model, it is necessary to construct a suitable variable. Recall that $r + \tilde{r}$ represents the level of aggregate irrigation use of the commune. For large irrigating societies, like those found in Vietnam[3], the level of irrigation use of the individual household is a relatively small portion of the total. Consequently, the error is negligible when $\tilde{r}$, and not $r + \tilde{r}$, is regarded

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[3] Note from Table 4.1 that the average number of irrigators in a commune is over 1000.

as aggregate irrigation use of the commune. For this reason, aggregate irrigation use of the commune is used to proxy $\tilde{r}$.

In order to arrive at a suitable estimate for aggregate irrigation use, it is important to consider the way in which irrigation affects rice production. Crop modeling systems offer a relation between rice yield and irrigation use. Reyes (1973) reports such a relationship for a number of rice varieties. Agronomic data was fitted to a logistic functional form to determine the parameters b_1, b_2, and b_3 of $y_r = \frac{b_1}{1 + b_2 e^{-b_3 r}}$, where y_r is rice yield and r is irrigation use. Reyes reports values of b_1 in the range [4.83, 9.08] where the lowest value is associated with low nitrogen levels and a particularly severe dry season (and consequently, high rates of evaporation). The values for b_1 are correctly interpreted as the maximum possible yields for the variety. When viewed as a production function, b_1 is a vertical shifter for marginal product. Similarly, b_2 is a horizontal shifter for the marginal product. The coefficient b_3 alters the rate of change of the marginal product. (See Appendix 3 for figures that illustrate features of the logistic function.) Note that specification of these three parameters (b_1, b_2 and b_3) fully specifies the marginal product of irrigation use. Inverting the function, one obtains irrigation use as a function of yield,

$$r = -\frac{1}{b_3}\ln\left(\frac{b_1}{b_2 y_r} - \frac{1}{b_2}\right) = -\frac{1}{b_3}\ln\left(\frac{\frac{b_1}{y_r} - 1}{b_2}\right) = -\frac{1}{b_3}\ln\left(\frac{b_1}{y_r} - 1\right) + \frac{1}{b_3}\ln(b_2).$$

Note that for $b_1/y_r < 1.1$, $\ln(b_1/y_r - 1) \approx \ln(b_1/y_r)$. This condition implicitly assumes that the actual yield is not less than, say, 90% of the biological maximum which is a function of the exogenously determined state of nature that is associated with the growing conditions. In other words, it is assumed that the optimal output level, given input prices and technological parameters, is not too far below the biological maximum. That this is a reasonable assumption is demonstrated in Appendix 3. Making this substitution and simplifying gives

$$r = -\frac{1}{b_3}\ln\left(\frac{b_1}{y_r}\right) + \frac{1}{b_3}\ln(b_2) = \frac{1}{b_3}\ln(y_r) - \frac{1}{b_3}\ln(b_1) + \frac{1}{b_3}\ln(b_2) = \frac{1}{b_3}\ln(y_r) + d$$

where d is some constant. The estimate of irrigation use is a linear transformation of the natural log of rice yield.

The next step requires the regression of the estimate of irrigation use on determinants of irrigation use. Linear regression allows the substitution of r with $\ln(y_r)$ since the former is a linear transformation of the latter. Formally, the regression model is

$$\ln(y_{ri}) = X_i\beta + \mu_i; \quad i = 1,\ldots,n$$

The fitted values of this regression represent the instrument for irrigation use. It is important to note that in the household production model yield is endogenous. By using fitted values instead of actual values the endogeneity is no longer a problem. If the value of the estimate of the coefficient on irrigation use is a desirable parameter, it is necessary to divide the parameter estimate by an appropriate value for b_3, say, 0.63 (the value obtained by Reyes for IR8, 100 kg/ha N, 1971 dry season, when irrigation use has units of mm per day and yield has units of metric tons per hectare) in order to obtain the average irrigation use in mm/day for a representative plot.

A variety of approaches to obtaining an estimate for aggregate irrigation use are available. The possible approaches range from primal estimation of an aggregate production function to dual estimation of an individual household production function. The method applied in this analysis estimates a primal production function at the commune level, appealing to the reasonable assumption that large transportation costs inhibit trade in inputs across communes. Assuming a Cobb-Douglas form of the production function allows the log-log form of the production function to be estimated by ordinary least squares, the variables of which are included in Table 4.1.

Regarding an appropriate measure of household irrigated rice production, it was observed that of the five types of rice in the survey, spring rice necessarily requires irrigation so that the yield of spring rice is a very good measure of rice yield under irrigation. As supporting evidence in this data set of the relationship between irrigated rice and spring rice, one should note that of the 3367 rice producing households, 2672 planted spring rice, 2653 had irrigated land and 2152 reported both irrigated land and spring rice cultivation. Furthermore, of those 2152 households, 1076 reported that the amount of land under spring rice cultivation was exactly equal to the amount of irrigated land operated by the household. Yield was calculated as the ratio of two reported numbers by the household, the amount of spring rice harvested and the amount of spring rice area. Of course, if the household reported no spring rice the household was eliminated from the analysis. A sample size of 2484 households resulted.

Other aggregated household data include irrigated land, insecticide expenditures, equipment value and the number of agricultural workers. As with the rice output data, these measures were agggregated over all rice irrigating households in the commune and then transformed to the natural logarithm to obtain LNLAND, LNINSC, LNEQUIP, LNWKR, respectively. Ordinary least squares regression results are presented in Table 4.2 for the Cobb-Douglas form of the production functions. The results suggest a technology that has increasing returns to scale and is relatively labor-intensive, both of which are plausible, intuitive results for the case of Vietnamese irrigation. Also, equation (2) shows that the coefficient on LNLAND is not significantly different from 1, verifying the validity of the yield relation of equation (1).

Table 4.2. Parameter estimates for the instrument for irrigation use

	LNYIELD (Natural log of irrig rice yield) (1)		LNOUT (Natural log of irrig rice prod) (2)	
Variable	Estimate	t	Estimate	t
C	6.36391	19.311	6.14789	14.722
LNLAND			1.04314	20.419
LNINSC	0.07601	3.002	0.06618	2.371
LNEQUI	0.07039	2.401	0.06855	2.328
LNWKR	0.14545	2.534	0.10696	1.458
R Square	0.29384		0.92445	
n	88		88	

The instrument of irrigation use is obtained by multiplying the coefficients in Table 4.2 by the 3 variables listed in equation (1) for each of the communes that have irrigated land. Thus, the aggregate irrigation use variable, COMIEST, is constructed as

$$COMIEST_i = 6.364 + 0.076 * LNINSC_i + 0.070 * LNEQUI_i + 0.145 * LNWKR_i; \quad i = 1,\ldots,88$$

Recall that the theoretical model predicts how the variables in Table 4.1 affect the probability of the formation of cooperatives. The coop formation model variables s, E, and $r + \tilde{r}$ are proxied by AREAIRGR, GINI and COMIEST, respectively. The expected signs of these variables on coop formation are +, -, and -, respectively. In order to learn something about household utilization of local cooperatives, a set of relevant household variables were constructed from the available data. Table 4.3 describes these variables. The coop utilization model variables Z, $r + \tilde{r}$, T, P, W, and X, are proxied by AREAILND, COMIEST, FEECOLL, AVGP, PREPWAGE and HHSIZE, respectively. The expected signs of these variables on coop utilization are +, -, -, +, +, and -, respectively. In the next section, evidence will be presented that suggests that the model of a congestible public input is quite relevant to irrigation in Vietnam.

The dependent variables- COOPS for coop formation and IRRINP for coop utilization- deserve a more thorough discussion than what is provided for these variables in Table 4.1 and Table 4.3. Regarding coop formation, the data suggest that a very precise notion of the institution prevails in rural Vietnam. Specifically, it appears that the question in the survey referred to those institutions which were formerly collective farms, so that the data presents the existence of cooperatives that have explicit ties to the state. This data happens to

Table 4.3. Descriptions and statistics of relevant household variables

Variable	Description
IRLNDCOM	binary (0,1)- 1 where the commune has some irrigated land
COOPS	binary (0,1)- 1 where the commune has a cooperative
IRRINP	binary (0,1)- 1 where the coop provided irrigation inputs on the annual crop land
AREAIRGR	estimate for the number of irrigators in the commune
DRYRAIN	total amount (mm) of rainfall during the dry season (November through April)
FEECOLL	amount of paddy (kg/ha) collected as water use fees
GINI	gini coefficient of net agricultural income for the commune (0 is perfect income equality)
AVGP	average of three reported prices (000 dong) for ordinary rice in the commune
RPI	regional price index (calculated by the World Bank)
PREPWAGE	wage (000 dong) reported by the commune for a day's work for a man doing field preparation
AREAILND	estimate of the amount (ha) of irrigated land in the commune
COMIEST	instrument for the level of aggregate irrigation use in the commune
HHSIZE	number of household members

Table 4.3. (continued)

	n=3114		n=2446		n=1830	
Variable	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
IRLNDCOM	0.7855	0.4106	1.0000	0.0000	1.0000	0.0000
COOPS	0.6953	0.4604	0.7482	0.4342	1.0000	0.0000
IRRINP	0.5100	0.5000	0.6451	0.4786	0.8623	0.1273
AREAIRGR	1120.7227	915.4135	1420.5500	803.5883	1517.7832	721.6326
DRYRAIN	341.1220	206.8049	334.6791	203.8914	336.6694	213.7665
TRADIRR	33.2416	18.5180	32.3591	18.2201	25.5433	12.5909
FEECOLL	55.1497	36.9823	63.9685	35.7063	80.0891	22.7277
GINI	0.0469	0.0263	0.0474	0.0269	0.0363	0.0133
AVGP	1.2251	0.3802	1.1800	0.3501	1.1982	0.3643
RPI	1.0328	0.0630	1.0420	0.0621	1.0662	0.0482
PREPWAGE	9.5745	4.3361	9.3283	3.9922	8.2410	3.4604
AREAILND	3757298.9469	4452957.6943	4703075.6637	4551819.5384	3523780.5718	1839157.5520
COMIEST	6.4251	3.3615	8.1798	0.1679	8.1391	0.1273
HHSIZE	5.0299	2.1133	4.9137	2.1024	4.6858	2.0310

be quite useful since current policy discussions touch on the issue of whether the residual institutions from decollectivization should be fostered or discouraged. The results of this analysis suggest that state organized irrigation institutions have an economically viable role even after market reforms.

Regarding coop utilization, irrigation services represent the relevant criterion that determines the association of the household with the cooperative. That is, household utilization of the cooperative is determined exclusively by the household decision of whether or not to receive irrigation inputs from the cooperative. Household utilization of non-irrigation services provided by the coop is not considered here in order to focus attention on the role of irrigation in establishing the economic viability of an agricultural cooperative which has explicit ties to the state.

Discussion of Results

Discussion of coop formation

Recall that coop formation depended upon the total benefits of the shared facility, the total cost of the shared facility, the manner in which benefits and costs are distributed and community characteristics that support or undermine collective action in the community. The results of the probit model of coop formation are reported in Table 4.4. Consistent with a public good, the number of irrigators in the commune (AREAIRGR, an estimate for the number of irrigating households in the commune) positively affects the likelihood of coop formation. This result would not be expected in the context of a private shared good, in which case an additional member would diminish the amount of the good available for the rest of the members by the amount consumed by the additional member. Total benefits to the coop would be fixed by the amount of the shared good. In contrast, if a fixed amount of a public good is shared the sum of the benefits to coop members increases when the number of members increase. This is precisely the effect that is observed with this data.

