REFINING THE POSITIVE AND NEGATIVE EXTERNALITIES OF TAIWANESE PADDY RICE PRODUCTION[1]

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ABSTRACT

Rice is often singled out as the largest consume of irrigation water. There is also increasing acceptance of the fact that paddy irrigation yields social benefits beyond those directly resulting from rice production. But there is considerable dispute about the magnitude of those benefits. The dispute results in part from lack of relevant data and in part from the use of inappropriate methodologies. This paper outlines the issues associated with the valuation of externalities, identifies the sources of external benefits and costs in paddy rice culture, and reviews the problems associated with various methodological approaches. The authors conclude that there is a general misconception of the amount of water depleted by rice cultivation, and that return flows from rice cultivation generate important positive as well as negative externalities. However, existing studies may overestimate the potential benefits of paddy rice cultivation. There is a need for a new more objective methodological approach, but in many instances data may often be lacking for the successful application of this approach.

1. INTRODUCTION

Paddy rice is the primary food production industry in many Asian countries and accounts for approximately 50 percent of the irrigated area in Asia. As a result countries have paid close attention to the rice industry and have employed multiple market intervention policies to promote farmers' welfare and protect the food supply for the public.

Over time the range of non-trade concerns (externalities) has broadened to include food security, food safety and quality, and animal welfare and rural development, in addition to the collection of attributes encapsulated in the term "multifunctionality." While the latter concept has many interpretations, the intent is to recognize the multiple-output nature of agricultural production in which many commodity as well as non-commodity outputs are produced jointly. In addition to food, fiber, and agricultural raw materials, these multiple outputs may include environmental effects, landscape amenities, and cultural heritage (aspects of how land is used) that yield "social" benefits or impose "social" costs not traded in organized markets.

The interest in valuing the range of externalities has increased recently with the desire of many countries to meet the free trade objectives of the World Trade Organization (WTO). Under WTO rules government efforts to support the domestic agricultural sector must rely less on price

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supports and other domestic policies that distort international trade.

This paper is based upon ongoing research on the non-commodity benefits and costs of paddy irrigation in Taiwan. The research is being undertaken by the International Water Management Institute in collaboration with the Agricultural Engineering Research Center in Taiwan, and the Department of Applied Economics and Management, Cornell University. The objective of this research is to evaluate the methodological options both in determination of the magnitudes of paddy irrigation externalities and in their valuation.

The next section of the paper deals broadly with the issue of identifying and valuing non-commodity outputs. The third section is concerned with non-commodity externalities in the context of paddy rice production in Taiwan. The fourth section summarizes and compares previous studies estimating the value of multifunctional outputs from Taiwan paddy rice identifying the strengths and weakness of these approaches. Additional research currently being undertaken to develop more rational estimates of the benefits of multifunctional outputs of paddy rice is discussed in the summary and conclusions.

2. THE *MULTIFUNCTIONALITY* VALUATION ISSUE

Although not a universally held view, many would agree that the demand for amenities, environmental quality, and other multi-functional outputs of agriculture is substantial, and it is likely to increase in countries where incomes and wealth are on the rise. There is however, no consensus on how multifunctionality can be reconciled with freer trade and the reform of domestic agricultural policy. The issues surrounding multifunctionality have global, country-specific, regional, and local dimensions that are just too complex to resolve within traditional commodity-oriented domestic agricultural policy. Rather what is needed is a new domestic agricultural policy paradigm that focuses directly on the sector's importance as a user of land and other highly valued natural and environmental resources.

According to the OECD (2001) the definition of *multifunctionality* is:

> Beyond its primary function of supplying food and fiber, agricultural activity can also reshape the landscape, provide agricultural benefits such as land conservation, the sustainable management or renewable resources and the preservation of bio-diversity, and contribute to the viability of many rural areas.

The *non-commodity* outputs of *multifunctional* agriculture can be positive or negative externalities. The distinguishing feature of the non-commodity outputs is that they are not traded in organized markets. Thus, in order to reformulate policy to recognize explicitly this new role of a multifunctional agriculture, we must derive values for these non-commodity outputs using one or more of some well-established non-market valuation techniques. Application of these methods in the case of jointly produced multiple outputs is not an easy task.

Research on the valuation of non-market goods is largely in the domain of environmental economists. As Cropper and Oats (1992) indicate in their review article, there are both direct and indirect methods for measuring the benefits or costs of non-market goods.

