

# Farm-level cost of adaptation and expected cost of uncertainty associated with climate change impacts in major river basins in India

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## Abstract

**Purpose** – Researchers and policymakers are figuring out the adaptation technologies to cope with the changing climate. Adaptation strategies for crop production followed by the farmers at selected study locations had ranged from 6-30 per cent only, and this was mainly due to lack of awareness about the actual cost associated with adaptation and non-adaptation of these strategies.

**Design/methodology/approach** – Hence, this study aims to address the cost of adaptation for rice using joint probability distribution of rainfall and crop prices.

**Findings** – Cost of adaptation varied from INR2,389 to 4,395/ha for System of Rice Intensification (SRI); INR646 to 1,121/ha for alternate wetting and drying (AWD) and INR8,144 to 8,677/ha for well irrigation (WI), whereas expected cost for not using these technologies has ranged from INR6,976 to 9,172/ha for SRI; INR4,123 to 7,764/ha for AWD and INR10,825 to 17,270/ha for WI. Hence, promotion of the adaptation technologies itself will minimize the income losses to the farmers.

**Research limitations/implications** – Even though, there are many ways for farmers (other than technology), to adapt to climate change (such as out-migration to cities, selling farm assets, focus on children's education, etc.), this report, given the framework of the major research study undertaken, addresses only farm-level adaptation of the technologies to enhance farm income.

**Originality/value** – Public-private partnership in providing the technologies at cheaper costs, capacity building in handling the technologies and creating awareness about the technologies to minimize the expected cost of adaptation are suggested to improve the adoption level.

**Keywords** Climate change, India, Adaptation technologies, Cost of adaptation, Cost of uncertainty, Joint probabilities

**Paper type** Research paper



## 1. Introduction

Agricultural production will face uncertainty, as there is regional variation of rainfall, temperature, soils, crop yields, cropping systems and management practices (Palanisami *et al.*, 2011). The crop losses may increase further, if the predicted climate change increases the climate variability. Simulation models on crop growth also indicated that yield of some crops in tropical regions would decrease generally even with a minimal increase in temperature under dryland agriculture (Prasad Rao *et al.*, 2008). To strengthen the climate forecasts, researchers are also developing ex ante-type climate change forecasts by innovative approaches to assess the uncertainty of the climate impacts (Mendelsohn *et al.*, 2000; Immerzeel, 2008). Kavi Kumar and Parikh (2001) and Sanghi and Mendelsohn (2008) have estimated that, under moderate climate change scenarios, there could be about a 9 per cent decline in farm-level net revenues in India. A one-degree increase in temperature may reduce yields of wheat, soybean, mustard, groundnut and potato by 3-7 per cent (Kavi Kumar *et al.*, 2010). The yield losses are likely to be substantially higher with the long-term climate change scenarios (Nagothu *et al.*, 2012). Such climate-forecast tools and scenarios can help evaluate sector-specific, incremental changes in risk over the next few decades (Wilby *et al.*, 2009). The clear message from these studies is that climate change will affect crop production and income and therefore appropriate adaptation measures are necessary at the farm level.

Adaptations are adjustments or interventions which take place to manage the losses or take advantage of the opportunities presented by a changing climate (IPCC, 2001). Adaptation occurs at two levels:

- (1) Farm-level adaptation which mainly focuses on farming-related interventions or adjustments and are related to short-term periods and influenced by seasonal climate variations and local agricultural cycles.
- (2) The regional- or national-level adaptation which focuses on the agricultural production at the macro level, linking domestic and international policy (Kandlinkar and Risbey, 2000; Bradshaw *et al.*, 2004).

The assessment of farm-level adaptation strategies is important in providing information necessary to the implementing agencies and government for formulating the needed policies. The adaptation strategies include physical investment in creating farm structure, as well as management technologies such as improved crop and water management practices, several of which have been already examined by the researchers. For example, Palanisami *et al.* (2011) have studied the adaptation measures such as direct seeding of rice (DSR), AWD, machine transplanting, system of rice intensification (SRI) and water management options for maize and incorporated them in the optimization model that could help minimize the incidence of climate change impacts on crop yields, labor use and water use in selected river basins in India. Abraha and Savage (2006) studied the potential impact of climate change on maize yield at Cedara, KwaZulu-Natal, South Africa with different planting dates, such as on normal dates, 15 days earlier and 15 dates later. The farm management components appear to be prominent in the literature (Till *et al.*, 2010) where most of the adaptation practices had included the adjustments in farm management and technology (53 per cent), followed by knowledge management, networks and governance (15 per cent), diversification

(14 per cent), government interventions (13 per cent) and financial management of farms (5 per cent).

The question is how best farmers can follow-up with the adaptation measures to cope with the climate change impacts. Charles and Hassan (2007) had studied the farm-level adaptation strategies in southern Africa such as using different varieties, planting different crops in different planting dates, diversifying from farm to non-farm activities, increasing number of irrigations and adopting soil conservation techniques. But, many farmers do not want to invest on such technologies due to inadequate know-how on the technologies, lack of financial support, poor climate-change forecasts and high cost of the technologies (Clements *et al.*, 2011). Further, adoption level of the technologies is influenced by the occurrence of various climate events such as variation in rainfall during different periods (Palanisami *et al.*, 2011). In general, farmers see only the actual benefits (which are comparatively small) due to the technology adoption from their past experiences but do not foresee the expected costs (which are comparatively high) for not following the adaptation strategies. Exposing the farmers to the actual cost of adaptation, as well as to the expected income associated with adaptation measures, may motivate them toward better adaptation measures. However, the main question is how to estimate the actual cost of adaptation and the expected cost of not using the adaptation technologies given the occurrence of the climate events (such as variation in rainfall and variations in crop prices). More specifically, the questions are:

- Q1. What is the expected cost of the status quo?
- Q2. What are the actual costs of various adaptation options for reducing that cost?
- Q3. What approach will be necessary to upscale the technology adaptation?

