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IRRIGATION WATER PRODUCTIVITY IN CAMBODIAN RICE SYSTEMS

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Responsibility for the ideas, facts and opinions presented in this research paper rests solely with the authors. Their opinions and interpretations do not necessarily reflect the views of the Cambodia Development Resource Institute.

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Acronyms and Abbreviations

ADB	Asian Development Bank
AusAID	Australian Agency for International Development
CDRI	Cambodia Development Resource Institute
FWUC	Farmer Water User Community
GDP	Gross Domestic Product
IMR	Inverse Mills Ratio
MAFF	Ministry of Agriculture, Fisheries and Forestry
MOWRAM	Ministry of Water Resource Management and Meteorology
PDOWRAM	Provincial Department of Water Resource and Meteorology
RGC	Royal Government of Cambodia
UN	United Nations
WRMRCDP	Water Resource Management Research Capacity Development Programme

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EXECUTIVE SUMMARY

Cambodia's economy is based largely on the agricultural sector which contributes 33 percent of the national GDP and employs more than 67 percent of the national labour force. Rice production is central to this sector: not only do the majority of Cambodia's farmers depend directly and indirectly on the success of the rice crop each year, but being the main food staple, rice production is a significant factor in the national effort to promote food security. Despite its importance, rice farming in Cambodia has traditionally been dependent on rainfall rather than irrigation. Rainfall distribution determines the success and size of the harvest and, as a result, farmers generally only grow only one crop per year.

Recognising the importance of water management to promoting the country's rice production, the Royal Government of Cambodia and donors are making efforts to expand the irrigated area in Cambodia. The expectation is that irrigation will make farmers less reliant on rainfall, allowing them to cultivate more crops with more certainty and predictability, resulting in higher productivity and better livelihood outcomes. The government's current planning document emphasises the importance of water management to increase agricultural productivity and stresses 'rehabilitating and enhancing irrigation potential' (RGC 2009:28).

However, despite the importance given to irrigation in Cambodia's development strategies, there is lack of quantitative information regarding the value of water at the farm level. This paper presents key findings from the economic component of the Water Resources Management Research Capacity Development Programme (WRMRCDP) to address this question and discusses some of the policy implications of these findings, particularly in regard to the definition of irrigation fees.

The key findings of this paper are that estimates of the extra yield produced as a result of irrigation, when measured in terms of rice production, are very low. This is particularly the case in the wet season: an increase of 1 percent in the amount of water used leads to an increase in rice yield of only 0.06 percent in the wet season and 0.12 percent in the dry season. For amounts of water larger than 1000 cubic metres per plot, and controlling for other inputs (including land), very little is added to yield size.

The overall key policy implications are that:

- The marginal return from water use to farmers in the wet season is low; therefore, farmers will not be willing to pay much for water during the wet season;
- This lack of willingness to pay for water limits the feasibility of cost-recovery policies as well as decisions on infrastructure investment and maintenance;
- Increasing productivity in the wet season is central to any effort to better manage irrigation water.

1 INTRODUCTION

Globally, population growth, rising incomes and urbanisation are increasing the demand for water. Each of these drivers of demand is present in the Cambodian context. The country's population is expected to increase from the current 14.2 million to between 20.4 and 27.4 million by 2050 (UN 2008; ADB 2010a), while simultaneously, the economy is expected to experience a strong record of economic growth. Economic growth between 1998 and 2008 alone averaged 9.1 percent (ADB 2010b) and, against the recent global financial crisis, is estimated to be as high as 6 percent in 2011 (ADB 2010a). Increases in per capita income and urbanisation are also expected (UN 2007), with the resulting rise in the demand for food estimated to be between 109 percent and 206 percent by 2020 compared to year 2000 levels (Hoanh *et al.* 2003). If this upward trend in demand is to be satisfied by increased domestic agricultural production, a greater strain will be placed on agricultural resources, including water.

In addition to these drivers of demand for water, it is also anticipated that climate change will influence water availability in Cambodia. Changes in climate are expected to increase the overall flow of the Mekong by 4.3 percent, though this increase will be concentrated in the wet season (with an expected increase in flow of 5.14 percent), with a reduction in the dry season flow of 2.18 per cent (Keskinen *et al.* 2009). The Mekong drains 86 percent of the land area of Cambodia (Dore 2003) and provides 60 percent of the water for the Tonle Sap Plains, the main agricultural region (Sarkulla *et al.* 2009). The country will become slightly warmer with increasingly variable rainfall, though it will be similar on average for the first half of this century (Keskinen *et al.* 2009). Water availability in Cambodia will also be affected by the construction of dams in the Mekong River Basin: there will be less water in the wet season and more water in the dry season, though specific impacts will depend on the characteristics of dams and their locations (Lamberts 2008; Sarkkulla *et al.* 2009).

