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Research Report

Analysis of Water Availability and Water Productivity in Irrigated Agriculture

Chaiyasit Anuchitworawong

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Abstract

During the past 20 years, Thailand witnessed droughts of varying intensity which put pressure on farming activities. Since the water scarcity problem has placed agricultural production at risk, this poses a serious challenge to farmers to cope with when relying on irrigation for crop cultivation. Despite the analysis of the impact of climate variability on crop yield and the future of production of certain crops using scientific-based crop model reported elsewhere, attempts to address the issues by integrating simulated scientific-based climate factors into economic modeling is still limited. This study analyzes the following issues based on economic concepts by taking irrigated agriculture in the Chao Phraya river basin during the dry season as a point of emphasis: a) the impact of extreme weather conditions on the decision making of farmers about land use for agriculture and productivity improvement, b) the efficiency of irrigated water used in the production of key economic crops, c) the projection of rice production in the face of increasing vulnerability of extreme weather conditions, and d) the reasons explaining why more efficient use of limited water resources should be at the heart of any future water management policy.

With regard to the effect of climate conditions, the study confirms that extreme drought weather condition and climate anomalies associated with El Niño and La Niña conditions negatively affect both the farmers' decision on allocation of agricultural land areas and crop yields. The availability of irrigation water for agriculture at the beginning of dry season also appears to be an important decision-making factor for farmers. In addition, by examining the efficiency of irrigation water used in agriculture, the findings indicate that, by using the same one unit of irrigation water in agriculture, the efficiency of irrigated water used in agricultural production varies widely across location (with higher economic value in the east area of the Chao Phraya river basin) and types of crops planted (with higher value for sugarcane). It is also expected that at the recorded low level of available irrigation water coupled with extreme drought condition in the future, the yield and total production of rice will reduce by 13.4 percent and 30.9 percent respectively. The future water scarcity may become a pressing concern as the urbanization in the areas above Bhumibol and Sirikit dams continues to grow and the warm phase of ENSO cycle is likely to be seen more in the future.

To tackle the problem of future water scarcity and climate variability, the appropriate measures of water demand management such as water market and water rights should be one of top priorities to be addressed and considered to assure a more efficient use of limited water resources. Both autonomous (private) and anticipatory (public) adaptation measures should

be encouraged and supported to help improve the adaptive capacity of farmers in dealing with the risk of water shortage and climate variability more effective in the long run. Importantly, the government's intervention programs must be implemented with care in such a way that they will not cause significant market distortion.

ค่า S.D ของฝน / จะคำนวณฤดูฝน และ impact on agriculture from CO2 / Other than Enso, IOD

Policy implication: Water management → Community level (Experiment) but water rights may be to rigid not flexible. → test to find how to create mechanism

1) CC impacts Yield
2) Inefficient use of water (Suphanburi)
3) Include conflict case
4) Water user → Close system (at present) how to expand good practices to other areas

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1. Introduction

During the past decades, there has been a continued development of water resources at different scales, from small to large scale projects, to meet a growing water demand for consumption, farming and industrial uses. However, water availability has come under increasing pressure due to a number of reasons, particularly changing weather pattern,[1] growing demand and competition for limited water supplies between various economic sectors, inefficient management of irrigation system, political intervention, water use behavior of people and farmers, and the like.

Because agricultural sector consumes the largest proportion of water in the country, accounting for 106 billion cubic meters or about 65 percent of total water demand of all sectors (Royal Irrigation Department, 2009), this study therefore focuses on water related issues only in agriculture. During the past several decades, irrigation system at various scales has been developed and expanded over years; however, farmers in various parts of the country still encounter with inadequate water supply. The recent evidence of water shortage problem in Thailand could be observed as farmers were urged not to plant a second rice crop in order to reduce stress on water supply. Although the problem tends to be only temporary, the situation signalizes that the problem of water shortage should not be ignored, but should become an issue of pressing concern. To describe how important the problem will be in the future at a global scale, the 2030 Water Resources Group (2009) presented in a report entitled “Charting Our Water Future” that the global water demand in 2030 will be much greater than the existing sustainable, reliable water supply, accounting for a global water shortage of 4,200 billion cubic meters or 40 percent greater than the current water supply. This conjecture was based on the current projections of population and economic growth.[2]

In Thailand, because agricultural sector consumes substantial amount of water, it is worth examining how serious water availability issues will be in the future and investigating whether irrigation water was used productively in agriculture. This study aims at addressing the following issues: a) the impact of extreme weather conditions on the decision making of farmers about land use for agriculture and productivity improvement, b) the efficiency of irrigated water used in the production of key economic crops, c) the projection of rice production in the face of increasing vulnerability of extreme weather conditions, and d) the reasons explaining why more efficient use of limited water resources should be at the heart of any future water management policy. However, to study these issues, we take agricultural farming in the Chao Phraya river basin during the dry season as a point of emphasis since the Chao Phraya river basin is the largest and the most important basin of Thailand and the area of the basin is substantially used for agriculture which consumes most.

To begin with, we describe and analyze whether, in addition to economic factors, climate related factors have significant impact on agricultural production in the Chao Phraya river basin. In Section 3, the efficiency of irrigated water used in producing rice and sugarcane is evaluated. Section 4 then presents the forecast of dry-season rice production during the next 24 years by taking into account projected extreme weather condition as a proxy for climate variability and analyzes the cost of climate variability

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[1] The long term climate trend in the GMS is predicted to be warmer and wetter (Snidvongs, 2009). The number of cold days and nights has decreased and the number of warm days and nights has increased on the global scale (IPPC, 2013). Most land areas will experience an increase in average temperature, along with more frequent heat waves, and periods of heavy precipitation.

[2] The projection was based on assumptions that there are no efficiency gains and global water demand will grow at about 2 percent a year, which is expected be driven by increased agricultural and industrial production, greater water use by rising middle classes in emerging economies.

measured in terms of a reduction in agricultural productivity. The next section further discusses about an increasing importance in more efficient use of water by analyzing key factors that have significant influence on the level of water inflow into the Bhumibol and Sirikit dams which are the major sources of water for irrigated areas in the Central Plain of Thailand. In the last section, we conclude and provide policy implications.

2. Impact of economic and climate factors on agricultural production

This section analyzes factors that influence farmers' decision to allocate land for agriculture and to improve yield of crops during the dry season. The sample for the analysis is a pooled cross-section, time series data at the irrigation project level which covers the period from 1990 to 2012, and includes only large irrigation projects in the Chao Phraya river basin and the Nan river basin. The irrigation projects are grouped into 5 areas: a) the irrigation projects in the upper east side of the Chao Phraya river basin (Manorom, Chong Khae, Khok Kathiam, Roeng Rang, Maharaj, South Pasak, and Nakhon Luang), b) the upper west side (Pholathep, Thabote, Samchook, Don Chedi, Prophraya, Boromathat, Chanasutr, Yangmanee, Phakhai, and Bang Ban), c) the lower east side (North Rangsit, South Rangsit, Khlong Dan, Khlong Priaw, Phra-ong Chaiyanuchit), d) the lower west (Chao Ched Bang Yeehon, Phraya Bunlue, Phrapimol, Pasicharoen, Tupsela), and e) the Phitsanulok irrigation projects (Naresuan Dam, Plai Chumpol, Dong Setthi, Thabua).

2.1 Methodology and data sources

To model the effect of climate and non-climate factors on the production of major crops grown in the basins, the analysis follows the indirect approach of modeling crop supply response by decomposing supply response into area and yield responses and estimating area and yield response equations to examine what economic and climate variables affect the farmers' decision to allocate land for agriculture and the yield of a crop. The models are specified as follows:

Area response equation:

A system of area share equations for different crops is formulated and it is hypothesized based on an economic theory that the area share of each crop depends on economic variables such as price of own output, price of substitute outputs, costs of factor inputs, technology to reduce the risk of climate factors, and climate-related variables as other shift factors. Basically, the area share equation for crop j can be written as:

$$\begin{aligned} s_{j,t} = {} & a_j + \sum_i \beta_{ji} \ln(\text{Price of Crop Output})_{i,t-1} + \sum_k \gamma_{jk} \ln(\text{Cost of Factor Input})_{k,t} \\ & + \sum_m \theta_{jm} \ln(\text{Shift Factors})_{m,t} + \varphi\text{Area share of crop}_{j,t-1} + u_{j,t} \end{aligned} \tag{1}$$

where $s_{j,t}$ represents the area of crop j expressed as a ratio of total planted area for main crops produced in year *t*. β_{ji}, γ_{jk}, θ_{jm} are coefficients on price of crop *i* at time *t-1*, cost of factor input *k* at time *t*, and other shift factors (including the amount of irrigation water and extreme climate indicators) respectively whereas φ takes into account partial adjustment process. u_{jt} is error term. To perform econometric estimation, the parameters of area response equations are estimated by using seemingly unrelated regression (SUR) technique to take care of possible correlation between error terms across the equations investigated.[3] In the estimation, we also impose cross-equation restrictions on the coefficients to obtain efficient estimates.