Nevertheless, several external adaptation strategies such as out-migration to cities, intensifying nonfarm activities, selling farm assets, focusing on children's education, etc. are observed in the study regions. This report attempts to document the farm-level adaptation technologies followed in the three major river basins, Godavari, Krishna and Cauvery, work out the actual cost of adaptation and expected cost of non-adoption of the adaptation technologies and suggest approaches to enhance technology adaptation.

## 2. Review of studies and concepts

The science of climate change and adaptation is of very recent origin and large uncertainties remain in all components of the climate change analysis. Climate changes could impose large adaptation costs due to the interplay of several factors. However, not many studies have addressed the cost of adaptation due to climate change. Nelson *et al.*, 2009 had worked out the cost of adaptation in agriculture at the macro (country) level. They indicated that to assess the costs of adaptation alone, it is important to identify agricultural productivity investments that reduce child malnutrition with climate change to no-climate-change levels, holding all other macro changes constant, such as income and population growth. At farm level, the cost of adaptation refers to the

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farmers' expenditure towards the adaptation measures which also have direct and indirect components. The direct component refers to the additional cost of the technology over the conventional practices and the indirect component refers to the other expenses related to adopting of the technologies in the field (Palanisami *et al.*, 2012).

Another important aspect is to determine the cost of not adopting the adaptation strategies. As climate change will lead to wide-ranging impacts on the natural and man-made environment across different sectors and regions that, in turn, will lead to economic costs, these costs of climate change can be referred to as the cost of inaction. However, information on the costs of inaction remains limited (EEA, 2007). EC Communication (2005) termed the economic effects of climate change as the "cost of inaction". Also the economic impact can be divided into direct and indirect impacts, where direct impact reflects on the agricultural production and the indirect impact reflects on the changes in production associated with the price changes. Expressing such impacts in monetary terms provides a common metric to assess the cost of inaction across sectors. Further, in most economic analyses, future costs and benefits of climate change are discounted before they are summed up. The use of a larger discount rate means that a smaller weight is given to future costs and benefits (Ackerman and Stanton, 2006).

Following this analogy, the expected cost due to climate change will reflect the reduction in revenue. For example, in case of crop production, occurrence of the rainfall and price events during the crop season will influence the farmers' choice of technology adoption. Under such circumstances, quantifying the reduction in crop revenue is important. The expected cost can be termed as expected cost of uncertainty as farmers cannot predict the climate event before the crop season. In this context, the value of information about the uncertainty in the states of nature[1] is important, as it could address all uncertainties about the outcomes for making alternative decisions among the available technologies.

Value of information could thus reflect the costs associated with not adopting the adaptation technologies. Laxminarayan and Macauley (2012) referred to value of information as state-of-the-art methodology, investigating how information on the use of different options is valued across multiple spectra. Researchers in the health field have developed some of the most innovative methodologies for valuing information, which is used to help determine, for example, the value of diagnostics in informing patient-treatment decisions. In the field of space, recent applications of value-of-information methods are critical. In the case of the agriculture sector, it reflects the benefits foregone for not adopting the adaptation strategies where, increased uncertainty in crop production due to climate change provides an incentive to defer investments.

Howard (1966) proposed the expected value of perfect information (EVPI), a measure of how much it would be worth to learn the "true" values for all uncertain input variables. While providing a highly useful measure of sensitivity to uncertainty, the EVPI does not directly capture the actual improvement in decisions obtained from explicitly representing and reasoning about uncertainty. In other words, if uncertainty relating to climate change is explicitly taken into account when the production decision is made, expected benefits will be higher. In decision theory and quantitative policy analysis, the expected value of including information is the expected difference in the

value of a decision based on a probabilistic analysis versus a decision based on an analysis that ignores uncertainty. Thus, the value of perfect information provides an easily calculated benchmark about the worth of making alternative decisions to address the climate change impacts.

In this paper, we apply the cost of adaptation, cost of uncertainty and value of information in analyzing the different adaptation practices in the farming sector. This paper thus contributes in strengthening the measurement methodologies in the climate impact evaluation.

### **3. Methodology: study regions, technologies, sample, data and tools of analysis**

#### *3.1 Study region*

This paper is based on a major study on climate change adaptation technologies implemented by the International Water Management Institute (IWMI) in collaboration with Bioforsk Norway, and funded by the Norwegian Embassy during 2010-2012. The study covered three major rice-growing river basins in Southern India, viz., Godavari, Krishna and Cauvery, as the main focus of the Norwegian collaboration was on climate change adaptations focusing on rice. As the basins are so vast in terms of hydrological boundaries spreading into other states, only the reservoir command areas falling within Andhra Pradesh state under Godavari and Krishna basins and those falling in Tamil Nadu state under the Cauvery Basin were included for in-depth study. Accordingly, in the Godavari River Basin, the Manjeera command in Medak District and Sri Ram Sagar Project command areas from Nizamabad District were included for the data analysis (Figure 1).

