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*Full Length Research Paper*

# How important are climate characteristics to the estimation of rice production function?

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**Considerable attention has been given to the impact of climate variability on farm production, and most of the researches have been provided by agronomists to identify the bio-physical relationship between climatic factors and crop production. Relatively, little attention has been given to this relationship from the standpoint of agricultural economists. This study aims to fill this void by assessing the potential cost of ignoring the impact of weather variability on the estimation of rice production function. Using nationwide representative farm-level data in Taiwan in 2008 and the Geographic Information System method, we merged the appropriate weather data with the existing farm data. Our results point to a biased estimation of the input elasticities if weather conditions are not considered. Moreover, the effects of temperature on rice production are more pronounced than the effects of rainfall.**

**Key words:** Climate variability, farm production function, input elasticities, rice, Taiwan.

## INTRODUCTION

Estimating farm production elasticities is a longstanding economic issue in many countries (Hayami and Ruttan, 1970; Nin et al., 2003). Conventional wisdom maintains that the farm production function can be estimated solely on the basis of production inputs and outputs without considering the effects of climate characteristics. However, the expressed concern over global climate variability in the emerging literature has sparked intense debate on the interaction between climate change and agricultural production, and its implications for agricultural policy (Oram, 1985; Matthews et al., 1996; Brown and Funk, 2008). Considerable attention has been given to the effects of climate variability on crop production (Matthews et al., 1996; Lansigan et al., 2000; Ainsworth and Ort, 2010). It is evident that long-term climatic fluctuations (such as El Niño, La Niño) and short-term dramatic weather aberrations have a wide range of impacts on cropping systems and plant yield (Lansigan et al., 2000; IPCC, 2001; Hansen et al., 2006; Goodwin, 2008). Although, a considerable body of literature has assessed the impact of climate factors on farm production, most of these studies, which focus on the relationship between bio-physical and natural conditions and crop yield are based on agronomic research (Mathauda et al., 2000; Horie et al., 2000; Aggarwal and Mall, 2002; Jintrawet and Chinvanno, 2008; Watanabe and Takashil, 2009; Satyanto et al., 2009). Limited studies of agricultural economic analyses (for example, Audibert, 1997; Dhungana et al., 2004; Kwon and Lee, 2004) have been found that address the same issue. Instead, most of the economic analyses solely focus on the relationship between input uses and outputs represented by the production elasticities.

The primary objective of this study is to bridge the two concerns by assessing the impact of climate characteristics on the estimation of the rice production function. In particular, we examined the potential cost when climate characteristics are ignored. Our study goes beyond previous studies in three ways. First, the study uses a relatively large-scale random survey of rice farms in Taiwan in 2008. This dataset was conducted by the

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Council of Agriculture (CoA) in Taiwan. Secondly, whereas the traditional production function analysis relies solely on the data of production inputs and outputs, this study takes into consideration climate characteristics, land quality and various farm inputs. Third, to link the farm production data and appropriate climate conditions, we utilized the Geographic Information System (GIS) to merge the local climate conditions of each farm. To the best of our knowledge, this study is among the first to combine nationwide farm-level data with appropriate physical measures of weather conditions in farm production analysis.

## MATERIALS AND METHODS

### Data

Our data were drawn from the Rice Production Cost Survey (RPCS), conducted by the Council of Agriculture in Taiwan in 2008. In Taiwan, there are two crop seasons for paddy rice production. The first crop season of rice extends from February to June, whereas the second crop season is from July to November. In each crop season, approximately, 550 rice farmers were randomly selected and interviewed. The sampling criterion of the RPCS is based on the proportion of the rice field area in each administrative region, and thus, it yields a nationwide representative data file of the rice farmers in Taiwan (Agriculture and Food Agency, 2008). The primary objective of the RPCS is to investigate the production cost structure of rice production in Taiwan. All participants are requested to report detailed information about their production inputs and output. Some additional information, including the socio-economic characteristics of rice farmers and their families is also documented. The sample size of the most recent survey, which was in 2008, consisted of 1,089 respondents. After deleting few observations with missing values, we had a final sample of 525 and 515 rice farmers for the first and second crop seasons, respectively.