In the analysis, this study considers three types of crops which consist of paddy rice, sugarcane and other field crops grown during the dry-season, and three main factor inputs which include labor, fertilizer, and capital. All crop price variables are expressed in index form based on the Divisia price index with 2007 as base year before the indices are deflated by the price index of non-agriculture sector. For the factor inputs, the cost of fertilizers is measured using the wholesale price of major fertilizers on the market in Bangkok deflated by the price index of agriculture sector whereas the costs of labor and capital are measured by average nominal wage rate (in baht per day) and the effective lending rate deflated by the consumer price index with 2007 as base year respectively.

With regard to supply shifters, the amount of available irrigation water (measured in millions of cubic meters) in the Bhumibol and Sirikit dams at the beginning of the dry season is used as a technological input whereas extreme drought and flood indices are used as proxies for extreme weather conditions in the gridded areas around the upper Ping river basin in Chiang Mai and Lampoon and the upper Nan river basin in Nan above the two dams. The indices are constructed by analyzing the following six variables with principal component analysis method (PCA). Note that the variables which are used to construct each index consist of annual total precipitation in wet days, simple precipitation intensity index, monthly maximum 5-day precipitation, annual count of days with at least 20 millimeter of precipitation, annual total precipitation when the daily precipitation amount on wet day is above the 95th percentile, and maximum number of consecutive dry days when the daily precipitation amount is less than one millimeter.

Yield response equation:

The yield of a crop is estimated as a function of economic variables such as price of crop and factor input prices, and other shift factors which include technology-related factors such as irrigation water and agricultural research and extension, and climate-related variables. The yield response equation can be written as:

$$\begin{aligned} \mathrm{Y}_{j,t} \;=\; & \delta_{\mathrm{j}} + \tau_{\mathrm{j}} \ln(\text{Price of Crop Output})_{j,t-1} + \textstyle\sum_{\mathrm{k}} \rho_{\mathrm{kj}} \ln(\text{Cost of Factor Input})_{\mathrm{j,t}} \\ & + \textstyle\sum_{\mathrm{m}} \vartheta_{\mathrm{mj}} \ln(\text{Shift Factors})_{m,t} + \mathrm{v}_{j,t} \qquad (2) \end{aligned}$$

where $Y_{j,t}$ represents yield per unit area of crop *j*. This study focuses mainly on the yield of rice and sugarcane measured in kilograms per rai. τ_{lj}, ρ_{kj}, ϑ_{mj} are coefficients of price of crop *j* at time *t-1*, cost of factor input *k*, and other shift factors (such as the amount of irrigated water, budget allocated to agricultural research and extension, extreme drought and flood indices) respectively. v_{jt} is error term. The variables used in the estimation are from the same set of variables described above. For detailed information, the definitions of variables are provided in Appendix A1. To perform model estimation, the ordinary least square method with robust standard errors is used to obtain the estimates of yield response equation (2).

For the data sources, the data used in the estimation of equations (1) and (2) are collected from different official sources. Total farm area of crops grown in the dry season and irrigation water are

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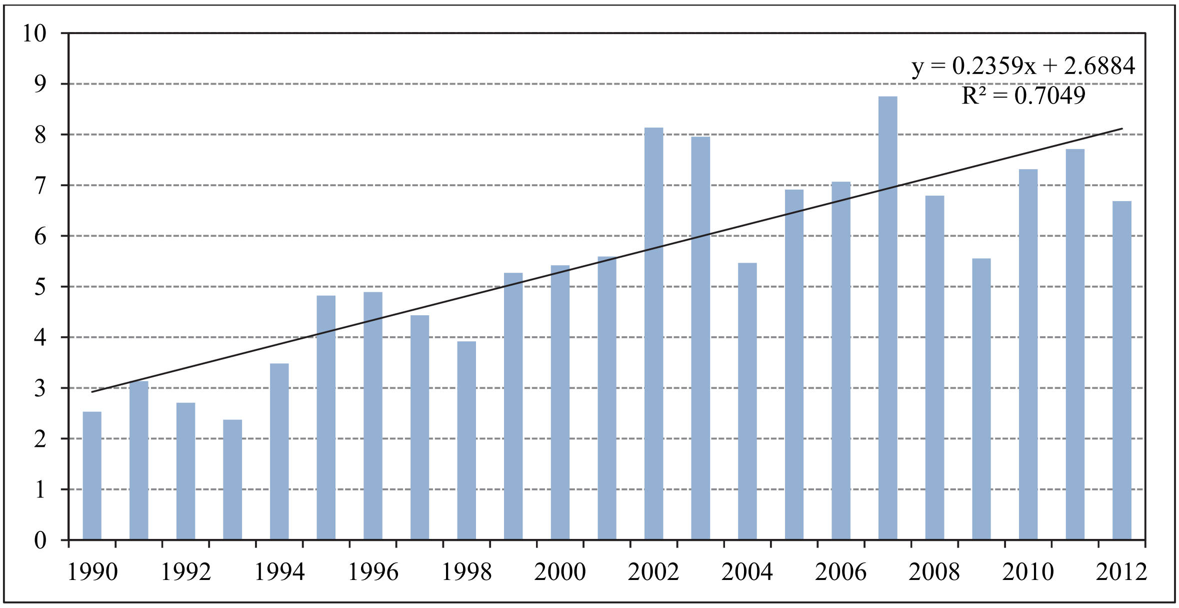
[3] Based on the seemingly unrelated regression method, the parameters of all equations are estimated simultaneously, and the parameters of each individual equation also take into account the information provided by other equations in the system of equations, resulting in greater efficiency of the parameter estimates.

obtained from the Royal Irrigation Department. The farm-gate prices for rice, sugarcane and other field crops, and the wholesale prices of fertilizers on the market in Bangkok are collected from the Office of Agricultural Economics (OAE). Average wage rates are computed using data from the Labor Force Survey (LFS). The cost of borrowing quantified by effective rate of lending is computed based on the information in the annual reports of the Bank of Agriculture and Agricultural Cooperatives (BAAC). The implicit price index of agriculture and non-agricultural sectors and the consumer price index are computed using the data obtained from the National Economic and Social Development Board and the Bureau of Trade and Economic Indices. With regard to weather-related variables, the extreme drought and flood indices mentioned above are constructed by Limsakul (2014) based on gridded daily rainfall data in 18 provinces in the Chao Phraya river basin. Note that the gridded data for historical (1979-2006) and near future (2015-2039) periods are simulated by the Water Resources System Research Unit, the Faculty of Engineering of Chulalongkorn University, based on the biased-corrected MRI-GCM data.[4]

Figure 1 plots total planted areas of crops (including rice, sugarcane, and other field crops) grown in the irrigation areas of the Chao Phraya river basin and the Phitsanulok irrigation projects during the dry season over the periods 1990-2012, indicating that the planted areas on average increased over years from just around 2.53 million rais in 1990 to 6.69 million rais in 2012, accounting for an average annual growth rate of 4.5 percent. In addition, by classifying agricultural areas into five main groups based on the location of irrigation projects, we find that the proportion of planted areas allocated for rice farming increased over the periods while the contrary is true for sugarcane and other field crops, suggesting that the pattern of agricultural land use in all five irrigation areas changed substantially during the past 22 years (Table 1). Coinciding with the decrease in the proportion of planted areas for sugarcane, the increase in average price of rice is found to be much higher than that of sugarcane, as reported in Table 2. This finding tends to suggest that crop prices may be one of important factors that enter into farmers' decision making process on land use. Table 3 further suggests that there has been an improvement in the productivity of rice and sugarcane production measured by average yield in kilograms per rai.

Figure 1: Total Planted Areas of Crops Grown in the Five Irrigation Areas during the Dry Season (Unit: million rais)



Source: Plotted by author using data from the Royal Irrigation Department of Thailand.

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[4] MRI-GCM is short for the Meteorological Research Institute-Global Climate Model.

Table 1: Percentage of Planted Areas during the Dry Season by Type of Crop and Irrigation Areas

Period	Type	Chao Phraya River Basin				Phitsanulok Irrigation	All
		Upper East	Upper West	Lower East	Lower West		
1990-1994	Dry season rice	40.39	75.00	79.96	94.61	80.65	72.00
	Sugarcane	8.09	15.44	12.00	5.24	0.12	7.67
	Other field crops	51.52	9.62	8.04	0.15	19.23	19.00
1995-2000	Dry season rice	93.85	92.16	96.42	96.46	99.76	94.90
	Sugarcane	0.85	6.93	0.00	2.40	0.00	2.82
	Other field crops	5.30	0.91	4.00	1.14	0.23	1.74
2001-2006	Dry season rice	98.85	97.56	99.28	99.17	98.45	98.50
	Sugarcane	0.25	2.09	0.00	0.47	1.52	1.00
	Other field crops	0.90	0.35	0.71	0.36	0.02	0.49
2007-2012	Dry season rice	99.37	97.89	99.02	69.54	99.98	94.10
	Sugarcane	0.40	1.90	0.00	30.00	0.00	4.00
	Other field crops	0.23	0.21	0.98	0.11	0.02	2.00

Source: Calculated by author using data from the Royal Irrigation Department of Thailand.

