Impacts of Water Supply Changes on the Rice Market of Lao PDR: Stochastic Analysis of Supply and Demand Model

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Poster paper presented for presentation at the International Association of Agricultural Economists Conference, Gold Coast, Australia, August 12-18, 2006

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1. Introduction

Rice production in Asia is widespread, with large number of small producers, and changes in the water supply available to the crop would seriously affect the agricultural sector and increase risks to producers. Laos is a rice producing country in South-East Asia where 64% of total food supply came from the staple crop in 2002. However, seasonal production is highly variable due to the low share of irrigated fields, i.e., about 10% in 2004. Laos covers 236,800 square kilometers and had a population of only 5.679 million in 2003, so the country is relatively land abundant. However, upland areas in Laos are experiencing population growth pressure and the productivity of shifting cultivation is declining. A stable water supply for wet season and upland rice cultivation is necessary for food security and farm management stabilization. The evaluation of water supply changes on rice yields and the resulting market responses from fluctuations in production are an essential theme of agricultural development in Laos. This paper analyzes the supply and demand of rice in Laos, focusing on the impacts of fluctuations of water supply on rice production and producer risk.

2. Model

A supply and demand model for rice which includes a water supply variable for regional yields is developed and planted area, yield, and production for each province, areas of province close to a small river basin, can be analyzed with the model. In evaluating the impact of water supply fluctuations, the analytical system includes a stochastic model to determine the available water supply and a risk neutral producer model is applied to evaluate the impact at the producer level.

2-1 Supply and demand model for rice

The supply and demand model for rice in Laos consists of yield functions, planted area functions, production identities, supply identities, a consumption function, an import function, and a price linkage function. The yield and area functions of wet season are estimated for all provinces and monthly evapotranspiration (ET) is used as an explanatory variable which is a proxy for available water supplies. The generalized forms of these functions are as follows:

Yield function of wet season rice: $YLi = f\,(T, ET\_Mayi, \dots, ET\_Novi)$, (1)

Area function of wet season rice: $ALi_t = f\,(ALi_{t\text{-}1}, FP_{t\text{-}1}, ET\_Mayi_{t\text{-}1}, \dots, ET\_Novi_{t\text{-}1})$, (2)

Production of wet season rice: $QLi = YLi * ALi \quad QL = \sum_i YL_i AL_i$, (3)

Yield function of dry season rice: $YI = f\,(T, ET\_Nov_{t\text{-}1}, \dots, ET\_May_t)$, (4)

Area function of dry season rice: $AI_t = f\,(AI_{t\text{-}1}, FP_{t\text{-}1}, ET\_Nov_{t\text{-}2}, \dots, ET\_May_{t\text{-}1})$, (5)

Yield function of upland rice: $YU = f\,(T, ET\_May, \dots, ET\_Nov)$, (6)

Area function of upland rice: $AU_t = f\,(AU_{t\text{-}1}, FP_{t\text{-}1}, ET\_May_{t\text{-}1}, \dots, ET\_Nov_{t\text{-}1})$, (7)

Production of dry season and upland rice: $QI = YI * AI$, $QU = YU * AU$, (8)

Total production: $Q = QL + QI + QU$, (9)

Total supply: $QS = Q + IMP - STC$, (10)

Demand function: $QS/POP = f\,(RP, GDP/POP)$, (11)

Imports function: $IMP = f\,(WP * EXR, Q)$, (12)

Price linkage function: $FP = f\,(RP)$, (13) where *T* is time trend, *ET_May* through *ET_Nov* are logarithmic evapotranspiration values for May through November, *YL*, *AL*, and *QL* are yield, planted area, and production of wet season rice, *i* is the number of provinces, *YI*, *AI*, and *QI* are yield, planted area, and production of dry season rice, *YU*, *AU*, and *QU* are yield, planted area, and production of upland rice, *Q* is total production, *IMP* is imports, *STC* is the annual change in stocks, *POP* is population, *GDP* is gross domestic products, *WP* is the world price of rice (Thailand, 5% broken, FOB), *EXR* is exchange rate, *FP* is the producer price of rice, and *RP* is the retail price of rice. All are specified as linear functions. Figure 1 through Figure 3 represent models for wet season rice production sector, dry season and upland rice production sectors, and the overall supply and demand sector respectively.