### Measures

#### Production inputs and output

Built on an empirical specification of rice production similar to previous studies (Fu et al., 1992; Audibert, 1997; Dhungana et al., 2004; Kwon and Lee, 2004), the output variable is defined as the production yield, measured in kilograms per hectare.

Production inputs are categorized into five groups. Seed input includes the cash expenses of total seed purchased. Labor input is measured by the total payments for the hired labors. For farm chemical uses, we include the expenses for purchased fertilizer and pesticide inputs as two additional inputs. We distinguished the fertilizer and pesticide expenses, because it has been documented that these two inputs have different implications for yield production (Just and Pope, 1979; Xu and Jeffrey, 1998). Finally, the other input, which measures the values of the variables costs including expenses per hectare for machinery and equipment. All input expenses are measured in NT$1,000 per hectare.

#### *Farm and household characteristics*

Some other variables related to rice production in Taiwan are also specified. We include the age and gender of the farm operator to reflect the effects of human capital on rice production. Since off-farm employment has been indicated as an important factor in farm production (Fleisher and Liu, 1992; Chang and Wen, 2011), a dummy variable is specified if the farm operator works off the farm (part-time farm=1). Because most of the rice farms in Taiwan are family farms, household characteristics may be important for rice production. To capture the effects of the household structure on rice production, we included a variable indicating the number of household members aged 18 to 60. This variable is likely to capture the effects of unpaid family labor on farm production (Audibert, 1997; Dhungana et al., 2004).

#### *Land quality*

In addition to the farm-level data, our analysis also utilizes data from other sources that enables us to include information on environmental characteristics using the GIS technique. After matching the geographic location of each farm with the land quality profile at the county level provided by the Agricultural Engineering Research Center in Taiwan, the study specifies four dummy variables to reflect the impact of different levels of land productivity on rice production.

#### *Climate variables*

With regard to weather characteristics, the cumulative rainfall and average temperature variables are specified to reflect climate conditions in the local area of each farm. We used daily records of precipitation and temperature which are provided by the Taiwanese Central Weather Bureau. Since we know the exact geographic location of each farm, we can use this information to compile additional information into the farm-level dataset. By employing the GIS mapping technique, we are able to create plot-specified climate data from the nearest meteorological station to the geographic location of each farm. Since the effects of weather conditions on rice production may differ at different stages of the rice growth period (Felkner et al., 2009), we constructed three types of weather variables to reflect the three growth phases of biological development: vegetative (growing), reproductive (flowering), and ripening (harvesting)[1]. Rainfall (I) indicates the cumulative rainfall (in millimeters) for the beginning 60-day period of rice production. Rainfall (II) and Rainfall (III) represent, respectively, the cumulative precipitation for the following 45-day flowering period and 35-day harvesting period. In the same manner, we defined the temperature group variables as 60-day, 45-day, and 35-day average temperatures (°C) for three different rice growth periods.

### Statistical analysis

In the empirical analysis, we specified two different types of linear regression models for rice production yield. Equation (1) is the conventional production function, which examines the relationship between production inputs and output after controlling for several variables that reflect socio-demographic characteristics of the farm operator and household factors. Therefore, Equation (1) serves as the baseline model. Following Mendelsohn and Dinar (2009), the production function is assumed to follow the quadratic functional

[1]As pointed out by an anonymous reviewer, rice production only occurred in the harvest period (i.e., phase III) so including the weather conditions of the first two periods are not necessary. However, it is possible that the rainfall conditions of the first two periods may also have cumulative effects on rice production. To have a more comprehensive picture of the transition of weather conditions during the entire production period, we accommodate three period data into our analysis. In so doing, we can empirically test whether the first two periods' weather characteristics are associated with rice production.