Table 2: Average Price of Rice and Sugarcane and Percentage Change in Average Price by Irrigation Areas (Unit: baht per ton)

Period	Type	Chao Phraya River Basin				Phitsanulok Irrigation	All
		Upper East	Upper West	Lower East	Lower West		
1995-2000	Dry season rice	5,021	5,090	4,910	4,927	4,780	4,979
	(%)	(51.83)	(51.82)	(47.75)	(51.63)	(54.01)	(51.39)
	Sugarcane	474	464	460	461	471	466
	(%)	(14.50)	(11.00)	(10.00)	(10.89)	(27.58)	(13.54)
2001-2006	Dry season rice	5,363	5,429	5,271	5,345	5,222	5,348
	(%)	(62.18)	(61.92)	(58.60)	(64.49)	(68.25)	(62.62)
	Sugarcane	527	532	528	530	556	533
	(%)	(27.47)	(27.24)	(26.31)	(27.63)	(50.50)	(29.90)
2007-2012	Dry season rice	9,347	9,424	9,299	9,402	9,146	9,347
	(%)	(182.65)	(181.09)	(179.82)	(189.35)	(194.67)	(184.21)
	Sugarcane	760	756	755	761	826	766
	(%)	(83.68)	(80.80)	(80.69)	(83.15)	(123.65)	(86.80)

Note: Figures in the parenthesis indicate percentage change in average price from the period 1990-1994.

Source: Calculated by author using data from the Office of Agricultural Economics.

Table 3: Average Yield Per Rai of Rice and Sugarcane by Irrigation Areas (Unit: kilograms per rai)

Period	Type/Area	Chao Phraya River Basin				Phitsanulok	All
		Upper East	Upper West	Lower East	Lower West	Irrigation	
1990-1994	Rice	592	616	588	620	705	618
	Sugarcane	8,301	9,562	7,049	7,922	7,240	8,308
1995-2000	Rice	700	768	677	747	721	729
	Sugarcane	8,858	10,231	8,000	9,076	8,683	9,175
2001-2006	Rice	699	729	696	713	690	709
	Sugarcane	9,534	10,659	9,056	9,707	9,286	9,816
2007-2012	Rice	696	710	706	712	667	701
	Sugarcane	11,585	12,316	10,421	12,506	11,462	11,766

Source: Calculated by author using data from the Office of Agricultural Economics.

To provide an overview of variables, Table 4 reports descriptive statistics of all variables used in the regressions. Apart from the change in land use pattern, yield performance and prices described earlier, it is found that, except for the cost of borrowing and agricultural research expenditures, there tends to be an increase in the prices of fertilizer, wage, and irrigation water. For climate related indicators, there was no clear climate pattern during the past 22 years.

Table 4: Descriptive Statistics of Variables in Area and Yield Response Equations

Variables	Average			
	1990-94	1995-2000	2001-2006	2007-2012
Proportion of rice area	0.72	0.95	0.99	0.94
Proportion of sugarcane area	0.08	0.03	0.01	0.04
Proportion of field crop area	0.19	0.02	0.00	0.02
Ln (Yield of rice)	6.40	6.59	6.56	6.55
Ln (Price index of paddy rice)	-0.23	-0.05	-0.09	0.29
Ln (Price index of sugarcane)	-0.06	-0.14	-0.13	0.05
Ln (Price index of other field crops)	-0.35	-0.27	-0.24	0.12
Ln (Fertilizer price)	9.22	9.18	9.27	9.38
Ln (Wage rate)	4.77	4.99	4.77	5.02
Ln (Cost of borrowing)	1.87	1.57	0.59	1.26
Ln (Irrigation water)	19.07	19.68	19.95	19.73
Ln (Agricultural research expenditures)	9.92	10.12	9.83	9.47
Extreme flood index	-0.12	0.31	0.04	n/a
Extreme drought index	-0.54	-0.06	0.15	n/a
El Niño condition	0.20	0.17	0.00	0.00
La Niña condition	0.00	0.33	0.00	0.33

Source: Calculated by author.

2.2 Empirical evidence

Based on the estimation results for area response equation presented in Appendix Table A2.1-A2.5 and yield response equation presented in Appendix Table A3.1-A3.2, there are four key findings. First, the farmers' decisions to allocate more land for the production of rice and sugarcane and to improve the yields are on average responsive to last year's price of crop they plan to produce in the coming season. Particularly about the land use pattern in agriculture, the government's intervention program through rice pledging scheme in the previous year appears to create more incentives for farmers to allocate more land for rice production.

Second, the climate factors, particularly extreme drought weather condition in the areas above Bhumibol and Sirikit dams which are the major sources of water for agriculture in the Chao Phraya River basin, tend to adversely affect not only the farmers' decision to allocate land area for rice production, but also the yield of rice and sugarcane in certain irrigation areas. Although it is not reported in the paper, we also look into the effect of climate anomalies associated with El Niño and La Niña conditions and find that the two types of anomalies tend to have a negative impact on the productivity of rice production in all five irrigation areas, with greater yield losses due to the warm (ENSO) periods during which high probability of subnormal rainfall is more likely to occur.

Third, the availability of irrigation water for agriculture at the beginning of dry season appears to be a rather important factor for farmers to decide whether they should increase or decrease land areas for rice and sugarcane farming. Besides, the more the availability of irrigation water for agriculture, the higher the yield of rice and sugarcane produced in most of the irrigation areas. It is found that a 10 percent increase in the amount of irrigation water tends to increase the proportion of rice and sugarcane farming areas by 0.6-1.7 percent and 0.1-0.9 percent respectively, and to improve the yield of rice and sugarcane by 0.1-0.63 percent and 0.3-1.4 percent respectively.[5]

Lastly, there is a positive relationship between the amount of budget allocated for agricultural research and extension activities and rice yield in particular. As adaptive capacity is shown in Kannika (2014) to be important for farmers to respond to some extreme weather events, the development and utilization of effective adaptation options are essential in agriculture. However, there are limitations to autonomous adaptation undertaken by individual farmers.[6] It is therefore indispensable for the government to allocate proper amount of budgets for research and development activities such as the development of new crop types that may be adapted to climate change and more effective adaptation strategies to strengthen the farmers' adaptive capacity.

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[5] In Appendix Tables A4.1-A4.2, we presented the estimates of equations 1 and 2 for the agricultural production in the rainy season in 29 provinces in the Chao Phraya River basin and sub-basins. Among all other variables (including average rainfall) that have significant relationship with the areas and yield of rice production, the average amount of water available in the Bhumibol and Sirikit dams is significantly and positively related with the proportion of rice production areas and also the yield of rice in the rainy season production. This suggests that the higher amount of water available at the beginning of the rainy season in the two dams can induce farmers to expand their rice production areas, causing the need for more water in the rice production over the season. The increase in water consumption during the rainy season production will to some extent put pressure on water availability at the beginning of the next season.

[6] In the context of adaptation, there are at least two major forms of adaptation, autonomous adaptation and anticipatory adaptation. Autonomous adaptation (referred to as private adaptation) describes measures that are taken in reaction to climate change or climate change stimuli and generally undertaken by individual households. Some of the measures are adjustment on planting calendar, irrigation schedule, and methods of planting. For anticipatory adaptation (referred to as public adaptation), it refers to adaptation measures that require investments usually made by the government and large private enterprises to build adaptation capital which will help create a stream of benefits in the future. However, the adaptation capital does not last forever and will need to be replenished. Examples of this form of adaptation are research and development into new crop types that may be adapted to climate change, and the development of large scale irrigation projects.

3. Efficiency of irrigated water

Based on the estimation of equations (1) and (2), we compute the elasticity of area response to irrigated water ($e_{a,w}$) and elasticity of yield response to irrigated water ($e_{y,w}$), to obtain the elasticity of supply to irrigated water ($e_{q,w}$) which will be used to measure the value of marginal product of irrigated water (VMP). The computed VMP for all selected irrigation areas are compared to see in which area has higher value of farm output per unit of water used. The higher the value of marginal product of irrigated water is, the more efficient the irrigated water is used in farming.

As depicted in Table 5, the computed value of marginal product of irrigated water (VMP) suggests that, by using the same one unit of irrigation water in agriculture, not all farmers can create the same level of economic value from the production of rice and sugarcane. The results indicate that agricultural production in the east region of the Chao Phraya river basin on average tends to generate about 2.3 times and 3.3 times higher economic value than in the west region for rice and sugarcane respectively. Apart from the difference in VMP by geographical areas, it appears that the VMP of sugarcane is about 10 times higher than that of rice. Overall, the efficiency of irrigated water used in agricultural production varies greatly with locations and types of crops planted.

Table 5: The Estimated Value of Marginal Product of Irrigation Water for Rice and Sugarcane Production during Dry Season in the Selected Irrigation Areas.