Agriculture is the main water user in Cambodia. Nesbitt (2005) puts water withdrawals for agriculture in the lower Mekong Basin at 80-90 percent of total extractions; in 2009, MOWRAM estimated these to be 95 percent. In the dry season, when there is a lack of water, accessing water for agriculture is time-consuming and expensive. The Cambodian government's planning and development document, the Rectangular Strategy (RGC 2004), emphasises the importance of increased agricultural productivity. Effective water management is central to this strategy, especially in regard to irrigation, as the potential benefits to rice production are of particular significance in Cambodia as 30.1 percent of the population lives in poverty (ADB 2010b). Irrigation has been shown to impact directly and indirectly on poverty reduction via greater yields and lowering the risk of crop failure (Hussain & Hanjra 2004), which in turn boosts income and employment opportunities while increasing options for crop diversification (Hasnip *et al.* 1999). More broadly, increased rice productivity increases food security and allows a greater diversification of employment and labour endowments (Hossain & Fischer 1995). The value of irrigation in agriculture is also evident at the national level, as found by Hussain *et al.* (2007) who estimated agricultural water values in the Indus valley in Pakistan ranging from USD0.04 per m^3 at farm level to USD0.22 per m^3 at national level .

As part of its water management strategies, the Cambodian government has decentralised the responsibility for the operation and maintenance of irrigation schemes to Farmer Water User Communities (FWUCs) by Prakas 306 in 2006 (Perera 2006). As part of this legislation, farmers are required to pay fees to FWUCs for the operation and maintenance of irrigation schemes. Water is no longer a free public good, but instead belongs to the state and is managed by the FWUC. However, the roles and responsibilities of the FWUCs are often unclear, and 91 percent of water user fees imposed by the FWUC were not paid in the areas assessed in this study (CDRI 2009). Knowledge of the 'value of water' thus becomes particularly important in order to determine why farmers do not pay fees and how water should be priced.

This paper aims to assess the value of irrigation to farming in Cambodia by looking at the marginal productivity[1] of water in rice agriculture. The marginal productivity of water from supplementary irrigation[2] in lowland rice systems in Cambodia is estimated using primary plot level panel data, taking into account farmer and plot heterogeneity as well as self-selection of supplementary irrigation. Thus, it will determine the extra rice yield obtained at the plot level as a result of using irrigation. These estimates can then be used to inform the discussion on water pricing policy.

The paper proceeds as follows. Section 2 identifies key aspects of the existing literature on water productivity in rice systems. Sections 3 and 4 describe the methodology, focusing first on the data and secondly on the empirical approach. Section 5 outlines the results and discussion. Section 6 concludes and posits recommendations and ways forward.

1 Where 'marginal productivity' is the change in output (rice) due to the use of one extra unit of water (in m3)

2 In this paper 'supplementary irrigation' refers to water used in addition to rainfall.

2 WATER PRODUCTIVITY

Water productivity refers to the ratio between output (e.g. yield) and water use. However, the issue of most concern to this paper is not how to define water productivity, but rather how to measure it.

Water productivity can be measured in a number of ways depending on the questions to be answered and the type and availability of data. For example, water productivity can be evaluated at different scales, from country to plot level. It is important to take this into consideration for two reasons. First, the level of assessment changes the definition of water used and, with it, the value of water productivity, a point noted by Hafeez *et al.* (2007): larger scales of assessment are generally associated with higher levels of water productivity. Second, different outcomes are relevant to different stakeholders at different levels (Kijne *et al.* 2003). There are also a variety of ways of defining output and input in any studies of water productivity, as noted by Kijne *et al. (ibid.)*. Output is most commonly defined in terms of physical quantities (especially in studies that focus on one crop) or some measure of value, either gross or net of input costs (in studies that deal with agricultural production without focusing on one crop). Kijne *et al. (ibid.)* use a variety of measures of water input including gross water inflows, precipitation, irrigation inflows and actual and potential evapotranspiration. This approach reflects more clearly the data limitations and the assumptions regarding water productivity in agriculture.

Table 1 presents a brief summary of the studies listed above which have tried to quantify water productivity, with a particular emphasis on (but not limited to) South East Asian countries. It is clear from these studies that a focus on water use as quantified by different measures of evapotranspiration (actual, as in Bastiaanssen & Zwart 2004 potential; as in Goto *et al.* 2008; and reference, as in Allen *et al.* 1998) dominates the existing knowledge. The use of these measures carries with it one important limitation however, namely that these studies are often based on data from experimental stations or greenhouse/pot experiments which may not reflect actual production conditions[3]. These studies also differ in their assumption regarding the importance of different flows: particularly important from a policy perspective, several (for example, Mainuddin and Kirby (2009); Haddeland *et al.* (2006)) assume that irrigation during wet season is not important for rice production. Finally, only a small number of these studies consider the lower Mekong basin, and an even smaller number consider Cambodia.

3 Other studies (for example Bouman & Tuong 2001) use experimental methods to quantify water productivity under different production scenarios, some of which may not be practiced in the field.

