Wheat Diversity and Productivity in Indian Punjab after the Green Revolution

Melinda Smale, International Food Policy Research

Joginder Singh, Punjab Agricultural University, India E-mail: ravibaba@satyam.net.in

Salvatore Di Falco, University of East Anglica

Patricia Zambrano International Food Policy Research

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1. Introduction

The center of origin of wheat is "diffuse" (Harlan , 1992). Though India is not considered a primary center of diversity, evidence suggests that farmers have c ultivated wheat in India since 3000 B.C (Tomar et al. , 2004). Until the early 1990s, farmers are thought to have grown a wide range of landraces and landrace mixtures. Some of these served as the basis for the Indian breeding program, initiated with the es tablishment of the Agricultural Research Institute in 1905. Since then, India has contributed important wheat genetic resources to modern plant breeding programs in numerous countries, as demonstrated in the recorded pedigrees of modern wheat varieties (see, for example, Zeven and Zeven-Hissink, 1976).

The Green Revolution in wheat began in Indian Punjab during the late 1960s, as did the c oncern for genetic erosion caused by the displacement of local landraces (Harlan , 1972; Frankel, 1970; Hawkes , 1983). Even during the Green Revolution and post -Green Revolution periods, however, farmers maintained wheat variety   diversity by continuing to grow local strains for home consumption and to   minimize any risks associated with successive introductions of high-yielding varieties.

Genetic erosion is not easy to quantify, in any case. In regions with high productivity potential like the Indian Punjab, much of the area was already planted   with earlier products of modern plant bre eding programs when the Green Revolution began (Jain, 1994). These cultivars were more genetically similar and less productive than the semi-dwarf wheat varieties that succeeded them.

Seeking resistance to wheat diseases was a central motivation for early plant breeding programs. Since the Green Revolution, plant breeders have sought to diversify genetic resistance to diseases in modern wheat varieties in order to reduce the vulnerability of the crop to epidemics. Nonetheless, from year to year, diversifying the mix of varieties grown can gene rate costs in terms of annual yield losses relative to yield potential, especially in favored environments (Heisey et al., 1997). Challenging the efficacy of c entralized breeding programs, Witcombe (1999) has argued that productivity gains might be achieved by delivering more diverse varieties to farmers, even in high potential production environments such as the P unjab of India.

In this paper, we define and summarize indices of variety change and genetic diversity for the modern wheat varieties released and grown in Indian Punjab since 1980. We then test the effects of the two indices on wheat productivity in the post-Green Revolution period. The first is the area-weighted average of varietie s grown. This index measures the rate of variety change, adjust ing for the spatial distribution of varieties. In modern, intensified farming systems, the speed of variety change substitute s to some extent for th e spatial heterogeneity found in landrace systems, and is an important means of counterac ting the uniformity that can lead to pathogen mutation and plant diseases. Variety change is determined in large part b y variety release and se ed industry policies. The second is the average coefficient of diversity, computed from the average coefficient of parentage. This index measures the exten t of dissimilarity among wheat varieties conferred by inheritance, or plant breeding. A generalized Cobb -Douglas production function is estimated with these indices specified as technical efficiency parameters, after testing for the exogeneity of each index.

The next section defines diversity in modern wheat systems , along with the diversity concepts and indices used in this paper. De scriptive summaries of the indices follow, with interpretation. The econometric model is then spec ified, and the estimation procedure de tailed. Findings are reported. Conclusions and policy implic ations are dra wn in the final section .

2. Measuring diversity in modern wheat systems

The Green Revolution in wheat refers specifically to the rap id adoption of varieties with semi-dwarf stature (conferred by Rht1 and Rht2 genes) during the late 1960s and early 1970s. Other dwarfing genes and other c ultivars of short stature exist in wheat, and taller varieties produced by modern plant breeding programs were released before 1960 and have been released since . When grown with increased levels of fertilizer and a controlled water supply, these varieties performed signif icantly better t han the varieties they replaced. Initially, they sprea d rapidly throughout many of the irrigated zones of the developing world where wheat cultivation was concentr ated and where population densities were high—often replacing improved varieties with tall stature. Later, more widely adapted descendants of these varieties spread gradual ly into less favorable environments, including rainfed areas with relatively modest production potential —often replacing landraces. This paper focuses on this later period, often called the post -Green Revolution.