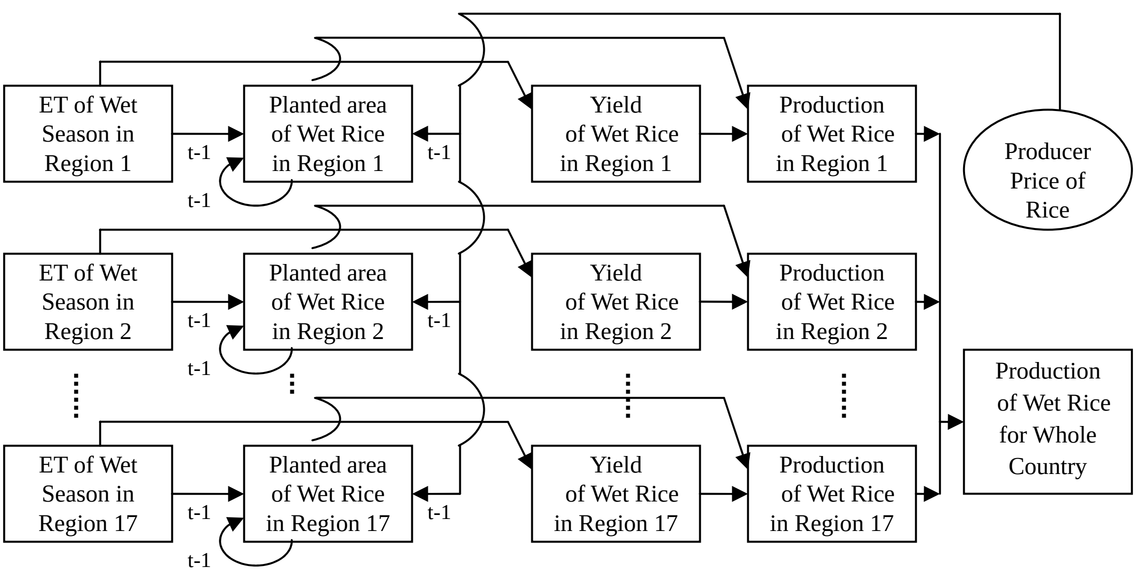

Figure 1 Flowchart of wet rice production sector

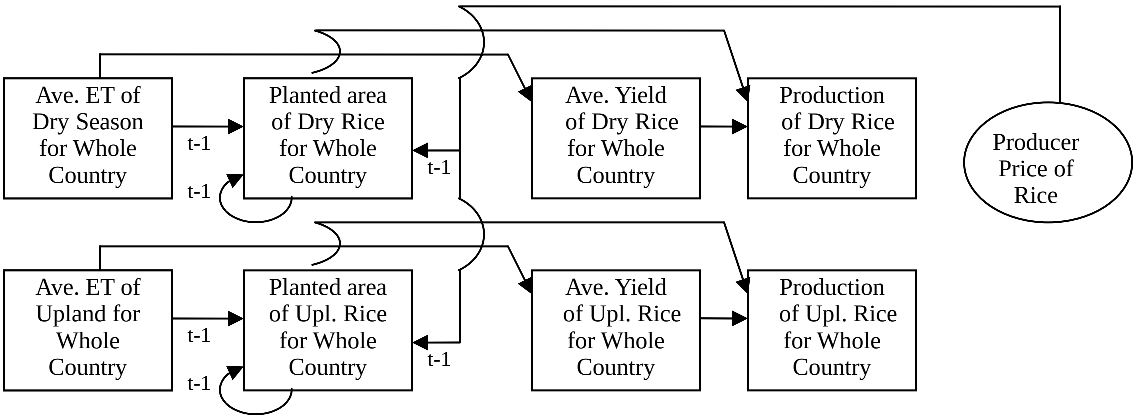

Figure 2 Flowchart of dry season and upland rice production sector

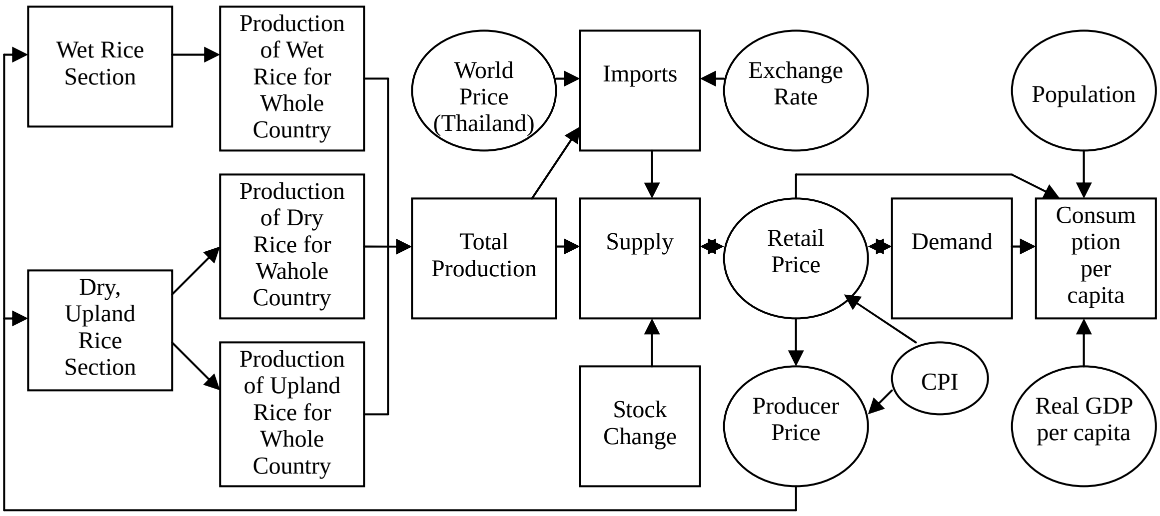

Figure 3 Flowchart of supply and demand sector

2-2 Stochastic model

The ET variable is exogenous to the supply and demand model, entering into yield and area equations. To evaluate the impacts of changes in the water supply on rice markets, the ET value must be endogenized in a model which then feeds the greater supply and demand model. The following basic seasonal ET models with a lagged dependent value using monthly data are estimated:

$$ETi_t = f\,(ETi_{t\text{-}1}, D\_Feb, \ldots, D\_Dec) \qquad (14)$$

where *D_Feb* through *D_Dec* are the dummy variables for February through December.

The equations are specified as linear functions and errors are obtained using estimated and actual data. The empirical distributions and correlations of the resulting errors are maintained and employed to obtaining a set of random ET variables consistent with history. With the use of the historical error correlated matrix and random draws on a normal distribution, correlated normal standard deviates for each province are created and through the uniform distribution are transformed into draws on the empirical error distributions which maintain their historical correlated relationship. This process creates 500 sets of error draws which are then inserted back into the evapotranspiration model and used to create 500 future ET paths. The procedure for creating correlated random ET variables is based on the program of Richardson, 2004 and the system is shown in Figure 4 and Figure 5. The distributions of the error terms can be expanded to simulate increased variation in future ET distributions.