Table 4.4. Estimates for coop formation

Variable	Model Variable	Coop Formation Probit (COOPS) Estimate	t-stat
C		2.6557600000	2.289
AREAIRGR	s	0.0007549980	2.025
DRYRAIN	χ	-0.0015405700	-1.456
TRADIRR	χ	-0.0536250000	-2.294
FEECOLL	χ	0.0200410000	2.197
GINI	E	-25.2293000000	-2.027
COMIEST	$\tilde{\tau}$	-0.0479400000	-0.673
Log Likelihood		-24.309	
n		115	

Another result that is consistent with the theoretical predictions of the model is the effect of member homogeneity on coop formation. The data suggests that income inequality has a negative effect on coop formation. Although the variable, GINI, was calculated for a sample from the entire commune and not from the subset of coop members, the sets are nearly the same in many communes, particularly in the north. Consequently, GINI should adequately represent the degree of homogeneity among coop members. Assuming this is the case, the analysis suggests that the effect of like populations on coop sustainability is substantial. Since the empirical model does not distinguish between a fixed-use and a variable-use model, no direct statement can be made about the non-rival characteristics of irrigation, whether the irrigation facilities are the non-rival good (as in a fixed-use club) or whether the irrigation services, which are made possible by the facilities, are the non-rival good (as in a variable-use club). The result obtained here is consistent with what one would expect when use of public facilities is paid for by an area-based irrigation fee. Such a situation requires that members have similar characteristics in order to sustain a cooperative. Consequently, the results provide some empirical support for the hypothesis that the facilities themselves and not the services which are derived from those facilities represent the non-rival good.

Collective farms and cooperatives represented the cornerstone of agricultural policy in the late 1970's. Despite vigorous attempts to organize southern farmers into cooperative production units, few cooperatives formed. With the advent of market liberalization, efforts to organize farmers ceased. But strikingly, the cooperatives in the north did not spontaneously disband as if the government's coercion was the only glue that held the cooperatives together. Rather, a stark disparity exists in which coop formation is high in the north and non-existent in the south. Such a disparity also exists in the GINI variable in which low values prevail in northern communes and higher values prevail in southern communes. Figure 4.1 plots the GINI variable against the commune number which increases from north to south. Noticeably higher levels of income inequality exist in the south.

The notion that irrigation in Vietnam motivates collective action is further supported by a substitution effect between irrigation and the amount of rain that falls during the dry

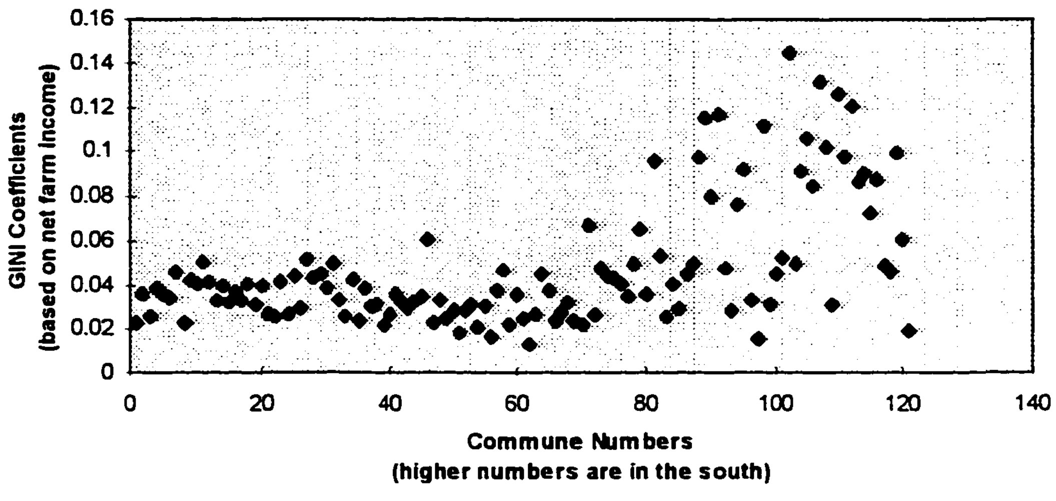

Figure 4.1. Standardized GINI coefficients for Vietnamese communes

season (DRYRAIN). That is, an increase in rainfall during the months of the dry season significantly reduces the probability of coop formation. It is important to note that DRYRAIN is not a disparate variable with respect to the north and south regions.

There are also substitutes for the irrigation services provided by the state cooperative. Note that in areas where traditional practices of irrigation (TRADIRR) like "swing baskets, buckets, small private pumps, and perhaps small gravity diversions" (Svendsen (1995), p. 4) which are not organized by formal government schemes are prevalent, there is a significant decrease in the probability of coop formation. This is further evidence that irrigation activities are being coordinated through the cooperative in places where the cooperative exists. It should be pointed out that TRADIRR has very little variation. In fact, there are only eight values corresponding to the eight regions in Svendsen (1995). Each region is associated with many communes. Consequently, TRADIRR is rightly considered to be exogenous to the commune.

The sustainability of collective agriculture in the face of widespread market reforms depends upon the ability of the collective to cover the fixed costs of providing the shared good. In other words, the supply of cooperatives requires adequate financing of the shared good. Thus, the extent to which financial resources are extracted from households for irrigation services partly determines the sustainability of the cooperative. This is precisely the effect observed for FEECOLL.

In general, the results of the coop formation analysis are consistent with the model that was formulated earlier. The rather simple characterization of collective costs and benefits matched the data fairly well. This analysis finds that market-oriented models explain the existence of cooperatives which have strong ties to the state. Specifically, where those cooperatives are organized around a public good, like irrigation, the association with the state does not imply inefficiency. In fact, such institutions perform a welfare-enhancing role in a market-oriented economy.

Discussion of coop utilization

Examining coop utilization is another way to evaluate the nature of cooperative institutions. Some have suggested that state-affiliated cooperatives still resort to coercion in order to maintain participation levels even after market reforms.[4] What will emerge in this analysis is a picture of a transition economy that is representative of neither a pure centrally planned economy nor a pure market economy. The distinction between the two is observed most readily at the level of the cooperative where the participation incentives vary greatly under the two institutions. In a centrally planned economy, the existence of a cooperative (or collective farm) implies full participation of the agricultural population since the cooperative is an agent that the government uses to extract surplus from agriculture. In a market economy, the existence of a cooperative (or club) implies a set of incentives such that only a subset of the population will choose to participate, assuming the cooperative provides an excludable and partially non-rival good or input. Thus, the level of participation provides a clue as to the nature of the institution. Of the 1830 observations which reside in communes which have both a coop and irrigated land, only 252 (14%) did not receive irrigation inputs from the coop. However, only 167 of these reported that they did not receive irrigation inputs from the cooperative even though they had irrigated land. Figure 4.2 presents these facts in terms of two variables- IRRINP (from Table 4.3) and IRRTOT (the total amount of irrigated land for the household). The data reveal a high incidence of coop provided irrigation services to those households that have irrigated land. It should also be pointed out that all of the 1830 households received from the coop some kind of services which include biological protection, plowing or protection of crops, as well as irrigation.

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[4] Tran and Nguyen (1995) state that "other cooperatives, in the Red River Delta, however, suffer bad management and their relationships with households are still overbearing and monopolistic." (p. 203)

		IRRTOT	
		0	>0
IRRINP	0	86	166
	1	21	1557

Figure 4.2. Correlation of two variables.

These facts demonstrate that household level interactions with the coop are widespread in areas where the coop and irrigated land coexist. Where it continues to exist, the cooperative may indeed have institutional features that are similar to institutions of a centrally planned economy.

The model of coop utilization that was developed earlier assumed that no institutional constraints (or compulsions) exist that impinge on the household's decision. The estimates from that model are presented in Table 4.5. Where the empirical results depart from the expected theoretical results, there may be reason to infer that market institutions which underly the theory are not fully formed.

Table 4.5. Estimates for coop utilization

		Coop Utilization Probit (IRRINP)			
		(1)		(2)	
Variable	Model Variable	Estimate	t-stat	Estimate	t-stat
C		-5.7953000000	-1.244	9.6918400000	2.644
DRYRAIN	χ	0.0018505800	6.504		
FEECOLL	T	-0.0285850000	-3.903	-0.0035517200	-0.711
AVGP	P	1.1220100000	6.067	1.2460300000	6.893
RPI	V	23.4408000000	7.338	11.2010000000	5.252
PREPWAGE	W	0.0199990000	1.533	0.0287190000	2.198
AREAILND	Z	0.0000000754	2.958	0.0000000976	3.931
COMIEST	$\bar{r}$	-2.1738800000	-5.795	-2.6817200000	-7.366
HHSIZE	X	-0.0445470000	-2.265	-0.0506520000	-2.665
Log Likelihood		-552.312		-579.23	
n		1830		1830	

In general, the results confirm the theoretical model. The theory predicts that an increase in the irrigation facilities strictly increases the probability of participating in the cooperative. As irrigation capacity increases, congestion from irrigation use is reduced, increasing prduction and farm profits and increasing the incentive to participate in the cooperative. The coefficient on AREAILND confirms this effect insofar as AREAILND captures the variation of irrigation facilities across communes.

The enhanced value of the cooperative due to the facilities is offset by the level of irrigation use. That is, aggregate irrigation use increases congestion and reduces production, reducing the incentives to participate in the cooperative. As the instrument for aggregate irrigation use, COMIEST has a negative and significant effect on coop utilization, as expected.

The charge assessed on households for irrigation services represents a disincentive to join the cooperative. In areas where water fees are high participation in cooperatives should be relatively weak. This effect is observed for FEECOLL, whose coefficient is negative but significant only in equation (1), Table 4.5. According to the theory, per unit irrigation fees reduce irrigation use of participating households. Similarly, per unit irrigation fees reduce maximal profits (and utility) for the household so that the likelihood of participating in the coop is also reduced. In addition, fixed irrigation fees may constitute membership fees in an irrigators' club. In this case, an increase in fees (whether flat fees or per unit fees) decreases participation in the irrigators' club. That the effect of FEECOLL is unclear suggests one or both of the following effects

(a) collected fees do not exactly correspond to charges on individuals.

(b) irrigation is non-excludable

Regarding (a), a supply side argument may be appropriate. That is, just as a decrease in the corporate tax rate may increase total tax revenues generated from the tax rate, a decrease in the irrigation charge may also increase total irrigation fees collected. Suppose that the irrigation fees are indexed to the level of production. A decrease in the irrigation fee may induce the household to utilize irrigation more intensively, boosting yields and possibly increasing the total irrigation payment. This notion is confirmed somewhat by Svendsen (1995): "In spite of its relatively low fee levels, the Red River Delta generated more revenue per hectare (101 kg/ha) than any other region during the past three years" (p. 15). In this case, the total fees collected corresponds poorly to the charges assessed on households.

Regarding (b), it is helpful to think of fee collection for services and excludability from services as two sides of the same coin. When the services are non-excludable, fee collection is more difficult since there is no immediate recourse for non-payment, like shutting off the water. In this case, participation may occur regardless of the level of fees since the participants believe that the likelihood of actually having to pay the fee is small. In other words, the likelihood of free-riding behavior is large. In the opposite case where irrigation services are excludable, fee collection should be relatively high since the likelihood of free-riding behavior is small. Taken together, these two scenarios suggest that fee collection should be high when excludability is high. Excludability may, in fact, vary across irrigation schemes so that the effect of fee collection on coop participation is ambiguous.

Regarding the price variables, the intuition is roundly confirmed by the data. Specifically, the output price for household production (i.e. the rice price) is expected to increase participation in the coop based largely on intuitive reasons for supposing that rice supply is greater for coop irrigators than non-irrigators. The effect of AVGP bears out this intuition. Also, supposing that irrigation is labor-saving, it is expected that the labor wage increases participation in the coop so that higher levels of income can be secured. This effect is observed for PREPWAGE, whose coefficient is positive but significant only in equation (2), Table 4.5.

