Crop Biodiversity, Farm Productivity and the Management of Environmental Risk[1]

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July 6, 2004

[1] This is a draft. Comments are very welcome.

Abstract

In managed systems, such as agroecosystems, crop genetic resources are the raw materials for modern crop breeding, selection programmes, pest resistance, productivity, stability and future agronomic improvements. A number of studies in the agro ecology literature suggest that genetic variability within and between species confers at least the potential to resist stress, provide shelter from adverse conditions, and increase the resilience and sustainability of agroecosystems. This paper employs farm level data to analyze the impact of crop biodiversity on the mean and variance of yields. To this end a Just and Pope stochastic production function in adopted. It is found that biodiversity is positively correlated to the mean of production and negatively correlated to the variance of yields. Therefore, biodiversity has an important role in the managment of environmental risk.

1 Introduction

Natural scientists have long been concerned with the effects of widespread adoption of genetically uniform varieties on the productivity and stability of yields. A number of studies has been published on the assessment of the diversity - productivity hypothesis and the diversity - stability hypothesis. Crop biodiversity erosion increases the vulnerability of the crop to biotic and abiotic stresses. For instance, it has been found that biodiversity reduction promotes build-up of crop pest and pathogen populations[1] (Abalu, 1976, Singh, 1981, Sumner, 1981, Walker, 1983). Therefore, the greater is the diversity between and/or within species and functional groups, the greater is the tolerance to pests. This is because pests have more ability to spread through crops with the same genetic base (Sumner, 1981, Gleissman, 1986, Altieri and Lieberman, 1986, Trenbath, 1986; Heisey et al., 1998). Further, the performance of different species varies with climatic and other agroecological conditions. The agroecosystem is subject to stresses caused by inadequate rainfall and soil moisture, randomness of temperature, and potential evaporation, these all have all the potential to shape crop development and variation (Loss and Siddique, 1994, Pecetti et al., 1992).

Having functionally similar plants that respond differently to weather

[1] In a couple of studies on India, plot surveys showed that intercropping would reduce the probability of absolute failure of crop (Singh,1981), and that crop diversification increases crop income stability (Walker et al.,1983).

randomness contributes to resilience and ensures that "whatever the environmental conditions there will be plants of a given functional type that thrive under those conditions" (Heal, 2000) and it allows the agroecosystem to maintain productivity over a wider range of conditions (Tilman et al., 1994, 1996, Naeem et al., 1995, Bellon, 1996). Hence, crop biodiversity confers potential resistance to droughts and other environmental stresses and the cost of crop genetic uniformity can potentially be high. Therefore, crop biodiversity has economic importance in production systems, regardless of whether crop populations are characterized predominantly by old varieties, modern varieties or landraces (Meng et al.).

Concurrently with natural scientists, a number of studies on the driving forces of crop biodiversity loss have been published (Brush, Heisey, Smale, Meng,Van Dusen, Birol..) in the agricultural and resource economics literature. Market integration, agroecological conditions, the adoption of new high yielding varieties, and farmers' attitudes towards risk were found to be the key determinants of crop biodiversity management in the fields.

Surprisingly, less attention has been devoted to the empirical analysis of the diversity - productivity hypothesis and the diversity - stability hypothesis and the studies to date provide a rather mixed evidence. These studies are limited to Smale and Widawsky. For instance, Smale et al., 1997, estimated the effects on productivity of diversity among modern varieties in a stochastic production function framework (Just and Pope, 1977) using data from districts of Punjab of Pakistan. This study found that diversity is positively related to the mean of yields and negatively correlated with the variance of yields in rain fed districts. However, the analysis becomes statistically weaker when the relationship is tested in irrigated districts. Widawsky and Rozelle (1998), using data from regions of China, tested the impact of rice varietal diversity on the mean and the variance of yields. They found that the number of planted varieties reduces both the mean and the variance of yields, although the variance estimates are not statistically significant. Farmers' varietal choice is intrisically connected with the management of risk.

Keeping different varieties is a straightforward way to hedging against environmental risk. This is particularly true when production takes place in remote areas where there is no large technological progress and weather variability is present. In such circumstances local adaptation is of paramount importance.

This paper's contributions to the on going debate on crop biodiversity are twofold. First, it presents an assessment of the role of crop biodiversity on farm productivity and the farm management of environmental risk. To this end data from durum wheat farms of Sicily (Italy) are used[2]. Second, it provides a simulation exercise to understand if the productivity enhancing

[2]To our knowledge this is the first paper using

farm level data in this strand of literature role of biodiversity dominates the risk management role. The paper proceeds as following. Next section provides the conceptual background. The description of the area, farming techniques, data sources and variables is presented in section three. Section four provides the empirical analysis and section five concludes the study offering some concluding remarks.