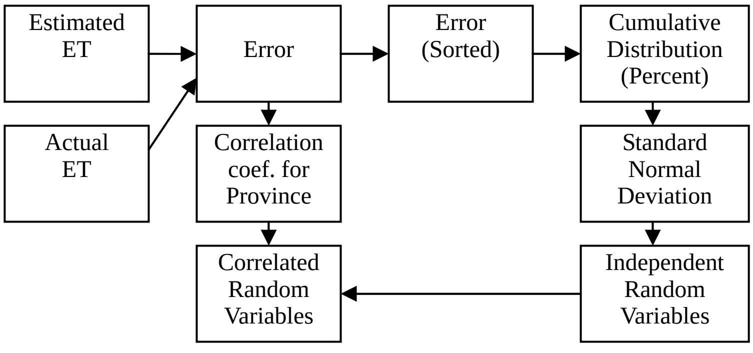

Figure 4 Creating correlated random variables

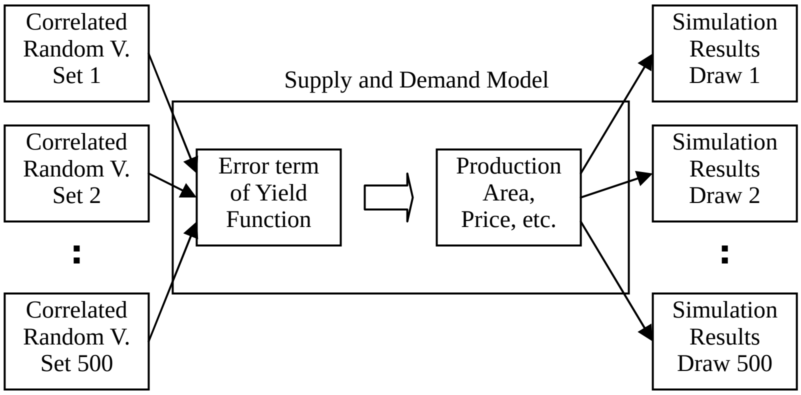

Figure 5 Simulation of stochastic model

2-3 Risk neutral farm model

To evaluate the changes in water supply and the resulting price change risk, a risk neutral model for a producer is used. Sadoulet and de Janvry, 1995 constructed a risk neutral farm model based on the model of Newbery and Stiglitz, 1981 and it is modified for the standard deviation of price in this paper.

The expected profit maximization problem of a risk neutral farm is as follows;

$$\text{max.}\quad E[\pi] = E[pq] - wx = E[p]E[q] + \text{cov}(p,q) - wx \qquad (15)$$

$$\text{s.t}\quad q = \theta f(x) \qquad (16)$$

where π is profit, p is the producer price which is a random variable, q is production, w is the input price, x is one of the input quantities, θ is the random variable; which has the following expected value and variance,

$$E[\theta] = 1, \quad \text{var}[\theta] = \sigma_\theta{}^2,$$

and cov(p,q) is the covariance of price p and production q. If there is a negative correlation between price and production, the expected profit in equation (15) will be lower than the case without price fluctuation. The correlation coefficient between price p and random variable θ under the assumption of a linear relationship is as follows:

$$corr(p,\theta) = \frac{\text{cov}(p,\theta)}{\sqrt{\text{var}(p)\,\text{var}(\theta)}} = -b \tag{17}$$

Multiplying non-random variable $f(x)$ by the definition of the correlation coefficient (17), the following equation is obtained:

$$corr(p,\theta) = \frac{E[p\theta f(x)] - E[p]E[\theta f(x)]}{f(x)\sqrt{\text{var}(p)}\sqrt{\text{var}(\theta)}} = \frac{\text{cov}(p,\theta f(x))}{f(x)\sqrt{\text{var}(p)}\sqrt{\text{var}(\theta)}} = \frac{\text{cov}(p,q)}{f(x)\sigma_p\sigma_\theta} \tag{18}$$

where the variance of price is $\sigma_p{}^2$. The covariance between price and production is written as follows:

$$\text{cov}(p,q) = -b\sigma_p\sigma_\theta f(x) \tag{19}$$

The first order condition of the expected profit maximization problem, i.e., (15) and (16), for input x is as follows:

$$\frac{\partial E[\pi]}{\partial x} = \frac{\partial(E[p]E[q] + \text{cov}(p,q))}{\partial f(x)}\frac{\partial f(x)}{\partial x} - w = \left(E[p] + \frac{\partial\,\text{cov}(p,q)}{\partial f(x)}\right)\frac{\partial f(x)}{\partial x} - w = 0 \tag{20}$$

Substituting equation (19) into equation (20), the following equation is obtained:

$$(E[p] - b\sigma_p\sigma_\theta)\, f'(x) = w \tag{21}$$

The price of equation (21), i.e., ($E[p] - b\sigma_p\sigma_\theta$) is the action certainty equivalent price and the difference between it and market price, i.e., $-b\sigma_p\sigma_\theta$ is used for the evaluation of price risk.

3. Data

The time series data for production and planted area for each province is provided by the

Department of Planning in the Ministry of Agriculture and Forestry of Laos. The farm price for rice is obtained from FAO-STAT and the retail price of rice is obtained from the National Statistics Center of the Committee for Planning and Cooperation of Laos. These prices are a national average for Laos. CPI, GDP, and population are from the Asian Development Bank and the exchange rate and the world price of rice are numbers from the IMF. The estimation period for functions (1) through (13) is from 1980 to 2000 which starts in the earliest available year for CPI and ends in the last year of available ET values.