Finally, the effect of the household labor endowment on coop participation represents a measure of the differential of marginal utility of income. Presuming that household income is greater in the cooperative, the differential of marginal utility of income is negative for risk averse households. The significantly negative coefficient on HHSIZE suggests risk aversion among rural households.

Summary

The empirical analysis in this section exposed two important realities. First, the analysis confirmed the publicness of irrigation and the appropriateness of the model outlined in an earlier section. Second, the analysis confirmed the viability of an irrigation institution that has explicit ties to the state. It was shown that where the coop continues to exist, provision of irrigation services represents a raison d'être. Irrigation was determined to be an important coop service that increased the likelihood of coop formation and increased the likelihood of individual household participation. The analysis substantiated the notion that irrigation services of a coop make it a viable institution in a market economy. Such institutions promise to enhance community welfare as measures are taken to price irrigation services at appropriate levels.

CHAPTER V. THE IMPACT OF IRRIGATION ON LABOR MARKET CONDITIONS

That technical externalities destroy the efficiency of a competitive equilibrium is a well known result that has undergirded arguments promoting the establishment of a strong, intervening government. There is, however, much more to be learned about the economic consequences of production interdependencies. While much attention has been focused on the production consequences of unregulated commons situations, very little attention has been focused on the consequences on input demand, input substitution or resource supply.

The conceptual foundation is actually quite simple. In a commons situation, the decisions of all the other appropriators restrict the production possibilities of a single appropriator. In an irrigation context, the irrigation decisions of all the other irrigators restrict the irrigation decisions of a single irrigator. To the extent that irrigation is a substitute for other inputs, the demands for those inputs depend on aggregate irrigation usage. In household production units, household labor is a substitute for irrigation. Consequently, the supply of household labor to the labor market is also affected by aggregate irrigation use. This study investigates the effects of irrigation use and the level of irrigation facilities on household labor supply.

Irrigation in Vietnam has important public consequences. Among the less obvious consequences are possible effects on the emerging labor markets in rural Vietnam. In this chapter, I exploit the link between labor markets and household production which utilizes irrigation. An extension of the household production model to include irrigation as a club input was described and analyzed in detail in Chapter III. In this chapter, the theoretical relationships established in Chapter III are analyzed empirically. The results suggest substitutability between labor and irrigation at the household level. In addition, the public nature of irrigation is supported by evidence of negative congestion effects of irrigation use and positive production effects of irrigation facilities.

The Theoretical Model

Consistent with the model of Chapters II and III, it is assumed here that the household is the relevant decision-making unit which faces resource constraints represented by labor and money and which maximizes a utility function that depends on consumption and leisure. Optimal levels of consumption and production can be determined by solving the following optimization problem.

$$\max_{y,x,r,x_m,x_l} U(y,x_l,\phi) \quad \text{s.t.} \quad \begin{array}{c} X = x + x_l + x_m \\ Pf(x,r,c(r+\tilde{r},Z),\tau) - Tr + Wx_m = Vy \end{array}$$

Note that the consumable good (y) is purchased for price V as before with the income derived from off-farm employment (x_m) which receives the wage W plus the sale of the household produced agricultural good which receives price P, less the cost of irrigation use (r) assessed at price T. Household production depends positively on on-farm labor (x), household irrigation use (r) and negatively on congestion (c(.)) which depends on the irrigation use of all other households plus the household's irrigation use $(r + \tilde{r})$ and the irrigation facilities (Z). Total household labor (X) is allocated among the following possible uses: on-farm labor, off-farm labor and leisure.

Demand functions are obtained for y, x_l, x, x_m, and r. In the presence of a well-functioning labor market the demand for x, x_m, and r is independent of the demand for y and x_l. This is the non-recursive or separable feature which produced the clean results of Propositions 1 through 3 in Chapter III. Although employment opportunities are scarce for rural households in Vietnam, there are seasons when opportunities to do fieldwork are abundant. The market for field work is all that is necessary. We can write the off-farm labor supply equation as

$$x_m = x_m(W, P, V, \tilde{r}, Z, X, T, \tau, \phi)$$

The Reservation Wage

The reservation wage (W^r) for the household is the largest wage available to the household for which the household does not allocate labor to non-farm employment opportunities (i.e. $x_m = 0$). Consequently, we can write, $W^r = W^r(P, V, A, \tilde{r}, Z, X, T, \tau, \phi)$, where τ and ϕ are technology and taste parameters, respectively. The probability of wage work, then, is precisely the probability that the actual wage is greater than the reservation wage.

It is important to emphasize that the model stipulates that the off-farm decision is made simultaneous with the decisions regarding on-farm labor, leisure, consumption of market goods, and irrigation use. In general, the estimation of a single equation in the model yields biased results since there is no accounting for the dependence of the choice variables on the error terms of the other equations. However, certain conditions remove this bias. Specifically, the existence of a well-functioning labor market separates the production decisions from the consumption decisions as was demonstrated in Singh, Squire and Strauss (1986). Consequently, the disturbances in the consumption variables, y and x_l, are not transmitted to the production variables x and r Furthermore, if the production function is weakly separable in the factors of production then the optimal input levels do not depend on the disturbances of the other inputs.[1] Under these conditions, plausible estimation procedures include single equation estimation techniques. The next section describes one such technique.

The Empirical Model

Having developed the theoretical foundations for the labor supply decision, it is now necessary to develop an empirical model that is consistent with these foundations. In particular, it is assumed that households allocate labor to off-farm employment opportunities if and only if the wage received exceeds the reservation wage of the household.

Following others (e.g. Huffman and Lange [1989], Tokle and Huffman [1991], Huffman and Tokle [1994]), let $z^* = W - W^r(P, V, A, \tilde{T}, Z, X, T, \tau, \phi)$ represent the wage differential that the household faces. As before, W is the wage received from off-farm jobs. By assumption, the household supplies labor to off-farm activities whenever z* is positive. Unfortunately, the reservation wage (W^r) is not directly observable. However, whether

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[1] See Hoch (1958) for an example using the Cobb-Douglas form.

households allocate labor to off-farm uses is observable. The decision to supply off-farm labor is a binary variable that is correlated with the latent wage differential variable. Formally, the empirical model can be represented as

$$(1)\quad z_i^* = \gamma'\mathbf{w}_i + u_i; \qquad i = 1,\ldots,n$$

$$z_i = 1 \quad \text{if } z_i^* > 0$$

$$z_i = 0 \quad \text{if } z_i^* \leq 0$$

$$\Pr ob(z_i = 1) = \Pr ob(u_i > -\gamma'\mathbf{w}_i) = \Phi(\frac{\gamma'\mathbf{w}_i}{\sigma}); \qquad i = 1,\ldots,n$$

$$\Pr ob(z_i = 0) = \Pr ob(u_i \leq -\gamma'\mathbf{w}_i) = 1 - \Phi(\frac{\gamma'\mathbf{w}_i}{\sigma}); \qquad i = 1,\ldots,n$$

If u_i is distributed normal with mean zero and variance σ^2, then $\Phi(.)$ is the cumulative distribution function for the standard normal distribution. The likelihood function can be written as

$$L = \prod_i P_1^{z_i} P_2^{(1-z_i)}$$

where P_1 is the probability that $z_i = 1$ and P_2 is the probability that $z_i = 0$.

Taking logarithms yields

$$\ln L = \sum_{i=1}^{n} z_i \ln P_1 + (1 - z_i) \ln P_2 = \sum_{i=1}^{n} \ln \Phi(\frac{q_i \gamma'\mathbf{w}_i}{\sigma})\,.^2$$

Maximum likelihood methods can be used to estimate the parameters, γ/σ.

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[2] See Appendix 2 for an explanation of the variable transformation for q_i.

The Variables

Table 5.1 presents the variables used in the analysis. Many of the variables used in this model are the same as those used in the previous chapter. Specifically, AVGP is used as a proxy for the price (P) of the household product. AREAILND is used as a proxy for the level of the facilities (Z) of the coop, HHSIZE is used as a proxy for the labor endowment (X) of the household, and FEECOLL is used as a proxy for the irrigation fee (T) assessed on the household. COMIEST is used as a proxy for aggregate irrigation use ($\tilde{r}$).

Table 5.1. Descriptions and statistics of relevant variables

Variable	Description
WGWORKHH	binary (0,1)- 1 where the household has some wage income
RPI	regional price index (calculated by the World Bank)
AVGP	average of three reported prices (000 dong) for ordinary rice in the commune
PREPWAGE	commune daily wage (000 dong) reported for a man doing field preparation
HHSIZE	number of household members
AREAILND	estimate of the amount (sq m) of irrigated land in the commune
COMIEST	instrument for the level of aggregate irrigation use in the commune (see Chapter IV)
FEECOLL	amount of paddy (kg/ha) collected as water use fees

Table 5.1. (continued)

	n=3114	
Variable	Mean	Std Dev
WGWORKHH	0.4145	0.4927
RPI	1.0328	0.0629
AVGP	1.2288	0.3830
PREPWAGE	9.5526	4.3372
HHSIZE	5.0299	2.1133
AREAILND	3742446.4672	4447421.2211
AREAIRGR	1116.7366	915.0208
COMIEST	6.4251	3.3615
FEECOLL	54.9476	37.0082

Recall that the proofs of propositions 1-3 in Chapter III relied on fixed use of irrigation services (r) fo the household, at least in the short run. Note that in equation (2) of Table 4.2, variation in LNLAND explains virtually all of the variation in irrigation use, suggesting strong complementarity between irrigation use and land use. Since land is fixed in the short run, irrigation use is also properly considered fixed in the short run.

With an effective labor market, the theoretical results derived in Chapter III as propositions 1-3 are expected. Specifically, an increase in the price (P) of the household product increases the value of marginal product of household labor which increases the reservation wage of the household which decreases the probability of wage work. Similarly, an increase in the level of the irrigation facilities (Z) increases the value of marginal product of household labor which decreases the probability of wage work by the same mechanism; an increase in the level of aggregate irrigation use ($\tilde{r}$) decreases the value of marginal product of household labor which increases the probability of wage work by the same mechanism. Also, an increase in the labor endowment of the household (X) increases the probability of wage work since the additional leisure, which is due to increased income, cannot fully offset the additional labor. An increase in water use fees represents a pure income effect which lowers the farm income curve and lowers the reservation wage (assuming leisure is normal), so that the probability of wage work increases. An increase in the price of the consumption good (V) has offsetting income and substitution consequences. Finally, an increase in the labor wage (W) strictly increases the probability of wage work and has no effect on the reservation wage. It should be emphasized that these comparative static results depend upon the separation of consumption and production decisions. To summarize, the signs of the effects on the probability of wage work given changes in AVGP (P), AREAILND (Z), COMIEST ($\tilde{r}$), HHSIZE (X), FEECOLL (T), and PREPWAGE (W) are -, -, +, +, +, and +, respectively.

Discussion of Results

Table 5.2 summarizes the results of the reservation wage analysis. In general, the signs of the estimates obtained in this analysis are consistent with those predicted by the theory.

