The impact of risk and uncertainty on irrigation decision for paddy production in North Sumatera Indonesia

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Abstract. The risk in agricultural profitability is mainly due to risk in crop yield and volatility in crop prices. The risk in agricultural profitability would change the optimal choices of input use, especially water as a main resource for crop growth. Weather variability and limited water resources are main issue in paddy farming. The optimal choices of irrigation intensity are determined by agricultural profitability and farmer’s risk preference. Paddy is a water-sensitive crops that require intensive irrigation. The SERF analysis found risk neutral farmer are fond of irrigation intensity at 2.5 cm, but greater risk averse preference would change the optimal choice to irrigation intensity of 1 cm. The increase in risk would affect higher risk averse preference to change the optimal choice from risk neutral behavior.

1. Introduction
The risks in agricultural production are mainly due to weather variability, climate change, and limited irrigation water resources. High volatility on weather creates a big challenge for farmers to succeed the desired crop production. Climate change and high weather variability result in a high risk of failure in crop production. In addition, another risk faced by farmers is the risk of variability in crop prices. The high risk in crop production and crop price variability will affect the profitability of farming. Moreover, Production risk and price risk will govern farmers' decisions on irrigation intensity.

Paddy is the main food crop in Indonesia that requires intensive irrigation. Paddy growth and productivity is sensitive to the availability of irrigation sources during the planting season. One of the characteristics of paddy crop that makes it able to grow in conditions of inundation is because of an aerenchyma channel shaped like a pipe on its root that extends to the tip of the leaf functioning as a provider of oxygen from the dying area [1].

This study focuses on paddy farming and farmer decisions on irrigation intensity influenced by his risk preference. This research was carried out by developing the previous optimality irrigation model, which only focused on production variability, by including price variability factors on farmer irrigation strategy decision [2]. Previous study found the most optimum irrigation intensity is not at the highest rate [2], [3], [4].

The most typical irrigation strategy, that farmers can implement in defiance of weather variability and limited water availability, is to change the intensity of water (intensive irrigation), which is known as deficit irrigation. In the case of limited water resources, farmer also may change irrigation acreage area to compensate the increase on irrigation intensity [3], [5], [6].
This study objectives focuses on risk analysis for optimal irrigation choices affected by profitability and risk preference. Risk analysis is carried out using the Stochastic Efficiency Respect to Function (SERF) method with the assumption that farmers have risk preferences with the characteristics of Constant Absolute Risk Aversion (CARA) criterion. The results of this study are not only be used for the development of risk-based farmers’ decision models in Indonesia but can also be used as input for the development of government policies in resource sharing and the establishment of subsidies and price stability programs for agricultural products.

2. Methodology
The optimization on irrigation intensity choices is developed based on utility maximization model. Research takes into account the risk factors due to weather uncertainty and crop price volatility. The paddy farming is presented with a random production function [7]:

\[ y = f(w, \mu) \]  

where \( y \) is production, \( w \) is irrigation intensity, and \( \mu \) is an uncertainty factor caused by weather and price volatility. Bras and Cordova [8] state that the optimal irrigation intensity is influenced by changes in soil moisture that vary randomly affected by weather variability. Farmers choose an optimal irrigation intensity with the aim of maximizing net profit based on random variations in soil moisture [8].

Farmers are considered to be making decisions on resources that are used with the aim of maximizing mean utilities considering his risk preference shown as [7]:

\[ \max EU (\pi, p) = \max \{EU \{h(\mu)(f(w, \mu) - xzi, p)\} \}, \]  

where \( p \) is the coefficient that defines the farmer's risk preference, \( z \) is the input cost and \( \pi \) is the net profit. \( h(\mu) \) shows the volatility of paddy price in the market. The risk coefficient \( p \) does not depend on the initial conditions of net profit \( \pi \), presume that farmer has Constant Absolute Risk Aversion (CARA) preferences. Based on the assumption utility mean model corresponds to the exponential negative utility model with SERF analysis as shown below:

\[ \max_{[w]} CE(RAC) \]  

s. t. \[ CE(RAC) = \ln(1 - E[u(\pi_i)])^{-1/RAC} \]  

\[ E[u(\pi_i)] = \int u(\pi_i) dF(z, p_i) \]  

\[ u(\pi_i) = 1 - e^{-r \cdot \pi_i} \]  

\[ \pi_i = p_i * f_i(w, \mu) - xzi \]  

SERF analysis is considering the risk and the farmers risk preference. The nature of farmers' preference for risk is represented by Absolute Risk Averse Coefficient (ARAC). The ARAC range is from 0-4, which 0 ARAC states for risk neutral preference and the higher ARAC indicates more risk averse preference. The SERF analysis assumes farmer have a Constant Absolute Risk Aversion (CARA) preference or the risk preferences are not affected by the initial wealth.