Table 1: Water Productivity

Study	**Country**	**Period**	**Irrigation**	**Water measure**	**Scale**	**Water productivity**
Hafeez *et al.* (2007)	Philippines	2000-200 (dry season)	Included	Gross	1 Scheme (1500-18000 ha)	0.05-0.18 kg/m^3
Mainuddin and Kirby (2009)	Laos	1993-2004	Excluded	Rainfall + surface + underground	Province	0.20-0.49 kg/m^3
	Thailand	1995-2003	Excluded	Rainfall + surface + underground	Province	0.20-0.30 kg/m^3
	Cambodia	1993-2003	Excluded	Rainfall + surface + underground	Province	0.11-0.24 kg/m^3
	Vietnam	1995-2004	Excluded	Rainfall + surface + underground	Province	0.30-48 kg/m^3
Phengphaengsy and Okudaira (2008)	Laos	2006-2007 (dry season)	Included	Rainfall + surface + underground + irrigation	Scheme	0.09 kg/m^3
	Thailand	2006-2007 (dry season)	Included	Rainfall + surface + underground + irrigation	Scheme	0.12 kg/m^3
	Cambodia	2006-2007 (dry season)	Included	Rainfall + surface + underground + irrigation	Scheme	0.04 kg/m^3
Loeve *et al.* (2004)	China	2000	Included	Gross	Sub-basin	0.32kg/m^3
		2000	Included	Gross	Plot	0.67kg/m^3
		2000	Included	Irrigation	Sub-basin	2.19kg/m^3
		2000	Included	Irrigation	Plot	1.65kg/m^3
Cabangon *et al.* (2002)	Malaysia	1988-1994 (dry season)	Included	Irrigation	Plot	1.48kg/m^3
		1988-1994 (wet season)	Included	Irrigation	Plot	0.62kg/m^3

3 DATA

The data used in this study was collected as part of the wider Water Resource Management Research Capacity Development Programme (WRMRCDP) addressing water management in the Tonle Sap watershed, Cambodia. A household survey was conducted in 10 irrigation schemes across three provinces: Kampong Chhnang, Kampong Thom and Pursat. These 10 schemes were selected to represent different agro-ecological conditions within the catchment, including upstream/downstream locations. The characteristics of each scheme are presented in Table 2.

In each irrigation scheme, 30 households were selected to be interviewed in a baseline survey. Because of the relatively small sample size, households were selected with the help of village heads to represent a range of wealth and plot characteristics typical of each scheme. These households were interviewed in mid-2008 using a questionnaire that was designed to capture information on variables that are more or less constant through time: household composition, characteristics of the head of the household (gender, age, education), plot characteristics and assets. This baseline questionnaire was followed by the main questionnaire which was fielded after each wet and dry season. This survey focused on changes in household composition and on decisions related to income generation (including farm and non-farm production) as well as other sources of income (transfers) and production shocks.

The survey module which was used to ask about production data was designed to closely follow the module used in the World Bank Living Standards Measurement Surveys (Reardon & Glewwe 2000). This World Bank survey, however, does not attempt to collect data on water use, a matter of central importance in this study. For that reason, it is worth explaining in more detail how we obtained information on water use at plot level. The survey questions relating to the value of water were:

- Do you irrigate?
- If yes, do you use gravity or pumping?
    - If you use gravity, what depth do you irrigate to and how many times do you do this during the dry season?
    - If you pump water, what is the pump's capacity and how many hours is it used for?

The answers to these questions were then used (together with other questions regarding the area of irrigated land and the frequency of irrigation per season) to determine the value of irrigation water used. Using this dataset, it was possible to estimate the relationship between the amount of irrigation water used and the rice yield in both the wet and dry seasons.

Data for each of the seasons for which we have data (2008/2009 wet seasons and 2009/2010 dry season) is presented in Table 3.

Table 2: Scheme Characteristics

Province	Catchment	Scheme	Construction year	Rehabilitation year	FWUC year	Population	Cropped Area		Stream position	Tonle Sap floodplain
							Wet	Dry		
Pursat	Pursat	Damnak Ampil	1978	2006	2005	93,800	26,703	1,230	Upstream	No
Pursat	Pursat	Kampang	2004	–	2004	5,800	2,000	1,570	Midstream	Yes
Pursat	Pursat	Wat Leap	1960	2003	2003	13,100	3,050	170	Downstream	Yes
Kompong Chhnang	Chrey Bak	Pok Paen	1969	2005	2005	4,000	1,980	0	Upstream	No
Kompong Chhnang	Chrey Bak	Svay Chek	1973	2005	–	6,100	1,900	0	Midstream	No
Kompong Chhnang	Chrey Bak	Tang Krasang	1976	2001	2001	8,200	2,600	0	Midstream	No
Kompong Chhnang	Chrey Bak	Trapeang Trabek	1987	1991	2001	5,800	2,340	1,220	Downstream	Yes
Kompong Thom	Chinit	Chinit	1978	2007	2002	20,800	3,700	520	Upstream	No
Kompong Thom	Chinit	O' Svay	1975	1998	–	11,500	2,540	0	Midstream	No
Kompong Thom	Chinit	Rolous	1960s	2004	2005	22,100	13,600	690	Downstream	Yes

