The Effects of Crop Generic Resources and Biodiversity on Agricultural Production: An Empirical Study on Rice Farming

By

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I. Introduction

Crop generic resources provide the basis of agricultural production. The productive value of biodiversity in agricultural production is often high lightened at a number of circumstances. One of them is related to the concept of multi-functionality of agricultural sector and biodiversity in agricultural production. There has been increasing recognition to the importance of this concept (Sumner, 1981; Cooper et al., 1992; Di Falco and Chavas, 2004; Di Falco et al., 2005; Di Falco and Perrings; Heisey et al., 1998; Smale et al., 1998; Tilman et al.; Widawsky and Rozelle, 1998). It has been reported in the literature that a loss of biodiversity generates adverse effects on the functioning of ecological system (see Laureau and Hector). However, less attention has been devoted to the empirical analysis of the effects of biodiversity on the performance of farming. The findings of previous studies are somewhat inconclusive. While Widawsky and Rozelle identified negative effects of crop biodiversity on crop productivity, Smale et al. found an evidence of significant positive biodiversity effects on crop productivity and negative effects on the variance of yield.

In this study, we intend to investigate the effects of biodiversity on agricultural production. In particular, we focus on crop biodiversity (expressed as varietal diversity) effects on the mean and variance of rice yield in Korea. As well known, rice is one of crucial agricultural products in most of Asian countries including Korea. Investigation of crop biodiversity effects on rice yield contributes to the valuation of rice generic resource from a viewpoint of crop production. Specifically, we develop a model which enables us to recover the benefits and costs of crop biodiversity in terms of the mean and variance of crop production.

Using a panel dataset of crop trials data, this paper investigates the effects of biodiversity on the mean and variance of yields of rice farming in Korea. We investigate the long run relationship between yields and the crop biodiversity by performing a dynamic panel data analysis. These analyses will extend our empirical understanding of the dynamic implications of crop biodiversity on productivity and risk in rice farming. Thus, this paper is expected to make empirical contributions to the understanding of economic values of conserving plant genetic resources. From the policy context, this paper provides useful information on the evaluation of the current policy regime in Korean agriculture emphasizing a single rice variety production plan—the most of the local governments in Korea are currently pursuing—in order to minimize the processing and marketing costs and to strengthen the brand power.

2. Econometric Model

In an attempt to analyze the effects of biodiversity on agricultural production, we consider a stochastic production function proposed by Just and Pope (1978, 1979). As well known, the Just and Pope stochastic production function approach allows inputs of interest to have impacts on both mean and variance of yields by relating the variance output to explanatory variables in a multiplicative heteroscedastistic regression model. This provides a method of estimating the marginal risk effects of explanatory variables. Letting y_{it} denote the rice yield at test plot i and time t, $\mathbf{x}_{it}$ be a vector of inputs in the production process affecting the mean production, and $\mathbf{z}_{it}$ be a vector of inputs in the production process affecting the variance of yields, we have

$$(1) \qquad y_{it}(\mathbf{x}_{it}, \mathbf{z}_{it}, \beta, \gamma, e_{it}) = f(\mathbf{x}_{it}, \beta) + e_{it}[h(\mathbf{z}_{it}, \gamma)],$$

where β and γ are parameter vectors to be estimated and e_{it} is a random variable with zero mean and positive variance. By taking the expectation and variance of y_{it} in equation (1), the mean and variance relationship between output and inputs can be easily recovered: $E(y_{it}) = f(\mathbf{x}_{it}, \beta)$ and $Var(y_{it}) = h(\mathbf{z}_{it}, \gamma)^2 Var(e_{it})$. Note that in this specification, the stochastic production function can be interpreted as a regression model exhibiting heteroskedasticity and explanatory variables need not be identical between the mean and variance functions. Of particular interest are the effects of inputs ($\mathbf{z}_{it}$) on the variance of output. This allows us to recover potential benefits of biodiversity expressed as plant generic resources on production risk.