form [3]. Assuming there are $J$ inputs (J=1....J); the empirical specification of Equation (1) can be shown as:

$$y_i = \alpha_0 + \sum_{j=1}^{J} \alpha_j{}' x_{ij} + \sum_{j=1}^{J} \beta_j{}' x_{ij}^2 + \lambda' Z_i + \varepsilon_i \qquad \text{(j=1...J)} \qquad (1)$$

Where $y_i$ is the rice production output measured in kilograms per hectare, and $x_{ij}$ and $x^2_{ij}$ are, respectively, the first-order and second-order terms of the input uses for the $j^{th}$ input of the $i^{th}$ farm. $Z_i$ is the vector of the other variables, including the socio-demographic characteristics and farm factors. $\alpha_j, \beta_j, \lambda$ are the parameters to be estimated, and $\varepsilon_i$ is the random error.

To accommodate the climate variability, Equation (2) includes the variables of the rainfall and temperature conditions in each rice growth period given as:

$$y_i = \alpha_0 + \sum_{j=1}^{J} \alpha_j{}' x_{ij} + \sum_{j=1}^{J} \beta_j{}' x_{ij}^2 + \lambda' Z_i + \rho' C_{ik} + \varepsilon_i$$

(j=1...J), (k=1...3) (2)

Where the vector $C_{ik}$ indicates the variables of the rainfall and temperature in the $k^{th}$ growth period, and $\rho$ is the corresponding parameter.

We estimated Equations (1) and (2) using separate samples for the first and second crop seasons. Each equation is estimated using the conventional ordinary least square (OLS) method. As commonly found in cross-section study, the data are likely to be heterogeneity across regions. That is, unobserved factors would make the farmers in the same region perform similar. To accommodate this unobserved heterogeneity, we used the adjusted standard errors clustered in the major administrative districts.[5] In using this method, and by further controlling for the unobserved effects of geographic heterogeneity on rice production, we make the standard errors more robust (Greene, 2010).

## RESULTS AND DISCUSSION

Our results are presented in several sets. The sample statistics of the selected variables are presented in Table 1. Tables 2 and 3 present the estimation results of the rice production functions for the first and second crop seasons. Based on the estimates of the production function, the input elasticities are calculated and reported in Table 4[6]. Table 5 reports the calculated elasticities of the weather conditions on rice production.

### Geographical location and the sample statistics of the selected variables

Before turning to our discussion of the findings, we first depicted the geographic location of the rice farms in our sample in Figure 1. The left and right panels show the location of each farm in the first crop and the second crop seasons, respectively. This information should help to underscore the potential spatial heterogeneity of agricultural production in Taiwan[8]. The results in Figure 1 reflect the unique geographical condition in Taiwan. Taiwan geography is characterized by the Central Mountain Range from the northern to the southern tip of the island. Almost two-thirds of Taiwan is covered by forested mountains (Government Information Office, 2012). The western side of the island is more flat and featured with plains. Therefore, agricultural activities, especially for crop production, are more concentrated on the western plains. In contrast, less agricultural activity is observed in the eastern side of the island. The results in Figure 1 also demonstrates a significant spatial heterogeneity of our sample in that the survey contains most of the area in the island, which is also consistent with the nature of the survey design (that is, a national representative sample). Table 1 summarizes the definitions and sample distributions of the selected variables. The average rice yield for each crop season is 6,660 kg and 4,267 kg/ha, respectively. The first crop season of rice has an average yield of about 56% higher than the second crop season. This result is accordance with the findings of Chang (1985) and Lur et al. (2009). Regarding the input uses, the largest amount of input expense per hectare is for hired labor, whereas the least expense is for purchased pesticide in the first crop season. In regard to the socio-demographic characteristics of the rice farmers, it is evident that nearly 94% are males, 65% are part-time farmers, and their average age is 63.57 (±10.76). Among the 525 rice farms of the first crop season in 2008, 8% had the highest land productivity, 32% had the second highest productivity, 16% had the second lowest productivity, and 45% had the lowest productivity.

