The Cost of Wheat Diversity in China

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Abstract:

Using a unique data set on wheat varietal diversity in China, we estimate the "marginal cost" of crop genetic diversity using a Cobb-Douglas cost function. Crop genetic diversity is measured using an ecological index of spatial diversity constructed from variety area shares and wheat morphology groups. Specifying crop genetic diversity endogenously in a simultaneous system with a cost equation and input shares enables us to link it more explicitly to policy variables and the economic decisions of farmers.

Paper presented at the 1999 Meetings of the American Agricultural Economics Association, Nashville, Tennessee. We would like to thank the research staff of CCAP for valuable assistance and acknowledge the financial support of the Australian Center for International Agricultural Research.

The global initiative to conserve biodiversity encompasses the diversity both among and within wild and domesticated species. Much of the economic research on biodiversity conservation focuses on the costs and benefits of preventing the extinction of species that have aesthetic, intrinsic, or indirect use value to humans through supporting the ecosytem in which they live (Swanson; Pearce and Moran). A number of the issues related to the conservation of crop genetic diversity, motivated by fears that potentially valuable genes or genetic combinations will disappear from farmers' fields as higher-yielding modern varieties are adopted (Harlan; Frankel), pivot on whether society should forego the welfare benefits of today's productivity gains for the uncertain benefit of future generations of producers and consumers.

For many governments of developing countries, however, the choice between the needs of today's consumers and producers and the uncertain welfare benefits of future generations is unequivocal. Due to concerns for food security, increasing and sustaining yield levels over time historically have topped the list of research priorities. Close to 90 percent of all wheat area in the developing world is currently planted to modern wheats, including semi-dwarf and other wheats released by plant breeding programs (Heisey, Lantican, and Dubin, 1999). Why should the governments of these countries care about the management of crop genetic diversity?

Crop scientists have long been concerned about the effects of widespread cultivation of genetically uniform varieties on the vulnerability of the crop to biotic and abiotic stresses (NRC). The cost of this vulnerability potentially can be very high. Attempting to influence the distribution of cultivars over a crop-producing landscape is one avenue for *preventive* control of genetic resistance (Priestley and Bayles; Dempsey; Heisey et al.). The spatial diversity of crop populations can therefore have economic importance in production systems, regardless of whether they are characterized predominantly by modern varieties or landraces.

Initial efforts to estimate the effects on productivity of diversity among modern varieties in a production function framework (Smale et al.; Widawsky and Rozelle) have been unsatisfactory in at least two respects. First, the conventional primal approach estimates the marginal effects of diversity on technical efficiency but does not examine issues of allocative efficiency. Producer behavior with respect to prices is not explicitly addressed. Second, measures of genetic diversity previously used may not necessarily have fully represented the diversity present in the crop. The development and incorporation of a biologically meaningful index of crop genetic diversity into an economic decision-making model is not straightforward (Meng et al., 1999). Previous studies have most often used diversity measures based on named varieties or pedigree information; however, advances in statistical and scientific methods have permitted increased accuracy in the representation of diversity.

In this paper, we employ recently developed methods for classifying crop populations (Franco et al.) and indices of spatial diversity adapted from the ecology literature (Magurran) to measure crop genetic diversity and link it to economic decisions through estimation of a cost function. With this framework, we examine the marginal economic cost (or benefit) of wheat genetic diversity as well as its effect on input allocations.

The next section presents a description of the techniques used to calculate indices of wheat genetic diversity and examples of their application to the data. This is followed by a brief review of recent changes affecting the costs and efficiency of wheat production in China. Data and methods used to estimate the cost function are then presented, followed by results. The paper closes with a discussion of policy implications.

Wheat Genetic Diversity in China

Defining the wheat population

Crop populations can be classified by the names or criteria that farmers use to describe them, by their genealogies as recorded by plant breeders, or by the genetic identity that molecular analysis reveals. The use and interpretation of diversity indices requires caution since distinctions based on one method of classification, or taxonomy, may not be distinguishable when other criteria are used. Relying on named crop populations may overestimate diversity if populations identified by different names are similar or underestimate diversity if those identified by the same name possess important underlying genetic differences.

