Water productivity in rice-based systems in Asia – variability in space and time

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Abstract
Rice is the largest user of water in Asia, probably accounting for more than half of irrigation water withdrawals. Two key trends in the Asian rice economy that are affecting water productivity are the rapid spread of pump irrigation and direct seeding. The number of pumps has grown exponentially in Bangladesh and Vietnam, and pump irrigation now dominates gravity irrigation in many countries. Direct seeding accounts for about one-fifth of rice area in Asia, but this share is increasing. Comparing water productivity values is difficult across space and time; in general, it is more relevant across time. Water productivity has increased over time in several selected systems, primarily due to increased yields of modern varieties and improved management of large-scale water flows. There is less evidence of field-level water management increasing water productivity, although this may have also contributed. The extent to which agricultural water scarcity will affect poverty in Asia depends crucially on how well societies will be able to create incentives for users to save scarce water, thus facilitating the adoption of new technologies. Because of the rapid spread of pumps, incentives to save water in rice cultivation are growing. Even for gravity flow surface water, new institutions are developing in China that promise to improve incentives. International trade in agricultural products, or trade in "virtual water," may also have a role to play and should be encouraged.

Media summary
Incentives to save water in Asian rice cultivation are increasing due to the rapid spread of pump irrigation and new forms of surface water rights.

Key Words
Water productivity, pump irrigation, water rights, virtual water, direct seeding

Introduction
Irrigation water is the largest user of water in the world (Cai and Rosegrant, 2003). Approximately 56 percent of total world irrigated area is in Asia, a figure roughly the same as its share of world population. Rice is by far the most important irrigated crop in the region (Dawe et al, 1998). For Asia in the aggregate, rice accounts for 40-46% of net irrigated area, although this figure varies considerably across sub-regions. In Southeast Asia, rice occupies from 64-83% of net irrigated area, while in South Asia the figure is only 30-35%. East Asia is in the middle, with 46-52% of net irrigated area being cropped with rice (see Appendix Table 1 for details of the calculations).

These figures are for area, not consumptive water use. Rice's share of consumptive water use (ET) is most likely higher than its share of area because wheat and maize, the other two most important Asian crops in terms of area, have lower consumptive water use per unit area. Tuong and Bouman (2003) show that grain production per unit ET is highest for maize, but about the same for rice and wheat. Because production per unit area is about the same for rice and maize in Asia, this implies that consumptive water use per unit area is less for maize than for rice. On the other hand, production per unit area is much higher for rice than for wheat in Asia. Given similar grain production per unit ET, this implies that consumptive water use per unit area for wheat is also less than for rice. The greater ET per unit area for rice arises because rice is often grown under ponded conditions, making evaporation higher than for other crops. Photosynthesis per unit transpiration is also higher for maize because it utilizes a C_4 type photosynthetic pathway. Because of rice's large share in the use of irrigation water in Asia, and because Asia is home to most of the world's poor (UNDP, 1997), changes in water productivity in rice cultivation will potentially have a major impact on the extent to which the looming water crisis affects the world's poor during the next 20 to 50 years.

Some key trends in the Asian rice economy

More than 75% of Asian rice production occurs in irrigated areas, which occupy about 55% of total rice area in this region. Despite a growing scarcity of water, the proportion of rice area that is irrigated is increasing. This is primarily because large areas of upland (3 million ha) and deep-water (1.2 million ha) rice land were lost between the late 1970s and the early to mid-1990s, constituting a 25 percent decline in the rice area in these ecosystems (Huke and Huke, 1997). In addition, irrigated rice area increased during these years at an average annual rate of about 0.9 percent per year, or about 600,000 hectares annually (this includes gains due to intensification, i.e., single cropped area being converted to double cropped area). Thus, while irrigated area comprised about 51 percent of total rice area in the late 1970s, it accounted for 55 percent of total rice area in the early to mid-1990s. Excluding China, where large areas of irrigated rice were lost during this period of time, the relative increase in irrigated area is more significant, rising from just 35 percent of total area in the late 1970s to 44 percent in the early to mid-1990s.