In addition, the climate conditions varied noticeably between the two crop seasons largely in response to seasonal change, for example, from summer to autumn. In general, the first crop season was drier but cooler than the second crop season. The highest cumulative precipitation occurred in August and mid September, when the second season of rice crop was in the

[3]Although, the translog production function is widely used in production analysis, the specification of this function requires the logarithm transformation of the output and input variables. In our case, taking the logarithm transformation will result in a loss in sample size for those inputs with zero values. Therefore, the functional form in equation (1) is assumed to be a quadratic function. Similar to the translog production function, the quadratic function still allows the possibility of a non-linear relationship between inputs and outputs.

[5]We adjust the standard errors based on the 23 major administrative districts. In so doing, we can further control for the unobserved heterogeneity of the regional level on rice production.

[6]The input elasticity can be calculated based on the estimated coefficients of the model. $\varepsilon_j = \frac{\partial y}{\partial x_j}\frac{\bar{x}_j}{\bar{y}} = \hat{\alpha}_j + 2*\hat{\beta}_j \bar{x}_j$, where $\varepsilon_j$ is the estimated input elasticity. $\bar{x}_j, \bar{y}$ are evaluated at the sample means. $\hat{\alpha}_j, \hat{\beta}_j$ are the estimated parameters of the model.

[8]We thank the suggestion from an anonymous reviewer.

**Table 1.** Definition and sample statistics of the selected variables.

| Crop season | Definition | First crop season | | Second crop season | |
|---|---|---|---|---|---|
| Sample | | 525 | | 515 | |
| Variable | | Mean | SD | Mean | SD |
| Production outputs and inputs | | | | | |
| Yield | Production yield (kg/hectare) | 6660.18 | 1126.98 | 4267.03 | 912.17 |
| Seed | Purchased seed cost (NT$ 1,000/ha) | 7.72 | 1.79 | 6.99 | 3.02 |
| Labor | Labor cost (NT$ 1,000/hectare) | 67.44 | 7.52 | 61.90 | 11.00 |
| Fertilizer | Purchased fertilizer cost (NT$ 1,000/ha) | 8.17 | 2.96 | 9.48 | 3.23 |
| Pesticide | Purchased pesticide cost (NT$ 1,000/ha) | 7.66 | 3.66 | 8.95 | 4.57 |
| Other inputs | Other input cost (NT$ 1,000/ha) | 23.35 | 5.28 | 17.47 | 4.77 |
| Farm and household characteristics | | | | | |
| Age | Operator age (year) | 63.57 | 10.76 | 62.47 | 10.72 |
| Male | If operator is male (=1). | 0.94 | 0.23 | 0.94 | 0.24 |
| Hhsize_1860 | Number of household member aged 18-60 | 2.71 | 1.97 | 2.79 | 1.99 |
| Part-time | If part-time farmer (=1). | 0.65 | 0.48 | 0.64 | 0.48 |
| Land_quality4 | If bad land productivity (=1). | 0.45 | 0.50 | 0.49 | 0.50 |
| Land_quality3 | If medium land productivity (=1). | 0.16 | 0.36 | 0.16 | 0.36 |
| Land_quality2 | If good land productivity (=1). | 0.32 | 0.47 | 0.27 | 0.45 |
| Land_quality1 | If high land productivity (=1) | 0.08 | 0.27 | 0.08 | 0.28 |
| Climate variables | | | | | |
| Rainfall (I) | Cumulative rainfall of first growth period (millimeter) | 72.46 | 59.74 | 384.15 | 172.50 |
| Rainfall (II) | Cumulative rainfall of second growth period (millimeter) | 112.00 | 73.04 | 439.93 | 181.43 |
| Rainfall (III) | Cumulative rainfall of third growth period (millimeter) | 276.44 | 134.97 | 61.68 | 38.55 |
| Temperature (I) | Average temperature of first growth period (°C) | 17.68 | 1.71 | 28.48 | 1.24 |
| Temperature (II) | Average temperature of second growth period (°C) | 24.21 | 1.47 | 27.20 | 1.13 |
| Temperature (III) | Average temperature of third growth period (°C) | 26.45 | 1.20 | 24.24 | 1.16 |

1,040 rice farms are selected from the 2008 rice farmer survey in Taiwan.

reproductive state. By contrast, the lowest cumulative precipitation, which was also found in the second crop season, was in the ripening phase, between mid October and November. Moreover, the average temperature ranged from 17.68 to 26.45°C during the first crop season, whereas the temperature range was between 24.24 to 28.48°C during the second crop season.