Table 3: Production Data

Variable	Wet Season, 2008					Wet Season, 2009					Dry Season, 2009-10				
	Obs	Mean	S.D.	Min	Max	Obs	Mean	S.D.	Min	Max	Obs	Mean	S.D.	Min	Max
Area (ha)	1017	0.52	0.88	0.002	11	1010	0.53	0.91	0.002	11	143	0.89	1.03	0.02	5
Irrigated area (ha)	621	0.54	0.90	0.003	10	606	0.55	0.95	0.002	10	136	0.87	0.99	0.02	5
Yield (kg)	1017	951	1852	0	27500	1010	867	2040	0	33000	143	2880	4282	0	23000
Irrigation water (m^3)	467	3393	8126	5	99000	458	8355	105308	0.15	2248200	121	7190	10312	50	53640
Household labour (days)	1009	16.7	18.7	0.22	139	1001	17.4	20.6	0.22	275	138	24.6	23.2	2	142
Hired labour (days)	1009	27.8	62.9	0	200	1001	6.61	19.7	0	305	138	6.6	15.2	0	120
Fertiliser (N, kg)	1009	7.23	31	0	618	1001	9.54	50	0	1125	143	29.1	43.6	0	338
Shocks:															
Disease	1017	0.17				1010	0.14				143	0.42			
Pest	1017	0.45				1010	0.41				143	0.79			
Flood	1017	0.07				1010	0.17				143	0.04			
Drought	1017	0.10				1010	0.21				139	0.30			

It was noted that attrition could be a problem between the baseline survey and subsequent surveys. The reduction in the number of households interviewed is relatively important, with 64 households not being interviewed in the 2008 wet season survey, though there was no significant reduction in the number of households interviewed in subsequent rounds[4]. This initial reduction of interviewees corresponds to an attrition rate of 21 percent, raising the possibility that the subsample for which we have production data is statistically different from the original sample. To confirm whether this was in fact the case, we performed a series of t-tests of differences in mean values of variables relating to wealth, demographics and observable plot characteristics between households included in the first and second surveys, with the result that no difference was found between the mean values of different variables.

4 We were able to interview 235 households during the 2008 and 2009 wet seasons and 218 households during the 2009-2010 dry seasons.

4 ECONOMETRIC MODEL

In order to estimate the contribution of irrigation water to rice production, we use a Cobb-Douglas production function:

$$Y_{it} = A_i W^{\beta}_{it} X^{\theta}_{it} e^{\lambda Z_{it} + \mu T + \varepsilon_{it}} \quad (1)$$

taking logs on both sides of the equation, this can be rewritten as

$$lnY_{it} = A_i + \beta\, lnW_{it} + \theta\, X_{it} + \lambda\, Z_{it} + \mu\, T + \varepsilon_{it} \quad (2)$$

where Y is rice yield, W is irrigation water, X is the set of other inputs used, Z is a set of shocks, and i represents plot and t represents time. We account for common seasonal effects through a time fixed effect, T. Finally, ε is statistical error and, in estimating equation 2, we assume that

$$\varepsilon it \sim N(0, \sigma^2) \quad (3)$$

$$E(\varepsilon it, \varepsilon jt) = 0 \text{ if } i \neq j \quad (4)$$

$$E(\varepsilon it, \varepsilon jz) = 0 \text{ if } t \neq z \quad (5)$$

where equations 4 and 5 formalise the assumptions that, controlling for the exogenous variables, the error term is not correlated through space or time.

In equation 2 we assume that the Cobb-Douglas is an adequate functional form to represent the relation between output and conventional inputs. Other more flexible functional forms (namely translog) were estimated but we were not able to reject the hypothesis that the additional items were not jointly statistically significant and, for that reason, we only report the Cobb-Douglas results. The specification of equation 2 takes advantage of repeated observations at plot level to account, through the estimation of plot specific intercept A_i, for unobserved plot heterogeneity and, given that land markets are virtually non-existent, farmer heterogeneity.[5] One problem with estimating equations such as equation 2, in log form, is how to deal with zero values in the original observations. In this case, we followed the Battese (1997) solution and replaced the logged value as 0 but included a set of dummy variables that account for this arbitrary decision.

When estimating equation 2 we must also address the possibility that irrigated plots are systematically different from those which are not irrigated, with "better" plots being irrigated while others may not be seen to warrant the extra effort associated with supplementary irrigation. In short, the decision to use irrigation water during the wet season, even after controlling for input use and shocks, would still reflect unobserved heterogeneity. In this case, the assumption of normally distributed errors (equation 3) would not hold and the effect of irrigation water on

5 Plots are not usually rented out or in and, if they had been, they would not have been observed as the unit of the survey is the household.

rice output could be overstated. Heckman (1984) has shown that it is possible to correct for this problem by first estimating the probability of each plot to receive supplementary irrigation through a probit model of the form:

$$I(W_i > 0) = \Phi(X_i) \qquad (6)$$

This first stage regression allows us then to estimate the statistic $\frac{\phi}{\Phi}$, also known as the Inverse Mills Ratio (IMR) which can be interpreted as the likelihood that plot i will be irrigated. We can then estimate a second stage:

$$lnY_i = \beta\, lnW_i + \theta\, X_i + \lambda\, Z_i + \alpha IMR_i + \varepsilon_i \qquad (7)$$

This is a modification of the model specified in equation 2 in three important aspects. Firstly, through the inclusion of the IMRi variable which indicates the likelihood of plot i receiving supplementary irrigation, we can correct for self-selection in supplementary irrigation. Secondly, through the absence of t from equation 7. As noted, the use of Heckman's correction procedure requires the estimation of the IMRi through a probit model but due to the incidental parameter problem, there is no estimator of such models that allows for the inclusion of fixed effects. Third, and because of our inability to take advantage of repeated plot observations to account for unobserved heterogeneity, we need to expand the vector X to include other plot characteristics for which we have information (slope, soil type…) and that are both time invariant and possibly correlated with the amount of water used by farmers.