The spread of pump irrigation

In irrigated systems, privately owned pump irrigation has been steadily growing in importance for the past 40 years due to the rapid spread of relatively inexpensive pump sets, many of them manufactured in China. In India, the share of net irrigated area irrigated by wells grew steadily from 30% in 1964/65 to 57% by 1997/98 (this applies to all crops, not just rice, as do all of the statistics in this paragraph). Between 1982/83 and 1998/99, consumption of electricity for agricultural purposes (presumably primarily for irrigation) increased more than five-fold, from 17.8 to 97.2 million Kwh (Agricultural Statistics of India). In Bangladesh, the total number of operating shallow tubewells increased from 45 thousand in 1981/82 to more than 800 thousand by 1999/2000 (Ministry of Agriculture, Bangladesh). Most of these are used for irrigating rice, which occupies about 70% of total crop area harvested in Bangladesh. Between 1979/80 and 1999/00, tubewell irrigation increased from 15% to 71% of irrigated area. Surface water irrigation using low lift pumps accounts for another 15% of irrigated area, for a total of 86% of irrigated area using pumps (Bangladesh Bureau of Statistics). In Pakistan, tubewells and other wells accounted for more than half of growth in total irrigated area from 1961-1981. From 1982-95, all of the growth in irrigated area came from tubewells, with the area irrigated by other sources actually declining in absolute terms (Dawe et al, 1998). The number of pumps has experienced rapid growth in Sri Lanka as well (Randy Barker, personal communication).

Although the pump revolution has been most pronounced in South Asia, it has also been important in other parts of Asia. For example, in Vietnam, the number of pumps more than quadrupled in just 11 years (1988-99), from 124 thousand to nearly 800 thousand. Pumps are especially common in southern Vietnam (Vietnam General Statistical Office, 2000). In the Philippines, approximately 23% of rice farms now use pumps to access water, either from subsoil reservoirs, drainage canals, or natural creeks and rivers. Among these three sources, groundwater is the most important (unpublished data, PhilRice – Bureau of Agricultural Statistics).

Direct seeding

Another key trend that may have important influences on the future evolution of water productivity is the adoption of direct seeding methods of crop establishment. As of the late 1990s, Pandey and Velasco (2002) estimated that about one-fifth of rice area in Asia was direct seeded. Furthermore, direct seeding is spreading rapidly in many parts of Asia, and will most likely continue to do so in the future. In Zhejiang, China, rice farmers practiced transplanting as little as four years ago, but today, the transition to direct seeding is almost complete. A similar transition occurred in the Central Plain of Thailand in the late 1980s and early 1990s (Isvilanonda et al, 2000). The driving force behind these changes is economic growth, which, notwithstanding the financial crisis of a few years ago, is continuing at a rapid pace in most Asian countries. With economic growth comes increased labor demand, which in turn puts upward pressure on wages or reduces the availability of labor for many farm operations. This has encouraged farmers to switch from transplanting, which requires 25-50 person-days per hectare, to direct seeding, which requires at most only about 5 person-days per hectare.

Direct seeding has several effects on water use in rice cultivation. First, it reduces water use during land preparation because the land is prepared dry. Furthermore, farmers who practice transplanting sometimes (but not always) retain water in the field while the seedlings are still in the seedbed. On the other hand, direct seeding increases the duration of crop growth in the field, leading to increased water use during the crop growth period. In addition, the lack of puddling during land preparation means that percolation losses will be larger during crop growth. Bhuiyan et al (1995) reported that direct seeding reduced water input at a site in the Philippines because of substantial water savings during land preparation. Cabangon et al (2002) also found that direct seeding reduced water inputs compared to transplanting in the Muda Irrigation System in Malaysia. Nevertheless, as Cabangon et al (2002) emphasize, these conclusions may be specific to these particular systems. Thus, for Asia as a whole, it is not clear if the transition towards direct seeding will reduce or increase water inputs for rice cultivation.

Trends in Rice Area and Consumption

Perhaps surprisingly to many, area planted to rice increased throughout the 1990s in spite of urbanization trends, reaching a peak in 1999. This increase in rice area most probably implied increased use of irrigation water. Since then, however, rice area has declined slightly, both inside and outside of China (raw data from FAO). It is not yet clear if this decline is temporary, or if 1999 was a turning point.

In any event, demand growth for rice is slower today than in the past, primarily because population growth rates are declining across most of Asia (raw data from FAO). In addition, once countries reach a threshold level of income (which varies from country to country), per capita consumption of rice begins to decline as consumers satisfy a universal urge to diversify their diets. This turning point was reached a long time ago in Japan, and per capita rice consumption is now about half its peak level. Current rice consumption per capita is now 36%, 30%, and 29% below peak levels in Korea, Malaysia, and Thailand. Even in much poorer countries like China and India, per capita rice consumption has started to decline. After 25 years of rapid economic growth in China, per capita rice consumption is 9% below the peak reached in the mid-1980s. In India, the decline has been smaller to date at just 4%, but further economic growth will reduce rice consumption further. As populations stabilize and per capita rice demand falls, rice area could decline sharply, and with it much of agriculture’s demand for irrigation water. For example, rice area in Japan has declined nearly 50% since 1960.