The indirect methods rely on observed choices and there are three basic approaches: cost avoidance, weak complementarity, and hedonic price. Examples include:

> *cost avoidance or substitutive cost*: water infiltration costs avoided in a household because of specific improvement in water quality; placing a value on the paddy fields for flood control by calculating the cost of additional reservoir capacity to serve the same purpose.

> *weak complementarity*: an improvement in environmental quality results in an increased demand for visitors to the rural area – the value of the environment being measured by the net addition to consumer surplus.

> *hedonic price*: the price of goods can be decomposed into the prices of various attributes of the good: the size of the house, number of rooms, quality of the environment surrounding the house, etc.

e alternative to these indirect methods is to gather evidence on the value of non-market goods ough surveys based on the contingent valuation method (CVM) or through experiments ducted in a laboratory for experimental economics. According to Randall (2002) the basic a is:

> If we design and ask questions with enough care, perhaps people can provide reliable evidence of amenity values by telling us their willingness to pay (WTP) or willingness to accept directly (WTA); or by telling us what they would do (e.g. buy or not buy … or choose this alternative rather than that) given well specified choice situations that we construct for them…

the case if agriculture's supply of these non-commodity outputs and attributes (e.g. ironmental goods; welfare-friendly production), whether one takes the direct or indirect roach, there are several reasons why the valuation process is particularly difficult. There are dimensions to the problem: what to include in the list of non-market goods and how to asure or articulate the characteristics to be valued.

THE PADDY RICE CONTEXT

ost of the recent studies on *multifunctionality* deal with the specific context of *paddy rice oduction* rather than the more general context of crop irrigation. Almost half of the irrigation in sia is devoted to rice production. Rice is often viewed in the context of *culture* and *food curity* rather than the narrower context of *crop production.* Some Asian countries are concerned ith protecting paddy rice production in the face of WTO requirements to move toward free ompetition and remove rice price supports.

Before moving to the discussion of multifunctionality, we comment briefly in the next section on common misconceptions regarding water requirements for paddy rice production (Barker and Molden 1999). Many people believe that there is considerable wastage of water in rice irrigation, because the quantity of water delivered to rice field typically far exceeds that of other crops. Based on this point of view, rice irrigation is the target for efficiency improvements , or labeled as an inappropriate crop in many contexts, because of water scarcity..

3.1 How much water does rice consume?

The question is how much water can be saved from rice irrigated areas? Related to this question is how much water does rice really consume? The answer is that there is much less opportunity for saving water in rice irrigated areas than expected because rice does not consume as much water as commonly believed. Return flow water, that not consumed by crop evapotranspiration is the source of many positive and negative externalities. Let us consider them in some detail.

Consider the flow of water in a river basin where rice irrigation is practiced. Rainfall that is not immediately evaporated flows to aquifers or the river system. Water is diverted from rivers to rice irrigated areas. Conveyance structures carry water to farmers' fields where it is applied to the soil. Water evaporates directly from the surface of the field, or by crop transpiration. The remaining water either flows horizontally as surface runoff, or as lateral seepage, or vertical deep percolation.

What happens to runoff, deep percolation, and seepage? Are these losses? Common in rice irrigated areas is the movement of water from field to field either as surface runoff or seepage. One farmer's drainage is another farmer's supply. Eventually excess water may reach a larger drain that removes excess water from the irrigated area. Drains represent another source of water for irrigated rice farmers who ingeniously divert water or pump water from these drains. Similarly, aquifer water, recharged by deep percolation, is pumped to fields. Water truly follows a "tortuous path" within rice irrigated areas, and in many cases is applied several times. This use and re-use of water is referred to as recycling of water.

Eventually, water drains out of the irrigated area. Drainage flows that re-enter the river system are known as "return flows". Return flows are very often an important source of water for downstream users, and can be the source of water for wetlands, so there is yet another possibility of recycling. Eventually, return flows cannot be reused, either because (a) they flow into a sea or other sink, or (b) there are no users downstream that could use this water.

To help conceptualize water savings it is useful to consider: *delivery* to a use, and *depletion* of water by that use (Molden 1997). Water is delivered to a field and applied to land. Water is depleted when there is no further opportunity for re-use downstream. Depletion occurs either when water is vaporized by evaporation or transpiration, or flows to a sink such as a sea, or an inland lake with no drainage outlets.