5 RESULTS AND DISCUSSION

5.1. Wet Season

The main findings regarding the wet season are that:

1. The estimates of the extra yield produced as a result of irrigation, when measured in terms of rice production in the wet season, are very low. For an increase of 1 percent in the amount of water used, rice yield increases by only 0.06 percent in the wet season. The empirical estimates of the production function (equation 2) during the wet season are presented in Appendix Table 1.
2. The area under irrigation during the wet season is higher than the area under irrigation during the dry season: 46 percent of the plots surveyed used irrigation water during the wet season in both 2008 and 2009, but only 10 percent of the plots were irrigated during the dry season.

Of the variable inputs, household labour and fertiliser appear to be the most significant variables in explaining yield. However, the econometric model used could not account for the possibility that farmers selectively irrigate plots. We addressed this problem by estimating a Heckman selection model, using maximum likelihood. The estimates for the Heckman selection model for the 2008 wet season, the 2009 wet season and then for the entire sample are presented in Appendix Tables 2, 3 and 4, respectively. As the identifying instrument, we used changes in the dependency ratio (as changes in the number of dependents would, presumably, lead to changes in the plots used for production but, given that dependents do not contribute with labour, would not influence production directly) and the position of the scheme along the watershed (that, conditional on water used in the plot, should not matter to yield).

The significance of the estimate of ρ in all three models signals that there is in fact some selectivity in the decision about which plots are irrigated. However, the estimates of water productivity do not seem to be significantly affected by this fact: if we consider the estimates presented in Appendix Table 4, which include both wet seasons and, as such, are more easily compared with the results presented in Appendix Table 1, the estimate of water productivity is now 0.069, quite similar (and statistically identical) to 0.057. The fact that they are slightly above our fixed effects estimates is, however, puzzling and suggests that the estimates of water productivity may be biased, as they would reflect the effect of both water and other correlated (but not included) variables such as plot characteristics, for example. In an effort to test whether this is the case, we re-estimated the Heckman selection model using data for both seasons and adding extra control variables, namely soil type and slope and distance to the plot from the homestead. The results are presented in Appendix Table 5 and, although they confirm our suspicion, the changes are minimal: the estimate of water productivity is now 0.066, almost identical to our previous results. In conclusion, although farmers appear to be selectively choosing which plots to irrigate (as we would expect), conditional on all other variables for which we have information, this does not seem to matter much for our estimates of water productivity.

It is useful at this point to examine how our estimates compare with those in the literature presented in Section 2. We start by noticing that the estimates presented in this paper differ fundamentally from the previous estimates of water productivity given in Section 2, as our estimates are elasticities, hence the marginal productivity of water can be estimated for the entire range of water input values and, in this sense, our results differ to previous estimates of water productivity which are applicable to only a limited range of water input values. This, however, raises the question: what is the overlap between the productivity estimates in the examined literature, and the productivity estimates as shown in our data? We address this question by relating the literature estimates of average productivity with the frequency of water input values in our data. These comparisons are summarised in Table 4, and their meaning can be understood by looking, for example, to the average productivity values recorded by Mainuddin and Kirby (2009) for total inflow (assuming negligible irrigation volumes) in Cambodia. The values of average productivity reported in this study, between 0.110 kg per m3 and 0.242 kg per m3, correspond to a range of water input volumes between 1500m3 and 3500m3, which account for 9.1 percent of the water volume used by the farmers that we surveyed. Similarly, the average productivity presented by Loeve *et al.* (2004) for irrigation water at the plot level in China corresponds to water volumes that, overall, account for approximately 34 percent of the water used by farmers in this study, and Cabangon *et al.* (2002) approximately 8.6 percent. In short, the literature seems to substantially overstate real (farmer) water productivity compared to the results we have found in Cambodia.

Table 4: Comparison of Results with Existing Literature

Study	Estimates (kg/m3)	Wet season		Dry season	
		Water use range (m3)	Water use	Water use range (m3)	Water use (%)
Mainuddin and Kirby (2009)	0.110-0.252	1500-3500	23.7	>22500	11.9
Loeve et al (2004)	1.65	Not in range		2500	3.3
Cabangon et al (2002)	0.62 (wet); 1.48 (dry)	500	34	2500-3000	7.4
Hafeez et al (2007)	0.05-0.18	Dry season only		>29000	4.9

5.2. Dry season

The main findings regarding the dry season are that:

1. Production in the dry season is not generally feasible without irrigation: 83 percent of the plots that registered any production in the dry season used irrigation.
2. Marginal productivity of irrigation water is substantially higher in the dry season: an increase of 1 percent in the amount of water used leads to an increase in rice yield of 0.12 percent in the dry season (double our estimate for the wet season).