Interpreting quantitative measures of water productivity: proceed with caution

While greater water productivity in the aggregate will almost certainly be necessary to reduce the negative impacts of future water scarcity, it is important to keep in mind that for any specific technology, project, or policy, higher water productivity does not necessarily result in increased benefits to society (Barker et al, 2003). For example, some interventions may raise water productivity only at the expense of using other scarce resources (e.g. land, labor, capital), with the net effect being a reduction in economic efficiency. This is not to say that increases in water productivity must come without using other resources, only that those other resources must also have a value attached to them.

In light of these observations, how do we interpret measurements of water productivity? Below are several examples of what can and what cannot be learned by comparing measures of water productivity.

Should water productivity be used to evaluate the benefits of a technology when the government gives water free to farmers?

This perhaps seems like a reasonable solution when farmers do not pay for surface water, or if they do, the amount that they pay is independent of the amount of water used. In such cases, farmers are unlikely to perceive any benefits from a water-saving technology unless it actually increases yield, yet it is entirely possible that the technology in question benefits society. In such cases, the proper solution is to calculate economic efficiency in social terms by attaching an opportunity cost to the water and then constructing a social profit and loss statement with and without the technology. Economists have well-developed methods to deal with such situations, but none of them involve calculations of water productivity (e.g. the Policy Analysis Matrix of Monke and Pearson, 1989).

Do different values of water productivity in different parts of an irrigation system indicate that policies or new allocation schemes should correct the imbalance?

Economic theory states that water should be re-allocated from one use to another until the marginal cost of transferring the water is equal to the marginal benefit in the area that receives the water. However, water productivity is an average concept, not a marginal one, so there is no *a priori* reason to expect that water should be re-allocated from areas of high water productivity to areas of low water productivity or vice-versa. There are several possible techniques that can be used to address the questions of water allocation within a system or a basin, and all of them involve calculations of profit and loss for different crops and different types of farmers. For good examples, see Hussain et al (2003) and Cai et al (2001).

Do different values of water productivity in different rice irrigation systems (perhaps in different countries) indicate that water management is better in the system with higher water productivity?
For a single crop (e.g. rice), values of WP_{ET} (rice production per unit of evapo-transpiration) can vary across locations for many reasons that are not amenable to direct human intervention and have nothing to do with water management (e.g., different climate, different crop growth duration). Thus, it is not clear that a higher value of WP_{ET} in one location indicates a more desirable situation than a lower value of WP_{ET} in another location (the same would be true for WP_{IP}, i.e. rice production per unit of water input from irrigation and rainfall). These statements are true even if water is equally scarce in both locations. If the degree of water scarcity differs across locations, then comparisons are even more difficult to make, because the concavity of the water production function implies that the economically optimal quantity of water to use will not in general maximize water productivity. Variability in rainfall also presents problems for measurements of WP_{IP}, because rainfall that is just adequate for a good crop will lead to high values of WP_{IP}, while excessive rainfall in a particular year will lower values of WP_{IP}. In such high rainfall conditions, however, low values of WP_{IP} probably do not indicate mismanagement of water. When cropping patterns are different across locations, then matters become even more complicated.

The best that can be said of such a comparison is that higher water productivity in one location compared to another might indicate a particularly promising area for more research, especially if land productivity is similar in the two systems and researchers have a direct knowledge of some specific irrigation practices that are better in one system than in the other. However, it is entirely possible that there is greater scope for improving water management in the system with high water productivity.

To be sure, similar complaints can be made about comparing yield (land productivity) across locations. And, in fact, a higher yield in one location does not necessarily indicate a more desirable situation than a lower yield in another location. As a practical matter, it is difficult to compare rice yields from one country to another, precisely because yields are influenced so strongly by biophysical factors such as solar radiation and length of the growing season, as well as general economic conditions (e.g. wage rates).