Where the Krishna River Basin was concerned, the Nagarjuna Sagar command area and Krishna Western Delta of Guntur districts were covered. Where the Cauvery River Basin was concerned, the Lower Bhavani project command area was covered.

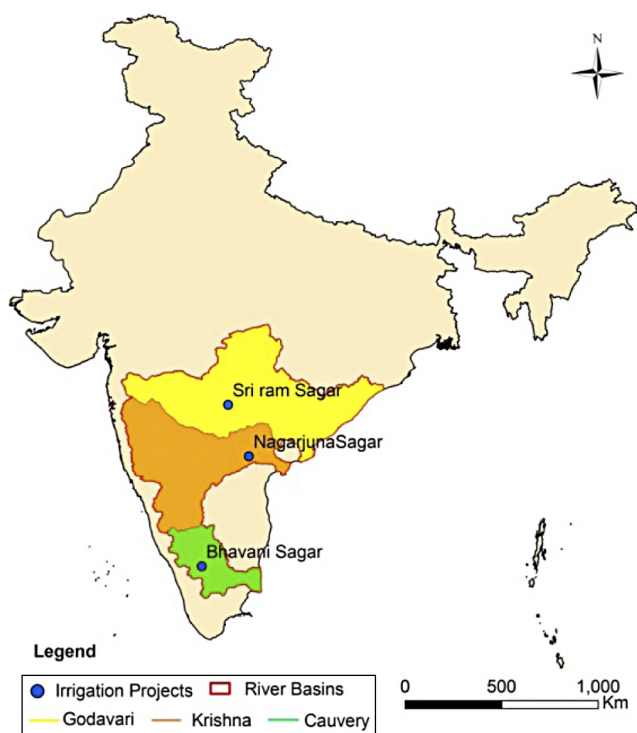
#### *3.2 Identification of the adaptation technologies in the basins*

The technologies prevalent in the selected study locations were surveyed and analyzed in detail for their adoption level. Because the technologies are mostly related to the irrigated rice situations, the technologies followed in the three basins are considered adequate to address the climate change adaptations by the farmers. An earlier study conducted by Palanisami *et al.* (2012) in the region has also identified similar technologies to address the climate change adaptations in rice. Accordingly, the following farm-level technologies were included in this study for analyzing the farm-level adaptations:

- The Godavari River Basin (Manjeera command and Sri Ram Sagar Project command areas): SRI, alternate wetting and drying (AWD) and well investment (WI).
- Krishna River Basin (Nagarjuna Sagar command area): subsurface drainage (SSD), SRI, AWD and DSR.
- Cauvery River Basin (Lower Bhavani project command area): SRI, AWD and WI.

#### *3.3 Sample*

The farmers who have adopted the above farm-level technologies in the selected project locations were enumerated and they formed the sample for the study. The sample



**Figure 1.**  
Map showing the  
selected project  
locations in the three  
river basins in India

farmers varied among the project locations, as well as among the technologies. In all, 294 farmers were covered in the three river basins as detailed below:

- (1) Godavari River Basin (Manjeera command and Sri Ram Sagar Project command areas): 100 farmers.
- (2) Krishna River Basin (Nagarjuna Sagar Project command area): 104 farmers.
- (3) Cauvery River Basin (Lower Bhavani Project command area): 90 farmers.

### 3.4 Data

Data relating to socioeconomic aspects of farm households (such as age, gender, education, experience in farming), farm size, irrigation sources, water supplies, crop pattern, crop yield, cost of crop cultivation and cost and returns of different climate adaptation technologies being practiced in the three river basins were collected from farmers through the survey method using a pretested questionnaire during July 2011 to June 2012. As not all the sample farmers are adopting, all the identified technologies, the crop yield, cost of cultivation and income under the current practices were also collected from those farmers who have not adopted the adaptation technologies. For example, farmers adopting SRI may not be adopting the AWD and hence a cross-comparison of the farmer technology adoptions was made and this way, the sample farmers were able to provide information necessary on the costs and returns of different technologies. The cost of technologies includes both capital costs and operating costs. The capital costs

were mostly related to farm-level investment by the farmers to get the technology backups (e.g. SSD and supplemental irrigation from wells).

In addition to the crop production and physical investment costs (e.g. well investment and SSD), farmers also incurred some non-input costs associated with the adoption of the technologies. For example, in the case of SRI, farmers used to spend several hours in visiting the extension officials to get the eligible subsidy toward cono weeders, etc. In the case of WI, farmers spent extra time and money in mobilizing the bank loans. Under such circumstances, the total time spent in mobilizing the services for technology adoption was obtained through farmer discussions, and the time spent was converted into monetary values using imputed value of the farmers' time using market wages. If the farmer spends two days for getting the cono weeder, it is equivalent to INR400 as his total wage earnings (at INR200/day). Similarly, the money spent for facilitating the loan approval for WI, as well as for SSD, was added to get the total non-input cost which is referred to here as transaction cost associated with that technology. The definition of the transaction cost is the same as that used in another study on the adoption of the SRI (Palanisami *et al.*, 2013).

As no records on the actual adoption of the technologies are available, the actual adoption levels of the technologies in the basins were obtained from focus group discussions and stakeholder meetings held in different project locations in association with the agricultural extension officials who helped in the estimation of the adoption levels. The number of focus group discussions varied from three to four in each project location and the stakeholder meetings ranged from two to three in each location. In each focus group discussion, 20-25 farmers participated, and in each stakeholder meeting, 10-15 persons participated.