Type	Chao Phraya River Basin				Phitsanulok Irrigation	Average
	Upper east	Upper west	Lower east	Lower west		
Rice:						
Elasticity of Supply to Irrigation Water	0.212	0.084	0.139	0.063	0.245	
Value of Marginal Product of Irrigation Water (VMP)	0.653	0.262	0.571	0.280	0.633	0.48
Sugarcane:						
Elasticity of Supply to Irrigation Water	3.858	0.716	0.138	0.080	2.269	
Value of Marginal Product of Irrigation Water (VMP)	16.247	3.252	0.720	0.466	7.471	5.63

Source: Calculated by author.

4. Projection of crop production and the cost of climate variability

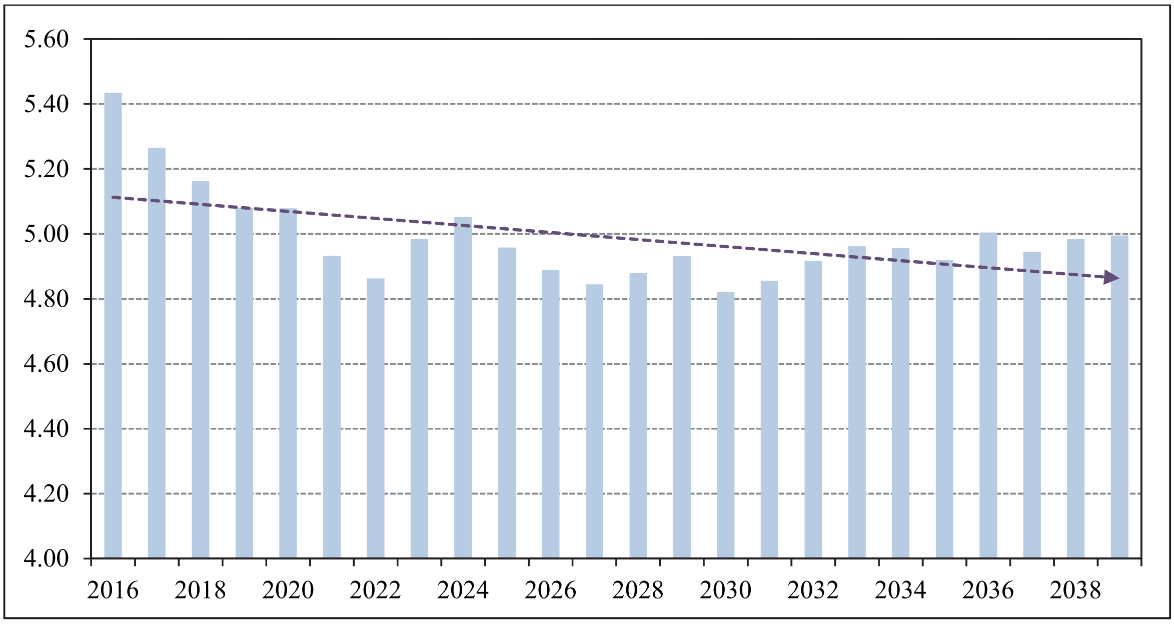
This section provides a projection of rice production for the next two decades by using the estimates derived in Section 3 and taking into account expected change in weather conditions based on simulated amount of rainfall and temperature for the next 23 years during 2015-2039 obtained from Meteorological Research Institute-Global Climate Model (MRI-GCM). To calculate the projected rice production, we assume other things do not change, except for the following three variables: a) the level of water available for agriculture which is set to be at the minimum level during the past 16 years, b) the extreme drought and flood indices to vary according to the simulated amount of rainfall and temperature from MRI-GCM. Figures 2-4 plot the forecast of planted areas, rice yield and total production for the period from 2015 to 2039, and) the rice pledging schemes set to be no longer implemented.

Based on the projection, the total planted areas of rice in the irrigation areas of the Chao Phraya river basin and the Phitsanulok irrigation projects is expected to decline from 6.3 million rais in 2012 to 5 million rais in 2039, accounting for a reduction of about 17 percent (Figure 2). With respect to production yield of rice, Figure 3 shows that average yield per rai of rice produced in the region is expected to decline from 716 kilograms per rai in 2012 to 620 kilograms per rai in 2039, accounting for the decline of about 13.4 percent. Overall, the rice production will substantially be reduced from 4.5 million tons to 3.1 million tons in 2039 or about a 30.9 percent decline (Figure 4).[7]

5. Driving factors for water inflow into the Bhumibol and Sirikit dams

Water is important to farming because it is an essential nutrient for plants to grow. Without adequate amount of water for agriculture, it will certainly affect crop production especially during the dry season. Take irrigation farming in the Chao Phraya river basin as a point of focus. The irrigated agriculture in various provinces in the Chao Phraya river basin during the dry season has to rely very much on the amount of water released from two dams, including Bhumibol and Sirikit dams.

Figure 2: The Forecast of Total Planted Areas of Rice in the Irrigation Areas of the Chao Phraya River Basin and Phitsanulok Irrigation Projects during 2016-2039 (Unit: million rais)



Source: Forecast by author.

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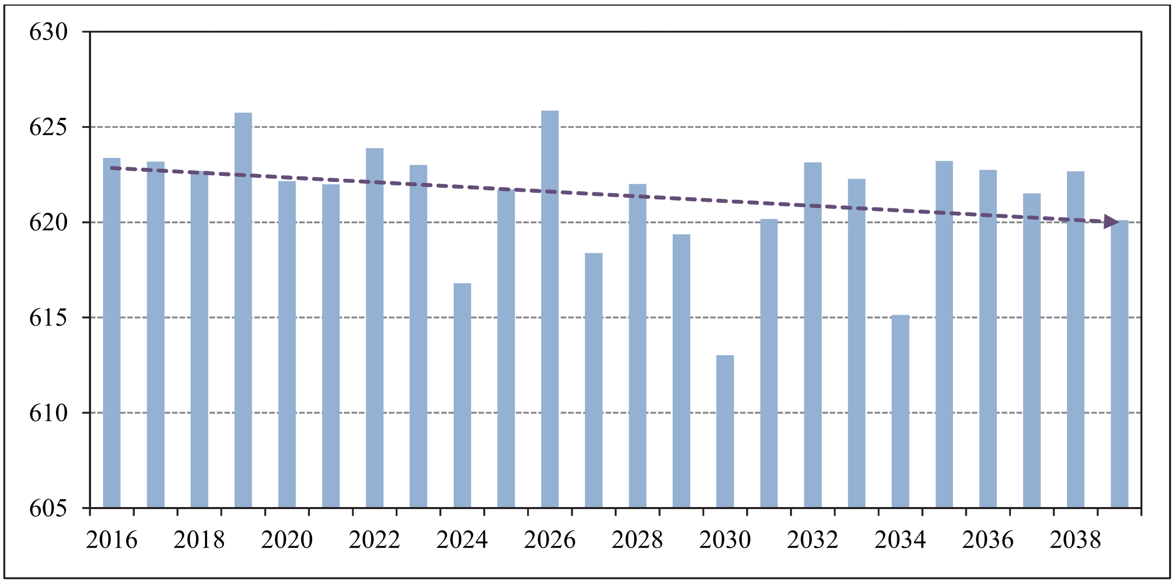
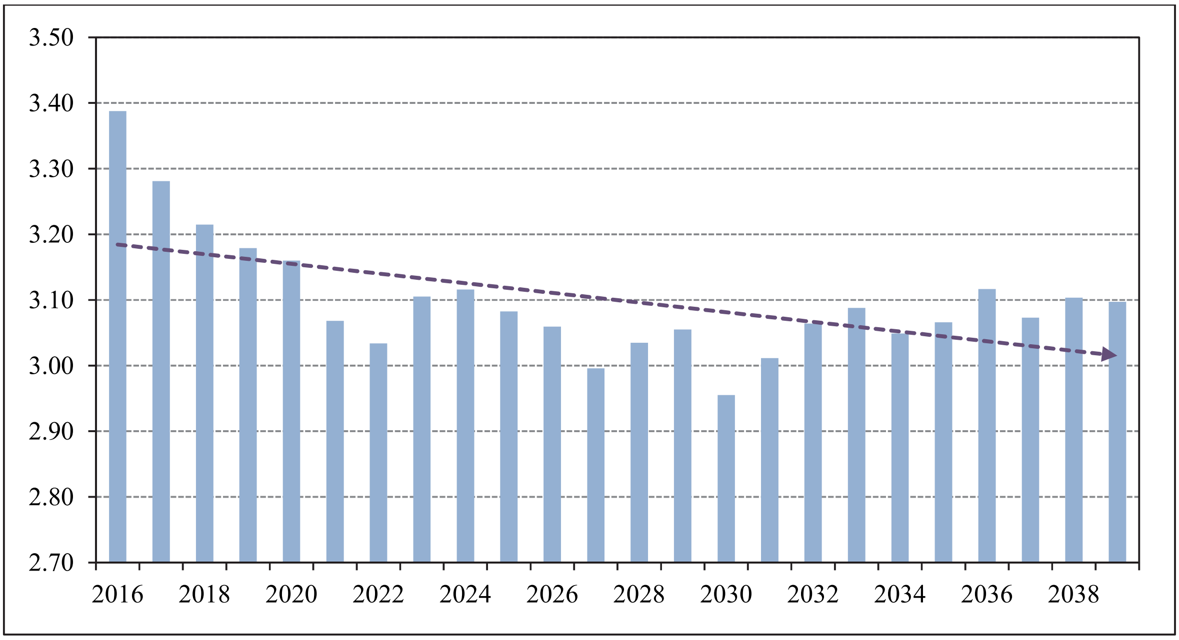
[7] Holding other things constant, a 3-day increase in average number of consecutive dry days will reduce the yield per rai of rice by nearly 3.8 percent.