Meng et al. (1998) summarize the issues related to measurement of diversity for economic analysis. A panoply of diversity indices are found in the crop science and ecological literature. No single index of diversity is inherent ly superior to another.

Different indices represent different concep ts and can be constructe d with various types of raw data. Meng et al. (1998), in addition to an extensive technical literature in the crop sciences, discuss the advanta ges and disadvantages of various indices employ ed to study the genetic diversity of crop plants. More recently, Brock and Xepepadeas (2003) have also analyzed classes of more generalized classes of diversity indices from the perspective of a unified, theoret ic economics framework.

To characterize the d iversity on farms in production system s with modern varieties, three conce pts are relevant. Spatial diversity refers to the geographical distribution of varieties. A second, the rate of variety change, substitute s to some extent in modern systems for the spatial diversity found in landrace sy stems (Apple, 1977; Plucknett a nd Smith, 1986). Spatial diversity and variety change among modern varieties in farmers' fields is determined in l arge part by the e conomic factors affecting their profitability and the performance of agricultural research in stitutions and seed industries. A number of issues related to variety change in modern wheat systems have been analyzed in previous work (Heisey, 1990; Heisey and Brennan, 1991). Brennan and Byerlee (1991) developed and applied the area -weighted average a ge used here.

Pedigree analysis has been used by crop scientists to assess the latent genetic variability among a set of modern varieties, such as those grown in a district of Indian Punjab in one cropping season. A practical method for incorporating p edigree information into a usable form is through calculating a coefficient of diversity, equivalent to one minus the coefficient of parentage. In wheat, the coefficient of parentage (COP) measures the probability that two cultivars are identical by descen t for a character that varies genetically (Malecot, 1948). In calculating the average coefficient of parentage for

a set of cultivars, each pair has e qual weight. Average coefficients of parentage plotted over time provide an indication of the relative ch ange in diversity due to plant breeding. The average coefficient of diversity was developed and applied to a nalysis of wheat varieties in Pakistani Punjab by Souza et al. (1994) .

3. Wheat Diversity in Indian Punjab

The number of different parental comb inations and the number of distinct landrace ancestors in the ped igrees of modern wheat varieties grown in Indian Punjab from 1970 are shown in Table 1, ordered by date of release and variety name. There is a positive , step trend in the number of different parental c ombinations, illustrating the role of plant breeders in continuing to bring in new materials and make new crosses. The number of different landrace ancestors in the pedigrees of the varieties has a stat istically significant, but imperceptible trend. Comparing the ratios of the figures at different time periods suggests that a declining number of new landraces are used in parental c ombinations. For example, the rat io of unique landraces to unique parental combinations is nearly two - thirds in 1966, as compared to one -third after 3 decades.

The average and area -weighted average age of wheat varieties , representing the speed of variety change, are shown for Indian Punjab from 1970 to 2001 in Figure 1. In this generally high potential production env ironment, the unweighted and weighted average age s move closely together in a cyclical pattern , suggesting that varieties are fairly uniformly distributed spatially over the time period as they are introduced into the system and others are discarded by far mers. The exception to t his pattern is visible from

about 1998, when fewer varieties are grown and they tend to be older, leading to an increase in the average age.