The historical ET values are calculated by Ishigooka et al., 2005 and the calculation method is based on the Penman-Monteith equation (Allen et al., 1998). The climatic data for the calculation are 0.5 degree grid data and these are averaged for each province.

4. Simulation results

4-1 Results of estimation of yield functions

The yield functions for each province are specified as linear functions of a time trend and monthly ET values, and the estimation method is OLS. Table 1 shows the elasticity of yield with respect to ET evaluated at the average value for yield and ET. The results indicate that if the ET value for May or September increases, the resulting yield will increase, and if the ET value for June increase, the yield will decrease in many provinces. The results suggest that the water supply during the planting and flowering season greatly impacts production.

4-2 Simulation results of supply and demand model

The simulation term is from 2001 to 2015. The assumptions of the simulation are as follows; (1) the forecast growth rate of CPI is the average between 1995 and 2002, (2) the growth rate of real GDP is the average between 1980 and 2002, (3) the growth rate of exchange rate is the average between 1993 and 2002, (4) the growth rate of the population is the average between 1980 and 2002, (5) the linear trend of the yield functions are continued, (6) The trend of area functions are flat except for upland rice which is in decline.

Table 1 Elasticities of yield of wet season rice for ET

Province	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
Phongsaly	-	-	-	-	-0.505	-	-	-0.569	-
Luangnamtha	-	0.273	-0.371	1.196	1.294	-	-	-	-
Oudomxay	0.188	-0.355	0.379	-0.331	-	-0.309	1.067	0.523	0.965
Bokea	0.252	-0.125	1.253	-0.946	1.923	-	2.107	-	2.035
Luangprabang	-	0.126	-	-	-	-	-	-	-
Huaphanh	-	-	0.230	-	-0.656	-	-	-	-
Xayabury	-	-0.109	0.429	-	-	0.446	-	-1.197	-
Vientiane city	0.319	-	-	-0.421	0.704	-	0.890	-0.392	0.480
Xiengkhuang	-	-	0.488	-0.517	-	-0.308	0.845	-	0.411
Vientiane	0.270	-0.089	0.643	-1.321	1.657	-0.538	2.686	-	0.579
Borikhamxay	-	-	0.194	-	-0.744	-	-	-0.560	-
Khammuane	-	0.243	-	-	-1.010	-	-0.573	-	-
Savannakhet	-	-	0.303	-	-0.580	-	-	-	-
Saravan	-	-	-	-	-0.605	-	-	-	-
Sekong	-	-	-	-0.655	-	-	0.614	-	-
Champasack	-0.366	-	-	-1.005	-	-	0.654	1.293	-
Attapeu	-	-	-	-0.309	-	0.821	0.372	-0.481	0.484

Figure 6 through Figure 8 show the simulation results for the production of wet season, upland and dry season rice. The production of the wet season rice will increase 166,000 MT (metric tons) from 2005 to 2015. The dry season rice will also increase 111,000 MT during the period. However, the production of upland rice will decrease from 268,000 MT to 202,000 MT during the period, due to the shorter cropping cycle of shifting cultivation. Figure 9 shows the simulation result of the equilibrium nominal farm price. The farm price will be stable at around 13,000 kip per MT or 150 kip per MT deflated by CPI with a base year of 1995.