In general, the choice of functional form and specification of the mean and variance response function reflects the purpose of the investigation and data limitations. Here, our main purpose of the analysis is to test hypothesis regarding the effects of crop biodiversity expressed as varietal heterogeneity on the mean and variance of output. Keeping this in mind, to measure directly the tolerance-to-pest increasing effects of having affluent biodiversity on crop production, we first estimate the following crop disease function:

(2) $p_{it} = \alpha_0 + \alpha_1 N_{it} + \alpha_2 DI_{it} + \alpha_3 DI^2_{it} + \alpha_4 PD_{it} + \alpha_5 T_{it} + u_{it}$,

where p_{it} is crop pest index, N_{it} is the amount of Nitrogen fertilizer applied, DI_{it} is the biodiversity index, PD_{it} is the deviation from the mean value of precipitation during the growing season (from the early May to the late October), and T_{it} is time dummy as a proxy for technical change. Our biodiversity measure focuses on spatial biodiversity referring to the area distribution of varieties. The count of varieties has been a popular diversity index used for empirical studies (Di Falco and Chavas, 2004). However, a large number of varieties does not necessarily mean a high degree of genealogical diversity. This is because the degree of genetic diversity of two genetically similar varieties may be lower than that of less genetically similar varieties (Di Falco and Chavas, 2004). Following Weizman (1992) and Smale et al. (1998), we utilize pedigree information to measure the degree of genetic dissimilarity more accurately. In this paper, the number of parental combinations in the pedigree of the variety for the varieties grown in each test plot in each year is used as biodiversity indicator. As the degree of genetic diversity increases, our index approaches to 0, implying the presence of affluent crop genetic resources (i.e. a high degree of crop biodiversity). On the other hand, as the degree of genetic diversity decreases, this index approaches to 0, implying the presence of scarce crop genetic resources (i.e. a low degree of crop biodiversity). In an extreme case, when there is only one variety planted, the index takes the value of 1. Finally, a pest index is constructed. Since the information on a number of pest occurrences on six major rice pests (including rice stripe virus, bacteria leaf blight, blast, and Sheath blight), we constructed a pest index as the mean occurrence of pest per each test plot. Given the same test plot size for each variety, this equals the total number of pest occurrences per unit of test area. It is expected that the estimated relationship between crop pest and nitrogen will be positive, meaning that nitrogen fertilizer is pest-increasing input. The biodiversity effect on crop pest is expected to be negative. This captures the tolerance-to-pests increasing effects of biodiversity index, providing useful information on the decomposition of total crop biodiversity effects on the mean and the variance of yields into (i) tolerance-to-pests increasing effects and (ii) effects from resisting to other environmental stresses. The effects of precipitation on crop pest are expected to be positive since precipitation will provide benevolent environments for pests to be active.

The mean response function $f(\mathbf{x}_{it}, \beta)$ is specified as a quadratic function allowing for nonlinear relationship between rice yield and conventional inputs (such as Nitrogen fertilizer and weather conditions) and biodiversity index,

(3) $$f(\mathbf{x}_{it}, \beta) = \beta_0 + \beta_1 T_{it} + \beta_2 N_{it} + \beta_3 N^2_{it} + \beta_4 DI_{it} + \beta_5 DI^2_{it} + \beta_6 \hat{p}_{it} + \beta_7 SD_{it},$$

where $\hat{p}_{it}$ is predicted value of crop disease from equation (2), N_{it} is the amount of Nitrogen fertilizer applied, DI_{it} is the diversity index, SD_{it} is the deviation from the mean value of the amount of sunshine during a grain filling period which is known as the most critical period during a growing season for rice yield and T_{it} is time dummy as a proxy for technical change. Due to data limitations, we use a proxy for SD_{it}, a number of days with zero precipitation. The marginal effects of crop diversity on mean yield response are equal to $\hat{\beta}_4 + 2\hat{\beta}_5 DI_{it}$. Note that these effects are associated with the effects from resisting to environmental stresses other than crop pest whereas $\hat{\alpha}_2 \times \hat{\beta}_6$ captures the tolerance-to-pest increasing effects of crop biodiversity. The variance function $h(\mathbf{z}_{it}, \gamma)^2$ is specified as a exponential function of conventional inputs (nitrogen fertilizer) with biodiversity index measuring the value of having diverse generic resources on yield risk:

(4) $$h(\mathbf{z}_{it}, \gamma)^2 = \exp(\gamma_0 + \gamma_1 T_{it} + \gamma_2 N_{it} + \gamma_3 DI_{it} + \gamma_4 DI^2_{it} + \gamma_5 PD_{it}).$$

In this variance response specification, the coefficient estimates γ_3 and γ_4 captures the biodiversity effects on yield risk. Also note that inclusion of nitrogen fertilizer allows us to test hypothesis on whether nitrogen fertilizer is a risk-increasing input in rice production as found in the literature (Just and Pope, 1979). We also include PDit to capture the effects of precipitation during the growing season on yield risk. Note that in equation (4), we used the absolute value of PD_{it} given the implicit assumption that the impacts of small rainfall on rice yield and those of big rainfall on rice yield are equivalent.