The weather uncertainty is exhibited by the difference in soil moisture for land block with different treatment level. The study uses experimental methods with non-factorial Randomized Block Design (RBD) with one treatment into waterlogging consisting of 8 treatment levels and 4 replications. The level of treatment was determined based on the water needs of the paddy crop.

| Application | T1  | T2  | T3  | T4  | T5  | T6  | T7  | T8  |
|-------------|-----|-----|-----|-----|-----|-----|-----|-----|

Table 1. Randomized Block Design for Irrigation Treatment
Irrigation Intensity – 2.5cm = 1.16 l/sec/ha
0,0cm = 1.18 l/sec/ha
2.5cm = 1.20 l/sec/ha
5.0cm = 1.22 l/sec/ha
7.5cm = 1.24 l/sec/ha
10,0cm = 1.26 l/sec/ha
12,5cm = 1.28 l/sec/ha
15,0cm = 1.30 l/sec/ha

The paddy prices are a producer price that are collected by farmer. The paddy price data is collected from Statistical Bureau Center (BPS) for 2008-2016. Data in table 2 shows the paddy price has an increasing trend between 2008-2016.

Table 2. Paddy Price 2008-2016 (in Rupiah)

| Year  | Paddy Price  |
|-------|--------------|
| 2008  | 2,811.95     |
| 2009  | 2,987.22     |
| 2010  | 3,547.93     |
| 2011  | 4,046.03     |
| 2012  | 4,463.04     |
| 2013  | 4,592.50     |
| 2014  | 4,766.58     |
| 2015  | 5,303.46     |
| 2016  | 5,455.38     |

Source: BPS, 2019

3. Result and Discussion
The highest production is found when farmer apply 2.5 cm irrigation intensity (see table 3). Similarly, the highest revenue also found when farmer apply 2.5 cm irrigation. Similar finding on production and revenue because the estimation of revenue uses Statistical Bureau Center (BPS) paddy on-farm estimation standard [9]. The estimation of revenue is assuming the cost of input depends solely on amount of crop production and no economics of scale on production cost.

Table 3. Production (tones), Revenue (Rupiah) and Profit (Rupiah) by Irrigation Intensity

| Irrigation Intensity | Indicator | Min   | Max   | Mean  | Standard deviation |
|----------------------|-----------|-------|-------|-------|--------------------|
| 0                    | Production| 4.50  | 9.30  | 7.32  | 1.61               |
|                      | Revenue   | 12,653.775 | 50,735.034 | 30,885.593 | 9,539,139      |
|                      | Profit    | (905,225) | 37,176.034 | 17,326.593 | 9,539,139    |
|                      | Production| 7.70  | 11.60 | 9.26  | 1.49               |
| 1                    | Revenue   | 21,652.015 | 63,282.408 | 39,071.119 | 10,479,930   |
|                      | Profit    | 8,093.015 | 49,723.408 | 25,512.119 | 10,479,930  |
|                      | Production| 7.20  | 12.30 | 9.64  | 1.68               |
| 2.5                  | Revenue   | 20,246.040 | 67,101.174 | 40,674.470 | 11,243,760  |
|                      | Profit    | 6,687.040 | 53,542.174 | 27,115.470 | 11,243,760  |
|                      | Production| 5.30  | 7.90  | 6.24  | 0.94               |
| 5                    | Revenue   | 14,903.335 | 43,097.502 | 26,328.702 | 6,879,825   |
|                      | Profit    | 1,344.335 | 29,538.502 | 12,769.702 | 6,879,825   |
|                      | Production| 4.80  | 7.70  | 6.38  | 0.95               |
| 7.5                  | Revenue   | 13,497.360 | 42,006.426 | 26,919.410 | 7,007,055   |
|                      | Profit    | (61,640) | 28,447.426 | 13,360.410 | 7,007,055   |
|                      | Production| 3.50  | 6.30  | 5.50  | 1.05               |
| 10                   | Revenue   | 9,841.825 | 34,368.894 | 23,206.388 | 6,689,205   |
|                      | Profit    | (3,717,175) | 20,809.894 | 9,647,388 | 6,689,205   |
| 12.5                 | Production| 4.70  | 9.80  | 7.28  | 1.69               |
The variation on production is smaller when the irrigation intensity is at 5, 7.5, 10, and 15 cm (see table 3). Contrarily, the high variance on production were found at irrigation intensity of 0 cm, 1 cm, and 2.5 cm. Higher irrigation intensity affect smaller variation in paddy production. This evidence proofs water is a risk reducing input for paddy yield, which is come as no surprise because paddy is a water-sensitive crop.