## The importance of climate characteristics on rice production

Since the impact of climate characteristics is the focus of this study, we begin our discussion by evaluating its importance on the estimation of the rice production function. First, the results in Tables 2 and 3 showed that climate conditions during the three different growth phases are significantly associated with the amount of rice produced. In particular, the significance of the weather variables in the first two periods indicates a cumulative effect of the weather conditions in rice production. This finding confirms the belief that the climate condition of each production period matters for the rice production. Therefore, ignoring the climate variables will lead to a biased estimation of the input uses on rice production. This result is consistent with the findings of agronomic studies that rice growth is very sensitive to temperature, and the effect of temperature differs for different stages of growth period (Horie et al., 2000). The importance of considering climate factors on the production of rice is reinforced by a comparison of the goodness-of-fit between models with and without climate variables. As Table 2 shows, the adjusted R-square values of these two models are 0.485 and 0.308, respectively. This indicates that the goodness-of-fit in the model with climate variables is much better than in the traditional production model. What is the cost of ignoring the climate characteristics on the estimation of the rice production function? The answer to this question can be found in Table 4, which uses the estimated coefficients of the models with and without climate variables (Tables 2 and 3) to compare the input elasticities. As exhibited in

**Table 2.** Estimation of the yield production equation of the first crop season.

| Model | With climate variables | | Without climate variables | |
|---|---|---|---|---|
| **Variable** | **Coefficient** | **SE** | **Coefficient** | **SE** |
| Production inputs | | | | |
| Seed | 138.58 * | 88.67 | 397.32*** | 93.04 |
| Seed square | -9.38 | 7.21 | -29.51*** | 7.45 |
| Labor | 187.40*** | 52.91 | 267.81** | 58.59 |
| Labor square | -1.17*** | 0.38 | -1.72*** | 0.42 |
| Fertilizer | 37.17 | 47.49 | 95.38* | 51.97 |
| Fertilizer square | -2.61 | 2.26 | -3.48 | 2.50 |
| Pesticide | 36.47 | 39.38 | 152.21*** | 41.92 |
| Pesticide square | -0.99 | 2.06 | -4.38** | 2.28 |
| Other inputs | -40.13 | 50.98 | -33.42 | 55.94 |
| Other inputs square | 0.89 | 1.04 | 0.67 | 1.15 |
| | | | | |
| Farm and household characteristics | | | | |
| Age | -4.93 | 3.57 | -4.40 | 4.03 |
| Male | -44.82 | 162.59 | 3.87 | 183.45 |
| Hhsize_1860 | -22.11 | 21.63 | -59.15** | 24.14 |
| Part-time | -188.32** | 86.89 | -222.73** | 97.18 |
| Land quality4 | -689.90*** | 208.53 | -681.69*** | 233.73 |
| Land_quality3 | -460.68** | 204.87 | -473.85** | 228.05 |
| Land_quality2 | -271.85 | 179.08 | -509.95*** | 199.95 |
| | | | | |
| Climate variables | | | | |
| Rainfall (I) | -0.10 | 1.74 | | |
| Rainfall (II) | -7.12*** | 1.38 | | |
| Rainfall (III) | 0.82 | 0.57 | | |
| Temperature (I) | -249.25*** | 74.20 | | |
| Temperature (II) | 541.63* | 249.40 | | |
| Temperature (III) | -438.96** | 196.51 | | |
| Constant | 3531.50 | 2671.67 | -4536.22** | 2184.31 |
| Adjusted $R^2$ | 0.485 | | 0.308 | |