Table 5.2. Maximum likelihood estimates for the labor supply equation

		WGWORKHH	
Variable	Model Variable	Estimate	t-stat
C		-1.6958000000	-2.717
FEECOLL	T	-0.0008058550	-0.682
AVGP	P	-0.3013160000	-4.534
RPI	V	0.9033050000	1.454
PREPWAGE	W	0.0498400000	7.936
AREAILND	Z	-0.0000000145	-2.223
HHSIZE	X	-0.0797020000	7.002
COMIEST	$\tilde{r}$	0.0206430000	2.235
Log Likelihood		-2030.76	
n		3114	
% Correct Pred		0.620103	

Consider first the club variables, AREAILND and COMIEST, which confirm the effects derived in proposition 1. That is, as a proxy for irrigation facilities, an increase in AREAILND increases both the output level and the marginal product of labor by reducing congestion. The reported sign on AREAILND is negative, as expected. In contrast, an increase in COMIEST represents an increase in congestion and, by contra-positive reasoning, an increase in the probability of wage work. The reported sign on COMIEST is positive, as expected.

The output price effect derived by Lange is confirmed in this data set. That is, an increase in AVGP increases the value marginal product of agricultural labor, increases the reservation wage and decreases the probability of wage work. The negative coefficient on AVGP is statistically significant. Similarly, the predicted effect of off-farm wage rate results from this data set. As the off-farm wage (PREPWAGE) increases, the probability of wage work also increases. This effect is also statistically significant. The parameter estimates for FEECOLL and RPI do not have statistical significance.

Summary

Among the assumptions made in the analysis, a well-functioning labor market ensured the separation of production decisions from consumption decisions. Such a separation along with weak separability in the production function allowed single equation estimation of the labor supply decision. Empirical analysis of the labor supply decision produced results in general agreement with theoretical predictions.

Some evidence was obtained for the theoretical link between labor decisions and utilization of irrigation. The notion that congestion effects, which are either abated through irrigation facilities or exacerbated through aggregate irrigation use, affect the marginal product of labor and not just output levels is confirmed with this data.

Where the model fails to perform as expected, one finds reason to reconsider the underlying assumptions. Further research should relax the assumption of a well-functioning labor market. Such an assumption may not be appropriate for this data since, at the time of collection, labor markets were only beginning to emerge. Also, use of a system of equations which allows for interdependence of input and consumption decisions may provide stronger evidence of the link between labor and irrigation.

CHAPTER VI. SUMMARY AND CONCLUSIONS

The previous four chapters have contained a considerable amount of material which is both theoretical and empirical. It appears necessary to sift through the material, to extract the key contributions, conclusions and implications and to present them in abbreviated form. These items will be organized as theoretical contributions and empirical results, respectively. This chapter is not intended to rederive results or to reexplain conclusions. For those discussions the reader is referred to the chapter indicated.

Regarding the theoretical contributions, a model was developed that has not yet appeared in the literature. Club models have routinely focused on the consumption of a partially non-rival, excludable consumption good. A club model was developed which focused on a partially non-rival, excludable production input. (Chapter II) Conditions for production efficiency were derived and compared with the efficiency conditions of a club good model. (Chapter II). The model was inserted into a household production model in order to forge a link between a partially non-rival input and labor supply decisions. (Chapter III) The top level efficiency conditions were derived and served to highlight the distinctiveness of the club input model vis-à-vis the club good model. (Chapter III) In particular, it was noted that the membership condition hinges on the substitutability between leisure and the consumable good and the substitutability between labor and irrigation in production. Thus, the membership condition in a producer club is considerably more complicated than the membership condition in a consumer club.

Regarding the empirical results, household production and club theories were applied to the specific context of irrigation in Vietnam. Evidence was found to support the notion that irrigation has non-rival properties (Chapter IV), that the irrigation facilities, rather than irrigation services derived from the facilities, have some non-rival properties (Chapter IV), and that cooperatives can coordinate irrigation decisions (Chapter IV). Also, the transition to a market economy has not yet produced institutional reform at the level of the cooperative (Chapter IV). Thus, the results of this analysis support the findings elsewhere that economic reforms in Vietnam as in China have taken a pace slow enouch to allow for the development of appropriate insitutions. Also, quantitative measures are available from the results of the output differentials between coop members and non-members and of the substitutability of labor for irrigation (Chapter IV).

In order to support further empirical work, the economic implications of a logistic production function were derived. (Appendix 3) The logistic form of the production function provided a tractable and internally consistent means to obtain an estimate for a missing variable, irrigation use. Using this variable, estimates were obtained for a labor supply model. (Chapter V) Although considerably weaker than the other results, some support was found for dependence of labor supply on features of irrigation (Chapter V).

Regarding the empirical analysis of coop formation, the results would be a good deal more enlightening if institutional data was available. Unfortunately, such data does not exist and collecting the data would be very expensize since it would involve surveys of cooperatives throughout the country. If the questionnaire can be designed to afford analysis of other issues such as farmer level cooperation and deterioration of social capital, the expense may be justified.

It appears that the presence of a shared public good is not the entire story behind coop formation and participation in Vietnam. Others have noted the importance of crafting institutions which directly address the issues surrounding human interactions within a cooperative. An analysis of this sort which probes the nature of these interactions and the institutions which support or undermine productive interactions requires a more sociological bent than what I have presented here. Such a direction which explicitly examines human interactions promises to shed light on a variety of interesting issues regarding cooperative farming practices in Vietnam.

APPENDIX 1. DESCRIPTION OF THE DATA

The Viet Nam Living Standards Survey

The Coverage of the Data

The Viet Nam Living Standards Survey (VNLSS) was conducted between September 1992 and October 1993. The sample covers 4800 households throughout Viet Nam. 150 communes were selected from the 10,000 that currently exist in Viet Nam. For each commune 32 households were interviewed (32*150=4800). 120 communes are rural; 30 are urban. For each household, extensive questioning regarding household agricultural production, health, schooling, employment, migration, housing, fertility, self-employment, and expenditures on food and durable goods produced a large set of information on each household.

In addition to the household surveys, VNLSS contains information on each of the 120 rural communes. The community questionnaire includes information on each community's demography, economy, infrastructure, education, health and agricultural systems. The price questionnaire includes on a community level the prices of 36 food items, 31 nonfood items, 9 medicines, 7 insecticides/fertilizers and 5 types of services from local markets. The price questionnaire was completed for 118 of the 120 rural communes.

Selected Characteristics of the Data

A preliminary review of the data provides the following information that is relevant to the proposed research project:

1. Of the 120 community questionnaires of rural communes, 77 indicate that there is a cooperative in the commune (i.e. a yes answer to "Is there a cooperative in this community?"). The southernmost of these communities is Di Linh in Lam Dong province, 150 km northeast of Ho Chi Minh City. Consequently, the data set does not include information on cooperatives in the Mekong Delta if they exist.

2. Of the 78 communes with a cooperative, 60 indicate that they collect irrigation payments (i.e. a check in the E box to the question "What is the kind of items give to the Cooperative or Government? A. Allocation, B. Land Preparation, C. Fertilizer, D. Seed, E. Irrigation, F. Insecticide, G. Management Fee, H. Fund, I. Other"). These 60 communities represent 450,000 people.

3. Of the 78 communes with a cooperative, 9 indicate that they give nothing to the cooperative (i.e. no checks in any of the boxes of the question "What is the kind of items give to the Cooperative or Government? A. Allocation, B. Land Preparation, C. Fertilizer, D. Seed, E. Irrigation, F. Insecticide, G. Management Fee, H. Fund, I. Other").

4. Of the 4800 households, 2044 received at least one of the following 4 services from the cooperative not represented by the 5 in the table. These are irrigation, biological protection, plowing, and protection of crops. Of the 2044, 1325 can provide an estimate of the cost to them of the services received from the cooperative. Of the 1325, 1032 provided an estimate of the cost of each of the four services received from the cooperative. Of the 1032, 199 provided an amount that they paid for irrigation.

5. The 199 households that paid the cooperative for irrigation are located in 25 separate communes, of which 7 are represented by only one household. Of the remaining 18 communes, 10 are represented by more than 8 households. These 10 communes represent 167 of the 199 households and are located in 4 provinces (Hai Hung, Nam Ha, Thua Thien and Binh Dinh). The southernmost commune is Tay Son in Binh Dinh province located 440 km northeast of Ho Chi Minh City. One of these ten communes (commune number 50) is not among the set of communes which indicated that there was a cooperative in the commune.

6. Of the 4800, 3961 indicated that some member of the family "worked as an independent farmer or family worker on a farm belonging to the household or raised animals belonging to the household."

It should also be noted that annual crop land owned by rural households in Vietnam is categorized in the survey according to one of three institutions which conferred the ownership rights to the household. The three types of annual crop land are 1) allocated land which was transferred by the State or cooperative to the individual household, 2) auctioned land which was obtained by a competitive bidding process and 3) private land which had no prior ownership by the State. Of primary concern in this project is allocated land because of the high correlation with irrigation.

Consider the irrigation information in the data set. For each household surveyed the amount of allocated, auctioned and private land is provided as well as the amount of each which is irrigated. The total amount of irrigated land serves as a proxy for the level of irrigation facilities or infrastructure.

The Legates Surface and Shipboard Rain Gauge Observations

In addition to the LSMS data, global rainfall data is available from The Legates Surface and Shipboard Rain Gauge Observations data set, referred to more succinctly as the Legates data set. Units of observation in the data set are surface areas represented by the global lattice constructed by 0.5 degree units latitude and 0.5 degree units longitude. This unit of observation is smaller than the average size of a province in Vietnam. The data set consists of monthly mean rainfall levels averaged over the years 1920 to 1980. Thus, the Legates data set provides both the level of annual rainfall and the distribution of rainfall over the year. A lengthy description of the data can be found in Legates (1987).

APPENDIX 2. STATISTICAL THEORY OF A BIVARIATE PROBIT

The bivariate probit model is stated formally below where equation 1 is the probit equation for coop formation and equation 2 is the probit equation for coop participation. In equation 1, y_{1i}^* is the latent variable, coop formation, and $\mathbf{x}_{1i}$ are the variables that affect coop formation. Similarly, in equation 2, y_{2i}^* is the latent variable, coop participation, and $\mathbf{x}_{2i}$ are variables that affect coop participation. Note that equation 2 is relevant only for those observations for which a coop exists.

$$
\begin{aligned}
&(1)\quad y_{1i}^* = \beta_1'\mathbf{x}_{1i} + u_{1i}; \qquad i = 1,\ldots,n\\
&y_{1i} = 1 \quad \text{if } y_{1i}^* > \bar{y}_1^* = 0\\
&y_{1i} = 0 \quad \text{if } y_{1i}^* \le \bar{y}_1^* = 0\\
&\text{Prob}(y_{1i} = 1) = 1 - \Phi(-\beta_1'\mathbf{x}_{1i}); \qquad i = 1,\ldots,n\\
&\text{Prob}(y_{1i} = 0) = \Phi(-\beta_1'\mathbf{x}_{1i}); \qquad i = 1,\ldots,n
\end{aligned}
$$

$$
\begin{aligned}
&(2)\quad y_{2i}^* = \beta_2'\mathbf{x}_{2i} + u_{2i}; \qquad i = 1,\ldots,n \quad \text{observed only if } y_{1i} = 1\\
&y_{2i} = 1 \quad \text{if } y_{2i}^* > \bar{y}_2^* = 0\\
&y_{2i} = 0 \quad \text{if } y_{2i}^* \le \bar{y}_2^* = 0\\
&\text{Prob}(y_{2i} = 1) = 1 - \Phi(-\beta_2'\mathbf{x}_{2i}); \qquad i = 1,\ldots,n\\
&\text{Prob}(y_{2i} = 0) = \Phi(-\beta_2'\mathbf{x}_{2i}); \qquad i = 1,\ldots,n\\
&(u_{1i}, u_{2i}) \sim \text{bivariate normal}(0,0,1,1,\rho)
\end{aligned}
$$

Three events are considered in this analysis: 1) coop non-formation, 2) coop formation and household receipt of services from the coop, and 3) coop formation and household refusal of services from the coop. The probabilities of these events are the following:

$$
\begin{aligned}
P_1 &= \mathrm{Prob}(y_{1i}=0) = \Phi(-\beta_1'\mathbf{x}_{1i}) \\
P_2 &= \mathrm{Prob}(y_{1i}=1, y_{2i}=1) = \mathrm{Prob}(u_{1i}>0, u_{2i}>0) = 1-\Phi(-\beta_1'\mathbf{x}_{1i}) - \Phi(-\beta_2'\mathbf{x}_{2i}) + \Phi^{bv}(-\beta_1'\mathbf{x}_{1i}, -\beta_2'\mathbf{x}_{2i}, \rho \\
&= \Phi^{bv}(\beta_1'\mathbf{x}_{1i}, \beta_2'\mathbf{x}_{2i}, \rho) \\
P_3 &= \mathrm{Prob}(y_{1i}=1, y_{2i}=0) = \mathrm{Prob}(u_{1i}>0, u_{2i}\le 0) = \Phi(-\beta_2'\mathbf{x}_{2i}) - \Phi^{bv}(-\beta_1'\mathbf{x}_{1i}, -\beta_2'\mathbf{x}_{2i}, \rho) \\
&= \Phi^{bv}(\beta_1'\mathbf{x}_{1i}, -\beta_2'\mathbf{x}_{2i}, -\rho)
\end{aligned}
$$

where $\Phi(.)$ and $\Phi^{bv}(.)$ denote the standard normal cumulative distribution functions for the univariate and bivariate cases, respectively.