Is it useful to have data on water productivity for different rice varieties or different crops?
If farmers in an irrigation system growing a specific crop have only a fixed quantity of water available for use in a given season, it may be that achievement of economic efficiency becomes essentially identical to maximization of crop production. Under these conditions, it is sensible to maximize water productivity. If conditions like these become sufficiently common in the future, then it may be helpful for irrigation managers and farmers to know which rice varieties have the highest water productivity, similar to the way in which farmers often want to know which varieties have the highest land productivity. Data on the water productivity of different varieties would be useful provided that each variety is tested under different irrigation regimes. If each variety receives only one irrigation treatment in the trials, then water productivity will be directly proportional to land productivity, and there is no gain in information. On the other hand, if prospective varieties are grown under different irrigation regimes, then one could compare the water productivity of different varieties subject to different irrigation management strategies. Measurements of water productivity in these circumstances are likely to be helpful, provided that different irrigation regimes do not require substantially different levels of inputs other than water. Nevertheless, it will still be important to calculate net financial returns for each of the irrigation regimes.

Under similar circumstances (i.e., a fixed quantity of water available for use in an irrigation system), measurements of water productivity could also be used to evaluate the merits of different crops (e.g. wheat instead of rice during the dry season in Bangladesh), provided that the comparisons are made on the basis of net returns (revenues minus costs) per unit water, and not on the basis of kilograms of crop per unit water. A financial comparison accounts for the different economic value of different crops, as well as the different input requirements for growing them.

What is indicated by different values of water productivity over time in the same irrigation system?
In general, quantitative comparisons of land productivity are most useful when made over time for the same crop in the same location, although such analysis is not without its pitfalls. Thus, it is also probably more useful to make comparisons of water productivity across time instead of across space. Such comparisons can help in assessment of broad trends in water productivity, and the technologies, policies, and institutions behind those trends. This information should be helpful to policymakers and irrigation system managers. To my knowledge, only a few studies of long-term trends in water productivity in rice-based irrigation systems have been conducted.

Amarasinghe et al (1998) conducted an impact assessment of irrigation system rehabilitation in the left bank of the Gal Oya Irrigation System in Sri Lanka. They found that water productivity (measured as kg rice per m^3 of irrigation water supply) approximately doubled after rehabilitation, and attributed this increase to several factors. First, land productivity increased. Some of this increase may have been endogenous to the rehabilitation, but yields in Gal Oya were increasing rapidly even before the rehabilitation, probably due to the diffusion of modern varieties in Sri Lanka around this time. Second, physical and institutional changes associated with the rehabilitation increased the irrigated area of the system by 20-40% even though total irrigation supply decreased slightly. The authors did not attempt a cost-benefit analysis of the rehabilitation, so it is not possible to state if it was economically efficient.

Hong et al (2001) measured changes in water productivity for rice over a period of more than 30 years for the Zhanghe Irrigation District (ZID) in Hubei, China. Rice was the dominant summer crop for the entire period. The authors found that water productivity (measured in kg of rice per m^3 of irrigation water), increased substantially over time. However, much of the increase was due to higher yields per unit land, which were probably exogenous to events occurring in the irrigation system (yield trends in ZID are similar to those in Hubei province). Even so, increases in land productivity cannot explain all of the increases in water productivity. Figure 1 graphs the trend in water productivity over time in ZID in actual practice, along with the counterfactual level of water productivity that would have been realized if yields throughout the period 1966-2001 were equal to the average during 1966-74. This analysis shows that counterfactual water productivity fluctuated around a flat trend from 1966-91, and then increased substantially.