Further, data relating to the occurrence of different rainfall events and price changes in a 10-year period were also collected from the published sources in the project area and using this, the probability of occurrence of rainfall as surplus, normal, deficit and failure were worked out. Similarly, the probability of occurrence of high, medium and low crop prices was worked out using the time series on crop prices.

### 3.5 Tools of analysis

Tools of decision analysis falling under the gamut of decision theory can be used to analyze economics of different interventions (Swarup *et al.*, 2012; Taha, 2010). The tendency of the farmers to adopt the interventions can be explained through the additional income generated by adopting them. For example, in the case of WI for supplemental irrigation, farmers prefer to have the well mainly to minimize the income loss due to poor crop yield in the event of rainfall failure. Hence, incorporating the behavior of the rainfall and prices in crop production is important to maximize the income of the farmers. In this situation, for example, farmers' current irrigation behavior ( $X_1$ ) is induced by rainfall distribution and can be described by a probability distribution as stated in Table I.

The next uncertain factor is the fluctuations in price of the crops. In cases of normal and surplus rainfall periods, when crop production is more, prices may comparatively decrease. The situation may reverse in below-normal rainfall periods when prices will be high due to reduction in production of crops. So the price of the crop ( $X_2$ ) has three levels: low ( $X_{21}$ ), normal ( $X_{22}$ ) and high ( $X_{23}$ ). The probability of their occurrence as low,

medium and high was calculated using 10-year time series, and calculated values were used in the estimation of the joint probabilities.

The probability distribution of  $X_2$  can be stated as given in Table II. Because the irrigation behavior and price levels are independent, their joint probabilities are given by the product of separate probabilities (Palanisami *et al.*, 2012):

$$\begin{aligned}
 p(X_{ij}) &= p_{ij} = p(X_1 = X_{1i}, X_2 = X_{2j}) = p(X_1 = X_{1i})p(X_2 = X_{2j}) \\
 &= p_i q_j \quad i = 1, 2, 3, 4; j = 1, 2, 3
 \end{aligned}
 \tag{1}$$

There are 12 combinations of irrigation strategies and price levels. Each combination ( $X_{1i}, X_{2j}$ ) can be called as a “state of nature” because the farmer has no control over either rainfall or price level. The probability distribution of the state of nature is given by equation (1).

In our case, farmers have different technology options to adopt such as SRI, AWD, DSR, WI and SSD. In the language of decision analysis, each technology is called an “alternative strategy” or simply “strategy”. For each technology adopted, the net return can be computed for each state of nature and then using the joint probabilities, the Expected Monetary Value (EMV) for each technology can be worked out as follows:

$$EMV_T = \sum_{i=1}^{i=4} \sum_{j=1}^{j=3} (R_{ij} - r_{ij}) p_{ij}
 \tag{2}$$

where,  $R_{ij}$  and  $r_{ij}$  are, respectively, the returns with and without technology  $T$  when the state of nature is ( $X_{1i}, X_{2j}$ ). Normally,  $R_{ij} \geq r_{ij}$ , because the farmer derives extra benefit due to application of technology and in the language of decision analysis, the difference  $R_{ij} - r_{ij}$  is called “payoff” corresponding to the state of nature ( $X_{1i}, X_{2j}$ ). The expected monetary value is defined as the weighted sum of the net benefits where the weights are the corresponding (joint) probabilities.

Serial no.	Farmers' irrigation strategy (depending on rainfall pattern)	Probability
1	Normal irrigation to crops ( $X_{11}$ ) to few crops ( $X_{11}$ )	$p_1$
2	Adopt water management practice ( $X_{12}$ )	$p_2$
3	Under-irrigate crops ( $X_{13}$ )	$p_3$
4	No irrigation ( $X_{14}$ )	$p_4$

**Table I.**  
Probability  
distribution of  
irrigation strategies  
of farmers

Serial no.	Crop price level	Probability
1	Low ( $X_{21}$ )	$q_1$
2	Normal ( $X_{22}$ )	$q_2$
3	High ( $X_{23}$ )	$q_3$

**Table II.**  
Probability  
distribution of price  
of crop

Equation (2) can be rewritten as:

$$EMV_T = \sum_{i=1}^{i=4} \sum_{j=1}^{j=3} R_{ij} p_{ij} - \sum_{i=1}^{i=4} \sum_{j=1}^{j=3} r_{ij} p_{ij} \tag{3}$$

The first term gives the expected gross return with technology and the second term refers to the expected gross return without applying the technology. Thus, the expected monetary value is the difference between expected gross return with and without technology. This is the expected net profit (or benefit) for adopting technology  $T$ .

Further, the farmer can choose that technology for which  $EMV_T$  is maximum and this is referred to as the *optimum technology*. That is,  $EMV$  is based on “Imperfect Information” because the farmer is not aware of what the state of nature will be, and so, it is called *expected value under uncertainty*.

Decision theory analysis further helps us compute the Expected Opportunity Loss (EOL) or EVPI which is the difference between the expected value with perfect information (about state of nature) and the expected value with current information. In other words, EVPI is the maximum amount a decision-maker should pay for additional information that gives a perfect signal as to the state of nature. We provide an in-depth analysis of this concept below and use slightly different notations.