The likelihood function can be written as:

$$
L = P_1^{(1-y_{1i})} P_2^{y_{1i}y_{2i}} P_3^{y_{1i}(1-y_{2i})}
$$

Taking logarithms yields

$$
\begin{aligned}
\ln L &= (1-y_{1i})\ln P_1 + y_{1i}y_{2i}\ln P_2 + y_{1i}(1-y_{2i})\ln P_3 \\
&= (1-y_{1i})\ln\Phi(-\beta_1'\mathbf{x}_{1i}) + y_{1i}y_{2i}\ln\Phi^{bv}(\beta_1'\mathbf{x}_{1i}, \beta_2'\mathbf{x}_{2i}, \rho) + y_{1i}(1-y_{2i})\ln\Phi^{bv}(\beta_1'\mathbf{x}_{1i}, -\beta_2'\mathbf{x}_{2i}, -\rho)
\end{aligned}
$$

The log of the likelihood function can also be written as

$$
\ln L = (1-y_{1i})\ln\Phi(\beta_1'\mathbf{x}_{1i}q_{1i}) + y_{1i}\ln\Phi^{bv}(\beta_1'\mathbf{x}_{1i}q_{1i}, \beta_2'\mathbf{x}_{2i}q_{2i}, q_{1i}q_{2i}\rho)
$$

where use has been made of the following variables proposed by Greene (1993)[1]

$$
\begin{aligned}
q_{1i} &= 2y_{1i} - 1 \quad \text{and} \\
q_{2i} &= 2y_{2i} - 1
\end{aligned}
$$

Note that these variables attach a sign (either positive or negative) according to the value of the binary variable. This allows the binary variables to be removed from the log of the

---

[1] See page 661 in Greene (1993) for more details.

likelihood function altogether since the function can be written in such a way that the sign chages correspond perfectly to the values of the binary variables. The limiting case is the present one in which no observations exist for a particular combination of the binary variables. (There are no observations for coop non-formation and coop participation.) In this case, the binary variable for coop formation must still be used so that use of the new variable (q_{1i}), while helpful to see the pattern in the function, is admittedly redundant.

Maximum likelihood methods require first order differentiation of this expression (to obtain the gradient) and second order differentiation of this expression (to obtain the Hessian). The gradient can be written as

$$\frac{\partial \ln L}{\partial \beta_1} = \begin{bmatrix} (1-y_{1i})\dfrac{\phi(-\beta_1'\mathbf{x}_{1i})}{P_1} - y_{1i}y_{2i}\dfrac{\Phi_1^{bv}(\beta_1'\mathbf{x}_{1i},\beta_2'\mathbf{x}_{2i},\rho)}{P_2} \\ -y_{1i}(1-y_{2i})\dfrac{\Phi_1^{bv}(\beta_1'\mathbf{x}_{1i},-\beta_2'\mathbf{x}_{2i},-\rho)_i)}{P_3} \end{bmatrix}(-\mathbf{x}_{1i})$$

$$= \left[(1-y_{1i})\frac{\phi(\beta_1'\mathbf{x}_{1i}q_{1i})}{\Phi(\beta_1'\mathbf{x}_{1i}q_{1i})} + y_{1i}\frac{\Phi_1^{bv}(\beta_1'\mathbf{x}_{1i}q_{1i},\beta_2'\mathbf{x}_{2i}q_{2i},q_{1i}q_{2i}\rho)}{\Phi^{bv}(\beta_1'\mathbf{x}_{1i}q_{1i},\beta_2'\mathbf{x}_{2i}q_{2i},q_{1i}q_{2i}\rho)}\right](q_{1i}\mathbf{x}_{1i})$$

$$\frac{\partial \ln L}{\partial \beta_2} = \left[y_{1i}y_{2i}\frac{\Phi_2^{bv}(\beta_1'\mathbf{x}_{1i},\beta_2'\mathbf{x}_{2i},\rho)}{P_2} + y_{1i}(1-y_{2i})\frac{\Phi_2^{bv}(\beta_1'\mathbf{x}_{1i},-\beta_2'\mathbf{x}_{2i},-\rho)_i)}{P_3}\right](-\mathbf{x}_{2i})$$

$$= \left[y_{1i}\frac{\Phi_2^{bv}(\beta_1'\mathbf{x}_{1i}q_{1i},\beta_2'\mathbf{x}_{2i}q_{2i},q_{1i}q_{2i}\rho)}{\Phi^{bv}(\beta_1'\mathbf{x}_{1i}q_{1i},\beta_2'\mathbf{x}_{2i}q_{2i},q_{1i}q_{2i}\rho)}\right](q_{2i}\mathbf{x}_{2i})$$

$$\frac{\partial \ln L}{\partial \rho} = y_{1i}y_{2i}\frac{\Phi_3^{bv}(\beta_1'\mathbf{x}_{1i},\beta_2'\mathbf{x}_{2i},\rho)}{P_2} + y_{1i}(1-y_{2i})\frac{-\Phi_3^{bv}(\beta_1'\mathbf{x}_{1i},-\beta_2'\mathbf{x}_{2i},-\rho)_i)}{P_3}$$

$$= y_{1i}q_{1i}q_{2i}\frac{\Phi_3^{bv}(\beta_1'\mathbf{x}_{1i}q_{1i},\beta_2'\mathbf{x}_{2i}q_{2i},q_{1i}q_{2i}\rho)}{\Phi^{bv}(\beta_1'\mathbf{x}_{1i}q_{1i},\beta_2'\mathbf{x}_{2i}q_{2i},q_{1i}q_{2i}\rho)}$$

where Φ^{bv}_i is the derivative with respect to the ith argument of the cumulative bivariate standard normal distribution function, $\Phi^{bv}(.,.,.)$. Analytical expressions for these derivatives can be derived from the density function. Specifically, let the bivariate standard normal density function be written as:

$$\phi^{bv}(w,x,\rho) = \frac{1}{2\pi\sqrt{1-\rho^2}} e^{-\frac{1}{2(1-\rho^2)}(w^2-2\rho wx+x^2)}$$

so that the cumulative distribution function can be written as

$$\Phi^{bv}(W,X,\rho) = \int_{-\infty}^{W}\int_{-\infty}^{X} \frac{1}{2\pi\sqrt{1-\rho^2}} e^{-\frac{1}{2(1-\rho^2)}(w^2-2\rho wx+x^2)} dxdw$$

Distributing the integrals and simplifying yields

$$\Phi^{bv}(W,X,\rho) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{W} e^{-\frac{1}{2(1-\rho^2)}w^2} \frac{1}{\sqrt{2\pi(1-\rho^2)}} \int_{-\infty}^{X} e^{-\frac{1}{2(1-\rho^2)}(-2\rho wx+x^2)} dxdw$$

$$= \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{W} e^{-\frac{1}{2(1-\rho^2)}w^2} \frac{1}{\sqrt{2\pi(1-\rho^2)}} \int_{-\infty}^{X} e^{-\frac{1}{2(1-\rho^2)}((x-\rho w)^2-\rho^2 w^2)} dxdw$$

$$= \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{W} e^{-\frac{1}{2(1-\rho^2)}w^2} e^{-\frac{1}{2(1-\rho^2)}(-\rho^2 w^2)} \frac{1}{\sqrt{2\pi(1-\rho^2)}} \int_{-\infty}^{X} e^{-\frac{1}{2(1-\rho^2)}(x-\rho w)^2} dxdw$$

$$= \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{W} e^{-\frac{1}{2}w^2} \frac{1}{\sqrt{2\pi(1-\rho^2)}} \int_{-\infty}^{X} e^{-\frac{1}{2(1-\rho^2)}(x-\rho w)^2} dxdw$$

Now make the variable substitution, $v = \dfrac{x - \rho w}{\sqrt{1-\rho^2}}$, so that $dv = \dfrac{dx}{\sqrt{1-\rho^2}}$ and

$V = \dfrac{X - \rho w}{\sqrt{1-\rho^2}}$.

$$\Phi^{bv}(W,X,\rho) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{W} e^{-\frac{1}{2}w^2} \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{V} e^{-\frac{1}{2}v^2} \, dv dw$$

$$= \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{W} e^{-\frac{1}{2}w^2} \Phi\left(\frac{X - \rho w}{\sqrt{1-\rho^2}} \right) dw$$

Taking the derivative with respect to the first argument yields

$$\Phi_1^{bv}(W,X,\rho) = \frac{\partial \Phi^{bv}(W,X,\rho)}{\partial W} = \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}W^2} \Phi\left(\frac{X - \rho W}{\sqrt{1-\rho^2}} \right) = \phi(W) \cdot \Phi\left(\frac{X - \rho W}{\sqrt{1-\rho^2}} \right)$$

By symmetry, the derivative with respect to the second argument is

$$\Phi_2^{bv}(W,X,\rho) = \frac{\partial \Phi^{bv}(W,X,\rho)}{\partial X} = \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}X^2} \Phi\left(\frac{W - \rho X}{\sqrt{1-\rho^2}} \right) = \phi(X) \cdot \Phi\left(\frac{W - \rho X}{\sqrt{1-\rho^2}} \right)$$

The derivative with respect to the third argument, the correlation coefficient, is simply the probability density function

$$\Phi_3^{bv}(\mathrm{W},\mathrm{X},\rho) = \phi^{bv}(w,x,\rho) = \frac{1}{2\pi\sqrt{1-\rho^2}} e^{-\frac{1}{2(1-\rho^2)}(w^2 - 2\rho w x + x^2)}$$

In order to prove this assertion let

$$\phi^{bv}(w,x,\rho) = g_1(\rho)e^{g_2(w,x,\rho)}$$

where $g_1(\rho) = \dfrac{1}{2\pi\sqrt{1-\rho^2}}$ and $g_2(w,x,\rho) = -\dfrac{1}{2(1-\rho^2)}(w^2 - 2\rho wx + x^2)$