Figure 3: The Forecast of Average Rice Yield Per Rai in the Irrigation Areas of the Chao Phraya River Basin and Phitsanulok Irrigation Projects during 2016-2039 (Unit: kilograms per rai)



Source: Forecast by author.

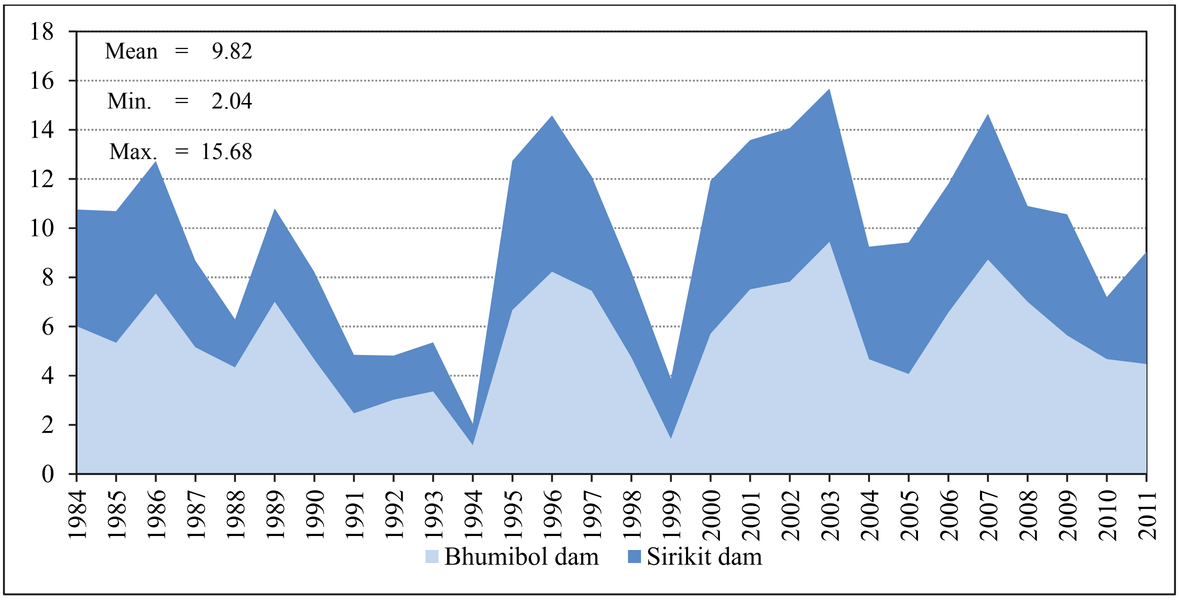
Figure 4: The Forecast of Total Rice Production in the Irrigation Areas of the Chao Phraya River Basin and Phitsanulok Irrigation Projects during 2016-2039 (Unit: million tons)



Source: Forecast by author.

However, during the past three decades, the two dams ever experienced a below-average level of total usable water stored at the beginning of the year for at least twelve times, with the lowest level at around 2 billion cubic meters occurred in 1994 (Figure 5), suggesting that it happened sometimes in the past that the water supply in the dams run low and the farmers living downstream in the irrigated area of the Chao Phraya river basin would inevitably experience insufficient water for agriculture during the dry season, particularly for dry-season rice cultivation. Overall, the low level of water stored in the dams is a scary problem for farmers. It is therefore important to understand about what are important factors that can influence the level of water inflow into the dams and to analyze whether changes in these factors will become a serious concern in the future.

Figure 5: Total Amount of Usable Water Stored in the Bhumibol and Sirikit Dams at the First of January (Unit: billion cubic meters)



Source: Plotted using data obtained from the Water Operation Center, Electricity Generating Authority of Thailand.

5.1 Methodology and data sources

To explain the issues empirically, this study models the amount of water inflow as a function of climate and non-climate variables as follows:

$$\begin{aligned} w_{r,t} = {} & b_0 + b_1 \ln(\text{Rainfall})_{r,t} + b_2 \ln(\text{Water stored})_{r,t} + b_3(\text{Rice area})_{r,t} \\ & + b_4(\text{Field crop area})_{r,t} + b_5 \ln(\text{Population density})_{r,t} \\ & + b_6(\text{Climate variable})_{r,t} + \vartheta_{r,t} \qquad (3) \end{aligned}$$

where $w_{r,t}$ represents the total sum of water inflow into dam r at time t. This study focuses only on two dams which are the Bhumibol and Sirikit dams where major sources of water come from the upper Ping river basin in Chiang Mai and Lampoon and the upper Nan river basin in Nan respectively. b_1, b_2, b_3, b_4, b_5, b_6 are coefficients on the natural logarithm of average rainfalls in the provinces above dam r, the natural logarithm of the amount of water stored in dam r, the percentage of rice farming area and field crop area in provinces above dam r, the natural logarithm of population density as a proxy for urbanization, and the climate variables respectively. However, for the climate variables, this study employs two sets of variables including the standardized departure of multivariate ENSO index as a proxy for climate variability, and the climate anomalies categorized as El Niño and La Niña (See variable definitions in Appendix A1).

The data for the periods 1984-2011 that are used in the analysis comes from different sources. The amount of water inflow during the rainy season, the amount of water stored in the dams at the beginning of the season, and average rainfall are obtained from the Royal Irrigation Department. The data on agricultural areas for rice and field crops is calculated using the data collected from the Office of Agricultural Economics (OAE) whereas the population density is measured based on the data from the Department of Provincial Administration. For climate variables used in the estimation, the data on multivariate ENSO index is obtained from the National Oceanic and Atmospheric Administration.

Table 6 reports descriptive statistics for all variables described in equation (3). With regard to water related indicators, the amount of water inflow into and water stored in both Bhumibol and Sirikit dams varied widely during the period with the coefficient of variation (CV) falling in between 25 and 75 percent whereas the coefficient of variation of average annual rainfall is at the low-to-moderate level of around 22-23 percent. Figures 6 and 7 show total amount of water flowing into the Bhumibol and Sirikit dams and average rainfall in the upper Ping and Nan river basins respectively.

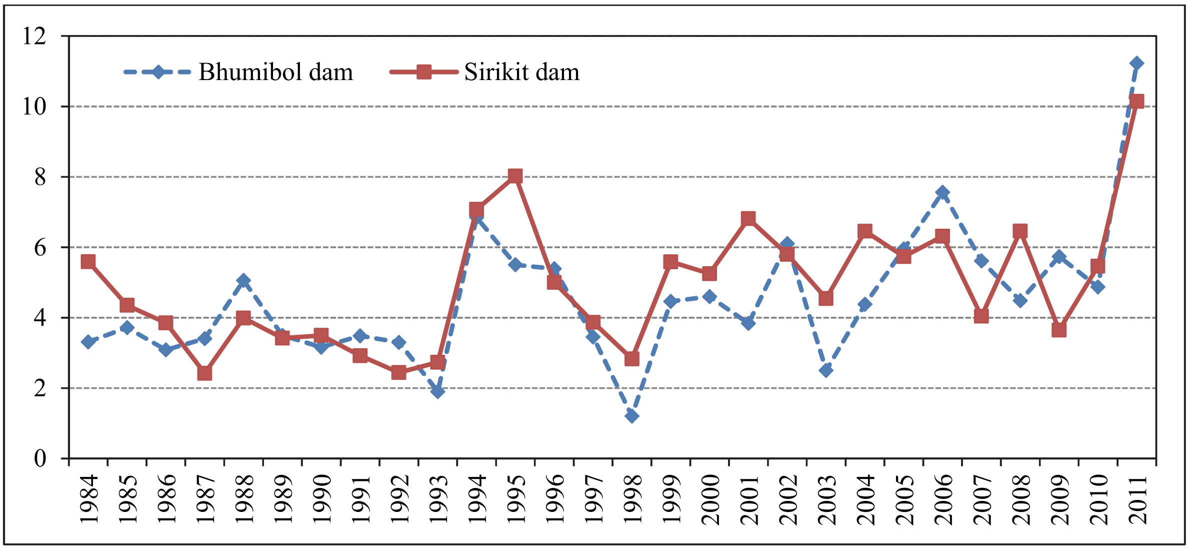
For the issue related with agricultural land use, it is observed that the change in land use pattern in the areas above Bhumibol dam varies widely during the period, compared with those above Sirikit dams. Although not reported, the statistics exhibit that the amount of water inflow during the rainy season is significantly and positively correlated with the average rainfall, and negatively related with the percentage of farm area allocated to rice farming.