2 Conceptual framework

Consider a production technology represented by the production frontier

$$y = g(x, v)$$

where y denotes the largest feasible output, x is a vector of controllable inputs (e.g., labor, capital), and v is vector of non-controllable inputs (e.g., weather conditions). In dry-land agriculture, weather conditions during the growing season are not known ahead of time. Then, at planting time, v is treated as a random vector, with a given subjective probability distribution. Just and Pope proposed to specify $g(x, v)$ as $g(x, v) = f(x) + [h(x)]^{1/2}\ e(v)$, where $h(x) > 0$ and $e(v)$ is a random variable with mean zero and variance 1. In this context, the Just-Pope production function becomes

$$y = f(x) + e(v)[h(x)]^{1/2}$$

It implies that $E(y) = f(x)$ and $Var(y) = h(x)$. Thus, $f(x)$ represents the mean production function, while $h(x)$ is the variance of output. Given

$\partial Var(y)/\partial x = \partial h/\partial x$, it follows that $\partial h/\partial x > 0$ identifies inputs x that are risk-increasing, while $\partial h/\partial x < 0$ identifies inputs that are risk-decreasing.

Note that $e(v)[h(x)]^{1/2}$ behaves like an error term with mean zero and variance $h(x)$. Thus, the Just-Pope specification corresponds to a regression model with heteroscedastic error term. After an appropriate parametrization of $f(x)$ and $h(x)$, the model can be consistently and efficiently estimated. This can be done by generalized least-squares using a three-step approach. First, estimate $y = f(x) + e$ by least squares. Second, use the least-squares residuals $[y - fe(x)]$ to estimate $h(x)$. Third, estimate the model by generalized least squares, using the estimated $he(x)$ as weight to take into consideration the heteroscedasticity. Alternatively, parametric assumptions can be made on the distribution of e, and the Just-Pope model can be consistently and efficiently estimated by maximum likelihood.

3 Area description, data and variables

The empirical analysis in this study is based on data drawn from the biggest island in the Mediterranean sea: Sicily. Production environment for durum wheat in Sicily is very difficult. Production takes places in remote and marginal areas (mostly on hills and mountains) where farmers have no access to irrigation. The area is characterized by typical Mediterranean weather, that is prone to severe droughts. The latter is a major constraint reducing cereal crop yields in many areas of the world. Nevertheless, Sicily is one of the biggest durum wheat producers in Italy. It accounts for more that 20% of the overall national production and circa 350000 hectares of land are allocated to durum wheat. The average land endowment of durum wheat farms is 48 hectares and the average productivity is equal to 29.2. Among the farm in the sample, production characteristics are quite homogenous. Both cropping technique and technological endowments are basically identical among the farmers. In august and September ploughing operations take place and two fertilizers applications are made. The first application is simultaneous to sowing in November. The second application follows in January. In this region farmers grows more than one cultivars in the same farm. The choice of cultivars is mainly driven by agroecological and climate conditions. In fact, this is an area prone to severe drought and there is no irrigation. Further, cultivars do differ for quality captured by protein, glutin concentration and color. The following table presents the main cultivars used by farmers in Sicily.

Variety	$\frac{\text{Land }\%}{1997}$	$\frac{\text{Land }\%}{1998}$	$\frac{\text{Land }\%}{2000}$	$\frac{Variation\ \%}{98-2001}$
Simeto	37.3	37.1	28.7	-8.6
Arcangelo	24.7	23.1	23.5	-1.2
Duilio	14.7	14.4	15.2	0.7
Colosseo	5.8	5.6	3.5	-2.3
Ciccio	0.1	2.1	11	10.9
Creso	3.3	3.4	3.1	-0,2
Appulo	3.1	2.8	2.9	-0.2
Tresor	1.6	2.9	2	0.4
Valbelice	1.4	1.6	1.6	0.2
Platani	1.8	0.7	2.2	0.4
Ofanto	1.5	1.9	0.4	-1.1
Rusticano	-	0.9	1.9	1.9
Norba	0.7	0.8	0.9	0.2
Radioso	0.5	0.2	0.2	-0.3
Others	3,7	2.3	2.9	-0.8

Table 1: Cultivars adopted in Sicily 1998 - 2001

3.1 Data source and variables

Data were obtained from a survey conducted by the *Consorzio per la ricerca su specifici settori della filiera cerealicola "Gian Pietro Ballatore"*[3]. The investigation was on sixty durum wheat farms in Sicily and refers to the average medium run production (five years from 1994/95 up to 1998/1999). Thirty farms are located in the west part of the island and the other thirty on the east part of the island and they all fall under five provinces[4].