***, **, * Significant at the 1, 5 and 10% levels respectively.

Table 4, the estimated input elasticities are different between these two models regardless of the crop season. The estimated input elasticities without the consideration of the climate conditions are consistent with the findings in Fu et al. (1992) and Chang and Wen (2011) who conducted the similar analysis using the same data in the earlier years. In the first crop season, it appears that the traditional model overestimated the contributions of the inputs to rice production. For instance, the elasticities of labor input are 0.299 and 0.361 respectively, in the model with climate and without climate variables. For this specific input, using the traditional model resulted in an overestimation of labor use on production by 21%. Results in the second crop season also reinforced the disadvantage of using the traditional model. Taking the results of the other input used, it is evident that the traditional model predicts a negative contribution of each input, which is inconsistent with the maximum profit behavior of the farm production theory.

## Effects of climate characteristics on rice production

Table 5 reports the elasticities of the weather conditions in each growth period and their effects on rice production. First of all, the effects of climate varied across different growing phases in both crop seasons. For example, in the first crop season, holding the other conditions constant, a 1% increase in cumulative rainfall during the vegetative phase (phase I) decreased rice production by 0.001%, whereas the same increase during the ripening phase (phase III) enhanced rice production by 0.034%. Results also show that temperature has a larger effect on rice production than rainfall. For example, the estimated elasticities of cumulative rainfall and average temperature in phase I of the first crop season were -0.001 and -0.662,

**Table 3.** Estimation of the yield production equation of the second crop season.

| Model | With climate variables | | Without climate variables | |
|---|---|---|---|---|
| **Variable** | **Coefficient** | **SE** | **Coefficient** | **SE** |
| Production inputs | | | | |
| Seed | 131.23*** | 51.03 | 215.05*** | 51.99 |
| Seed square | -10.44** | 4.77 | -17.41*** | 4.88 |
| Labor | 69.63*** | 19.58 | 62.08*** | 20.13 |
| Labor square | -0.36** | 0.15 | -0.31** | 0.16 |
| Fertilizer | 3.07 | 41.31 | -3.63 | 42.72 |
| Fertilizer square | -0.43 | 1.76 | -0.04 | 1.83 |
| Pesticide | 33.17 | 33.44 | 24.44 | 33.16 |
| Pesticide square | -0.77 | 1.52 | -0.13 | 1.56 |
| Other inputs | 45.91 | 31.42 | -48.06 | 29.64 |
| Other inputs square | -0.45 | 0.61 | 1.16 | 0.90 |
| | | | | |
| Farm and household characteristics | | | | |
| Age | 4.82 | 3.23 | 3.81 | 3.42 |
| Male | 62.68 | 137.69 | -25.27 | 145.69 |
| Hhsize_1860 | -7.47 | 19.53 | -22.98 | 20.19 |
| Part-time | 6.64 | 77.88 | 34.00 | 81.33 |
| Land quality4 | -190.55 | 161.56 | -251.63 | 168.19 |
| Land_quality3 | -27.25 | 161.94 | -134.36 | 167.14 |
| Land_quality2 | -266.27** | 135.89 | -360.71 ** | 143.18 |
| | | | | |
| Climate variables | | | | |
| Rainfall (I) | 1.47*** | 0.31 | | |
| Rainfall (II) | -0.94* | 0.53 | | |
| Rainfall (III) | 18.08*** | 2.37 | | |
| Temperature (I) | -1293.04*** | 229.81 | | |
| Temperature (II) | 2696.44*** | 488.87 | | |
| Temperature (III) | -1517.67*** | 269.09 | | |
| Constant | -959.96 | 2311.04 | 1519.74 ** | 756.46 |
| Adjusted $R^2$ | 0.396 | | 0.280 | |