Then

$$\Phi_3^{bv} = \frac{\partial}{\partial\rho}\int^W\int^X \phi^{bv}(w,x,\rho)dxdw = \int^W\int^X \frac{\partial}{\partial\rho}\phi^{bv}(w,x,\rho)dxdw = \int^W\int^X \frac{\partial}{\partial\rho}g_1(\rho)e^{g_2(w,x,\rho)}dxdw$$

$$= \int^W\int^X \frac{\partial g_1}{\partial\rho}e^{g_2(w,x,\rho)} + g_1(\rho)\frac{\partial g_2}{\partial\rho}e^{g_2(w,x,\rho)}dxdw$$

$$= \int^W\int^X g_1(\rho)e^{g_2(w,x,\rho)}\left(\frac{\partial g_1}{\partial\rho}\frac{1}{g_1(\rho)} + \frac{\partial g_2}{\partial\rho}\right)dxdw$$

$$= \int^W\int^X \phi^{bv}(w,x,\rho)\left(\frac{\partial g_1}{\partial\rho}\frac{1}{g_1(\rho)} + \frac{\partial g_2}{\partial\rho}\right)dxdw$$

Simplifying the expression in the parentheses gives

$$\frac{\partial g_1}{\partial\rho}\frac{1}{g_1(\rho)} + \frac{\partial g_2}{\partial\rho} = \left((2\pi)^{-1}\rho(1-\rho^2)^{-3/2}\right)\left((2\pi)(1-\rho^2)^{1/2}\right)$$

$$+ -\frac{1}{2}\frac{(1-\rho^2)(-2wx) - (w^2 + x^2 - 2\rho wx)(-2\rho)}{(1-\rho^2)^2}$$

$$= \frac{\rho}{(1-\rho^2)} + \frac{(1-\rho^2)(wx) - (w^2 + x^2 - 2\rho wx)(\rho)}{(1-\rho^2)^2}$$

$$= \frac{\rho}{(1-\rho^2)} + \frac{wx - \rho^2 wx - \rho w^2 - \rho x^2 + 2\rho^2 wx}{(1-\rho^2)^2} = \frac{wx + \rho^2 wx - \rho w^2 - \rho x^2}{(1-\rho^2)^2} + \frac{\rho}{(1-\rho^2)}$$

Now consider the function $h(w,x,\rho)$ such that

$$\iint h(w,x,\rho)\phi^{bv}(w,x,\rho)dwdx = \phi^{bv}(w,x,\rho)$$

Differentiating the expression gives

$$h(w,x,\rho)\phi^{bv}(w,x,\rho) = \frac{\partial^2\phi^{bv}(w,x,\rho)}{\partial w\partial x} = \frac{\partial}{\partial x}\left(g_1(\rho)\left[\frac{\partial g_2}{\partial w}e^{g_2(w,x,\rho)}\right]\right)$$

$$= g_1(\rho)\left[\frac{\partial g_2}{\partial w}\frac{\partial g_2}{\partial w}e^{g_2(w,x,\rho)} + \frac{\partial^2 g_2}{\partial w\partial x}e^{g_2(w,x,\rho)}\right] = g_1(\rho)e^{g_2(w,x,\rho)}\left[\frac{\partial g_2}{\partial w}\frac{\partial g_2}{\partial w} + \frac{\partial^2 g_2}{\partial w\partial x}\right]$$

$$= \phi^{bv}(w,x,\rho)\left[\frac{\partial g_2}{\partial w}\frac{\partial g_2}{\partial w} + \frac{\partial^2 g_2}{\partial w\partial x}\right]$$

so that

$$h(w,x,\rho) = \frac{\partial g_2}{\partial w}\frac{\partial g_2}{\partial w} + \frac{\partial^2 g_2}{\partial w\partial x} = \left(-\frac{w-\rho x}{1-\rho^2}\right)\left(-\frac{x-\rho w}{1-\rho^2}\right) + \frac{\rho}{1-\rho^2}$$

$$= \frac{wx-\rho x^2-\rho w^2+\rho^2 wx}{\left(1-\rho^2\right)^2} + \frac{\rho}{1-\rho^2}$$

It is now clear that the assertion is correct since

$$h(w,x,\rho) = \frac{\partial g_1}{\partial \rho}\frac{1}{g_1(\rho)} + \frac{\partial g_2}{\partial \rho}.$$

If the correlation coefficient is zero, the model simplifies to a sample selection probit model[2] and the gradients of the maximum likelihood estimates are greatly simplified. Specifically, if $\rho = 0$, then the coop formation and participation equations are independent and can be estimated separately with techniques that are much simpler than maximum likelihood methods and still yield consistent estimates of model parameters.

To be more formal, consider the likelihood function when independence is assumed. In that case, the bivariate standard normal cumulative distribution function can be written as

---

[2] A precise formulation of this model will be provided below.

$$\Phi^{bv}(W,X,0)=\frac{1}{\sqrt{2\pi}}\int_{-\infty}^{W} e^{-\frac{1}{2}w^2}\,\Phi\!\left(\frac{X-(0)w}{\sqrt{1-(0)^2}}\right)dw$$

$$=\Phi(X)\frac{1}{\sqrt{2\pi}}\int_{-\infty}^{W} e^{-\frac{1}{2}w^2}\,dw=\Phi(X)\Phi(W)$$

Consequently, the probabilities, P_1, P_2, and P_3, can be written as

$$P_1=\mathrm{Prob}(y_{1i}=0)=\Phi(-\beta_1'\mathbf{x}_{1i})$$

$$P_2=\mathrm{Prob}(y_{1i}=1,y_{2i}=1)=\mathrm{Prob}(u_{1i}>0,u_{2i}>0)=1-\Phi(-\beta_1'\mathbf{x}_{1i})-\Phi(-\beta_2'\mathbf{x}_{2i})+\Phi^{bv}(-\beta_1'\mathbf{x}_{1i},-\beta_2'\mathbf{x}_{2i},\rho$$

$$=\Phi^{bv}(\beta_1'\mathbf{x}_{1i},\beta_2'\mathbf{x}_{2i},\rho)=\Phi(\beta_1'\mathbf{x}_{1i})\Phi(\beta_2'\mathbf{x}_{2i})$$

$$P_3=\mathrm{Prob}(y_{1i}=1,y_{2i}=0)=\mathrm{Prob}(u_{1i}>0,u_{2i}\le 0)=\Phi(-\beta_2'\mathbf{x}_{2i})-\Phi^{bv}(-\beta_1'\mathbf{x}_{1i},-\beta_2'\mathbf{x}_{2i},\rho)$$

$$=\Phi^{bv}(\beta_1'\mathbf{x}_{1i},-\beta_2'\mathbf{x}_{2i},-\rho)=\Phi(\beta_1'\mathbf{x}_{1i})\Phi(-\beta_2'\mathbf{x}_{2i})$$

Using these probabilities and the variable transformations, q_{1i} and q_{2i}, the log of the likelihood function can be written as

$$\ln L=(1-y_{1i})\ln P_1+y_{1i}y_{2i}\ln P_2+y_{1i}(1-y_{2i})\ln P_3$$

$$=(1-y_{1i})\ln\Phi(-\beta_1'\mathbf{x}_{1i})+y_{1i}y_{2i}\ln\left(\Phi(\beta_1'\mathbf{x}_{1i})\Phi(\beta_2'\mathbf{x}_{2i})\right)+y_{1i}(1-y_{2i})\ln\left(\Phi(\beta_1'\mathbf{x}_{1i})\Phi(-\beta_2'\mathbf{x}_{2i})\right)$$

$$=(1-y_{1i})\ln\Phi(-\beta_1'\mathbf{x}_{1i})+y_{1i}y_{2i}\ln\Phi(\beta_1'\mathbf{x}_{1i})+y_{1i}y_{2i}\ln\Phi(\beta_2'\mathbf{x}_{2i})$$

$$+y_{1i}(1-y_{2i})\ln\Phi(\beta_1'\mathbf{x}_{1i})+y_{1i}(1-y_{2i})\ln\Phi(-\beta_2'\mathbf{x}_{2i})$$

$$=(1-y_{1i})\ln\Phi(-\beta_1'\mathbf{x}_{1i})+y_{1i}\ln\Phi(\beta_1'\mathbf{x}_{1i})+y_{1i}\ln\Phi(q_{2i}\beta_2'\mathbf{x}_{2i})$$

$$=\ln\Phi(q_{1i}\beta_1'\mathbf{x}_{1i})+y_{1i}\ln\Phi(q_{2i}\beta_2'\mathbf{x}_{2i})$$

Differentiating the log of the likelihood function with respect to the model parameters yields the following gradients.

$$\frac{\partial\ln L}{\partial\beta_1}=\left[\frac{\phi(\beta_1'\mathbf{x}_{1i}q_{1i})}{\Phi(\beta_1'\mathbf{x}_{1i}q_{1i})}\right](q_{1i}\mathbf{x}_{1i})$$

$$\frac{\partial\ln L}{\partial\beta_2}=y_{1i}\left[\frac{\phi(\beta_2'\mathbf{x}_{2i}q_{2i})}{\Phi(\beta_2'\mathbf{x}_{2i}q_{2i})}\right](q_{2i}\mathbf{x}_{2i})$$

It can be shown that the gradient for β_1 is exactly the same as the gradient that would be obtained by maximizing the function $\ln L = (1 - y_{1i}) \ln P_1 + y_{1i} \ln(1 - P_1)$, which is the log likelihood function for probit estimation of the coop formation equation. Note also that the gradient for β_2 has exactly the same form except that it is multiplied by the $(0,1)$ binary variable, y_{1i}, which indicates the existence of a cooperative. Consequently, probit estimation of the coop participation equation for those observations that have $y_{1i} = 1$ has exactly the same optimization condition. It is now clear that maximum likelihood estimation can be replaced without any loss of efficiency by the simpler technique of a sample selection probit model. This model has two separate probit equations- one for the coop formation equation and one for the coop participation equation where the sample has been restricted to those observations for which a cooperative exists. Thus, the independence of the error terms greatly simplifies the statistical analysis.

APPENDIX 3. MATHEMATICAL PROPERTIES: LOGISTIC FUNCTION

The logistic function is frequently used to model agricultural production in agronomic studies. In this appendix, the mathematical properties and economic consequences of this particular functional form will be discussed.

A production relation with a logistic functional form can be written in the following manner:

$$y = \frac{k}{1 + be^{-cx}}$$

where y is the output obtained from input x. The variables k, b and c are constant technological parameters which are frequently estimated in agronomic studies.

The marginal product of x is

$$\frac{\partial y}{\partial x} = \frac{kbc \cdot e^{-cx}}{\left(1 + be^{-cx}\right)^2}.$$

General Features

The shape of the curve conforms to basic economic assumptions, including positive function values and slopes throughout the range of positive real numbers, and decreasing slopes throughout a relevant range of positive real numbers. In the figures below, the function and its first derivative is plotted using k = 10, b = 5 and c = 0.5.