In order to estimate productivity during the dry season a different approach to that which measured wet season productivity had to be used, as we only have one round of data for production during the dry season (2009-2010), and because irrigation is almost always necessary for any production to take place in the dry season. In Appendix Table 6, we present the ordinary least squares estimates of the production function where we include additional controls for plot characteristics. It is immediately obvious that the estimates of water productivity are considerably lower than the estimates obtained during the wet season and are not statistically significant at the usual levels of significance. These are unexpected results given the importance of irrigation water during the dry season, and most probably reflect an incorrect specification of the statistical model. One alternative to this specification is possible if we are willing to assume that, controlling for other inputs, there is no significant technological difference between wet and dry season production. We are then able to take advantage of the existence of several rounds of data to adequately control for plot and farmer fixed effects, as is done for the wet season. The estimates of this model are presented in Appendix Table 7 and indicate an elasticity estimate of 0.125 which is statistically significant at the 10 percent level. Therefore, using the assumption that rice technology does not vary across seasons, irrigation water productivity in the dry season is roughly twice that of the wet season estimate.

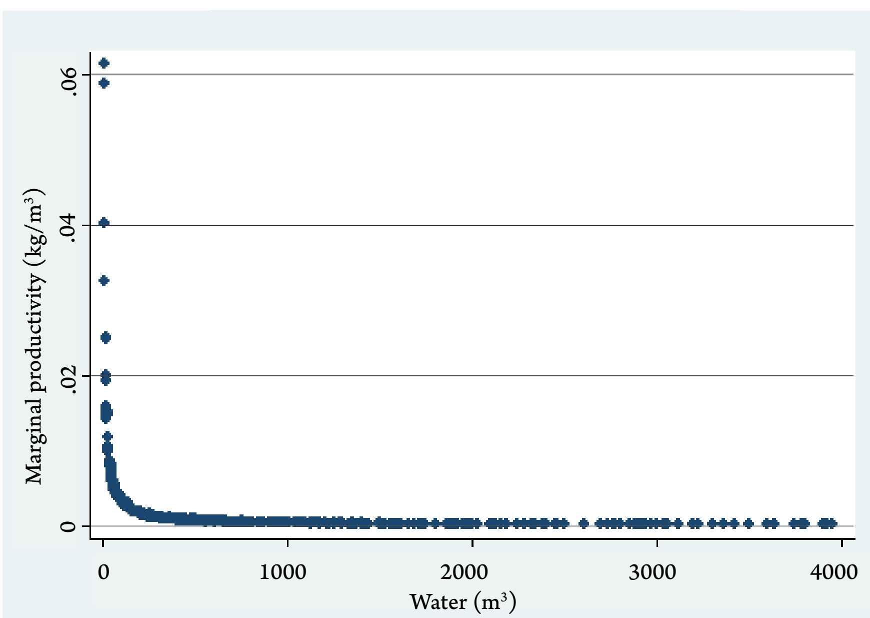
As in the wet season, the dry season estimates presented in this paper differ fundamentally from the literature estimates of water productivity, as they are much lower. It is possible to conclude that those studies substantially overestimate water productivity by Cambodian farmers.

6 CONCLUSION, RECOMMENDATIONS AND WAYS FORWARD

This paper has estimated the marginal productivity of water in its largest use in Cambodia, the irrigation of rice. The analysis utilises plot level panel data to estimate elasticities between 0.058 and 0.082 in the wet season, and 0.125 in the dry season. Fixed effects regressions were used to account for inputs in the production process which can be considered to be constant, such as plot slope, soil type and characteristics of the head of the household. Heckman regressions were used to correct for self selection of plots for irrigation. Comparisons of the results presented in this paper with those of previous research demonstrate the limitations of previous estimates. This is a result of the restricted range of water input values for which previous estimates apply (in relation to the water input values recorded in this study). Conversely, the estimates presented in this paper allow average and marginal productivities of water to be calculated over the full range of water input values.