Table 6: Descriptive Statistics on Determinants of Water Inflow into the Dams

Variables	Obs.	Mean	S.D.	Min.	Max.	CV[/1]
a) Bhumibol dam						
Water Inflow	27	4,604.66	1,978.66	1,205.04	11,226.59	42.97
Average rainfall	27	308.11	67.85	179.14	456.39	22.02
Water in the reservoirs	27	5,506.21	2,144.49	1,174.26	9,444.61	38.95
% of rice area	26	45.65	10.37	25.47	63.10	22.71
% of field crop area	26	12.10	2.93	9.01	22.15	24.19
Population density	27	79.03	4.81	68.10	84.33	6.09
MEI	27	0.02	1.01	-1.62	2.06	
Warm ENSO phase (El Niño)	27	0.11	0.32	0.00	1.00	
Cold ENSO phase (La Niña)	27	0.07	0.27	0.00	1.00	
b) Sirikit dam						
Water Inflow	27	4,913.89	1,859.41	2,418.29	10,141.87	37.84
Average rainfall	27	204.83	47.01	125.81	293.99	22.95
Water in the reservoirs	27	4,276.17	1,647.53	869.24	6,354.90	38.53
% of rice area	26	29.21	2.88	19.63	34.18	9.86
% of field crop area	26	49.24	5.31	42.49	57.48	10.79
Population density	27	40.69	1.88	36.38	42.67	4.62
MEI	27	0.02	1.01	-1.62	2.06	
Warm ENSO phase (El Niño)	27	0.11	0.32	0.00	1.00	
Cold ENSO phase (La Niña)	27	0.07	0.27	0.00	1.00	

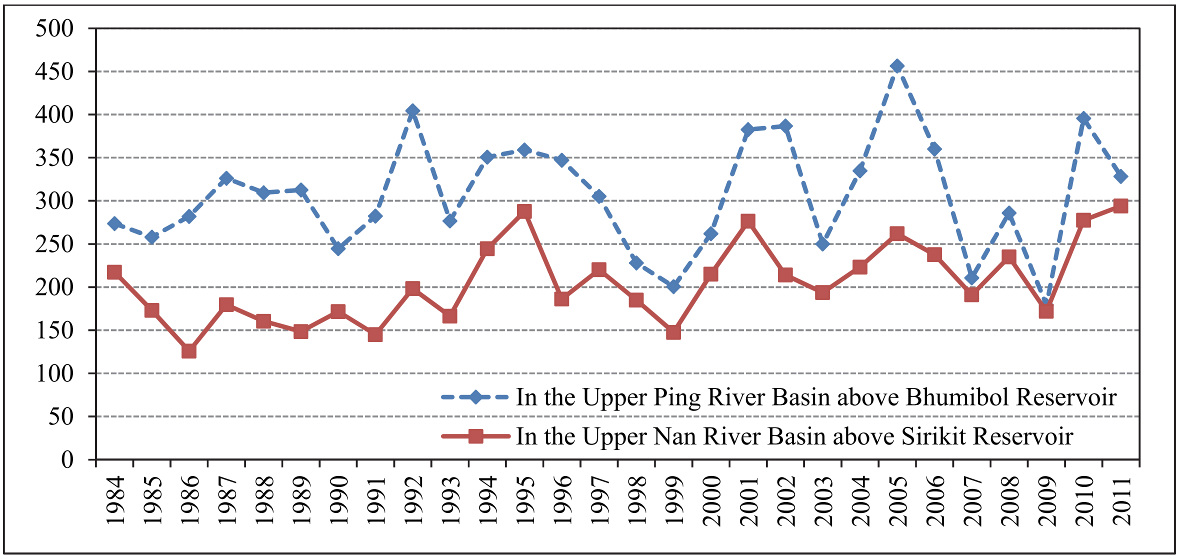
Note: [/1] CV is the abbreviation for coefficient of variation.

Figure 6: Total Amount of Water Inflow into the Bhumibol and Sirikit Dams (Unit: billion cubic meters)



Source: Plotted using data obtained from the Electricity Generating Authority of Thailand.

Figure 7: Average Annual Rainfall in the Upper Ping River Basin above Bhumibol Dam and the Upper Nan River Basin above Sirikit Dam



Source: Plotted using data obtained from the Thai Meteorological Department.

5.2 Empirical evidence

Both Bhumibol and Sirikit dams are the major source of irrigation water for cultivation areas in the downstream areas of the Chao Phraya river basin. However, as the amount of water available to be released from the Bhumibol and Sirikit dams for agricultural and other purposes in the downstream areas is highly restricted by climate and non-climate related factors in the areas in the upper Ping and Nan river basins, it is therefore important to understand about factors that have influential impacts on the amount of the water inflow into the dams.

Table 7 presents estimation results using random effects estimation method. Note that Hausman test for panel data is applied to select the appropriate estimation method. Overall, we find that both socio-economic factors and climate related factors are key determinants of the amount of water inflow into the dams. There are four important findings. First, the pattern of agricultural land use in the areas in the upper Ping and upper Nan river basins negatively affects the amount of water flowing into the dams and inevitably the amount of water available for agricultural and other purposes in the downstream areas. The estimation result indicates that a one standard deviation increase in the ratio of rice areas to total areas may decrease the amount of water inflow into the dams by about 16-18 percent or about 773-864 million cubic meters.

Second, greater population density which is considered as a proxy for expanding urbanization has an adverse impact on the amount of water inflow, suggesting that urbanization may contribute to water stress in the downstream areas because as population rises and urbanization tends to continue, the pattern of water demand is expected to change. The result suggests that a 10 percent increase in the level of population density is likely to lead to a decline in the amount of water flowing into the dams of about 13 percent.

Third, the quantity of rainfall during the season is an important source of water run into the dams. The estimation result suggests that a 10 percent increase in average annual rainfall leads to an increase in the amount of water inflow into the dams by 8.5-9.5 percent.

Lastly, the standardized dispersion of multivariate Enso index has negative impact on total water inflow, suggesting that climate variability may place stress on water supply or availability and exacerbate the already increasing demand on water resources for agricultural and consumption purposes. To make it clear about the impact of climatic anomaly, we run another specification using the climate anomalies categorized as El Niño condition (warm ENSO phase) and La Niña condition (cold ENSO phase). The finding shows that when there is El Niño weather pattern, this will affect the amount of water running into the dams. However, the converse is true for La Niña condition.

Overall, the fluctuation of water reserves in the Bhumibol and Sirikit dams may be explained by the amount of rainfall, drought conditions, population density, and the changing pattern of land use upstream in the upper Ping and Nan river basins. The question is "Will these factors have significant impact on the amount of water stored in the future?" Based on different studies, it is expected that amount of precipitation in the north may remain almost unchanged during the next 30 years (Chinvanno et al. 2009) whereas urbanization is going to continue to expand. It is thus conjectured that an increase in population density in the areas above the dams will likely be an important factor that contributes to water stress and may lead to some conflicts in the downstream areas as people fight over access to limited water resources. Apart from our findings, the emerging evidence suggests the mistakes in water supply management after the occurrence of flood in 2011 is likely to be a major cause of water shortage in the recent years. Owing to the problem of serious sea water intrusion and worrying low level of water available in the Bhumibol and Sirikit dams this year, this makes the Metropolitan Water Works Authority (MWA) in collaboration with the Royal Irrigation Department to implement the diversion of water from the west from Khlong Jorake Sampan in Kanchanaburi to Khlong Phraya Banlue in Pathum Thani and to be released to the Chao Phraya river in Ayudhaya to help alleviate the water quality problem in the central plain areas.[8] However, the implementation of diversion plan is likely to encounter with the opposition of people and farmers in Kanchanaburi. This gives rise to issues and challenges for a more efficient management of water supply and demand.

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[8] The diversion of water from the west to deal with water quality problem in the Chao Phraya river had ever been implemented in 2010 and 2013 (Metropolitan Water Work Authority, 2014).

Table 7: Determinants of Water Inflow into the Bhumibol and Sirikit Dams using Random Effects Estimation Method

Variables	Coefficient	S.E.	Coefficient	S.E.
Ln(Average rainfall)	0.8568***	0.187	0.9525***	0.192
Ln(Water stored at the beginning of the year)	-0.0534	0.089	0.0473	0.094
Ratio of rice area to total area	-0.0162**	0.006	-0.0145**	0.007
Ratio of field crop area to total area)	-0.0194	0.015	-0.0168	0.015
Ln(Population density)	-1.3154*	0.778	-1.3137*	0.790
Standardized departure (Enso: MEI)	-0.1781***	0.044		
Warm ENSO phase (El Niño)			-0.3473**	0.138
Cold ENSO phase (La Niña)			0.51***	0.172
Constant	10.6484***	3.892	9.1187**	4.022
Overall R-squared	0.548		0.547	
Wald Chi2	54.64***		53.16***	
Number of observations (groups)	52 (2)		52 (2)	

Note: ***, **, and * indicate statistical significance at the 1, 5, and 10 percent level respectively.