To identify the most ideal situation for decision-making, the exact outcome of the state of nature should be known. For example, let there be  $k$  alternative technologies (hereafter, we shall call them as *strategies*) and  $n$  states of nature whose probability distribution is  $p_i, i = 1, 2, \dots, n$ . Let  $P_{ij}, i = 1, 2, \dots, n; j = 1, 2, \dots, k$  be the payoff when the state of nature is  $i$  and the farmer selects strategy  $j$ . The payoffs can be represented in the form of a matrix known as “payoff matrix” (Table III).

Then the expected payoff for the strategy  $j$  is given by:

$$EMV_j = \sum_{i=1}^n p_i P_{ij}, j = 1, 2, \dots, k \tag{4}$$

Then the optimal strategy for the farmer will be to select that strategy for which  $EMV$  is maximum. So the expected monetary value is given by:

$$EMV = \text{Max}_j \{EMV_j, j = 1, 2, \dots, k\} \tag{5}$$

	Strategy					
	1	2	·	$j$	·	$k$
<i>State of nature</i>						
1	$P_{11}$	$P_{12}$	·	$P_{1j}$	·	$P_{1k}$
2	$P_{21}$	$P_{22}$	·	$P_{2j}$	·	$P_{2k}$
·	·	·	·	·	·	·
$i$	$P_{i1}$	$P_{i2}$	·	$P_{ij}$	·	$P_{ik}$
·	·	·	·	·	·	·
$n$	$P_{n1}$	$P_{n2}$	·	$P_{nj}$	·	$P_{nk}$

**Table III.**  
Payoff matrix

This is the expected value under imperfect information. If the predicted state of nature is  $i$ , then the farmer will select that strategy which will correspond to maximum payoffs given in the  $i^{\text{th}}$  row. If  $R_i$  is the maximum payoff corresponding to the state of nature  $i$  predicted, then:

$$R_i = \text{Max}_j \{P_{ij}, j = 1, 2, \dots, k\}, \quad i = 1, 2, \dots, n \quad (6)$$

Then the expected payoff to the farmer *with* perfect information is:

$$EPwPI = \sum_{i=1}^n p_i R_i \quad (7)$$

This is the maximum payoff the farmer can achieve. From equation (6), for each  $i$ ,  $R_i \geq P_{ij}, j = 1, 2, \dots, n$  and so  $\sum_{i=1}^n p_i R_i \geq \sum_{i=1}^n p_i P_{ij}$ . That is:

$$EPwPI \geq EMV_j, j = 1, 2, \dots, n \quad (8)$$

This shows that the expected payoff with perfect information is always greater than the expected monetary value for any strategy  $j$  and from equation (5), it can be easily seen that:

$$EPwPI \geq EMV \quad (9)$$

Now consider the difference,  $EPwPI - EMV_j$ . This represents the opportunity loss corresponding to the strategy  $j$ , and we shall denote it by  $EOL_j$  and this loss will be a minimum when the farmer adopts the optimal strategy. The  $EVPI$  is the difference between expected payoff with perfect information and expected payoff with imperfect information. That is:

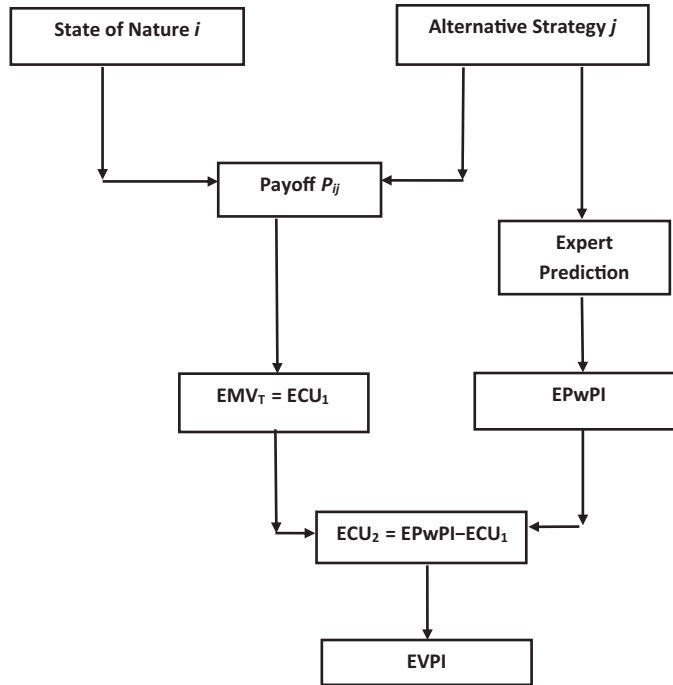
$$EVPI = EPwPI - EMV = \text{Min}_j \{EPwPI - EOL_j, j = 1, 2, \dots, k\} \quad (10)$$

The  $EVPI$  is also known as the Expected Opportunity Loss for not adopting the best decision. The above methodology can be represented in the form of a Flow Chart as shown in Figure 2. The expected monetary value of a technology,  $EMV_T$  given in equation (3) can also be interpreted as the net loss the farmer will incur if he is not adopting technology  $T$ . Because this measure is based on uncertainties in the state of nature, we shall term it as *Expected Cost of Uncertainty 1* (or  $ECU1$ ). The difference  $EPwPI - ECU1$  will be termed as *Expected Cost of Uncertainty 2* (or  $ECU2$ ). It can be easily seen that for optimal technology,  $ECU1$  will have a maximum value and  $ECU2$  will have a minimum value. Further,  $EVPI$  is the minimum value of  $ECU2$ . Finally, the sum of  $ECU1$  and  $ECU2$  will always be equal to that of  $EPwPI$ .