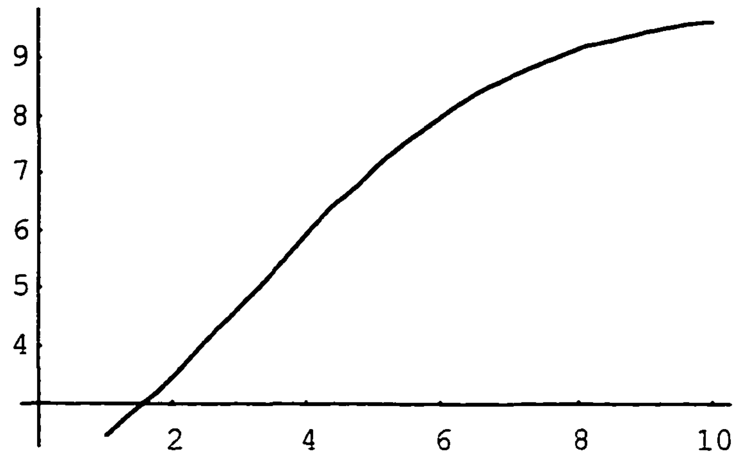

Figure A3.1. A Plot of a Logistic Function

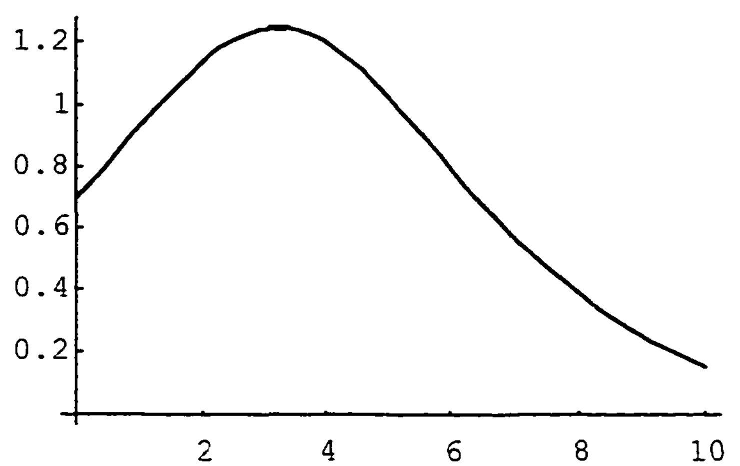

Figure A3.2. A Plot of the First Derivative of a Logistic Function

The function approaches k asymptotically so that k is frequently interpreted as the biological or technological maximum for the output. Consequently, an increase in k stretches the function to higher levels and shifts the marginal product curve up. An increase in b shifts the marginal product curve to the right and an increase in c shifts the marginal product curve upward and to the left. The effect of varying the value for c between 0.1 and 1 is presented in Figure A3.3.

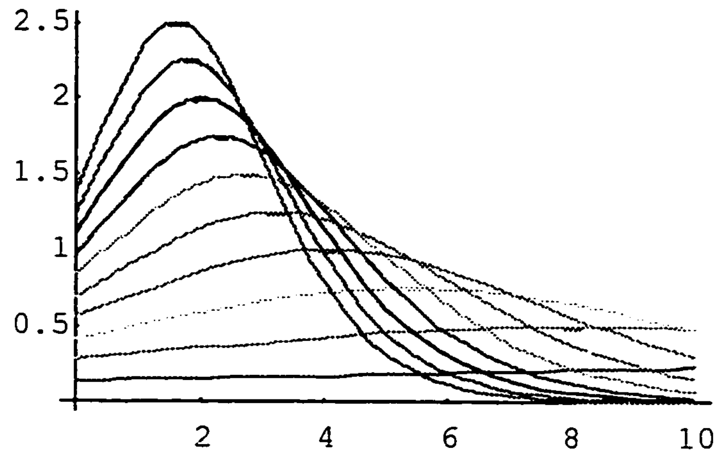

Figure A3.3. A Plot of the First Derivative, Varying c

Optimizing Behavior

The optimal level of x is obtained by setting the marginal product of x equal to the real cost of the input x (T/P).

$$\frac{\partial y}{\partial x} = \frac{kbc \cdot e^{-cx}}{\left(1+be^{-cx}\right)^2} = \frac{T}{P}$$

Solving for x involves an expression which is quadratic in e^{-cx}. Specifically, the expression is

$$\frac{kbcP}{T}e^{-cx} = 1 + 2be^{-cx} + b^2e^{-2cx}.$$

Simplifying the expression yields

$$\delta_2 z^2 + \delta_1 z + 1 = 0 \quad \text{where } z = e^{-cx}, \delta_1 = 2b - \frac{kbcP}{T}, \text{ and } \delta_2 = b^2.$$

The solution for z is simply

$$z^* = \frac{-\delta_1 \pm \sqrt{\delta_1^2 - 4\delta_2}}{2\delta_2} = \frac{-b\left(2 - \frac{kcP}{T}\right) \pm b\sqrt{\left(2 - \frac{kcP}{T}\right)^2 - 4}}{2b^2}$$

$$= \frac{\frac{kcP}{T} - 2 \pm \sqrt{\left(4 - \frac{kcP}{T}\right)\left(-\frac{kcP}{T}\right)}}{2b}$$

$$= \frac{\frac{kcP}{T}\left(1 \pm \sqrt{1 - \frac{4T}{kcP}}\right) - 2}{2b}$$

Note that real solutions to the optimization problem are obtained only when kcP/T > 4. It should also be noted that only one of the two solutions satisfies the second order conditions. It can be shown (but not here) that the marginal product curve is hill shaped and that only the solution on the downward sloped portion of the curve (where the second derivative is negative) satisfies the second order conditions. Consequently, the relevant solution for x is the greatest of the two real solutions. This solution corresponds to the least of the two real solutions for z. That is, the solution that satisfies the second order conditions is the solution that includes the negative sign, not the positive sign.

Substituting this expression into the production function yields the optimal output level.

$$y = \frac{k}{1 + be^{-cx}} = \frac{k}{1 + bz^*}$$

Rewriting this expression to obtain an expression for k/y yields

$$\frac{k}{y} = 1 + be^{-cx} = 1 + bz^{*} = 1 + b\frac{\frac{kcP}{T}\left(1 - \sqrt{1 - \frac{4T}{kcP}}\right) - 2}{2b} = \frac{kcP}{2T}\left(1 - \sqrt{1 - \frac{4T}{kcP}}\right)$$

A limit on k/y may be an important empirical question.[1] Moreover, it is desirable to know the restrictions a particular limit places on the constants. To investigate this issue, consider the following formulation for k/y.

$\frac{k}{y} = \frac{K}{2}\left(1 - \sqrt{1 - \frac{4}{K}}\right) \le L$ where K=(kcP/T) and L is some limit placed on k/y.

Solving for K as a function of L yields

$$\frac{K}{2}\left(1 - \sqrt{1 - \frac{4}{K}}\right) \le L$$

$$K - K\sqrt{1 - \frac{4}{K}} \le 2L$$

$$K - \sqrt{K^2 - 4K} \le 2L$$

$$K - 2L \le \sqrt{K^2 - 4K}$$

$$K^2 - 4KL + 4L^2 \le K^2 - 4K$$

$$-KL + L^2 \le -K$$

$$L^2 \le K(L - 1)$$

$$\frac{L^2}{(L - 1)} \le K = \frac{kcP}{T}$$

We now know the lower limit of kcP/T when an upper limit is placed on k/y.

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[1] In Chapter V, an assumption on the limit of k/y formed the basis of an important empirical step.

Consider an example. Suppose that L = 1.1, in which case the actual yield, y, is greater than 90% of the biological maximum, k. Drawing from the results reported in Reyes (1973), let k = 7.42 t/ha and c = 0.63. Drawing from the data reported in Svendsen (1995), let T/P (the real cost of irrigation services) = 0.047 t/ha. With these values, we obtain

$$\frac{L^2}{(L-1)} \leq \frac{kcP}{T}$$

$$\frac{1.1^2}{(1.1-1)} \leq \frac{7.42 * 0.63}{0.047}$$

$$12.1 \leq 99.46$$

This example shows that realistic values for technological parameters and prices produce a result for k/y such that it does not exceed 1.1. To reiterate, we have shown that under reasonable conditions, profit maximizing agents who have a logistic production function will choose an input level such that the resulting output will be greater than 90% of the biological maximum that is implied by the logistic production function.

REFERENCES CITED

Adams, R. D., and Royer, J. S. 1977. Income and Price Effects in the Economic Theory of Clubs. Public Finance 32(2):141-158.

Apinantara, A., and Sriswasdilek, J. 1986. An Evaluation of River Pump and Tank Irrigation Systems in Northeast Thailand. Pages 147-175 in K. Easter, ed. Irrigation Investment, Technology, and Management Strategies for Development. Westview Press, Boulder, CO.

Arrow, K. J., and Hahn, F. H. 1971. General Competitive Analysis. North Holland, Amsterdam. 452 pp.

Basu, K. 1989. A Theory of Association: Social Status, Prices and Markets. Oxford Economic Papers 41(4):653- 671.

Beresford, M. 1989. National Unification and Economic Development in Vietnam. Macmillan, London. 296 pp.

Berglas, E. 1976a. Distribution of Tastes and Skills and the Provision of Local Public Goods. Journal of Public Economics 6(3):409-423.

Berglas, E. 1976b. On the Theory of Clubs. American Economic Review 66(2):116-121.

Berglas, E. 1981. The Market Provision of Club Goods Once Again. Journal of Public Economics 15(3):389-393.

Berglas, E. 1984. Quantities, Qualities and Multiple Public Services in the Tiebout Model. Journal of Public Economics 25(3):299-321.

Berglas, E., and Pines, D. 1980. Clubs as a Case of Competitive Industry with Goods of Variable Quality. Economics Letters 5(4):363-366.

Berglas, E., and Pines, D. 1981. Clubs, Local Public Goods and Transportation Models: A Synthesis. Journal of Public Economics 15(2):141-162.

Berglas, E., Helpman, E., and Pines, D. 1982. The Economic Theory of Clubs: Some Clarifications. Economics Letters 10(3):343-348.

Blumel, W., Pethig, R., and von dem Hagen, O. 1986. The Theory of Public Goods - A Survey of Recent Issues. Journal of Institutional and Theoretical Economics 142(2): 241-309.

Boadway, R. W. 1973. Similarities and Differences Between Public Goods and Public Factors. Public Finance 28(3):245-257.

Boadway, R. W. 1980. A Note on the Market Provision of Club Goods. Journal of Public Economics 13(1):131-137.

Brueckner, J. K. 1994. Tastes, Skills and Local Public Goods. Journal of Urban Economics 35(2):201-220.

Buchanan, J. M. 1965. An Economic Theory of Clubs. Economica 32(125):1-14.

Callison, C. S. 1983. Land-To-The-Tiller in the Mekong Delta. University Press of America, New York. 391 pp.

Chambers, R. 1988. Managing Canal Irrigation: Practical Analysis from South Asia. Cambridge University Press, Cambridge. 279 pp.

Chung, D., and Weber, K. E. 1994. Economics of Rice Production of Different Farm Groups in Red River Delta, Vietnam: Policy Implications. Paper presented at the Agricultural Economics Workshop, January, Hanoi.

Cornes, R., and Sandler, T. 1986. The Theory of Externalities, Public Goods and Club Goods. Cambridge University Press, Cambridge. 300 pp.

Cornes, R., and Sandler, T. 1996. The Theory of Externalities, Public Goods and Club Goods, 2nd Edition. Cambridge University Press, Cambridge. 590 pp.

Dean, J. M. 1995. Market Disruption and the Incidence of VERs Under the MFA. Review of Economics and Statistics 77(2):383-388.

Deserpa, A. C. 1978. Congestion, Pollution, and Impure Public Goods. Public Finance 33(1):68-83.

Easter, K. 1986. Introduction and Conceptual Model. Pages 1-11 in K. Easter, ed. Irrigation Investment, Technology, and Management Strategies for Development. Westview Press, Boulder.

Easter, K., and Feder, G. 1996. Water Institutions and Economic Incentives to Ameliorate Market and Government Failures. Working Paper, University of Minnesota, Department of Applied Economics.

Fforde, A. J., and de Vylder, S. 1996. From Plan to Market: The Economic Transition in Vietnam. Westview Press, Boulder. 358 pp.

Fforde, A. J., and Seneque, S. 1995. The Economy and the Countryside: The Relevance of Rural Development Policies. Pages 97-138 in B. Kerkvliet, and D. J. Porter, eds. Vietnam's Rural Transformation. Westview Press, Inc., Boulder.