The average and area-weighted average coefficients of diversity (for brevity and to distinguish these from temporal diversity, we refer to them in the remainder of the paper as genetic diversity conferred through breeding) constructed from the pedigree data are shown in Figure 2. The pattern in the area-weighted indices echoes that observed for area-weighted variety age, but with sharper peaks and troughs, diverging more in direction from about 1990. A downturn is evident at the end of the period, rather than the upturn that is observed in the rate of variety change. Hence, in the final years of the 1990s, the relatively fewer varieties grown were not only older in age, but more similar in parentage than those of the first half of the decade. The area-weighted coefficient of diversity lies everywhere below the unweighted average, and is at its lowest since the early 1970s in 2000-01. The fact that Indian wheat breeders drew in more dissimilar parentage over the 1970-2000 period is also apparent, since the average coefficient of diversity among all varieties grow in Indian Punjab has generally floated upward to over 85 %. For purposes of comparison, the coefficient of diversity between a parent and offspring would be 25%, and would be close to 50% for a sibling, while the coefficient of diversity for varieties with no ancestors in common would be 1.

4. Analytical approach

Initial attempts to link diversity in modern cultivars to productivity are Gollin and Evenson (1998); Smale et al. (1998) and Widawsky and Rozelle (1998). Widawsky and Rozelle (township data for Zhejiang and Jiangsu Provinces) used a generalized Cobb-

Douglas production function with a stochastic specification to t est the e ffects of diversity on mean and variance or rice yields (Just and Pope , 1979). Diversity was measured using a Solow/Polasky distance index constructed fro m pedigree data, and the diversity index was entered as an interce pt shift in the regression equation. Sm ale et al. (1998) used a Cobb-Douglas function with Just and Pope specification to test the eff ects of wheat diversity on mean and variance of yields in the irrigated and rainfed districts of Punjab (1979-1985).

Consistent with these earlier studies , we test the effects of variety change and genetic diversity on crop p roductivity by adopting a Generalized Cobb-Douglas specification. Along with a s et of conven tional inputs (e.g. chemical inputs, labour, capital), the area-weighted average variety age and the average coefficient of diversity were specified as separate explanatory variable s. To analyze the interplay between the diversity conferred br eeding and the variety cha nge in farmers' fields, which is due variety release and seed supply, we added an interaction term. The introduction of an interaction term also generalize s the Cobb-Douglas function by relaxing the restrictive assumption of unita ry elasticity of substitution between inputs.

Let y = f($\mathbf{x}$) denote the product ion function, where y is quantity of durum wh eat and x is a n x 1 vector of inputs. In the single output case, the Cobb -Douglas production function is written a s:

$$y = A\Pi_{i=1}^{n} x_i^{\alpha_i}, \quad \text{where } \alpha_i > 0, \forall I = 1,...,n \tag{1}$$

By taking logarithms we have an expression that is linear in parameters,

$$\ln(y) = \alpha_0 + \alpha_i \Sigma_i \ln(x_i) \tag{2}$$

where $\alpha_0 = \ln(A)$.

This specification implies that $((\partial y/\partial x_i)/(y/x_i)) = \alpha_i$. The estimated *i-th* coefficient can be readily interprete d as the marginal productivity of the *i-th* input. We are interested in the est imated coefficients for variety change, genetic diversity and their interaction.

5. Data

The Farm Management Extension Wing of Punjab Agricultural University regularly collects data regarding the wheat varieties planted fr om a sample of 600-700 farmers distributing among the districts and different agro -climatic conditions of the state, with a rotating sample. Variety data were compiled for the period 1981 -82 to 2001 -02. The costs of various inputs were based on the data collected every yea r from 300 farmers under the Govt. of India sponsored "Comprehensive Scheme of Cost of Cultivation of Major Crops in Punjab". The data on cost items are expressed in Rs/ha. Observations are district by year.

6. Econometric estimation

The cross sectional and longitudinal na ture of the data a t hand suggests the appropriateness of a panel data estimator with fixed effect s to control for district character istics. After dividing all the variables per land size so that all variables are expressed in per hectare base, and performi ng a logarithmic transformation, we estimated $Y_{it} = \alpha + \beta X_{it} + \upsilon_i + \varepsilon_{it}$ where X is a matrix of explanatory variables, υ_i is the region-specific residual and $\varepsilon_{it} \sim IID (0, \sigma^2)$.