***, **, * Significant at the 1, 5 and 10% levels respectively.

**Table 4.** Estimated input elasticities.

| Input name | First crop season | | Second crop season | |
|---|---|---|---|---|
| | **With climate var.** | **Without climate var.** | **With climate var.** | **Without climate var.** |
| Seed | 0.007 | 0.067 | 0.024 | 0.046 |
| Labor | 0.299 | 0.361 | 0.367 | 0.343 |
| Fertilizer | 0.007 | 0.047 | 0.011 | 0.010 |
| Pesticide | 0.025 | 0.098 | 0.041 | 0.046 |
| Other inputs | 0.005 | 0.008 | *0.123* | -0.031 |
| Return of Scale | 0.342 | 0.582 | 0.566 | 0.415 |

All input elasticities are calculated based on the sample means.

respectively. The climate elasticities derived from the three phases of the second crop season are in line with those in the first crop season. It is noteworthy, however, that the effects of temperature are more significant in the second season. For instance, the estimated temperature elasticities in phase II are 7.187 and 1.969 in the second

**Table 5.** Estimated elasticities for climate variables.

| Climate variable | First crop season | Second crop season |
|---|---|---|
| Rainfall (I) | -0.001 | 0.132 |
| Rainfall (II) | -0.120 | -0.097 |
| Rainfall (III) | 0.034 | 0.261 |
| Temperature (I) | -0.662 | -8.631 |
| Temperature (II) | 1.969 | 7.187 |
| Temperature (III) | -1.743 | -8.622 |

All climate elasticities are calculated based on the sample means.