Deliveries to rice fields often far exceed other crops such as maize or cotton. But importantly evapotranspiration is only a small amount higher, on the order of 20% higher than for these other crops. The difference between deliveries and evapotranspiration are return flows, and the amount of depletion depends on what happens to the return flows. Many rice based systems are adapted to reuse return flows for many purposes.

Two general water saving scenarios occur with respect to return flows:

Scenario 1: Return flows can be reused, and depletion is only transpiration and evaporation.

Scenario 2: Return flows cannot be reused because they flow into a sink, and depletion is the combination of evapotranspiration and flows to sinks.

Diversions and return flows are the main causes of positive and negative externalities of rice cultivation. Diversions from river systems for rice have significantly altered river flow patterns. This may be considered positive in terms of flood reduction, but negative in terms of destruction of aquatic habitats. On the positive side, return flows can recharge aquifer or create other wetland environments. On the negative side, return flows can direct polluted waters to unwanted places.

In short, in a basin context, rice does not use as much water as is it may first seem based on an observation of deliveries. Evapotranspiration of rice is only slightly more than other grain crops. Rice irrigation tends to generate more return flows than other crops requiring special consideration. There is often considerable reuse of water in rice systems, so that when viewed from a larger basin perspective rice irrigation can be quite efficient (see Dong et al., 2001). To determine the actual amount of water that can be saved from rice practices needs careful accounting of the temporal and spatial patterns of flow within the basin. Careful consideration needs to be given to the externalities generated by rice irrigation to maintain or enhance positive benefits of rice cultivation, yet reduce negative impacts.

2 Potential Non-Commodity Externalities

Rice in monsoon Asia typically is grown in saturated soil, often flooded through most of the growing season. This generally is accomplished with a combination of bordered parcels (paddies) and irrigation. In addition to providing optimum growing conditions for the rice, this has the potential to affect (positively and negatively) the natural environment. These effects, non-commodity externalities, may include: (i) recharge of underground aquifers, (ii) amelioration of land subsidence; (iii) reduction of flooding; (iv) minimization of erosion; (v) change of water quality; and (vi) change in air quality. In addition, there may be important social and economic environment externalities relating to landscape and recreation, and food security. A more complete list of potential externalities in agriculture are presented in a number of publications (OECD 2001, Parts 2 and 3).

Recharge of underground aquifers: The ponded conditions of paddy rice production result in percolation of water into the soil. The rate of percolation will vary, depending upon the soil type, but the water moving downward should have a recharging effect on the groundwater. This effect will be to: (i) replace water withdrawn from the aquifer, (ii) raise the water table, or (iii) increase the outflow from the aquifer to springs, streams, or the sea. In some cases a rise in the water table will be sufficient to impede drainage, resulting in *waterlogging* with the potential for *salinization*.

Amelioration of land subsidence: Land subsidence occurs when water is withdrawn from underlying aquifers. The subsidence may be essentially irreversible when it is accompanied by significant changes in the soil structure (reorientation of soil particles to result in a more dense structure.) It may be partially reversible when the subsidence is due to the reduction in pressure of a confined aquifer underlying the area. Increasing the pressure through restoration of the original water conditions can result in reduced subsidence. Recharge of the groundwater may have this effect.

Reduction of flooding: The characteristic basin paddy rice culture provides opportunity for temporary storage of water during rainfall periods. Depending upon the area in paddy, height of the borders (bunds), and irrigation policy there may be significant storage volume. For example, in the Taiwan case, this is estimated to be approximately 145 million cubic meters, the equivalent of a major reservoir. This can result in reduction of flood peaks, particularly in the areas immediately downstream from the paddy areas. For relatively short duration moderate storms this reduction can materially affect the extent of flooding. For areas further downstream, longer duration storms and those with larger magnitudes the effects will be reduced.

Minimization of erosion: The construction of paddy areas provides a micro-topography that is level. This, combined with the bunds essentially prevents any soil movement from the area. In hilly or mountainous areas, this topographic change can radically reduce erosion. The Ifugao terraces in the Philippines are classic examples of the potential for erosion control in mountainous areas. However, the labor involved in maintenance of paddy terraces in the mountains is substantial and increasingly difficult to mobilize. Structural failure of terraces has the potential to accelerate erosion due to the release of the ponded water.