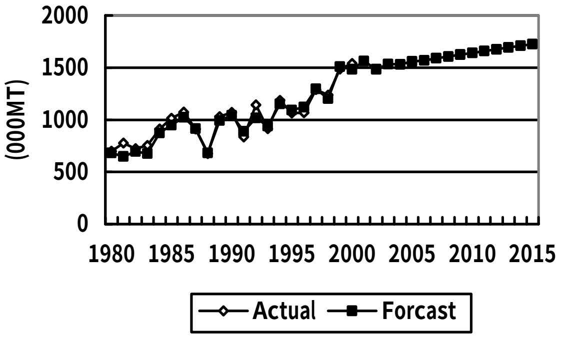

Figure 6 Production of wet season rice

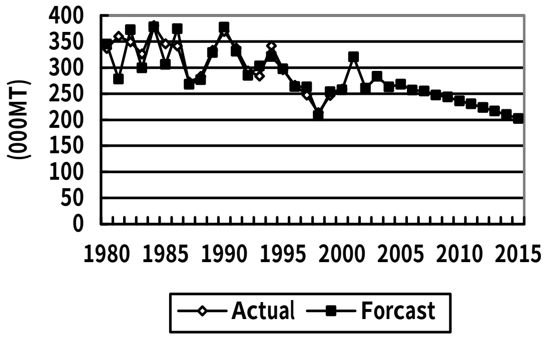

Figure 7 Production of upland rice

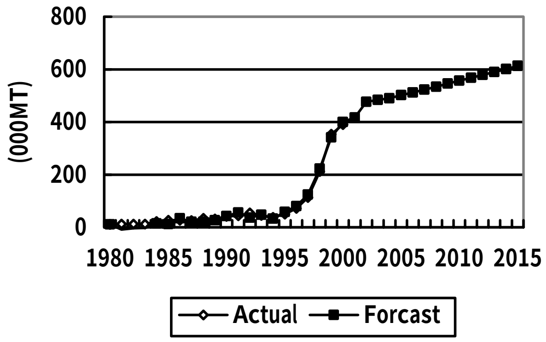

Figure 8 Production of dry season rice

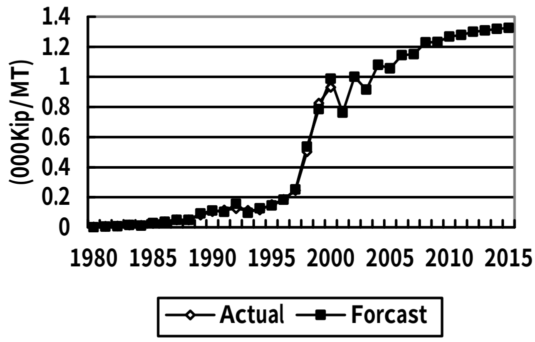

Figure 9 Farm price

4-3 Simulation results of stochastic model

The 500 sets of results of the simulation for correlated random ET values are distributed consistent with the historical fluctuations in the variable. To evaluate the expansion in fluctuations of water supply, the case of a 20% increase in the error distribution of ET is examined by expanding the original 500 sets of error terms.

The second column of Table 2 and Table 3 shows the coefficient of variation of production of wet season, dry season, and upland rice for the nation as a whole and wet season rice for each province. These numbers are the average values of the simulation results between 2005 and 2015. These results show that the variation in production for upland rice is quite high and that for wet season rice in the southern region, such as Champasack province, is higher than that in other regions. Figure 10 shows a map of the variation by province. The third column in these tables shows the coefficient of variation of production in the case of the expansion of the random errors of ET. The results show that if the fluctuation of ET expands, the rate of increase of the variation of production of wet season rice will be higher than that of upland rice, and provinces in the central region will have a higher level of variation in production than other regions. Figure 11 shows a map of the rate of increase of the coefficient of variation of wet season rice production.

Table 2 Variation of production and price risk for type of rice

Type of rice cultivation	Coeff. of variation of production			Market-certainty eq. price (kip)		
	Baseline	ET error 20% up	Rate of Increase	Baseline	ET error 20% up	Rate of increase
Wet season	0.0507	0.0609	20.1	48.5	150.8	210.9
Dry season	0.0727	0.0870	19.7	14.3	20.5	43.3
Upland	0.3226	0.3848	19.3	66.4	94.9	42.9

Table 3 Variation of production and price risk of wet season rice for province

Province	Coeff. of variation of production			Market-certainty eq. price (kip)		
	Baseline	ET error 20% up	Rate of increase	Baseline	ET error 20% up	Rate of increase
Phongsaly	0.0624	0.0746	19.6	1.0	1.3	30.0
Luangnamtha	0.1006	0.1192	18.5	2.8	4.0	42.9
Oudomxay	0.0860	0.1027	19.4	1.5	2.2	46.7
Bokea	0.0641	0.0770	20.1	2.7	3.8	40.7
Luangprabang	0.0562	0.0689	22.6	6.7	9.6	43.3
Huaphanh	0.0675	0.0812	20.3	1.1	1.7	54.5
Xayabury	0.1555	0.1877	20.7	9.8	14.7	50.0
Vientiane Mun.	0.0525	0.0641	22.1	3.6	5.4	50.0
Xiengkhuang	0.0662	0.0801	21.0	7.6	11.2	47.4
Vientiane	0.1099	0.1327	20.7	12.5	18.3	46.4
Borikhamxay	0.0906	0.1102	21.6	2.8	4.2	50.0
Khammuane	0.1464	0.1774	21.2	4.5	7.1	57.8
Savannakhet	0.1155	0.1377	19.2	14.6	20.7	41.8
Saravane	0.1049	0.1253	19.4	6.8	9.6	41.2
Sekong	0.1485	0.1765	18.9	4.5	6.3	40.0
Champasack	0.1994	0.2389	19.8	56.3	80.7	43.3
Attapeu	0.1733	0.2082	20.1	33.9	48.5	43.1