The variable used in this analysis are: quantity of durum wheat produced, fertilizers and pesticides, used by the farm. All variables are divided by the land endowment. In order to control for different topology (production in mountains or hills) a dummy variable is added. It is widely held that a major limitation of most biodiversity indicators is that no single indicator can adequately capture the interaction among genes or between genes and the environment (Smale et al, Brown). A popular index is the count of varieties. However, increasing the number of varieties does not necessarily implies expanding the gene pool. Two genetically similar varieties can be counted as different. Pedigree information can be used in order to have a more accurate metrics of the genepool. In this paper we follow the Smale et al (11997) approach by using the number of parental combinations in the pedigree of the variety as biodiversity indicator. The number of parental

[3]Data have been published on G. Fardella, Aspetti tecnici, economici e qualitativi della produzione di grano duro nel Mezzogiorno d;Italia, Stampa Anteprima, 1999

[4]Palermo, Agrigento, Caltanissetta, Enna and Catania

combinations is counted only the first time it appears and calculated the average over the varieties grown by the farmer[5]. The following table summarizes the list of variables and descriptive statistics:

Variables	Mean	Std Dev	Min	Max
Fertilizers	357.65	89.5035	200	745
Pesticides	14.96	51.10	0	400
Land	43.17	48.56	0.76	285.97
Diversity	0.0014	0.0021	0.001	0.17
Production	25.44	6.92	14.3	44.4

4 Empirical Analysis

The stochastic production function approach proposed by Just and Pope (1977, 1978) provides a straightforward methodology to assess the role of biodiversity on the mean and the variance of durum wheat yields. The Just and Pope stochastic production function allows inputs that have a positive impact on mean production to have either positive or negative impact on the variance of yields. The production function is:

$$y_i = f(\mathbf{X},\beta) + h(\mathbf{X},\beta)u_i$$

[5] The estimation has been runned also with the count of varieties as diversity index. And no. of landraces in the pedigree. The results were similar although statistically weaker

where the term y_i is the quantity produced of durum wheat and z is a set of convetional inputs plus the biodiversity indicator, and e is the error tem. As functional specification a flexible quadratic production function is chosen for the mean function. Therefore,

$$y = a_0 + \sum_{i=1}^{n} b_i z_i + \sum_{i=1}^{n} \sum_{j=1}^{n} b_{ij} z_i z_j + u$$

Where $b_{ij} = b_{ji}$ for all $i \neq j$. The variance of yields is assumed to be a linear function of the conventional inputs, topography and the indicator of crop biodiversity

$$u^2 = b_0 + \sum_{i=1}^{n} b_i z + v$$

In order to test if endogeneity is at play an endogeneity regression test has been implemented..It has been found that is not possible to reject the null of exogeneity. The following table reports the estimation results

In the mean function variables representing conventional inputs (fertilizers and pesticides) shows the expected signs and are statistically significant. The dummy variable for topography is also statistically signifcant and is negatively correlated to the mean production. Therefore, production in the hilly part of the region is more difficult. Biodiversity is positively and significantly correlated with yields. Further, biodiversity is negatively and significantly related to the variance of yields. In a rain fed agriculture keep-

Variables	Mean Function	Variance Function
Constant	1.8 (9.82)	10.04* (4.68)
Diversity	111.97* (55.76)	−130* (8.63)
Diversity Squared	-385^a (275.31)	
Fertilizes	0.097* (0.044)	0.0025 (0.0021)
Fertilizers Squared	−0.00010* 0.00157	
Pesticides	0.34* (0.18)	−0.054* (0.0038)
Pesticides Squared	−0.00078** (0.00044)	
Topology	−3.77* (1.38)	−0.71* 0.04
$Log\ likelihood = -142.19; Wald\ statistic[4\ d.f.] = 137$		
$Significance\ code : * = 1\%\ with\ one\ tailed\ test; a = 5\%\ two\ tail$		

Table 2: Mean and Variance

	Mean function	Variance function
Biodiversity	0.1	-0.9

Table 3: Calculated elasticities

ing crop biodiversity is an important strategy in managing environmental risks. Pesticides are also risk reducing inputs. The estimated coefficient for fertilizers, though not significant, is positively related to the variance of production. It is interesting to note that this latter result matches the original finding of Just and Pope (1978), where fertilizers were found risk increasing inputs. Finally, topography is negatively related to the variance of yields. The following table presents the elasticity of the mean function and variance function with respect to crop biodiversity

5 Concluding Remarks

This paper presented an empirical assessment of the potential role of crop biodiversity in keeping medium run productivity and managing environmental risk. Where agrecological conditions are not favorable crop biodiversity conservation becomes a key strategy in keeping medium run productivity and managing environmental risks.The results showed in the previous section are particularly strong compared to the existing finding in the literature. Further, productivity role is still very important in marginal agriculture characterized by difficult production environment.

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