We also examined whether the model may be subject to endogeneity due to correlations of variety change and genetic diversity indices with the error terms. If these

indices were correlated with the error term, the least-squares est imates of the effects of indices on wheat yield would be biased . Endogeneity of the two indices wa s tested with The Durbin-Wu-Hausman method, which compares ordinary least squares estimates with estimates obtained from an instrumental variable estimator. Lagged values were used to build up the instruments and the results compared to the same model estimated using OLS. We failed to reject the null hypothesis that th e ordinary least squares (OLS) estimate yields consistent est imates. Thus, endogeneity among the regressors has no deleterious effect s on OLS estimates and instrumental variables method was n ot required.

Finally, purchased fertilizers and purchased pesticides were aggregated as purchased chemicals, in order to reduce multicollinearity.

7. Hypotheses

Consistent with econo mic theory, conventional inputs are hypothesized to be positively related to wheat yields per hectare. These include machinery costs per hectare, costs for fertilizers and pesticides, and costs for hired labor (all in current Rs.) More rapid variety change on farms, is thought to contribute positively to wheat productivit y through mitigating the buildup of biotic pressures an d bolstering yield potential. When weighted by area, the index also accounts for relative abundance of some newer releases. The average coefficient of diversity, calculated from the coefficients of p arentage, is expected to positively affect wheat productivity through breeding advances.

8. Results

Regression results are presented in Table 2. The signs and significance of conventional inputs are as expected, cont ributing positively to marginal prod uctivity. Capital, labor a nd

chemicals use they all have positive marginal productivity, although the latter is statistically not significant. Dissimilarity of parentage in wheat varieties, augmented through successful breeding, clearly enhances wheat productivity in Indian Punjab from 1980 to 2000. Slower variety change, taking into account the spatial distribution of varieties, decreases productivity. The negative interaction effect also shows that slower variety change offsets breeding successes.

9. Conclusions

The Punjab of India is an historical source of key wheat genetic resources in national and global plant breeding. This region has also been a focus of concerns about some of the negative externalities of the Green Revolution, including the abandonment of local varieties and genetic erosion.

In this paper, we used a production function framework to test the role of genetic diversity conferred through plant breeding and the rate of variety change in the Indian Punjab during the Post-Green Revolution period. The study is one of the few that tests related hypotheses using a combination of diversity indices constructed from detailed pedigree data, variety area data, and data on conventional inputs. Econometric findings demonstrate that continued in fusion of diverse genetic materials through planting breeding has enhanced productivity in the wheat fields of Punjab in the Post-Green Revolution period. Slower rates of variety change dampen productivity, and also offset the positive impact of diversifying the genetic base through plant breeding. Clearly, policies that speed up variety change on farms, and encourage more diverse spatial distributions, would reinforce rather than counteract the progress made through crop

improvement. Even within a system that is charact erized by modern varieties, continued

investments in breeding and seed supply are critical to sustain crop productivity.

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Table 1
 Pedigree characte ristics of modern wheat varieties grown in Indian Punjab from 1970

Name	Release year	Number of different parental combinations in pedigree	Number of different landrace ancestors in pedigree
PV18	1966	58	37
S 308	1966	90	39
HD 1553	1967	90	39
KALYANSONA	1967	58	37
SONALIKA	1967	90	39
WG 357	1973	61	40
WG 377	1973	60	39
WL 1562	1979	88	43
WL 711	1979	106	45
DWL5023	1982	91	40
PBW 120	1982	150	55
PBW54	1983	121	52
HD 2285	1985	188	59
HD 2329	1985	153	58
PBW 34	1985	65	38
PBW 138	1986	112	51
HD 2428	1989	109	46
PBW 154	1989	144	54
PBW 226	1989	74	42
PBW 222	1990	112	48
PDW 215	1991	70	39
CPAN 3004	1992	164	57
HD 2009	1993	71	37
WH 542	1993	163	52
WH 542	1993	163	52
PBW 343	1995	192	65
PBW 373	1995	192	65
PDW 233	1996	103	41
UP 2338	1997	140	49

Source: Variety names from Punjab Agricultural University, pedigrees from
CIMMYT Wheat Impacts database and Pedigree Management System.