Change in water quality: As with other forms of agriculture, fertilization and pesticide use in paddy rice culture can have negative impacts on the natural environment . The fertilization effect usually takes the form of pollution of runoff water (frequently nitrogen and phosphorous) or of the groundwater (usually nitrogen.) Pesticide use can pollute both surface and groundwater, the specific nature of the pollution is dependent upon the pesticides used, their volumes and timing of application, as well as upon the soil and topography. Paddy culture however, has the potential for some positive effects on water quality. Sediments do not leave the paddies to pollute the water. In addition to the effect on turbidity of surface water soil particles carry nutrients and/or pesticide components which lower stream quality. The chemically reduced soil conditions that exist under the flooded conditions inhibit the formation of nitrates and the movement of nitrogen into the groundwater. Additionally, the soil can act as a purifying medium when polluted water is used for irrigation. When the pollutant is primarily organic, as in the case of domestic sewage, there is substantial cleaning of the water resulting from irrigation use. While there may be health risks associated with the water, there are benefits from the standpoint of the environment. Similarly, when the pollutants are industrial in origin there often are benefits derived from the deposition of heavy metals and other chemicals into the soil matrix. In this case there are questions of the long-term impacts on soil productivity and health, but in the short-run there are improvements in the water recharging the aquifers and streams.

Change in air quality: Paddy agriculture has both positive and negative externalities related to air quality. The rice plants take in carbon dioxide and release oxygen during the growing cycle – a benefit to air quality. At the same time, significant quantities of methane are produced contributing to the global warming problem.

Landscape improvement: The presence of an agricultural landscape often is an important aspect of the visual environment that is valued by a nation's population. This is especially true in those countries that are industrialized or industrializing rapidly. In Europe this is evident; in onsoon Asia, with rapidly increasing urban populations, there is increasing awareness of the lue of the scenic value of agricultural land.

Food Security: The ability to provide rice sufficient to meet a nation's food needs during iods of emergency often is an important part of public policy. In Taiwan, for example, the area oted to paddy rice production is determined as a matter of government policy on food rity.

ointness of Externalities

e is increasing recognition that the non-commodity outputs of agriculture (externalities or i-functions) and the commodity outputs are inexorably linked. Thus, agricultural policy, at national and international levels, must consider both types of outputs jointly. This is not y accomplished because some of the outputs are traded in the marketplace and others are ic good for which no market exists. The problem is further complicated because there often technical" interdependencies between and among the factors producing the outputs. For ple, the level of water in the paddies influences both the available storage for flood oration, and the rate at which percolation occurs. In this case they have opposite effects, less water resulting in greater storage and a lower rate of infiltration. Efforts are being made velop methodologies to deal with the "jointness" of agricultural outputs, and this will be ored further in section four.

ational vs Location Specific Evaluation

determination of the magnitudes and values of agricultural externalities is markedly enced by data availability. Many, if not most of these externalities are functions of the local ronment and, therefore, the accuracy and precision of the estimates of their magnitudes (and es) are dependent upon the degree to which the data reflect this environment. For example, *arge* is a function of the infiltration and percolation capacities of the soil. Clay soils have low olation rates (1-2 mm/day) and those for gravelly soils may be as high as 40-50 mm/day. le the soils used for paddy culture typically are clayey, there may be a ten-fold difference in olation rates among those soils. Thus, the determination of the magnitude of recharge lting from paddy areas is a function of how well the different soil types are reflected in the luation. Taiwan, Japan and Korea have the type of soils information that permits them to er consider recharge on a location specific basis or to develop reasonable weighted averages percolation on a national basis.

ilarly, the unit values of specific externalities often are location specific. Again, using harge as the example, the value is influenced strongly by the status of the underlying aquifer. the aquifer is in overdraft, i.e. the phreatic surface is declining over time, the recharge water y be considered to have a value equal to that of water stored above ground. If the aquifer is not ing stressed, the influence of recharge may be to replace extracted water and/or to sustain the se flow of springs and streams fed from the aquifer. This latter may have significant vironmental value, e.g. maintaining fish populations, but is likely to be much lower than that r the aquifer in overdraft. Thus, the value determined for the recharge externality based on tional-level data is likely to be significantly in error. In the case of Taiwan, data from five uifers in the country show only one to be in overdraft. Assuming the same unit value for the echarge water on a national basis would very likely lead to a significant error in the estimate of total value.