6. Policy implication

- Since available water is important to farm production in the dry season, farmers would demand more water for agriculture. However, to tackle the problem of water shortage and uncertainty in water available in the dams upstream in the same way as in the past through the development of large-scale dam is less likely to be successful at the present time due to a number of concerns on environmental and social impacts. It is therefore important that water demand management should be addressed to improve the quality and efficiency of water use. The government agency' practice of allocating water to farmers irrespective of economic value or efficiency of use should not be continued. Because water scarcity tends to be a critical phenomenon in the future, more efficient use of water in agriculture which consumes substantial amount of water should be promoted. In economics, there are two major economic instruments that are worth considering, including fee-based measures (pricing schemes, taxes, and charges) and property rights/tradable permits-based measures (water markets). However, any attempt to push forward the fee-based type of policies is likely to face with strong opposition of farmers. Alternatively, the concept of tradable water rights system where stakeholders can buy and sell water rights may be introduced. However, this seems to be effective only within a well-defined legal and institutional framework.

- Appropriate adaptation measures should be adopted. Since better use of irrigated water is highly likely for crops other than rice in some irrigation areas in terms of economic value generation, it would be necessary to consider more for crop change. However, this depends largely on appropriateness of agricultural land and agricultural knowledge of farmers.

- Because extreme weather events have grown more frequent and may generate shock and substantial impacts on farmers and the general public, it would be essential to build generic institutional capacity to plan and respond to any type of event to ensure greater preparedness overall. Relatively important, the dissemination of correct information is also essential.

- The anticipatory adaptation approach in which the government invests in research, extension, and development activities for agricultural sector should be supported extensively to help improve the adaptive capacity of farmers in dealing with the risk of climate variability effective in the long run.

- The government's price intervention program must be implemented with care in such a way that it will not cause significant market distortion.

- With respect to the relationship between the amount of water available in the Bhumibol and Sirikit dams and the decision on rice farming areas and rice yields, both for the rainy and dry season cases, there should be a more in-depth and further study on an integrated method for optimizing inter-seasonal water allocations from the dams especially during the long period of drought with changing economic factors and uncertainty associated with unpredictable climate change.

APPENDIX

Table A1: Variable Definitions

Variable	Definition
Area and yield related:	
Proportion of rice area$_i$	Proportion of rice area to total planted area in irrigation project *i*
Proportion of sugarcane area$_i$	Proportion of sugarcane area to total planted area in irrigation project *i*
Proportion of other field crop area$_i$	Proportion of other field crop (excluding sugarcane) area to total planted area in irrigation project *i*
Yield of rice$_i$	Average yield of rice (in kilograms) per rai in irrigation project *i*
Water related :	
Water Inflow	Total amount of water inflow (in million cubic meters) into the Bhumibol and Sirikit dams from May to October
Water in the dams	The amount of water (in million cubic meters) stored in the Bhumibol and Sirikit dams at the beginning of the season
Average rainfall	Average amount of rainfall (in millimeters) in the Upper Ping and Nan river basins during rainy season
Irrigation water	Irrigation water (in million cubic meters) for irrigation project *i*
Climate related:	
MEI	Standardized departure of multivariate ENSO index
El Niño condition	Binary variable equal to one if the standardized departure of MEI value is greater than 1.5 (referred to as warm ENSO phase)
La Niña condition	Binary variable equal to one if the standardized departure of MEI value is less than 1.5 (referred to as cold ENSO phase)
Extreme flood index	Composite index constructed based on PCA method using gridded data of six extreme indicators with more weights on wet conditions
Extreme drought index	Composite index constructed based on PCA method using gridded data of six extreme indicators with more weights on dry conditions
Non-climate variables:	
Price index of paddy rice	Average price index of second rice in irrigation project *i*[2]
Price index of sugarcane	Average price index of sugar cane in irrigation project *i*[2]
Price index of other field crops	Average price of other field crops in irrigation project *i*[2]
Fertilizer price	Wholesale price of fertilizers on the market in Bangkok averaged across five major formula of fertilizers deflated by GDP deflator
Wage rate	Average nominal wage rate (in baht per day) deflated by CPI with 2007 as base year
Cost of borrowing	Realized lending interest rate of the Bank for Agriculture and Agricultural Cooperatives (BAAC) deducted by actual inflation rate
% rice in pledging program	Amount of paddy rice pledged in the government's intervention program as a percentage of total rice production in a year
Population density	No. of people per sq. km. in the Upper Ping river basin above Bhumibol Dam and the Upper Nan river basin above Sirikit Dam

Notes: [1/] Total planted area is the sum of all area for the production of rice, sugarcane and other field crops in irrigation project *i*.

[2/] All price indices are constructed using the Divisia Price Index method with 2007 as base year and divided by the implicit price index for non-agriculture.

Table A2.1: Estimates of the Area Response of Crops Produced during the Dry Season in the Upper East Areas of the Chao Phraya River Basing using Iterative Seemingly Unrelated Regression

Independent variables	Paddy rice		Sugar cane	
	Coefficient	S.E.	Coefficient	S.E.
Price index of paddy rice (t-1)	0.2229*	0.126	-0.0304	0.153
Price index of sugarcane (t-1)	-0.0304	0.153	0.2229*	0.126
Price index of other field crops (t-1)	-0.1925*	0.101	-0.1925*	0.101
Fertilizer price	0.7375	1.297	-0.1644	0.228
Wage rate	0.4314	0.508	0.0382	0.124
Cost of borrowing	0.1607**	0.076	-0.0818*	0.044
Irrigation water	0.1269***	0.039	0.0994**	0.050
Extreme flood index (t-1)	-0.0125	0.063	-0.0666***	0.024
Extreme drought index (t-1)	-0.3144***	0.117	0.1371	0.086
% rice in pledging program (t-1)	2.1685**	0.841	-2.0963***	0.756
Area share (t-1)	0.6183***	0.077	0.1016	0.087
Constant	-11.5218	14.087	-0.3979	2.669
Dummy variables (Irrigation project)	Yes		Yes	
Dummy variables (Year)	Yes		Yes	
R-squared	0.8165		0.3335	
Number of observations	126			

Note: ***, **, and * indicate statistical significance at the 1, 5, and 10 percent level respectively.

Table A2.2: Estimates of the Area Response of Crops Produced during the Dry Season in the Upper West Areas of the Chao Phraya River Basin using Iterative Seemingly Unrelated Regression

Independent variables	Paddy rice		Sugar cane	
	Coefficient	S.E.	Coefficient	S.E.
Price index of paddy rice (t-1)	0.2514*	0.131	-0.2857**	0.137
Price index of sugarcane (t-1)	-0.2857**	0.137	0.2514*	0.131
Price index of other field crops (t-1)	0.0343	0.052	0.0343	0.052
Fertilizer price	-0.2834	0.778	-2.1289***	0.479
Wage rate	-0.2481	0.335	-1.1502***	0.218
Cost of borrowing	0.0577	0.037	0.8154***	0.194
Irrigation water	0.0631**	0.027	0.047***	0.015
Extreme flood index (t-1)	0.0167	0.035	-0.5615***	0.118
Extreme drought index (t-1)	-0.2666***	0.099	-0.4384***	0.085
% rice in pledging program (t-1)	0.8606*	0.506	4.1067***	1.050
Area share (t-1)	0.502***	0.059	0.6885***	0.045
Constant	2.8399	8.510	22.4643***	4.915
Dummy variables (Sub-projects)	Yes		Yes	
Dummy variables (Year)	Yes		Yes	
R-squared	0.6026		0.7461	
Number of observations	180			

Note: ***, **, and * indicate statistical significance at the 1, 5, and 10 percent level respectively.

Table A2.3: Estimates of the Area Response of Crops Produced during the Dry Season in the Lower East Areas of the Chao Phraya River Basin using Iterative Seemingly Unrelated Regression

Independent variables	Paddy rice		Sugar cane	
	Coefficient	S.E.	Coefficient	S.E.
Price index of paddy rice (t-1)	0.0001	0.000	-0.000003	0.000
Price index of sugarcane (t-1)	-0.000003	0.000	0.0001	0.000
Price index of other field crops (t-1)	-0.0001*	0.000	-0.0001*	0.000
Fertilizer price	1.3305**	0.608	-0.0003	0.000
Wage rate	0.2696	0.303	0.0003	0.000
Cost of borrowing	-0.1131	0.076	-0.00004	0.000
Irrigation water	0.0791**	0.037	-0.00001	0.000
Extreme flood index (t-1)	-0.075*	0.041	0.00001	0.000
Extreme drought index (t-1)	-0.2971***	0.094	0.00005	0.000
% rice in pledging program (t-1)	1.164*	0.667	-0.0009	0.001
Area share (t-1)	0.6078***	0.076	0.2818***	0.104
Constant	-14.8281**	6.712	0.0016	0.003
Dummy variables (Sub-projects)	Yes		Yes	
Dummy variables (Year)	Yes		Yes	
R-squared	0.6557		0.3228	
Number of observations	90			

Note: ***, **, and * indicate statistical significance at the 1, 5, and 10 percent level respectively.