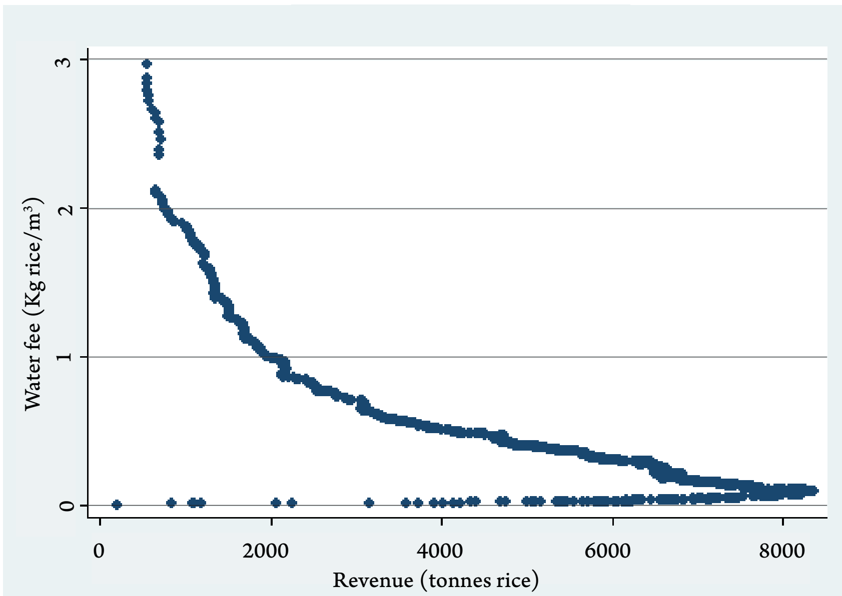
Knowledge of the average and marginal economic value of irrigation as estimated in this study can be combined with various prices (namely farm gate, provincial market or international) to give average economic values for water, akin to Phengphaengsy and Okudaira (2008), as well as marginal economic values. Without wanting to assume such prices, we can still estimate a demand curve, where the price is expressed in kg rice per m3 as represented in Figure 1. The main point to note is the wide range of water use for which marginal productivity is relatively low: uses above 1,000 cubic metres have a marginal productivity of almost 0.

Figure 1: Marginal Productivity of Irrigation Water



It is possible to then use the result of Figure 2 (where revenue is expressed in tonnes of rice and the water fee in kg rice per m^3) to evaluate the capacity of Farmer Water User Communities to raise revenue (and potentially be financially sustainable) through increases in water fees. If the fee is 0, the FWUC raises no revenue. Up to a relatively small amount (0.012 kg rice per m3), revenue increases as fees increase. However, above that value, fee increases lead to actual revenue decreases. Figure 2 shows that increasing fees "too much" is not the best way to raise revenue, as farmers may choose not to use water at all rather than paying fees. Hence for fees above the monetary value of 0.025kg of rice per m3, total revenue raised by the FWUC will decrease.

Figure 2: Revenue from Water Fees



The overall key findings of this working paper in relation to fees are that:

- Raising water fees is not necessarily the best way to raise revenue as farmers may then choose not to use water. This would result in a reduction in total fees collected;
- Farmers are very responsive to changes in water fees above a very small value; thus, increasing water fees could be used to reallocate water to other (potentially more valuable) uses;
- Increasing water productivity in rice production when water is most used (i.e. in the wet season) is a way to balance competing needs and policy objectives.

The key policy implications arising from this research are that:

- The marginal return from water use to farmers in the wet season is low; therefore, farmers will not be willing to pay much for water during the wet season;
- This low willingness to pay for water limits the feasibility of cost-recovery policies as well as decisions on infrastructure investment and maintenance;
- Increasing productivity in the wet season is central to any effort to better manage irrigation water.

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APPENDIX TABLES

Appendix Table 1: Estimation Results: Fixed Effects, Wet Season, 2008 and 2009

Variable	Coefficient	(Std Err)
Land (ln)	0.118	(0.093)
Household labour (ln)	0.141*	(0.059)
Hired labour (ln)	-0.015	(0.038)
Seed (ln)	0.025	(0.029)
Nitrogen (ln)	0.135**	(0.041)
Phosphate (ln)	0.127**	(0.034)
Water (ln)	0.057*	(0.028)
Disease	-0.004	(0.053)
Pest	0.027	(0.045)
Flood	-0.427**	(0.078)
Drought	0.079	(0.058)
Wet season 2008	0.247**	(0.042)
Intercept	5.395**	(0.329)
N	1948	
R^2	0.184	
F (16, 1035)	8.489	

*Significance levels: † =10%; * =5%; ** = 1%*

Appendix Table 2: Estimation results: Heckman correction, wet season, 2008

Variable	Coefficient	(Std Err)
Equation 1: Yield		
Land (ln)	0.458**	(0.046)
Household labour (ln)	0.102*	(0.041)
Hired labour (ln)	0.136**	(0.037)
Seed (ln)	-0.067	(0.104)
Nitrogen (ln)	0.071†	(0.043)
Phosphate (ln)	0.178**	(0.049)
Irrigation Water (ln)	0.063*	(0.026)
Disease	0.163†	(0.084)
Pest	0.065	(0.060)
Flood	0.136	(0.124)
Drought	-0.012	(0.090)
Intercept	6.562**	(0.393)
Equation 2: Irrigation water		
Change in dependency ratio, round 1	1.412	(1.019)
Upstream	0.042	(0.086)
Midstream	0.050	(0.078)
Intercept	-0.011	(0.065)
ρ	-1.373**	(0.136)
σ	-0.043	(0.062)
N	997	
Log-likelihood	-1218.119	
$\chi^2_{(15)}$	1141.802	