Land subsidence is, perhaps, even more of a location specific example. Subsidence usually occurs in relatively unique locations – areas where sediments were deposited and developed in a relatively unconsolidated form, or where an underlying confined aquifer is subject to compression. In the case of those areas where subsidence is due to consolidation of unconsolidated formations, recharge from paddy agriculture is not likely to have significant amelioration benefit other than to slow the rate of subsidence. There may be more benefit in those situations where recharge re-pressurizes confined aquifers. The evaluation of the benefit from subsidence amelioration, therefore, is highly dependent not only on the specific area affected, but also on the nature of the subsidence in each area. Since the damage due to subsidence may be substantial, the use of national or generalized information is almost sure to lead to inaccurate results.

Flooding presents two types of problems. The first relates to the fact that much of the benefit to 'upstream' flood amelioration measures occurs relatively close to the location of the measures. In the case of agricultural measures, such as ponding in paddy areas, it is likely that much of the benefit from flood protection will occur on agricultural land. Relatively few countries have good estimates of flood damage to agriculture. In the case of Taiwan, farmers can apply to the government for compensation for flood losses, but compensation is limited by the budgetary allocation given for this purpose. In addition, since there is a degree of bureaucratic complexity in applying for compensation, it is likely that many farmers do not apply.

The second problem relates to the possible impact on urban areas further downstream. While it is possible to make a reasonable estimate of probable flood storage in the paddies, the impact of this type of dispersed micro storage on flood hydrographs is difficult to determine. There may be a lengthening of the 'time of concentration' of the watershed, thus changing the probability of occurrence of a given flood level, but the calculation of this change is very difficult, except for relatively small watersheds. Since both the extent and type of damage in more urban areas is related to both the area affected and the depth of water, the uncertainty about depth effect leads to major uncertainty about valuation.

The determination of the value of erosion prevention also is complex because some of the value is derived locally, in terms of maintenance of the productivity of the land, and some obtained from amelioration of downstream impacts, such as sedimentation of reservoirs.

The impact on *water quality* has many of the same questions as recharge. The impact is a function of the quality of the water used for irrigation and the quality of the receiving waters. Where the quality of the incoming water is good, the externality may be negative, due to the addition of fertilizer nutrients and pesticides. Where the quality of the irrigation water is poor, there may be a substantial benefit from the filtering action of the soil. Where the receiving water is of good quality, the externality associated with any water leaving the paddy area is likely to be negative; conversely, in areas of poor quality receiving water, there is a likely benefit. Again, locally disaggregated data will result in more accurate evaluations of the benefits and costs associated with water quality impacts.

The dispersed nature of the impacts on *air quality* suggests that aggregate data on a national scale are appropriate for their evaluation.

The *landscape* externality again is difficult to define. While it is probable that the population relatively close to the paddy areas will be the beneficiary of the scenic situation, tourism broadens the numbers of people who might value preservation of the paddy landscape. Given the combination of uncertainty in valuing the landscape on a unit basis and the population affected, national aggregated data may be as appropriate as more local information.

In many instances, the question of the use of national v disaggregated data will be academic. Few countries possess the appropriate information in a disaggregated form that would permit reasonably accurate information. Thus, of necessity, national data will tend to be used, with the recognition that the answers gained are only "first approximations". However, as the issues related to agricultural externalities grow in importance, the need for more accurate estimates will grow. A data collection program to permit these more accurate estimates is imperative.

PREVIOUS STUDIES ESTIMATING THE VALUE OF MULTIFUNCTIONAL OUTPUTS FROM TAIWANESE PADDY RICE.

There have been four previous studies in Taiwan estimating the values of multifunctional outputs of paddy rice in Taiwan. Two of the studies by Chen (2001) and by Chen, Wu, and Chang (2002) apply contingency valuation methods to elicit values from a sample of Taiwanese residents. Two others, a somewhat earlier study by Tsai (1993) and a more recent one by Tan (2002) employ a series of indirect methods to estimate individual values for each of several multifunctional outputs of paddy rice. These studies follow quite closely the methodologies used in Japan (MAFF, 2000).