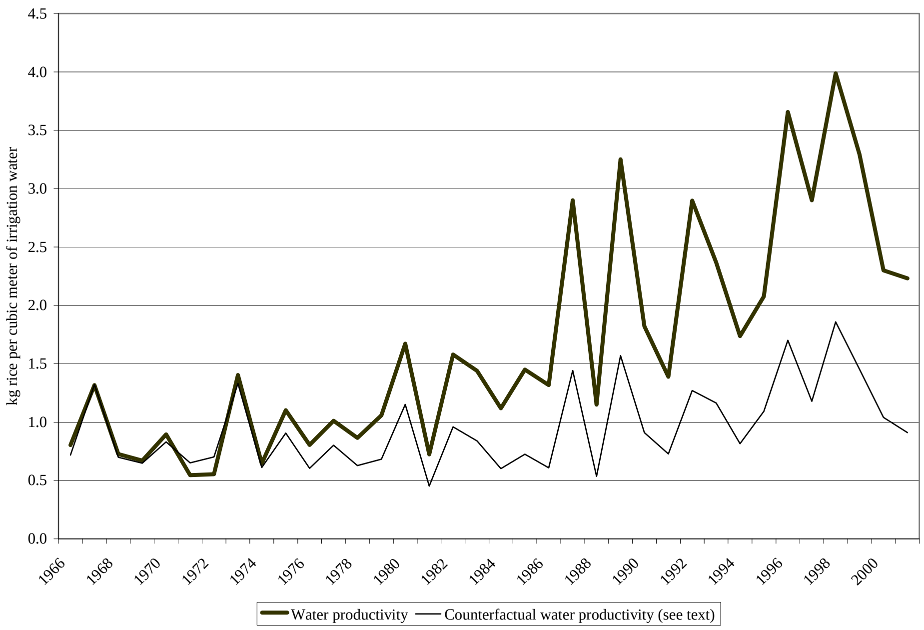

Figure 1. Water productivity in Zhanghe Irrigation District (ZID), 1966-2001.

During the period 1992-2001, counterfactual water productivity was 50% higher than during the 1966-1991 period. Many factors related to water management in ZID have changed during the past 35 years, including implementation of a system of volumetric water pricing (Loeve et al, 2001), extensive use of alternate wetting and drying (AWD) technology by farmers so that the crop is not continuously flooded, and improved management of the irrigation system. It was not possible to quantitatively determine which of these latter factors were most important for the increase in water productivity in the 1990s. An analysis by Moya et al (2001) showed that farmer adoption of AWD technology did not affect financial profitability, so to the extent that AWD results in real water savings in ZID, it has resulted in increased economic efficiency in social terms by transferring water to higher-valued uses without affecting farm profits.

Total water releases from the Angat Dam north of Manila in the Philippines fluctuated around a relatively constant trend line from 1968-1998. However, the share of these water releases allocated to non-agricultural uses in Manila increased steadily during the period, increasing from 12% in the first five years to more than 60% in the last five years. At first, water productivity (calculated as rice production divided by water not committed to Manila) increased substantially, but in the early years of the period the bulk of water not allocated to Manila was not allocated to agriculture either – it flowed to the sea instead. Thus, the increase in water productivity was not because of improved water management in agriculture, but because the capacity of the dam was excessive in the early years and less water was wasted in later years. In later years (1980-97), water productivity in the dry season declined slightly. Today, there is an acute conflict between industry and agriculture for the water stored in this dam, as reflected in the zero allocation received by farmers in the dry El Niño conditions during the first half of 1998. When this happened, farmers were essentially unable to plant any crops, and they had to replace the lost income by taking additional work or asking for additional remittances from friends and relatives working in Manila (Valencia et al, unpublished data). With the exception of strong El Niño events, however, allocations of water to agriculture in the dry season were generally constant during the period 1983-98. Nevertheless, rice production from this system has fallen slightly, due to declines in both area and yield, leading to a slight decline in water productivity.

Loeve et al (2003) discussed changes in water productivity during the period 1968-98 in Kaifeng City Prefecture, located along the Yellow River in Henan, China. Agricultural production in this prefecture is fed by four main irrigation systems, and cropping patterns in the summer season are quite diverse, including corn, peanut, cotton, soybean, and a small amount of rice. Because of the diversity of crops, it is not possible to calculate meaningful values of water productivity in units of kg per m^3. The best alternative, given available data, is to translate crop production into monetary equivalents. Holding prices of the main crops constant (i.e. adjusting for inflation), the gross value of agricultural production increased over the period without any increase in water diversions (it would be preferable to use data on the value of production net of input costs, but no such data exist). In fact, water diversions decreased substantially after 1978, but only due to the end of heavy diversions of Yellow River water that were designed to reclaim land by depositing sediments. Thus, it is certain that water productivity has increased in this system, but there is no evidence that water management practices at the field level have contributed to these increases. The main reasons for the increased value appear to be increased yields and to some extent a shift in cropping patterns to higher valued crops. In recent years, water diverted to agriculture has remained constant despite a large increase in industrial and domestic demand, but this has been possible only because of increased groundwater withdrawals. It is not clear whether groundwater withdrawals can continue at their current levels, as a cone of depression has materialized under the urban areas of Kaifeng City.