3. Estimation Strategies

The econometric model discussed in the previous section can be consistently and efficiently estimated by generalized least-squares method. First, in order to obtain the least-square residuals, apply least squares in equation (1). Note that the least-square residuals are consistent estimators of error terms. Second, use this residuals to estimate the variance function ($(h(\mathbf{z}_{it}, \gamma)^2)$). Third, estimate equation (1) by generalized least squares using the inverse of the square root of the predicted values of the variance of error terms as a weight to deal with heteroskedasticity of error terms. This is a straightforward three-step estimation approach.

To make use of the panel structure of our data, we use a fixed effects panel estimation method on the top of three-step approach. This allows us to control for unobservable cross-sectional variations. In particular, the fixed effect estimation method is convenient for us given the nature of our dataset. This is because it takes care of the effects of varietal differences across test area i, which are difficult to be captured econometrically due to a large number of varieties being experimented in a given test area.

4. An application to rice production

We apply the econometric framework developed in the previous sections to rice production, with a focus on the productivity and risk implications of crop generic resources and diversity. Our analysis relies on a panel dataset from rice variety trials for the period of 1997-2004 for 22 test areas in Korea.[1] The experiment has been conducted on these 22 test areas through the Southern Korean peninsular in order to develop and promote a region-specific rice variety under the leadership of Rural Development Administration. More than 143 rice varieties have been applied with a set of different nitrogen fertilizer applications. These rice trials also have rich information on a number of crop pest (including blast) occurrences and crop growth conditions such as planting date and earing period. The daily weather information obtained from Korea Meteorological Administration includes precipitation, the hours of sunlight and temperature.

Note that our analysis depends on crop trials data. This has the following implications. While other input conditions are controlled by maintaining adequate levels of P and K, applying herbicides, insecticides, and undertaking pest control cultivations, the estimation results need to be interpreted with caution especially when discussing real world problems where many forms of heterogeneity are involved compared to a well-controlled experiment setting. Table 1 summarizes the dependent

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[1] These are only japonica type rice varieties reflecting the fact that Koreans usually prefer japonica to indica.

variable, biodiversity indicator expressed as varietal diversity, and conventional inputs suggested by economic theory. Summary statistics for these variables are provided in Table 2.

5. Estimation Results

Focusing on the mean and variance of rice yield, this section presents an empirical investigation of (i) the determinants of crop pest occurrence, (ii) the mean yield response of varietal diversity, and (iii) the variance response of varietal diversity.

5.1. Crop pest function

We first estimate the factors influencing the occurrence of rice pest. The econometric results are reported in Table 3. The coefficient estimates have expected signs and relatively high level of significance for a selected group of variables. First, nitrogen fertilizer and the number of pest occurrences are positively related with each other confirming the notion that nitrogen fertilizer makes crops easily disposed to pest. Second, we found a concave relationship between diversity index and the number of pest occurrences. The sign of the marginal effects of biodiversity index on rice pest are inconclusive due to the nonlinearity involved in the rice pest function between biodiversity index variable and rice pest. However, once evaluated at the mean of explanatory variables, these marginal effects are found to positive, implying that greater pest occurrences are associated with high degree of concentration of varieties (i.e., less amount of diversity). While the individual coefficients associated with DI and DI^2 are not statistically significant, their joint effects on the number of pest occurrences might be significant. This was done by testing the null hypothesis that $\alpha_2 = \alpha_3 = 0$ in (2). Using a F-test, the test statistic for this hypothesis was 2.38. Under the null hypothesis, the statistics has a F-distribution with (2, 176) degrees of freedom. Using a 10 percent significance level, this leads us to reject the null hypothesis of biodiversity not having any impact on pest occurrences. Put differently, we found strong statistical evidence of pest increasing effects of varietal biodiversity during the sample period. Third, precipitation is found to have a positive relationship with the number of pest occurrences confirming our belief that precipitation provides a nice environment for pests to be active. This relationship is statistically significant. Also technical change (time dummy variable) is negatively related to the number of pest occurrences. Being statistically significant, this provides empirical evidence on technical change in favor of pest reduction.

5.2. Mean and variance yield function

We explore the implications of crop biodiversity on the mean and the variance of rice yield. The econometric results are presented in Table 4. In general, the coefficient estimates have expected signs and relatively high level of significance. First, in the estimated mean function, coefficients on nitrogen fertilizer are statistically significant and have expected signs. We found a concave relationship between nitrogen fertilizer and the mean yield. This finding is consistent with a number of previous studies including Vanotti and Bundy (1994, 1995). Biodiversity index (DI and DI^2) is also found to have statistically significant convex relationship with the mean yield. However, once evaluated at the mean of explanatory variables, these marginal effects are found to be positive, implying that higher yield is associated with high degree of genealogical diversity. The predicted value of pest (PESTHAT) is negatively related with the mean yield. This finding is intuitive and provides empirical evidence on the number of pest occurrences having negative impact on the mean yield. The deviation from the mean value of the amount of sunshine during a grain filling period (SD) turns out to be not critical for rice yield in our analysis.