Only positive externalities have been considered in these studies, mainly because there has been an implicit desire to obtain a high value to justify to WTO a high level of domestic subsidies for rice production (even thought these may no longer take the form of direct price supports). In fact, externalities not withstanding, there is a strong political desire in all three East Asian countries (Taiwan, Japan, and Korea) to maintain a relatively high level of rice self-sufficiency to ensure national food security.

Of the four studies described briefly below, two use contingent valuation methodology (CVM) and two use indirect methodology. We discuss the studies associate with each methodological approach separately.

4.1 Contingent Valuation Method

Chen (2001) – This paper estimates the social value of several environmental services of Taiwanese agriculture. A survey was mailed to eight hundred respondents, 200 households of agricultural professionals and 600 households from the general public. Overall response rate was 38 percent. Respondents were asked to provide a holistic willingness to pay for 10 categories of multifunctional services – recreation, resource conservation, flood protection etc. Using probit and logit regression analysis, Chen estimated the willingness to pay for services for different sub-groups - households of agricultural professionals, of parents with elementary school students, and of parents with college students.

Chen, Wu, and Chang (2002) – This study uses a survey of households in 21 district areas using a computer-assisted telephone interview system. A total of 7,638 calls were attempted with a 19 percent response rate. The questionnaire was complex, with a respondents being asked a range of questions such as personal experience with flooding and knowledge of organisms in the paddy field. Finally, they were asked to separate valuation questions dealing with the groundwater protection function of paddy and the landscape preservation function of paddy. Willingness to pay was in the form of tax money for protection and preservation of paddy fields obtained by reducing taxes for other public services.

The major challenge in contingent valuation is to develop a set of questions such that the individuals being surveyed are clear as to exactly what is being valued. Based on the CVM questions one would expect to obtain quite different information from the two CVM studies. Particularly in the Chen et al., study where the interview was conducted over the telephone, it seems very doubtful that participants understood clearly both the benefits (preservation of paddy land and water) and costs (reduced taxes for unspecified other services) associated with their willingness to pay. No attempt seems to have been made in this study to make sure respondents are valuing the same multifunctional outputs. Chen's benefit functions encompass a more holistic willingness to pay for 10 multifunctional services. If the two studies are to be compared, then Chen's analysis must be disaggregated to separate out the values assigned to groundwater and land protection that are the focus of the Chen et al., study.

4.2 Indirect methods

Tsai (1993) - Tsai used several indirect methods to place value on four separate types of benefits – groundwater recharge, flood protection, land subsidence, and air purification. To illustrate the procedures followed, we focus on methodology for assessing groundwater recharge and flood protection. The basic methodology here is *cost avoidance* or *substitutive cost.* For example, the value of the recharge is obtained by estimating the annual dam construction and operating costs required per cubic meter of storage to arrive at a raw water cost. This is then used to estimate the value of groundwater recharge in NT$ per hectare dividing by an average operations ratio. A similar method is used to assess the dam storage capacity needed for flood control and thus to assess the benefits. However, the value of water is not adjusted by an average operations ratio and is hence nearly double that used in calculating the value of groundwater recharge.

Tan (2000) – Tan employs a similar method in calculating the values for groundwater recharge. He estimates ground water recharge by multiplying the soil infiltration rate by the number of rrigation days and number of acres planted. He can thus estimate directly the amount of water eaching deep levels not having to make adjustment in values as in Tsai's study. Tan uses xactly the same method as Tsai in calculating the value of water stored for flood protection and lso does not adjust price by the average operations ratio.

ble 1 summarizes and compares the findings of the four studies. The magnitude of the per ectare valuation of externalities (in New Taiwan dollars, NT$) is compared with the per hectare oduction value of the rice crop. There is a wide variability in results with the contingency luation approach having a higher ratio of externalities to production value. The study by Tan ing almost the same approach as Tsai but with different assumptions gives the lowest valuation externalities.

hile we document some of the difficulties of these existing attempts, our purpose is not to be erly critical. As Randall (2002) suggests, there has been some work at developing thodology to resolve the various problems encountered, but these methods are untried. Thus studies should be seen as pioneering works and an important first step in applying methods to luate externalities in paddy rice.