#### 4. Technologies, cost of adaptation and expected cost of uncertainty in rice production

##### 4.1 Technologies adopted

Given the importance of crop management technologies in improving the crop yield, it is important to identify the relevant technologies that farmers can adopt as a measure to



**Figure 2.**  
Flowchart to  
compute EVPI

address the climate change impacts in agriculture that can be considered for adoption both in the short run and the long run. Data related to SRI in all the three basins show that the input application including water has been reduced. In the case of AWD, water is applied throughout the rice-growing season in a regulated manner without affecting the plant growth and grain filling (Rejesus *et al.*, 2011). On the other hand, supplemental irrigation from wells (WI) is used to overcome the water scarcity and crop loss during the final phase of the crop. Even though supplemental irrigation has increased the cost of irrigation, it has also resulted in increased yield.

The SSD is another important practice adopted in the low-lying regions to overcome the poor drainage and salinity. Water use did not vary with the technology but an increase in yields and operational costs has been noticed. Another practice adopted is the DSR which refers to the spreading of seeds in fields before or immediately after pre-monsoonal showers. The method does not require seed nursery and transplanting of seedlings. Instead, the seeds are directly sown in the main field by spreading manually or with the help of a tractor and attached implements at a depth of 2-3 cm. Based on the availability of water, fields need to be irrigated 45-60 days after sowing and turned into a wet system. Hence, the direct seeding method used less water and labor, and has lower cultivation costs without any penalty in the yields. The details of the technologies and their costs are given in Appendix.

#### 4.2 Adaptation cost of the technologies

We refer to the adaptation costs as the costs associated with the implementation of the agriculture and water management technologies by the farmers, as these technologies

are already available but not practiced by all the farmers. As explained in Section 3.4, the adaptation cost of these technologies includes both additional investment made (due to the technology over the traditional practices) plus the transaction cost (in terms of time and other expenses in getting the technology or practices in place). The additional investment and the transaction cost could vary among the technologies and affect the technology adoption level. It is seen from Table IV that the transaction cost is comparatively higher for WI and SSD due to their high capital investment followed by SRI due to its high management intensity. The cost of adaptation is thus ranging from INR3,520/ha for DSR to INR8,800/ha for WI.

#### 4.3 Adoption levels of the technologies

An earlier study has indicated that farmers' adoption levels are comparatively low (Palanisami *et al.*, 2012). In the case of the three study basins, the level of adoption of the technologies had ranged from 6 per cent in the case of SRI, SSD and DSR to 30 per cent in the case of WI, indicating the importance of upscaling the technologies, as well as identifying the constraints in their adoption (Table V).

Technologies	Additional cost of the technology (Rs/ha)	Transaction cost (Rs/ha)	Adaptation cost (Rs/ha)
<i>Godavari basin</i>			
SRI	1,279	1,110	2,389
AWD	1,664	150	1,814
Wells for supplemental irrigation (WI)	6,620	1,524	8,144
<i>Krishna basin</i>			
SRI	3,232	1,163	4,395
AWD	478	168	646
DSR	-4,300	780	-3,520
SSD	7,500	1,300	8,800
<i>Cauvery basin</i>			
SRI	2,232	1,222	3,454
AWD	956	165	1,121
Wells for supplemental irrigation (WI)	6,799	1,878	8,677

**Note:** USD1.00 = INR63

**Table IV.**  
Adaptation cost of the technologies in rice production

Technologies	Godavari basin	Adoption % Krishna basin	Cauvery basin
SRI	6	7	11
DSR	0	6	0
SSD	0	6	0
Supplemental WI	8	—	30
AWD	7	8	10

**Table V.**  
Adoption levels of technologies in the river basins

**Note:** Field surveys and stakeholder discussions in the basins

However, the adoption varies among the technologies, probably due to the preference of farmers in adopting a technology/practice available to them and the costs of adaptation. In the case of WI and SSD, the initial cost is high but the costs tend to decrease once the farmers expand the area under these technologies. Some technologies such as SRI, AWD and DSR are less costly, as they involve mostly the managerial inputs. Other factors such as farmers' poor knowledge in handling it, lack of skilled laborers in doing the crop operations, poor water control from canal systems, high transaction costs, etc. also constrain the adoption of the technology.

#### 4.4 Expected cost of uncertainty in rice production

It is important to see how the non-adoption will cost the farmers. The expected cost of uncertainty-1 (*ECU 1*) which is the profit forgone for non-adoption of the technologies will be a clear indication of the farmers' decision-making behavior which will vary according to the type of technology and the occurrence of uncertain events such as erratic rainfall pattern and varying crop prices. In the three basins studied, the *ECU 1* for SRI was calculated with the probability of using traditional transplanting methods at 0.8 and adopting SRI at 0.2. The probability of low-, normal- and high-output prices was arrived at 0.3, 0.4 and 0.3, respectively, for all the three basins based on the time series on prices which were used to compute the joint probabilities. Using equations (2) and (3) the expected cost of uncertainty 1, *ECU 1*, were computed. The *ECU 1* for SRI ranged from INR6,176 to 9,172/ha in the three basins (Table VI). Similarly, *ECU 1* for the other two technologies was computed. The *ECU 1* for AWD ranged from INR4,000 to 8,000/ha in the three river basins.