Second, in the estimated variance function, we found that nitrogen fertilizer has a positive impact on yield risk. Although this relationship is not statistically significant, it is consistent with a notion of nitrogen fertilizer as a risk-increasing input (Just and Pope, 1979). Time dummy variable (T) is found to be positively related with yield risk, suggesting the presence of technical change in favor of risk increase in rice production. We found a statistically significant concave relationship between biodiversity index variable and yield risk. The sign of the marginal effects of biodiversity index on yield risk are inconclusive due to the nonlinearity involved in the variance function between biodiversity index variable and yield risk. However, once evaluated at the mean of explanatory variables, these marginal effects are found to positive, implying that greater yield risk is associated with high degree of concentration of varieties (i.e., less amount of diversity).

Figure 1 depicts the mean and variance of rice yield for each year evaluated at sample mean. Risk in rice production seems to increase during the study period while mean yield fluctuates. These results seem consistent with current tendency of technological progress for new rice varieties; technological progress has been made to find a new rice variety searching for the quality and/or the functionality of rice variety, with less attention given to the productivity increase.

6. Summary and Concluding Remarks

This paper has investigated the effects of crop biodiversity on the mean and the variance of yield in rice production. It used panel data from 22 research station of Rural Development Administration in Korea during 1997-2004. The information on the number of pest occurrences reflects the strength of our dataset. This allows us to decompose total biodiversity effects into pest related effects and other environmental stress effects.

We found evidence that yield risk is positively related with crop biodiversity measured as genealogical dissimilarity reflecting the pedigrees of varieties. In other words, crop biodiversity is found to be a risk-decreasing input. The mean effect of crop biodiversity is found to BE convex and significant.

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Table 1. Definition of Variables

Variable	Definition
YIELD	Rice yield (kg/10a)
N	Nitrogen fertilizer (kg/10a)
PEST	The total number of pest occurrences per unit of test plot
SD	The deviation from the mean value of the amount of sunshine during a grain filling period (days without rain)
PD	The deviation from the mean value of precipitation during the growing season (mm)
DI	Genealogical diversity index
T	Time dummy

Table 2. Summary Statistics

Variables	Mean	Std. Dev.	Min	Max
ln(yield)	6.26	0.08	6.00	6.56
N	11.22	0.80	11.00	17.00
PEST	2.68	2.30	0.00	11.76
DI	0.07	0.03	0.03	0.17
SD	-0.23	6.71	-30.25	15.00
PD	-0.04	1.51	-4.05	4.81
T	4.40	2.23	1.00	8.00

* Number of observations: 225

Table 3. Estimation Results of Crop Pest Function ($R^2 = 0.0885$)

Parameter		Coefficient (Std. Err.)
α_0	Constant	0.6247 (2.5603)
α_1	N	0.1489 (0.2128)
α_2	DI	19.2914 (31.8981)
α_3	DI^2	-20.7428 (179.1460)
α_4	PD	0.2356 (0.0847)*
α_5	T	-0.2092 (0.0847)*

* significant at 1%.

Table 4. Mean and Variance Effects of Conventional Inputs and Varietal Diversity, Korea, 1997-2004

Parameter		Mean Function (R^2 = 0.9975)		Variance Function (R^2 = 0.0310)		
		Coefficient	(Std. Err.)		Coefficient	(Std. Err.)
β_0	Constant	16.1455	(7.0852)**	$\gamma0$	-11.8745	(3.2384)*
β_1	T	-0.0121	(0.0079)	$\gamma1$	0.0657	(0.0959)
β_2	N	0.9839	(0.0183)*	$\gamma2$	0.1156	(0.2665)
β_3	N^2	-0.0371	(0.0013)*			
β_4	DI	-8.9771	(4.2331)**	$\gamma3$	67.4569	(40.1562)***
β_5	DI^2	50.7186	(23.5622)**	$\gamma4$	-379.2790	(225.1691)***
β_6	PESThat	-0.0181	(0.0144)			
β_7	SD1)	0.0004	(0.0014)			
	PD1)			$\gamma5$	0.0554	(0.1881)

* significant at 1%, ** significant at 5%, *** significant at 10%

Note: 1) The absolute values of the deviation from mean values are used.

Figure 1. E-V frontier