NEGATIVE EXTERNALITY OF PADDY RICE PRODUCTION – METHANE MISSION OF TAIWAN

e rice fields of eastern Asian constitute a large proportion of total agricultural land area, and ough irrigation most fields have an abundant water supply during growing season. In Taiwan, example, the ratio of rice field area to total cultivated field is 41% in 1999 (COA, 2000); ost all fields are irrigated. Because methane is produced during rice production by aerobic omposition of soil organic material in flooded rice field and it generated oxidized by aerobic teria in the soil reaches the atmosphere causing the greenhouse gas problem. For this reason, thane emissions from rice fields are likely a significant problem in Taiwan.

th increased concern worldwide about greenhouse gas emissions, there is ongoing research o forecasting future methane emissions and into identifying mitigation strategies to reduce issions (EPA, 1999; Lin et al, 2002). For Taiwan, research related to methane abatement has to be published, but some research focusing on methane emissions and forecasting had been mpleted (Wu et al, 1997; Yang, 2000; Lin et al, 2002). To gain some perspective on the gnitude of the negative externalities associated with paddy rice production, we summarize in is section our current knowledge about the level of methane emissions and potential abatement sts.

1 Methane emissions

e results of two Taiwanese studies of methane emission provide most of what we know about ethane emissions from paddy rice. Yang (2000) combined the IPCC (1996) methodology and th local methane emissions coefficients from Taiwanese experimental studies to estimate ethane emissions from the agricultural sector between 1990-1999. His formula for estimating ethane emissions in each study year is: $M=A*B*C*D$, where M = methane emission of paddy ce field (thousand tons); A = paddy harvest area (m^2*10^{-9}); B = an adjustment coefficient (ratio f Taiwanese irrigation rice field compared to deepwater irrigation rice field reported by the IPCC method); C = an adjustment coefficient of fertilizer use compared to the IPCC method; D = methane emission coefficient (Taiwanese local coefficient) (thousand-tons).

In his paper, Yang sets the coefficients B, C equal to 1, and argues that the since the temperature of the second crop season is higher than for the first crop season, methane emissions of paddy rice fields in second crop season are also higher. He also summarized different laboratory results from different areas of Taiwan to establish the value for coefficient D.

Lin et al. (2002) argued that the emissions coefficient adopted by IPCC are not compatible to the situation in Taiwanese paddy cultivation; they mention several important differences between Taiwanese current situation and IPCC methodology. First, Taiwanese paddy cultivation is an irrigation system, but not a deepwater irrigation system such is found in the United States. Accordingly, methane emissions could be reduced significantly. Second, organic fertilizer is used for Taiwan paddy cultivation affecting soil quality differently from the chemical fertilizers used in the United States. For these reasons, Lin et al. adjust the coefficients of fertilizer use, deepwater irrigation, and soil quality from those based on IPCC and Yang's research. Estimates of methane emissions from these two studies are listed in table 2. Based on these adjustments to the coefficients, the annual estimates of methane emissions from the study by Lin et al. are on average 35% lower than those by Yang.

5.2 Potential abatement cost of China

Although to date no abatement analysis for methane emissions have been published for Taiwan, research from other countries provides a good reference point for Taiwan. After careful review of the literature, the methane abatement analysis from China (ADB, 1998) is used as this reference point due to the similar irrigation and cultivation practices in rice production. In this paper, the authors suggest three potential ways for estimating methane abatement for rice production. These methods are discussed below.

5.2.1 Manure management

According to experimental evidence, CH_4 emissions can be decreased by from 24 to 62 % when biogas residues, instead of barnyard manure, are used as soil treatment in rice fields. The disadvantage of this methodology for estimating abatement costs is that biogas residue production can only be used in a warm environment. Therefore, in that study the Northeast area of China, with its cold weather, was excluded from their analysis. This would have little effect in applying the results to Taiwan. Based on their analysis, the cost of methane abatement is estimated at US$ 85/ton-methane.

5.2.2 Seeding on dry nursery and thinning plantings

This is a new technology which can save labor and water usage of cultivation. The experimental evidence shows that CH_4 emissions can be decreased by from 2 to 6 % with his strategy. This abatement method can applied to areas of early rice harvest and are most applicable to southern China. The cost of abatement using this strategy is estimated at about US$400/ton-methane. However, this new technology requires additional training of rice farmers, as well as some new equipment.

5.2.3 Using hybrid rice with lower emission rates

Under the same cultivation conditions, the experimental evidence shows that methane emissions from some hybrid rice varieties can be reduced by 10 %. This strategy was thought to be applicable to all rice fields in China, regardless of different geographical features. The seed with lower emission rate methane emission is very expensive, estimated US$ 1,334/ton-methane.