Flatters, F., Henderson, J. V., and Mieszkowski, P. 1974. Public Goods, Efficiency, and Regional Fiscal Equalization. Journal of Public Economics 3(1):99-112.

Greene, W. H. 1993. Econometric Analysis. Macmillan Publishing Co., New York. 791 pp.

Gronau, R. 1977. Leisure, Home Production, and Work- The Theory of the Allocation of Time Revisited. Journal of Political Economy 85(6):1099-1124.

Heckman, J. J. 1979. Sample Selection Bias as a Specification Error. Econometrica 47(1):153-161.

Helpman, E. 1978. On Optimal Community Formations. Economics Letters 1(3):289-293.

Helpman, E., and Pines, D. 1980. Optimal Public Investment and Dispersion Policy in a System of Open Cities. American Economic Review 70(3):507-514.

Helsley, R. W., and Strange, W. C. 1991. Exclusion and the Theory of Clubs. Canadian Journal of Economics 24(4):888-899.

Helsley, R. W., and Strange, W. C. 1994. Exclusion and The Private Enforcement of Property Rights. Journal of Public Economics 53(2):291-308.

Henderson, J. V. 1994. Community Choice of Revenue Instruments. Regional Science and Urban Economics 24(2):159-183.

Hiebert, M. 1988. Less Cooperation in Store. Far Eastern Economic Review 140(17):76.

Hillman, A. L. 1978. Symmetries and Asymmetries Between Public Input and Public Good Equilibria. Public Finance 33(3):269-279.

Hoch, I. 1958. Simultaneous Equation Bias in the Context of the Cobb-Douglas Production Function. Econometrica 26(3):566-578.

Huffman, W. E. 1980. Farm and Off-Farm Work Decisions: the Role of Human Capital. Review of Economics and Statistics 62(1):14-23.

Huffman, W. E. 1991. Agricultural Household Models: Survey and Critique. Pages 79-111 in M. C. Hallberg, J. L. Findeis, and D. A. Lass, eds. Multiple Job-holding Among Farm Families. Iowa State University Press, Ames.

Huffman, W. E., and Lange, M. D. 1989. Off-Farm Work Decisions of Husbands and Wives: Joint Decision Making. Review of Economics and Statistics 71(3):471-480.

Huffman, W. E., and Tokle, J. G. 1994. Labor Supply by U.S. Nonmetropolitan Married Couples. Unpublished Manuscript.

Hutapea, R., Dirjasanyata, P., and Nordholt, N. 1978. The Organization of Farm-Level Irrigation in Indonesia. Pages 167-174 in D. C. Taylor, and T. H. Wickham, eds. Irrigation Policy and Management in Southeast Asia. Agricultural Development Council, Bangkok.

Kaufmann, F., Majone, G., and Ostrom, V. 1986. Guidance, Control, and Evaluation in the Public Sector. Walter de Gruyter, Berlin. 830 pp.

Khiem, N., and Pingali, P. L. 1994. Vietnam: Market Reforms and Food Supply System. Unpublished Manuscript.

Klein, D. B. 1990. The Voluntary Provision of Public Goods? The Turnpike Companies of Early America. Economic Inquiry 28(4):788-812.

Kurien, J. 1995. Collective Action for Common Property Resource Rejuvenation- The Case of Peoples Artificial Reefs in Kerala State, India. Human Organization 54(2):160-168.

Lange, M. D. 1979. An Economic Analysis of Time Allocation and Capital-Labor Ratios in Household Production of Farm Families in Iowa. Ph.D. Dissertation, Iowa State University, Ames, Iowa.

Legates, D. R. 1987. A Climatology of Global Precipitation. Publications in Climatology 40(1):1-84.

Maddala, G. S. 1983. Limited-Dependent and Qualitative Variables in Econometrics. Cambridge University Press, New York. 401 pp.

Martin, F. 1989. Common Pool Resources and Collective Action: A Bibliography. Workshop in Political Theory and Policy Analysis, Bloomington, IN. 310 pp.

McGuire, M. C. 1974. Group Size, Group Homogeneity, and the Aggregate Provision of a Pure Public Good Under Cournot Behavior. Public Choice 18:107-126.

McGuire, M. C. 1991. Group Composition, Collective Consumption, and Collaborative Production. American Economic Review 81(5):1391-1407.

Menezes, F., and Silva, E. D. 1995. Sustainable Clubs Under Variable Participation. Working Paper No. 289, Working Papers in Economics and Econometrics.

Ng, Y. 1973. The Economic Theory of Clubs: Pareto Optimality Conditions. Economica 40(159):291- 298.

Ng, Y. 1974. The Economic Theory of Clubs: Optimal Tax/Subsidy. Economica 41(163):308-321.

Oakland, W. H. 1972. Congestion, Public Goods and Welfare. Journal of Public Economics 1(3):339-357.

Ostrom, E. 1990. Governing the Commons: The Evolution of Institutions for Collective Action. Cambridge University Press, Cambridge. 280 pp.

Ostrom, E. 1992. Crafting Institutions for Self-Governing Irrigation Systems. ICS Press, San Francisco. 111 pp.

Ostrom, E., Schroeder, L., and Wynne, S. 1993. Institutional Incentives and Sustainable Development. Westview Press, Inc., Boulder. 266 pp.

Palanisami, K., and Easter, K. 1986. Management, Production, and Rehabilitation in South Indian Irrigation Tanks. Pages 91-110 in K. Easter, ed. Irrigation Investment, Technology, and Management Strategies for Development. Westview Press, Boulder, CO.

Pauly, M. V. 1967. Clubs, Commonality, and the Core: An Integration of Game Theory and the Theory of Public Goods. Economica 34(135):314-324.

Pauly, M. V. 1970. Cores and Clubs. Public Choice 9:53-65.

Pingali, P. L., and Xuan, V. 1992. Vietnam: Decollectivization and Rice Productivity Growth. Economic Development and Cultural Change 40(4):697-718.

Reyes, R. D. 1973. An Analysis of Some Factors Affecting Rice Yield Response to Water. Pages 37-52 in T. H. Wickham, ed. Water Management in Philippine Irrigation Systems. IRRI, Los Banos, Philippines.

Rosenzweig, M. R. 1980. Neoclassical Theory and the Optimizing Peasant: An Econometric Analysis of Market Family Labor Supply in a Developing Country. Quarterly Journal of Economics 94(1):31-55.

Sandler, T. 1984. Club Optimality: Further Clarifications. Economics Letters 14(1):61-65.

Sandler, T. 1992. Collective Action: Theory and Applications. University of Michigan Press, Ann Arbor. 237 pp.

Sandler, T., and Tschirhart, J. T. 1980. The Economic Theory of Clubs: An Evaluative Survey. Journal of Economic Literature 18(4):1481-1521.

Sandler, T., and Tschirhart, J. T. 1981. On the Number and Membership Size of Consumer Managed Firms. Southern Economic Journal 47(4):1086-1091.

Sandler, T., and Tschirhart, J. T. 1984. Mixed Clubs. Journal of Public Economics 23(3):381-389.

Sandmo, A. 1972. Optimality Rules for the Provision of Collective Factors of Production. Journal of Public Economics 1(1):149-157.

Schwab, R. M., and Oates, W. E. 1991. Community Composition and the Provision of Local Public Goods- A Normative Analysis. Journal of Public Economics 44(2):217-237.

Scotchmer, S. 1985a. Profit Maximizing Clubs. Journal of Public Economics 27(1):25-45.

Scotchmer, S. 1985b. Two-Tier Pricing of Shared Facilities in a Free-Entry Equilibrium. The Rand Journal of Economics 16(4):456-472.

Scotchmer, S., and Wooders, M. H. 1987. Competitive Equilibrium and the Core in Club Economies with Anonymous Crowding. Journal of Public Economics 34(2):159-173.

Scotchmer, S., and Wooders, M. H. 1987. Core Utilities and Abundance of Players. Working Paper, IMSSS, Department of Economics.

Sexton, R. J. 1984. Perspectives on the Development of the Economic Theory of Cooperatives. Canadian Journal of Agricultural Economics 32(2):423-436.

Sexton, R. J. 1986. The Formation of Cooperatives: A Game-Theoretic Approach with Implications for Cooperative Finance, Decision Making, and Stability. American Journal of Agricultural Economics 68(2):214-225.

Singh, I., Squire, L., and Strauss, J. 1986. Agricultural Household Models: Extensions, Applications, and Policy. Johns Hopkins University Press, Baltimore. 335 pp.

Small, L. E. 1994a. Achieving Financially Sustainable Irrigation Operation and Maintenance in Vietnam: Some Observations and Policy Recommendations. Paper presented at the Agricultural Economics Workshop, January, Hanoi.

Small, L. E. 1994b. Role of Collective Action in a Transition Economy (with special emphasis on irrigation). Paper presented at the Agricultural Economics Workshop, January, Hanoi.

Small, L. E. 1994c. Financing, Efficiency and Farmer Participation in Irrigation Projects in Southeast Asia. Paper presented at the Agricultural Economics Workshop, January, Hanoi.

Small, L. E., Bruns, B., and Herklots, P. 1993. Irrigation Operation and Maintenance Procedures and Policies. Mimeograph. United Nations Capital Development Fund, Washington, D.C..

Staatz, J. M. 1983. The Cooperative as a Coalition: A Game-Theoretic Approach. American Journal of Agricultural Economics 65(5):1084-1089.

Strauss, J. 1986. The Theory and Comparative Statics of Agricultural Household Models: A General Approach. Pages 71-91 in I. Singh, L. Squire, and J. Strauss, eds. Agricultural Household Models: Extensions, Applications, and Policy. Johns Hopkins University Press, Baltimore.

Svendsen, M. 1995. Agricultural Water Control Institutions in Viet Nam: Functions, Financing, and Sustainability. Working Paper prepared for the Joint Ministry of Water Resources, World Bank, Asian Development Bank, FAO Water Resources Sector Review.

Tabbal, D. F., and Wickham, T. H. 1978. Effects of Location and Water Supply on Water Shortages in an Irrigated Area. Pages 93-101 in D. C. Taylor, and T. H. Wickham, eds. Irrigation Policy and Management in Southeast Asia. Agricultural Development Council, Bangkok.

Tang, S. 1992. Institutions and Collective Action: Self-Governance in Irrigation. Institute for Contemporary Studies Press, San Francisco. 151 pp.

Tiebout, C. M. 1956. A Pure Theory of Local Expenditures. Journal of Political Economy 64(5):416-424.

Tokle, J. G., and Huffman, W. E. 1991. Local Economic Conditions and Wage Labor Decisions of Farm and Rural Nonfarm Couples. American Journal of Agricultural Economics 73(3):652-670.

Tran, T., and Nguyen, M. 1995. Changing Rural Institutions and Social Relations. Pages 201-214 in B. Kerkvliet, and D. J. Porter, eds. Vietnam's Rural Transformation. Westview Press, Inc., Boulder.

Trung, N. 1978. Economic Analysis of Irrigation Development in Deltaic Regions of Asia: the Case of Central Thailand. Pages 155-164 in D. C. Taylor, and T. H. Wickham, eds. Irrigation Policy and Management in Southeast Asia. Agricultural Development Council, Bangkok.

Varian, H. R. 1992. Microeconomic Analysis, Third Edition. W.W. Norton, New York. 506 pp.

White, C. 1985. Agricultural Planning, Pricing Policy and Co-operatives in Vietnam. World Development 13(1):97-114.

Wickham, T. H., and Valera, A. 1978. Practices and Accountability for Better Water Management. Pages 61-75 in D. C. Taylor, and T. H. Wickham, eds. Irrigation Policy and Management in Southeast Asia. Agricultural Development Council, Bangkok.

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