*Significance levels: † =10%; * =5%; ** = 1%*

Appendix Table 3: Estimation results: Heckman correction, wet season 2009

Variable	**Coefficient**	**(Std Err)**
	Equation 1: lnyield	
Land (ln)	0.396**	(0.048)
Household labour (ln)	0.117*	(0.047)
Hired labour (ln)	0.130**	(0.049)
Seed (ln)	0.093*	(0.041)
Nitrogen (ln)	0.039	(0.040)
Phosphate (ln)	0.353**	(0.052)
Irrigation Water (ln)	0.075**	(0.027)
Disease	0.004	(0.090)
Pest	0.152*	(0.070)
Flood	-0.392**	(0.118)
Drought	0.128	(0.086)
Intercept	5.792**	(0.307)
	Equation 2: water1	
Change in dependency ratio, round 3	0.803	(0.579)
Upstream	0.242**	(0.082)
Midstream	0.245**	(0.074)
Intercept	-0.206**	(0.066)
ρ	-1.864**	(0.191)
σ	0.189**	(0.073)
N	975	
Log-likelihood	-1219.298	
$\chi^2_{(15)}$	1361.538	

*Significance levels: † =10%; * =5%; ** = 1%*

Appendix Table 4: Estimation results: Heckman correction, wet seasons, 2008 and 2009

Variable	**Coefficient**	**(Std Err)**
	Equation 1: Yield	
Land (ln)	0.409**	(0.038)
Household labour (ln)	0.103**	(0.037)
Hired labour (ln)	0.131**	(0.032)
Seed (ln)	0.068*	(0.033)
Nitrogen (ln)	0.059†	(0.033)
Phosphate (ln)	0.289**	(0.039)
Irrigation Water (ln)	0.069**	(0.022)
Disease	0.068	(0.062)
Pest	0.111*	(0.045)
Flood	-0.253**	(0.082)
Drought	0.125*	(0.062)
Wet season 2008	0.277**	(0.056)
Intercept	5.940**	(0.245)
	Equation 2: Irrigation water	
Wet season	0.027	(0.032)
Change in dependency ratio, round 1	4.258**	(1.249)
Change in dependency ratio, round 3	2.053*	(0.956)
Upstream	0.139†	(0.072)
Midstream	0.138*	(0.069)
Intercept	-0.137*	(0.063)
ρ	-1.609**	(0.115)
σ	0.095†	(0.053)
N	1972	
Log-likelihood	-2455.214	
$\chi^2_{(16)}$	1616.376	

*Significance levels: † =10%; * =5%; ** = 1%*

Appendix Table 5: Estimation results: Heckman correction with additional control variables, wet seasons, 2008 & 2009

Variable	Coefficient	(Std Err)
Equation 1: Yield		
Land (ln)	0.408**	(0.038)
Household labour (ln)	0.095*	(0.038)
Hired labour (ln)	0.138**	(0.032)
Seed (ln)	0.072*	(0.033)
Nitrogen (ln)	0.061†	(0.034)
Phosphate (ln)	0.280**	(0.041)
Water (ln)	0.066**	(0.021)
Disease	0.087	(0.061)
Pest	0.105*	(0.044)
Flood	-0.282**	(0.081)
Drought	0.138*	(0.063)
soil: kadeng	-0.153	(0.163)
soil: kasach	0.025	(0.175)
soil: robuykasach	-0.286†	(0.167)
flat	0.248	(0.157)
slightly slope	0.064	(0.167)
moderate slope	0.014	(0.219)
wet season 2008	0.258**	(0.056)
Time to plot (hours)	0.025	(0.019)
Intercept	5.918**	(0.258)
Equation 2: water 1		
Wet season 2008	0.021	(0.032)
Change in dependency ratio, round 3	1.825†	(0.933)
Change in dependency ratio, round 1	3.991**	(1.247)
Upstream	0.142†	(0.074)
Midstream	0.164*	(0.071)
soil: kadeng	0.238	(0.178)
soil: kasach	-0.195	(0.192)
soil: robuykasach	0.241	(0.186)
flat	-0.172	(0.178)
slightly slope	0.044	(0.190)
moderate slope	-0.003	(0.234)
Time to plot (hours)	-0.041*	(0.020)
Intercept	-0.149†	(0.087)
ρ	-1.592**	(0.121)
σ	0.075	(0.055)
N	1966	
Log-likelihood	-2416.111	
$\chi^2_{(23)}$	1613.598	

*Significance levels: † =10%; * =5%; ** = 1%*

Appendix Table 6: Estimation results: linear regression, dry season, 2009-10

Variable	Coefficient	(Std Err)
Land (ln)	0.492**	(0.104)
Household labour (ln)	0.047	(0.108)
Hired labour (ln)	-0.030	(0.068)
Nitrogen (ln)	0.555**	(0.139)
Phosphate (ln)	-0.001	(0.148)
Water (ln)	0.036	(0.043)
Intercept	6.212**	(0.676)
N	95	
R^2	0.82	

*Significance levels: † =10%; * =5%; ** = 1%*

Appendix Table 7: Estimation results: fixed effects, dry season, 2009-10

Variable	Coefficient	(Std Err)
Land (ln)	0.166†	(0.086)
Household labour (ln)	0.127*	(0.050)
Hired labour (ln)	0.005	(0.034)
Nitrogen (ln)	0.141**	(0.037)
Phosphate (ln)	0.122	(0.030)
Water (ln)	0.125†	(0.068)
Intercept	5.439**	(0.363)
N	2049	
R^2	0.58	

*Significance levels: † =10%; * =5%; ** = 1%*

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