To summarize, there have been increases in water productivity in all four of the systems discussed, but most of these increases were due to major changes in the way irrigation water was diverted to the system (e.g. Angat, Kaifeng City Prefecture) or to increased crop yields. In Gal Oya, it appears that physical and institutional reforms helped increase water productivity, but it is not clear at what financial cost. ZID is the only case where improved field level water management may have contributed to increased water productivity. However, these irrigation systems are by no means a random sample of rice-based irrigation systems in Asia, so it is not clear to what extent this summary is representative of Asian experience.

Can water productivity be improved without adverse effects on the poor?

Ultimately, water productivity in rice cultivation is of importance insofar as it affects unit production costs. Lower unit production costs due to new technologies help reduce poverty in two ways. First, they help to increase the profitability of rice farming, which helps rice farmers who are poor and are able to adopt the technology. Second, lower unit production costs lead to lower market prices for rice, which help the rural landless and urban poor who must buy their rice on markets and often spend 20% -40% of their income on rice alone (Dawe, 1998). Efforts toward poverty alleviation in the next 20-25 years will be greatly facilitated by lower staple food prices (Senauer and Sur, 2000).

Effects of water scarcity on unit production costs

In the absence of new technologies, future water scarcity will increase unit production costs in several ways. As groundwater tables fall in some areas, pumping costs will increase. Some governments may begin to increase the fees that farmers pay for surface water deliveries. Other farmers may simply be denied allocations of water by governments so that industry and domestic uses can receive a higher share. All of these situations lead to higher unit production costs for rice.

Water and water-related costs can be an important part of rice production costs, although in many cases they are not. Valencia et al (2001) documents irrigation costs (including water fees and any pumping costs) for several sites in Asia where gravity flow surface irrigation is the dominant source of water. In some sites (Suphan Buri, Pho Phaya Irrigation System, Central Plain, Thailand; Aduthurai, Grand Anicut Dam, Cauvery Delta, Tamil Nadu, India), irrigation costs are zero. The highest level of costs was recorded in Jinhua, Zhejiang, China, where farmers paid US$25 ha^{-1} $crop^{-1}$ for irrigation water. Even these costs, however, were just 2.5% of gross revenue, compared to fertilizer costs of 12% of gross revenue and pesticide costs of 3.0% of gross revenue.

Not surprisingly, irrigation costs are much higher in systems where pumped water is dominant. For the Upper Pampanga River Integrated Irrigation System (UPRIIS) in Nueva Ecija in the Philippines, Moya et al (2002) find that farmers who use primarily gravity flow water had irrigation costs of $23 ha^{-1}, compared to $183 ha^{-1} for farmers who needed to pump for most of their water supply. These costs represented less than 2% of gross revenue in the former case, but more than 13% in the latter, where irrigation costs were about the same as the total of costs for fertilizer, pesticide, and seeds combined. In Bangladesh, pumping dominates in the *boro* (dry) season, but not in the *aman*, or wet season. Hossain and Deb (2003) calculated that irrigation costs in the *boro* season are about $118 ha^{-1}, compared to just $25 ha^{-1} in the *aman* season. The increased pumping costs are large enough that, despite an increase in yields in the *boro* season of 1.5 t ha^{-1}, unit costs of production are slightly lower in the *aman* season. Thus, in many situations, water is an important component of production costs.

Despite the increasing importance of pump irrigation, world rice prices (adjusted for inflation) are at their lowest levels in history. To some extent, this is due to macroeconomic phenomena, e.g. the depreciation of the Thai baht after the financial crisis of 1997 (Dawe, 2002). However, rice yields are still increasing, helping to put downward pressure on prices. Thus, while pump irrigation entails some increase in costs, it has not yet been sufficient to cause an increase in market prices.

The changing nature of incentives faced by rice farmers to save water

Many technologies have the potential to increase water productivity and reduce rice production costs (Tuong et al, this conference; Humphreys et al, this conference). Paradoxically, this may require governments to raise water costs in the short run (e.g. through water pricing or a system of tradable water rights), so that farmers have the incentives to adopt such technologies. In this regard, however, it is critical to realize one of the important consequences of the Asian pump revolution: many farmers are in fact now paying every time they irrigate their fields. Incentives remain more of a problem in gravity flow surface irrigation systems, but the relative importance of these systems in rice production is declining.