Result is table 3 shows a possible profit loss at irrigation intensity of 0 cm, 7.5 cm, 10 cm, and 12.5 cm. Contrarily, irrigation intensity at 1 cm, 2.5 cm, and 15 cm never gain any profit loss. The highest minimum profit is found at irrigation intensity of 1 cm. Figure 1 shows a high variation in profit at irrigation intensity of 0 cm, 1 cm, 2.5 cm, and 12.5 cm. Farmer, who has high risk averse preference, might not going to apply irrigation intensity of 0 cm and 12.5 cm because of its potential profit loss and high profit variance. Farmer will experience possible profit loss if the paddy yield is less than 5.5 tones and paddy price is less than Rp. 2,800.

![Figure 1](image_url)

**Figure 1.** Profit distribution by irrigation intensity

Figure 1 shows an increasing trend of profit when farmer increase irrigation intensity from 0 cm to 2.5 cm. Contrarily, the trend of profit is decreasing when irrigation intensity is above 2.5 cm but below 10 cm. The variation in profit seems decreasing in conjunction with the increase in irrigation intensity. There is a trade-off between raising the profit with the decrease in profit variance.

SERF analysis shows the highest certainty equivalent for risk neutral farmer is at irrigation intensity of 2.5 cm (see Figure 2). This is because the highest average profit is found at irrigation intensity of 2.5 cm. The
second-best choice is irrigation intensity at 1 cm and followed by 15 cm. The least irrigation intensity choice is at 10 cm.

The optimal irrigation choice is changing when farmer has risk averse preference. Figure 2 shows a slight change in risk averse preference, i.e. 0.1667, would change the optimal irrigation intensity at 1 cm. A change in irrigation intensity choices is because the smaller profit variation for irrigation intensity of 1 cm compared to 2.5 cm, even though the 2.5 cm irrigation intensity has the highest average profit.

![Figure 2. Certainty equivalent estimation with SERF model](image)

The optimal choice of 1 cm irrigation intensity is not changing for farmer with very high risk-averse preference. This finding is similar with Wibowo et al [2] but the rate of change in ARAC that cause changing optimal irrigation choices from risk neutral behavior is not the same. Wibowo et al. [2] found ARAC 0.125 causes optimal irrigation intensity to change from 2.5 cm to 1 cm. Our study found a higher ARAC at 0.1667 to stimulate the changing in irrigation intensity choice. The difference is because our current model includes the price volatility that increase the risk. Thus, the increase in risk would affect higher risk averse preference to change the optimal choice from risk neutral behavior.

4. Conclusion

Limited water resources, high volatility of crop prices and variability in weather are the main issue in agricultural profitability. Climate change and high weather variability result in a high risk of failure in crop production. Risk in crop production and crop prices volatility would change agricultural profitability, thus changes the optimal decision of input use. The optimal decision of input use is not only affected by the
profitability but also by risk preference of the farmer. Irrigation water is the main input for agricultural, thus choice of irrigation intensity may change because of the risk in profitability.

The highest production is found when farmer apply 2.5 cm irrigation intensity. The variation on production is smaller when the irrigation intensity is at 5 cm, 7.5 cm, 10 cm and 15 cm. Higher irrigation intensity affect smaller variation in crop yield, which proofs water is a risk reducing input. The optimal choice for risk neutral farmer is at irrigation intensity of 2.5 cm. However, as farmer has more risk averse behavior, the optimal choices is changing to irrigation intensity of 1 cm. Our finding is similar with previous study [2] but the rate of change in ARAC that cause the change in optimal irrigation choices is not the same. Our study found higher ARAC that causes the change in optimal irrigation choices. The differences in finding is because our model include the price volatility that increase the risk in crop profitability. Thus, the increase in risk would affect higher risk averse preference to change the optimal choice from risk neutral behavior.

5. References
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