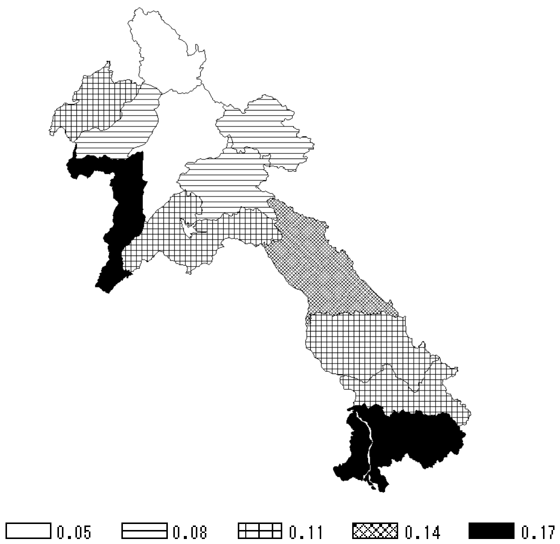

Figure 10 Coefficient of variation of production

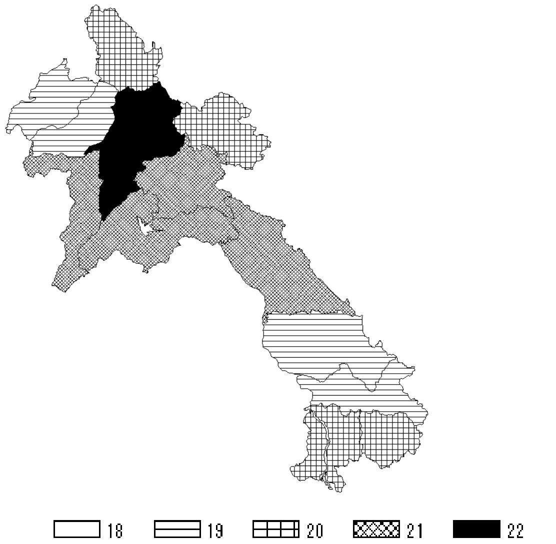

Figure 11 Rate of increase of the coefficient

Figure 12 and Figure 13 show the fluctuation of wet season rice production and realized price. If the random error of ET expands by 20%, the average width between the 10th and 90th percentile of simulated outcomes for wet season rice production will increase from 238,000 MT to 285,000 MT, and the range for the real farm price will increase from 54.5 kip to 65.3 kip. The distribution of price is slightly negatively skewed; the width between 90% and mean is 27.8 kip and that between 10% and mean is 26.7 kip for the baseline.