China has probably made more progress than any other developing country in terms of giving incentives to rice farmers that encourage them to conserve on the gravity flow water that they use. For many years, China has implemented a system of volumetric water pricing to groups of farmers, with allocation of water fees done on a pro-rata basis according to area (Loeve et al, 2001; Lohmar et al, 2003). Water prices vary across the country, with prices generally rising from south to north, i.e. as water gets scarcer. The groups can range in size from just a few members, to 30, to thousands, depending on the irrigation system and other factors. Free-rider problems can be a concern when water is sold to groups instead of individuals, and these problems are likely to grow more acute as the size of the group increases (Olson, 1965). Nevertheless, given the small size of rice farms in Asia, measuring the volume of water delivered to each and every farm is not likely to be a cost-effective solution to the problem of free-riding.

An alternative institutional arrangement that shows some promise is described and assessed in Wang et al (2003). In some irrigation systems in China, surface water management for a village (or other unit) is contracted to a single individual, the water manager. Farmers in the village pay water fees based on historical averages of how much water they have used, and these fees are given to the water manager. This system gives no incentives for farmers to conserve water. On the other hand, the irrigation manager is required to pay only for the water delivered to the village. If the water delivered to the village is below historical norms, then the water manager can keep the difference, generating incentives for the water manager to conserve water without reducing deliveries so much that farmers demand his replacement. Using multivariate statistical analysis, the authors find that systems where water managers have these types of incentives use less water, after controlling for a variety of other influences. This is an emerging institutional form in China, and it is not clear how widely it has spread. It is very similar to a system of water rights (Rosegrant and Binswanger, 1994), but instead of vesting such rights legally in each farmer (which might be very expensive when farm sizes are small), the rights are vested in the community, which can then temporarily assign them to individuals. Such institutional innovation has the potential to be very effective at conserving water.

In general, farmers who pump water have more incentives to save water than those who receive water by gravity flow. There are exceptions, however, especially in some parts of India where the water itself is free and the government subsidizes the cost of electricity or fuel, sometimes to the extent of making it free as well. Even when farmers receive no subsidies for pumping, however, it may still be the case that water tables are drawn down. This is happening to some extent in Bangladesh, although it is not clear to what extent this draw down will cause irreversible environmental damage, or if it will just raise rice production costs.

Draw down of water tables that exceeds natural recharge is not necessarily a negative outcome – there are not many people who would argue that world oil or mineral resources should never be exploited. And in fact, increased water pumping for rice cultivation in Bangladesh, Vietnam, and other locations during the past 20 years has arguably made a substantial contribution to poverty alleviation. Draw down of water tables becomes a problem when it is so rapid that the change becomes difficult to manage, for example if it leads to a deterioration of water quality that leads to land salinization and forces people to abandon agricultural land when they do not have alternative sources of employment. Undoubtedly, this is happening in some places. On the other hand, if the only consequence of drawing down a particular water table is that farmers are forced to shift from one crop to another, or from irrigated rice to rainfed rice, the costs are much less. In such cases, it may be inter-temporally optimal to exploit the water table for a certain limited period of time, grow irrigated rice temporarily, and then revert to rainfed rice (as opposed to growing rainfed rice in perpetuity). More studies that calculate not only the costs, but also the benefits, of declining water tables would be helpful in making decisions about groundwater regulation and the design of appropriate incentives for exploitation.

When farmers must pay the full energy costs of extracting groundwater, it is less likely that agricultural pumping will cause major environmental damage through draw down of water tables. It seems likely that pumping for industrial purposes has more potential to cause damage, because the marginal value of water is much higher in industrial use, creating more incentives for rapid draw down. Thus, some laws may need to be enacted and enforced in order to avoid excessive draw down of water tables that distorts the allocation of water across generations. In general, these laws will be more important in urban areas, because that is where the greatest drawdowns occur. Fortunately, that is where they will be easiest to enforce – in most developing countries, it is hard to imagine an effective enforcement system operating in rural areas.

Moving water, virtual and real

Other solutions to water scarcity skirt the difficult problems of raising prices, instituting a system of legal rights, or administratively restricting water allocations. One of the most promising is trade in what Allan (1998) has called “virtual water.” Barker et al (2003) cite the example of Mexico, which has experienced water shortages in recent years. Over the past 30 years, Mexico has increased imports of cereals while simultaneously exporting more fruits and vegetables. On balance, the net result has been the annual importation in recent years of more than 5 cubic kilometers of “virtual water” (the difference between the water requirements of the fruit and vegetable exports and the water requirements of the cereal imports). In the world rice economy, this already happens to an important extent – the water-scarce Middle East is one of the biggest rice importing regions in the world. Mainland Southeast Asia (Thailand, Myanmar, Cambodia, Laos, and Vietnam) has an abundance of water resources, and rice exports from these countries can help alleviate water shortages in a variety of other countries around the world.