In the case of SSD, the benefits were estimated for method of traditional flooding, adapted to SSD, of under-irrigating the crop and with no irrigation to the crop, with the

Technologies	Expected gross margin with technology (INR/ha)	Gross margin without technology (INR/ha)	Expected monetary value (or) <i>ECU 1</i> (INR/ha)
<i>Godavari basin</i>			
SRI	25,694	16,522	9,172
AWD	23,327	15,564	7,764
Wells for supplemental irrigation (WI)	19,810	2,540	17,270
<i>Krishna basin</i>			
SRI	26,296	19,320	6,976
AWD	21,441	17,318	4,123
DSR	10,792	4,923	5,869
SSD	6,350	-4,475	10,825
<i>Cauvery basin</i>			
SRI	26,194	17,825	8,369
AWD	23,241	16,496	6,745
Wells for supplemental irrigation (WI)	22,244	6,566	15,678

**Table VI.**  
*ECU 1* for non-  
adoption of the  
technologies

**Note:** USD1.00 = INR63

probability of 0.5, 0.2, 0.2 and 0.1, respectively. The *ECU1* for SSD worked out to INR10,825/ha for not investing in SSD measures. Thus, addressing the *ECU1* will help the farmers in their decision-making process on technology adoption.

The DSR is practiced in the semiarid and tail ends of the command area in the Krishna River Basin. The probability of adapting the DSR will be 0.3 and the rest (0.7) with the transplantation method. The *ECU1* for the DSR is INR5,869/ha. In the case of WI, the *ECU1* has ranged from INR15,000 to 17,000/ha.

In all the cases, the cost of uncertainty is higher than the cost of adaptation, indicating that farmers are incurring more losses for their non-adoption of the technologies (Figure 3). The possible reason might be that the costs of adaptation are more or less known before the crop season and they are related to the technology costs alone, whereas cost of uncertainty is unknown prior to the season due to the interplay of both the rainfall and price events and they are related to both adaptation costs and other crop production costs.

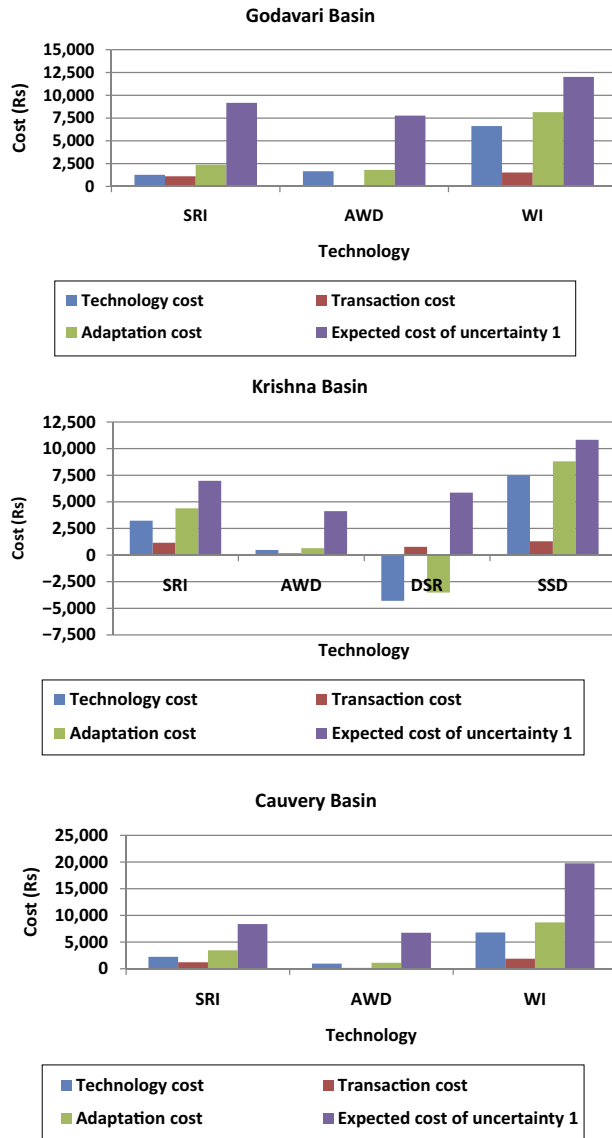
As the *ECU1* reflects the non-adoption cost of the technology, it is interesting to examine whether the farmers who have adopted the technologies are also maximizing their crop income through these technologies. In this context, a comparison of the various adaptation practices was made to get an idea of the farmers' optimal decision-making. Given the technologies that are adopted, the expected cost (reduction in revenue) for not adopting them at the level that gives the maximum income (optimal decisions) can be referred to as *ECU2*. As indicated earlier, the WI and the SSD are physical investments and the SRI, DSR and AWD are management interventions. In the case of the management strategies, the optimal decisions and the EVPI were analyzed using equations (4)-(7) and (10) and are given in Table VII. In the case of the physical investments, only one strategy (either WI or SSD) was adopted in the basins studied, and hence, the optimal decision level was not calculated.

The *ECU2* for AWD is high in all the basins. In the case of the Krishna Basin, as the present adoption of SRI has the maximum returns, *ECU2* is zero. Hence, it is important to see how best farmers' adoption of the technologies is close to the optimum decision-making so that the cost of uncertainty could be minimized. Given the *ECU1* and *ECU2*, it is important to focus on *ECU1*, as it is directly addressing the technology adoption.