5.3 Abatement cost of Methane emission in Taiwanese paddy production

It might be interesting to see the potential abatement cost of methane emission by combining the emission quantities of Taiwanese research and the abatement cast of China. Table 3 lists the various estimates of abatement costs for methane emissions based on these three different abatement technologies. The final two columns of the table provide abatement cost estimates based on the different emissions rates estimated by Yang and Lin et al.

6. THE WAY AHEAD

We have noted problems in measuring the potential benefits and costs of paddy rice production. One of the common misconceptions is that rice production is extremely costly in terms of water consumed. However, there are often opportunities for reuse is recycling of water "lost" through seepage, percolation, and surface runoff. Return flows from rice cultivation are often the source of positive and negative externalities, so water savings programs must carefully consider the use and value derived from these return flows.

This paper has focused on problems associated with measuring external benefits. The results of the studies in Taiwan noted above and of other studies conducted in Japan and elsewhere (Matsuno 2001) suggest that we need to develop a more objective methodology for valuation of externalities. Yet there are inherent difficulties in whatever approach we choose. If we choose contingency valuation (the direct approach), we must be extremely careful to be sure that respondents to questions have a very clear idea of what they are valuing. This, for example, cannot readily be achieved by telephone or mail questionnaire. If we choose the indirect approach we need to recognize the site-specific nature of benefits. We also need to be careful not to bias findings by ignoring the complementary or competitive nature of some benefits and by ignoring costs that result in this case from paddy rice farming.

In short there will always be instances where for political reasons there will be pressures to be less than objective either overvaluing the benefits, for example to meet WTO objectives, or undervaluing the benefits, as some accuse the Large Dam Commission of doing in their recent study (World Commission on Dams). The next step for researchers is to develop a methodological approach that assures a more objective valuation an extremely difficult task given the extreme limitation of data in most instances.

Table 1: Value of environmental externalities of Taiwan

	Indirect method		Contingent valuation method	
	Tsai (1993)	Tan (2002)	Chen et al (2002)	Chen (2001)
Items of environmental benefit	Groundwater recharge, flood protection	Groundwater recharge, flood protection	Water preservation, Land protection	All of the possible environmental externalities
Total externalities per hectare (NT$/ha)	59,156	50,000	125,668	612,992
Production value per hectare (NT$/ha)	88,595	102,089	104,155	104,155
Ratio	0.67	0.56	1.41	6.91

*Note: 1. The value of Tan (2002) only includes groundwater recharge, and flood protection, although they also included land subsidize.

2. Study period of Tsai (1993) was 1992, of Tan (2002) was 2000, of Chen et al (2002) and Chen (2001) was 1999. The production value of each study is corresponded to studying period of each study.

Table 2: Methane emissions for Taiwanese Paddy Rice (thousand tons)

Year	1995	1996	1997	1998	1999
Yang (2000)	44.6 (0.122)[a]	44.7 (0.128)[a]	43.9 (0.120)[a]	42.4 (0.118)[a]	42.8 (0.121)[a]
Lin et al (2002)	29.1 (0.080)[a]	27.8 (0.079)[a]	29.1 (0.079)[a]	28.6 (0.079)[a]	28.2 (0.079)[a]
Ratio of two studies (Yang/Lin ea al.)	0.652	0.621	0.662	0.674	0.658

Source: summarized from Yang (2000) and Lin et al (2002)
[a] Tons/hectare

le 3: Potential abatement cost of Taiwanese rice production

tement hodology	Average incremental abatement cost	Average abatement cost (Yang)*	Average abatement cost (Lin et al.) **
ure management	85 US$/ton 2,890 NT$/ton	10 US$/Ha. 350 NT$/Ha.	6.7 US$/Ha. 230 NT$/Ha.
nursery	400 US$/ton 13,600 NT$/ton	48 US$/Ha. 1,648 NT$/Ha.	32 US$/Ha. 1,086 NT$/Ha.
d rice adoption	1,334 US$/ton 45,356 NT$/ton	162 US$/Ha. 5,497 NT$/Ha.	107 US$/Ha. 3,622 NT$/Ha.

* Using Yang's methane emission quantity estimates for 1999.
** Using Lin et al.'s methane emission quantity estimates for 1999.
Exchange rate: 1 US$ = 34NT$