Movement of real water may also have some role to play, although it will most likely be confined to a limited set of circumstances due to the high transport costs of water relative to its value. The most prominent example of this will certainly be the south to north water diversion projects currently being undertaken in China. Whether or not it makes sense to build these canals, once they are constructed they will have the potential to move large quantities of water at very low marginal cost. Provided the right incentives can be created to save water in the water-surplus south, this water can then be transferred to the water-deficit north.

Conclusion

The extent to which agricultural water scarcity will affect poverty in Asia depends crucially on how well societies will be able to create incentives for users to save scarce water. To some extent, this is happening already. The importance of pump irrigation continues to increase, and unless the government intervenes with subsidies, there are some built-in incentives for conservation. China continues to experiment with institutional innovations for surface water management that may contain lessons for other Asian countries. Encouragement of greater agricultural trade may also have a role to play in conserving scarce water. It is important to further develop these incentives to encourage adoption of water-saving technologies and thereby reduce the impact of the looming water crisis.

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Appendix: The Importance of Rice as an Irrigated Crop in Asia

This discussion relies heavily on Dawe et al (1998). The estimates of the share of irrigated rice in total irrigated area were constructed as follows. First, for each country, gross irrigated rice area in column 1 (IRRI) was divided by total net irrigated area in column 2 (FAO). (See Appendix Table 1). For China and India, these calculations were done on a state or provincial level basis (data not shown). Gross irrigated rice area counts one hectare that is planted to rice two times in a year as two hectares, and is a measure of planted area. Net irrigated area counts this as only one hectare, and is a measure of physical area.

If all rice is single cropped, dividing column 1 by column 2 gives the share of net irrigated area cropped to rice. If some rice is double-cropped, however, this figure will be an overestimate. Thus, it is an upper bound on the share of net irrigated area cropped to rice. To obtain a lower bound estimate, data from Huke and Huke (1997) were used to estimate the largest possible percentage of gross irrigated rice area that could be double cropped with rice. This percentage was calculated by taking the smaller of dry or wet season irrigated rice area and dividing by gross irrigated rice area. If dry (wet) season irrigated rice area is smaller than wet (dry) season irrigated area, this assumes that all dry (wet) season rice area is cropped with rice in the wet (dry) season as well. This maximum share of double cropped rice in gross irrigated rice area is then used to convert the data on gross irrigated rice area by country (or by state for China and India) into a minimum estimate of net irrigated rice area, and these figures are presented in column 3. Dividing column 3 by column 2 gives a lower bound of the share of net irrigated area cropped to rice.

Because the calculations for China and India were done at the province or state level, it is not possible to re-create the upper and lower bounds based only on the data in the table. Data on irrigated rice area are lacking for Malaysia, Cambodia, North Korea, and Laos, but collectively these countries account for a small share of total rice area in Asia. For China, column 1 is rice area, not irrigated rice area, but Huke and Huke (1997) estimate that 95% of rice area in China is irrigated. Finally, the calculations in Appendix Table 1 show the share of net irrigated area that is cropped with irrigated rice at some point during the year. If this calculation were done for other crops, the sum across crops divided by net irrigated area would be greater than one if some irrigated areas are used for rice in one season and another crop in a different season.

Appendix Table 1. Irrigated rice area in Asia, early 1990s

Country/ Region	**Year**	Irrigated rice area (gross)	Total irrigated area (net)	Minimum irrigated rice area (net)	Percentage of rice irrigated area in total net irrigated area	
		(Thousands of hectares)			Upper bound	Lower bound
					(Percentage)	
Bangladesh	1992	2710	3229	2347	84	73
China	1995	30774	49857	21675	50	43
India	1991	19039	47430	15880	38	33
Indonesia	1991	7403	4432	3702	100	84
Japan	1992	2092	2802	2092	75	75
S. Korea	1993	975	1335	975	73	73
Myanmar	1992	957	998	542	96	54
Nepal	1991	325	883	314	37	36
Pakistan	1993	2207	17120	2207	13	13
Philippines	1993	2017	1580	1075	100	68
Sri Lanka	1993	548	550	329	100	60
Thailand	1992	2206	4433	1562	50	35
Vietnam	1991	3336	1850	1668	100	90
South Asia					35	30
East Asia					52	46
SE Asia					83	64
Asia					46	40