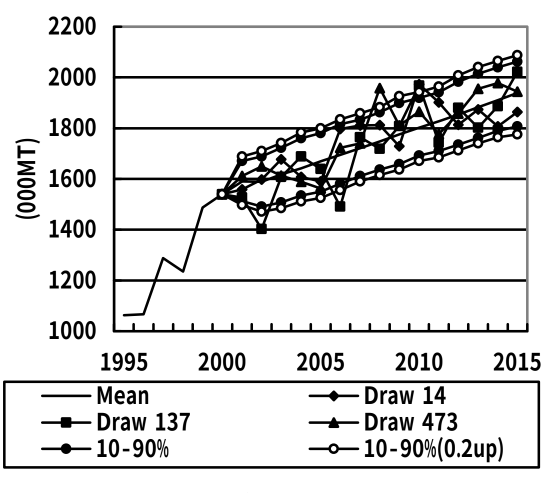

Figure 12 Fluctuation of wet season rice production

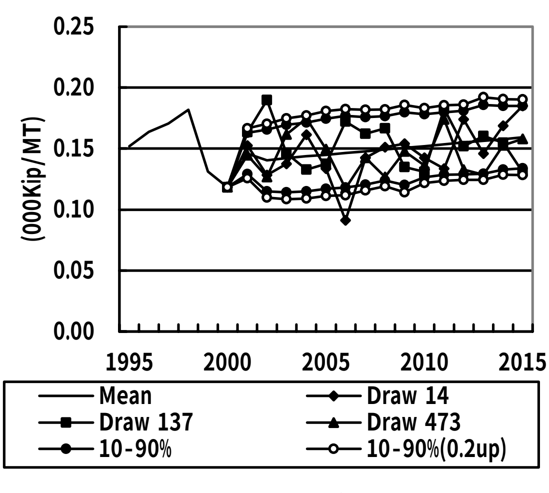

Figure 13 Fluctuation of real price

4-4 Price risk evaluation

The fifth column of Table 2 and Table 3 shows the difference between market and certainty equivalent prices. The greater the difference between the two prices, the greater the price risk to producers. The price gap for upland rice is the highest and it indicates that upland rice cultivation is riskier than wet and dry season rice cultivation. On the other hand, if the fluctuation of ET values is expanded, wet season rice cultivation is riskier than others. The sixth column of Table 2 and Table 3 shows the price gap for increase in the random ET error. The results indicate that wet season rice cultivation is quite risky under the volatile water supply scenario at the aggregate level. The price gaps for wet season rice are quite different among the provinces. The results show that wet season rice cultivation in Champasack and Attapeu is riskier than in other provinces. Figure 14 shows a provincial map of the difference between market and certainty equivalent price, i.e. price risk level. Figure 15 shows a map of the rate of increase in the difference between market and certainty equivalent prices due to the fluctuation of ET expanding 20% more than that in the baseline. The map indicates that the central region is sensitive to the risk associated with changes in ET, however, the risk level is lower than that in the southern region.

Figure 14 Market-certainty eq. price

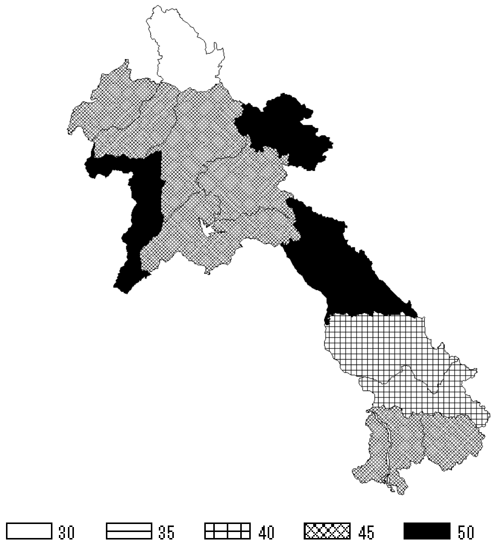

Figure 15 Rate of increase of price gap

5. Conclusions

A supply and demand model of rice in Laos which can analyze production and water supply impacts for each province is developed. Furthermore, the supply and demand model is modified with a stochastic model using random ET variables to investigate changes in variation of the environmental characteristic of evapotranspiration and its impact on producers. The results of the baseline analyses indicate that production of wet and dry season rice steadily increases and that of upland rice decrease due to the cycle change of shifting cultivation. Population growth will reduce the fertility of the upland crop due to the shorter cultivation cycle (Evenson, 1994).

Results of stochastic analyses show that the production of upland rice is highly influenced by changes in water supply, and thus adequate water management is required for upland cultivation to reduce risk faced by producers. However, when considering price risk, the wet season rice cultivation is most vulnerable to water supply changes. Rice farmers producing wet season rice in southern region, such as Champasack and Attapeu provinces, will incur serious damage under a scenario where the variation in the water supply expands. The distribution of farm price is negatively skewed and the probability of a higher price is greater than that of a lower price. It indicates that if the fluctuation of water supply expands, consumers, such as rural poor, will face higher rice prices. The regions or provinces which suffer from highly variable production and higher price risk may need to consider water management and alternative harvesting methods.

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