Table A2.4: Estimates of the Area Response of Crops Produced during the Dry Season in the Lower West Areas of the Chao Phraya River Basin using Iterative Seemingly Unrelated Regression

Independent variables	Paddy rice		Sugar cane	
	Coefficient	S.E.	Coefficient	S.E.
Price index of paddy rice (t-1)	0.2079**	0.096	-0.215**	0.096
Price index of sugarcane (t-1)	-0.215**	0.096	0.2079**	0.096
Price index of other field crops (t-1)	0.0071	0.013	0.0071	0.013
Fertilizer price	0.265	0.273	0.0098	0.256
Wage rate	-1.8259**	0.930	0.1217	0.140
Cost of borrowing	-0.1028**	0.051	0.0413	0.034
Irrigation water	0.009	0.031	-0.011	0.031
Extreme flood index (t-1)	-0.0239	0.017	-0.0151	0.027
Extreme drought index (t-1)	-0.157*	0.088	0.055	0.043
% rice in pledging program (t-1)	1.6353*	0.930	0.0848	0.200
Area share (t-1)	0.0272	0.065	-0.0852	0.065
Constant	6.9755	4.675	-0.5247	2.857
Dummy variables (Sub-projects)	Yes		Yes	
Dummy variables (Year)	Yes		Yes	
R-squared	0.4059		0.3707	
Number of observations	90			

Note: ***, **, and * indicate statistical significance at the 1, 5, and 10 percent level respectively.

Table A2.5: Estimates of the Area Response of Crops Produced during the Dry Season in the Phitsanulok Irrigation Areas using Iterative Seemingly Unrelated Regression

Independent variables	Paddy rice		Sugar cane	
	Coefficient	**S.E.**	**Coefficient**	**S.E.**
Price index of paddy rice (t-1)	0.0655*	0.039	0.0048	0.031
Price index of sugarcane (t-1)	0.0048	0.031	0.0655*	0.039
Price index of other field crops (t-1)	-0.0703*	0.042	-0.0703*	0.042
Fertilizer price	0.0697	0.450	-0.3891***	0.111
Wage rate	0.1898	0.311	-0.1225***	0.038
Cost of borrowing	-0.0567	0.052	-0.011	0.009
Irrigation water	0.1732***	0.046	0.0121*	0.007
Extreme flood index (t-1)	-0.0766**	0.037	-0.0054	0.008
Extreme drought index (t-1)	0.0629	0.065	0.0076	0.009
% rice in pledging program (t-1)	-0.4266	0.329	0.0319	0.074
Area share (t-1)	0.6107***	0.091	0.4455***	0.077
Constant	-4.4553	4.979	3.9684***	1.157
Dummy variables (Sub-projects)	Yes		Yes	
Dummy variables (Year)	Yes		Yes	
R-squared	0.7109		0.4784	
Number of observations	72			

Note: ***, **, and * indicate statistical significance at the 1, 5, and 10 percent level respectively.

Table A3.1: Estimates of the Yield Response of Rice Produced during the Dry Season in the Irrigation Areas of the Chao Phraya River Basing using OLS Regression with Robust Standard Errors

	Upper East		Upper West		Lower East		Lower West		Phitsanulok	
Independent variables	**Coefficient**	**S.E.**	**Coefficient**	**S.E.**	**Coefficient**	**S.E.**	**Coefficient**	**S.E.**	**Coefficient**	**S.E.**
Price index of paddy rice (t-1)	0.4401***	0.079	0.2686***	0.033	0.3417***	0.122	0.3647***	0.103	0.4303***	0.082
Fertilizer price	-0.1677	0.181	0.9795**	0.374	-0.3025	0.234	-0.5208**	0.221	-1.1909***	0.350
Wage rate	-0.2447**	0.122	-0.1219*	0.070	-0.1545	0.148	-0.3178**	0.146	-0.8813***	0.195
Cost of borrowing	-0.0582***	0.013	-0.0888***	0.013	-0.0693***	0.019	-0.0799***	0.023	-0.0895***	0.020
Irrigation water	0.0556***	0.015	0.0126*	0.007	0.0542***	0.016	0.0634***	0.020	0.0605**	0.023
Extreme Flood index	-0.0304**	0.013	-0.0142**	0.007	-0.0377***	0.011	-0.0238*	0.012	-0.0523**	0.020
Extreme Drought index	-0.0176	0.026	-0.092***	0.029	-0.0364*	0.021	-0.0554**	0.027	-0.1176***	0.028
Agricultural research expenditures	0.3028***	0.062	0.6662***	0.163	0.1978**	0.081	0.3863***	0.101	0.5233***	0.082
Constant	5.2615**	2.014	-8.5864*	4.885	7.135***	2.367	7.9278***	2.389	15.5651***	3.391
Dummy variables (Sub-projects)	Yes		Yes		Yes		Yes		Yes	
Dummy variables (Year)	Yes		Yes		Yes		Yes		Yes	
R-squared	0.924		0.9625		0.7777		0.8162		0.6307	
Number of observations	126		180		90		90		72	

Note: ***, **, and * indicate statistical significance at the 1, 5, and 10 percent level respectively.

Table A3.2: Estimates of the Yield Response of Sugarcane produced during dry season in the Irrigation Areas of the Chao Phraya River Basin using OLS Regression with Robust Standard Errors

	Upper East		Upper West		Lower East		Lower West		Phitsanulok	
Independent variables	**Coefficient**	**S.E.**	**Coefficient**	**S.E.**	**Coefficient**	**S.E.**	**Coefficient**	**S.E.**	**Coefficient**	**S.E.**
Price index of sugarcane (t-1)	0.6944***	0.100	0.1458**	0.073	0.5562***	0.114	0.2156**	0.102	0.4199***	0.087
Fertilizer price	-0.8682***	0.284	-0.9963***	0.211	-0.4227	0.535	-0.0334	0.356	-0.0839	0.489
Wage rate	-0.7563***	0.176	-0.2274**	0.112	-0.4771*	0.259	0.1046	0.134	-0.3135	0.249
Cost of borrowing	-0.1623***	0.018	-0.1185***	0.018	-0.17***	0.028	-0.089***	0.024	-0.0831***	0.018
Irrigation water	0.0714***	0.015	0.0776***	0.018	0.1382***	0.018	0.0797**	0.038	0.0375*	0.022
Extreme Flood index	-0.081***	0.016	-0.002	0.025	-0.1113***	0.026	-0.0828***	0.022	-0.0001	0.013
Extreme Drought index	-0.0963***	0.020	-0.2428***	0.054	-0.1192***	0.017	-0.0415*	0.024	-0.0589*	0.030
Constant	19.5587***	3.420	18.1857***	2.124	12.6314**	6.136	7.5106**	3.518	10.809*	5.531
Dummy variables (Sub-projects)	Yes		Yes		Yes		Yes		Yes	
Dummy variables (Year)	Yes		Yes		Yes		Yes		Yes	
R-squared	0.8198		0.6231		0.8619		0.6231		0.8588	
Number of observations	126		180		90		90		72	

Note: ***, **, and * indicate statistical significance at the 1, 5, and 10 percent level respectively.

Table A4.1: Estimates of the Area Response of Crops Produced during the Rainy Season in the Chao Phraya River Basin and sub-basins using Iterative Seemingly Unrelated Regression

Independent variables	Paddy rice		Field crops	
	Coefficient	S.E.	Coefficient	S.E.
Price index of paddy rice (t-1)	0.0237***	0.009	-0.0238***	0.009
Price index of field crops (t-1)	-0.0238***	0.009	0.0237***	0.009
Price index of fruits (t-1)	0.0001	0.000	0.0001	0.000
Fertilizer price	-0.0147	0.019	0.0306*	0.017
Wage rate	0.027	0.022	0.0016	0.018
Cost of borrowing	-0.0017	0.002	-0.001	0.003
Average rainfall	0.0046**	0.002	-0.0042**	0.002
Average water stored in two dams at the beginning of rainy season	0.0116	0.011	-0.0041	0.007
Area share (t-1)	0.9763***	0.005	0.9763***	0.005
Constant	-0.1096	0.208	-0.1839	0.199
Dummy variables (Irrigation project)	Yes		Yes	
Dummy variables (Year)	Yes		Yes	
R-squared	0.9831		0.9809	
Number of observations	604			

Note: ***, **, and * indicate statistical significance at the 1, 5, and 10 percent level respectively.

Table A4.2: Estimates of the Yield Response of Rice Produced during the Rainy Season in the Chao Phraya River Basin and sub-basins using OLS Regression with Robust Standard Errors

Independent variables	Rice	
	Coefficient	S.E.
Price index of paddy rice (t-1)	0.4968***	0.050
Fertilizer price	-0.0308	0.058
Wage rate	-0.4994***	0.145
Cost of borrowing	-0.0808***	0.018
Average rainfall	0.1219***	0.016
Average water stored in two dams at the beginning of rainy season	0.3034***	0.061
Agricultural research expenditures	0.0453**	0.022
Constant	5.2137***	1.105
Dummy variables (Sub-projects)	Yes	
Dummy variables (Year)	Yes	
R-squared	0.5019	
Number of observations	577	

Note: ***, **, and * indicate statistical significance at the 1, 5, and 10 percent level respectively.

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