## 5. Conclusions and policy recommendations

The impact of climate change in the river basins is fully acknowledged by several studies in recent years. Even though technologies/improved practices such as SRI, AWD, DSR, SSD and WI for supplemental irrigation are available to the farmers, the adoption level is very low. High cost of the technologies, as well as lack of awareness, and technical skills on the adaptation technologies are the key constraints in the better adoption of the adaptation technologies. Poor water control at the system level also contributed to the poor adoption of technologies such as SRI and AWD. As a result, the expected cost for not adopting the adaptation technologies in rice is significantly high compared to actual cost of the adaptations in the river basins. Hence, the results give a strong message for promoting the technology adaptation to address the climate change impacts in agriculture.

To speed up the technology spread, policy interventions in terms of supplying the quality seeds in time, machine transplanting (for SRI), water regulation in the canals,



**Figure 3.** Technology adaptation cost and expected cost of uncertainty in three river basins

**Note:** USD1.00 = INR63

capacity-building programs and monitoring the technology adoption in the fields through stakeholder participation are highly warranted.

Further, the study has given an idea of the cost associated with the technology adoption and the investment needed for technology transfer programs at macro level.

Event	Godavari basin			Krishna basin			Cauvery basin				
	JP	SRI	AWD	OPTD	SRI	AWD	DSR	OPTD	SRI	AWD	OPTD
1	0.24	8,389	7,324	8,389	6,000	3,900	4,926	6,000	12,388	4,324	12,388
2	0.32	9,660	5,900	9,660	7,400	3,750	6,167	7,400	6,000	5,900	6,000
3	0.24	9,320	8,350	9,320	6,900	3,750	6,197	6,900	8,000	9,350	9,350
4	0.06	8,840	1,3170	13,170	6,500	5,050	5,230	6,500	10,200	5,670	10,200
5	0.08	8,895	8,330	8,895	7,650	5,300	6,300	7,650	5,628	7,430	7,430
6	0.06	9,810	10,954	10,954	8,500	6,000	6,450	8,500	8,228	10,680	10,680
	EMV (ECU1)	91,72	7,764	9,500*	6,976	4,123	5,848	6,976*	8,369	6,745	8,984*
	ECU2	328**	1,736	—	0**	2,853	1,128	—	615**	2,239	—

**Notes:** Values shown under each practice is the difference between net income with and without adoption; OPTD = optimum decision; \* denotes EPwPI; \*\* denotes EVPI; other notations are as in the text. JP = joint probability

**Table VII.**  
ECU2 for non-  
adoption of the  
technologies

The policymakers can plan the technology transfer program and investment priorities accordingly.

## 6. Limitations of the study

Even though, there are many ways for farmers (other than technology) to adapt to climate change (such as out-migration to cities, selling farm assets, focus on children's education, etc.), this report, given the framework of the major research study undertaken, addresses only farm-level adaptation of the technologies to enhance farm income.

### Note

1. Combination of irrigation strategies and price levels ( $X_{1i}$ ,  $X_{2j}$ ), mentioned later on, can be called a "state of nature" because the farmer has no control over either rainfall or price level.

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**Table AI.**  
Details of the  
adaptation  
technologies, costs  
and returns in the  
three basins

Particulars	Godavari basin		WI
	SRI	AWD	
Seed rate (kg/ha)	5 (65-75)	65-75	65-75
Days to transplant	15-20 (30)	30	30
Labor use (days/ha)	40 (30)	35 (30)	30
Total water used (mm)	710 (1,300)	1,150 (1,390)	1,350 (950)
Yield (kg/ha)	6,040 (5,580)	5,400 (4,600)	5,190 (3,005)
Operating cost (INR/ha)	37,013 (35,734)	31,180 (29,516)	31,482 (26,917)
Gross return (INR/ha)	59,796 (52,256)	52,920 (45,080)	50,862 (29,449)
Gross margin (INR/ha)	22,783 (16,522)	21,740 (15,564)	19,380 (2,540)
Additional cost (INR/ha)	1,279	1,664	6,620*

(continued)

Particulars	Krishna basin			Cauvery basin			WI
	SRI	AWD	DSR	SSD	SRI	AWD	
Seed rate (kg/ha)	5 (65-75)	65-75	30-40 (60-75)	65-75	10 (60-75)	65-75	65-75
Days to transplant	15-20 (30)	30	0 (30)	30	15-20 (35)	30	30
Labor use (days/ha)	40 (30)	35 (30)	2 (25)	30	45 (40)	30	30
Total water used (mm)	594 (1,031)	1,450 (1,820)	995 (1,291)	1,370 (1,370)	740 (1,300)	1,300 (1,650)	1,300 (900)
Yield (kg/ha)	6,100 (5,540)	5,700 (4,900)	4,753 (4,565)	4,500 (2,589)	6,500 (5,690)	5,300 (4,800)	6,125 (3,867)
Operating cost (INR/ha)	38,758 (35,526)	31,180 (30,702)	36,211 (40,410)	34,650 (29,850)	40,720 (38,488)	31,500 (30,544)	38,129 (31,330)
Gross return (INR/ha)	60,390 (54,846)	55,860 (48,020)	47,198 (45,331)	44,100 (25,372)	64,350 (56,313)	52,260 (47,040)	60,025 (37,896)
Gross margin (INR/ha)	21,632 (19,320)	24,680 (17,318)	10,987 (4,924)	9,450 (-4,478)	23,630 (17,825)	20,760 (16,496)	21,896 (6,566)
Additional cost (INR/ha)	3,232	478	-4,300	7,500*	2,232	956	6,799*

**Notes:** Values in parenthesis under each practice in the basin are for conventional methods; \* additional cost includes annualized capital cost and operation and maintenance cost

Table AI.

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