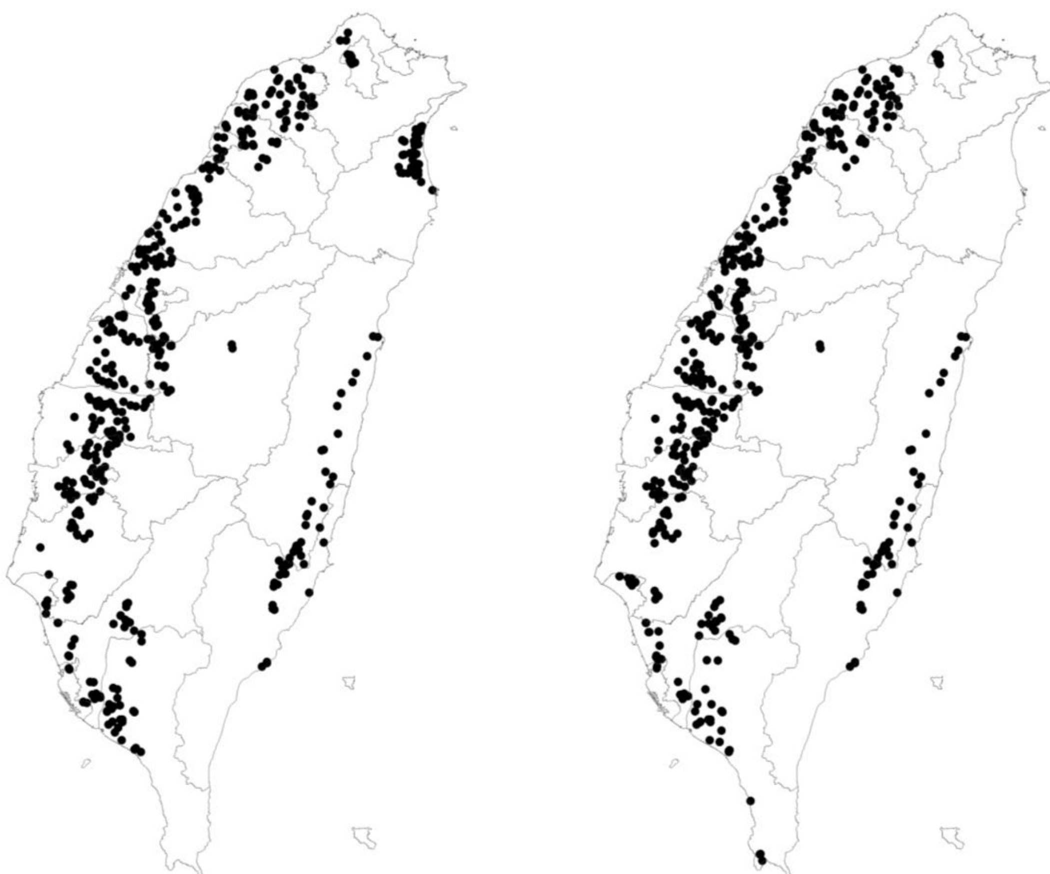

**Figure 1.** Spatial distribution of the selected rice farms. The left panel indicates the location of the 525 farms in the first crop season. The right panel indicates the location of the 515 farms in the second crop season. The background shows the geographical boundary of the 23 administrative districts in Taiwan.

and first crop seasons, respectively. This finding may reflect the variability of the three growing phases in the second season. The growth period of the second crop covers the change of season, from summer to autumn. Therefore, the temperature during this season has a decreased trend from phase I to III. According to our findings, rice production will be more sensitive when the temperature steadily decreases during the rice development period. Moreover, the less sensitive effects of rainfall on rice production than the effects of temperature can be possibly understood by the well-established irrigation system in Taiwan (Chiueh, 2011; Chiueh and Chen, 2008). With the well-controlled water supply of irrigation water, rice production can be less relied on the rainfall.

## Effects of other determinants

Regarding the effects of other determinants of rice production, the results showed that household characteristics and land quality play an important role. As Table 2 shows, part-time farming is negatively associated with rice production after controlling for input uses and weather conditions. Compared to full-time farmers, those who had off-farm jobs had lower rice production by 188 kg/ha in the first crop season. This finding is consistent with previous literature, which indicates a negative effect of off-farm employment on farm production in other countries (Phimister and Roberts, 2006; Minten et al., 2007; Fernandez-Cornejo, 2007; Chang and Wen, 2011). As expected, land quality is also significantly associated with the amount of rice production. For example, compared to the farms located in the best land productivity area (Land quality=1), those farms located in the lowest land quality area (Land quality=4) have lower rice production by 689 kg/ ha.

## Conclusion

Growing concern about the impact of global climate change on agriculture has stimulated academic and public policy awareness of the effects of climate variability on crop production. However, most of the studies have been conducted from the standpoint of agronomic analysis and little attention has been given from the standpoint of agricultural economic analysis. This study aims to fill this void by estimating the production elasticities in rice production in Taiwan. Our study is unique in that it uses the GIS method to merge a nationwide representative farm-level data with the weather conditions of each farm.

Several findings may be noted. First, failing to consider climate conditions will result in a biased estimation of the input elasticities in rice production. The traditional farm production model without climate variables overestimates the effect of production inputs on rice yield; including the climate factors significantly improves the accuracy of yield estimation. Second, regarding the impact of climate variables, we find that the effects of temperature on rice production are more pronounced than the effects of rainfall. Third, we find that these climate effects are different in the different growth periods of the two crop growing seasons.

Although, climate change is expected to have many impacts on various sectors, few sectors are as important as agriculture. In this regard, a better understanding of the sensitivity of climatic environment on crop production is crucial. Our study provides a protocol of the analytical framework to assess the change in crop production due to the change in climatic characteristics. Although, the findings of this study are drawn from the data in Taiwan, our analytical framework can be easily applied to the cases in other countries with similar environmental features (such as many areas of China). In an initial step of the analysis, future researchers may have to utilize the GIS system to identify a reliable indicator of the temperature and rainfall in each geographic region. In addition, a good farm-level dataset of crop production should be available. In the farm-level data, detailed information on output and input uses or expenses has to be well documented. In what follows, the climatic data in the geographic region can then be merged to the farm-level data based on the region that each farm is located. Conducting similar analyses in other countries and comparing the findings of these findings to the one of this paper should be interesting. For instance, given the similarity in the climatic characteristics between Taiwan and many areas of China, it will be interesting to see how crop production may respond differently between China and Taiwan. A comparison of our findings to the ones revealed in other case studies conducted in other countries should provide a more comprehensive picture of the sensitivities of crop production to the climatic environment.

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