Table 2
Estimated production function with temporal and genetic diversity

Variables	Coefficients	Std. Errors
Temporal	-0.42**	0.189
Genetic diversity	0.71**	0.35
Temporal*Genetic	-0.125*	0.7
Capital	0.107***	0.398
Labor	0.0000503**	0.0000239
Chemicals	0.17	0.97
Constant	2.12***	0.3

R squared: 0.52; F -Test: 16.47, Significance code: *** =1%, ** =5%, *= 10%;

N: 108. All conventional inputs are in Rs/ha. See text for calculation of temporal and genetic diversity variables.

Figure 1. Average and area-weighted average age of wheat varieties grown in Indian Punjab, 1970-2001
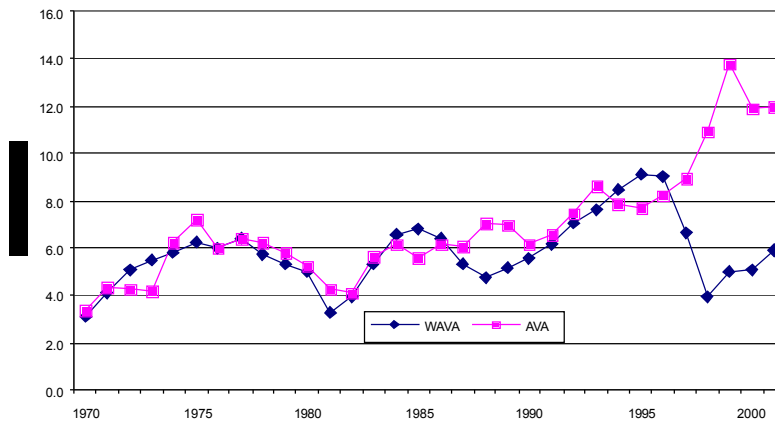
Source: Data from Punjab Agricultural University. Calculations based on Brennan and Byerlee (1991).

Figure 2. Average and area-weighted average coefficient of diversity for wheat varieties grown in Indian Punjab, 1970-2001
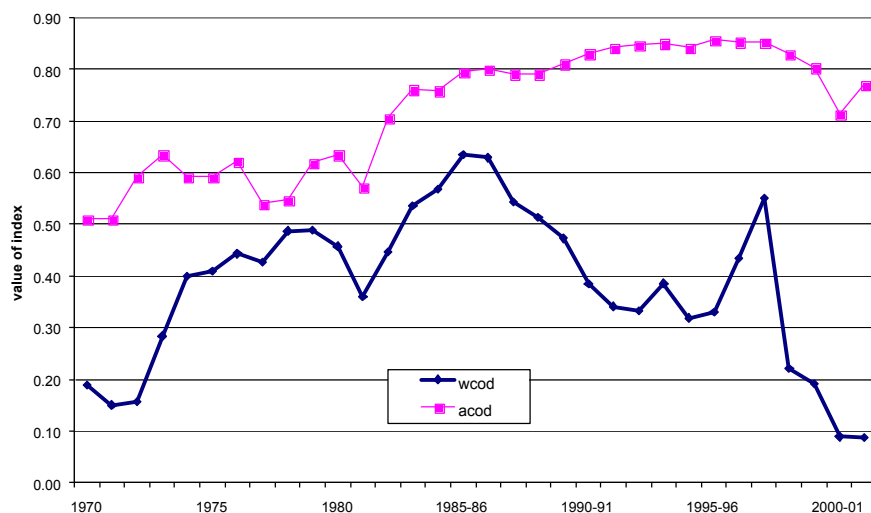
Source: Data from Punjab Agricultural University. The average coefficient of diversity (acod) is the average of 1 -cop(ij) where cop(ij) is the pairwise coefficient of parentage between any two varieties of the j varieties grown in each year. The area -weighted average coefficient of diversity (wcod) is the average of 1 -cop(ij) where cop(ij) is the pairwise coefficient of parent age between any two varieties of the j varieties grown in each year, weighted by the areas planted to them (Souza et al 1994).