Variation in plant characteristics and other types of descriptors can also serve as the basis of the taxonomy. Analysis based on specific characteristics and performance of plant populations decreases the likelihood of overlooking some of the differences that may not be picked up when relying on names. Morphological traits are physically observable descriptors often used in the crop science literature to describe plant populations and assess their diversity. These traits can be measured both quantitatively (e.g., height, spike (wheat) or ear (maize) length, thousand kernel or cob weight) and qualitatively (e.g., kernel or grain color, awn presence). Because observable variation in plant characteristics can result from either genetic differences or differences in the environment, precautions must be taken to account for interactions between genotype and environment before drawing any conclusions regarding diversity levels.

To construct diversity indices for wheat production in China we use for comparison purposes both named wheat varieties and groups of varieties defined by morphological traits. The morphology-based groups were formed by combining maximum likelihood estimation with a clustering method to predict group membership statistically based on plant characteristics obtained from experimental trials (Franco et al., 1998). Specifically, the clustering is based on pairwise Gower distances among varieties measured on habit, resistance to stem rust, duration, height and kernel weight at time of release. Several other traits that were available for analysis were not used due to their high level of correlation with the selected traits. The means of some of the selected characteristics and yield are shown in Table 1. By using data from experimental trials that are designed to minimize the interaction between genotype and environment, we increase the certainty that the observed variation in traits reflect genetic differences.

Adapting ecological indicators of spatial diversity to the study of crop populations

Although indices developed in the ecology literature are used primarily for analyzing the spatial diversity of species in a community of flora or fauna, they can be adapted to the study of spatial diversity in crop populations in an area of production. Magurran (1988) classifies ecological indices of species diversity in terms of three concepts: (1) richness, or the number of species encountered in a given sampling effort; (2) abundance, or the distribution of individuals associated with each of the species; and (3) proportional abundance.

Table 1. Mean characteristics of wheat morphology groups grown in the major wheat-producing provinces of China from 1982 to 1994[1]

Group	Yield	Kernel Weight	Kernel Number	Duration	Height
1	355.60	41.68	35.13	242.74	85.86
2	325.51	43.53	45.01	183.32	88.15
3	281.38	38.02	30.00	258.77	102.57
4	396.58	40.53	35.16	234.81	84.46
5	361.22	42.54	35.61	237.25	83.14
6	293.84	37.82	37.28	204.50	100.20
7	336.17	40.41	30.39	250.28	90.19
8	356.50	36.24	43.80	205.00	73.33
9	372.78	39.33	35.76	228.41	87.26
10	302.13	36.46	33.33	96.80	91.17

1 From trial data at time of release

A count of species reported or collected in the area, although usually the most simple to implement, assumes that all species at a site contribute equally to its biodiversity (Harper and Hawksworth, 1995). Since often this is not the case, frequency counts of individuals within a species provide more information. Indices of abundance detect whether or not certain varieties or groups of varieties dominate others, or whether there is "evenness" in their distribution across a landscape. Also called "equitability," it refers to the degree of equality in the abundance of the individuals, or the relative uniformity of their distribution across species. When all species in a sample are equally abundant, evenness reaches a maximum (Ludwig and Reynolds, 1993).

The third category, which combines the richness of species with a measure of their relative abundance, includes the widely used Shannon[1] and the Simpson indices. They have been termed "heterogeneity indices" and "non-parametric indices" because they account for both and make no assumptions about the shape of the underlying species abundance distributions. The Shannon index has been commonly employed to evaluate species diversity in ecological communities. It has also been widely applied in the agronomic literature to compare sets of

[1] Shannon and Wiener independently derived the function which is most well known as the Shannon index (Magurran, 1998).

varieties by transforming qualitative traits into a scalar measure (Spagnoletti Zeuli and Qualset, 1987; Jain et al., 1975).

For applied economists, one of the major dilemmas with respect to diversity indices is how to relate these concepts defined on biological and genetic phenomena to the economic decisions of farmers and breeders in a way that is suitable for policy analysis. Economists studying crop genetic diversity have often used indicators of spatial diversity in empirical applications (see Meng 1997; Brennan et al., 1999; Widawsky and Rozelle, 1998; Pardey et al., 1996; Smale et al., 1998; and Smale, Bellon, and Aguirre, 1998). In this paper, we have adapted and applied several of the ecological indices used to represent spatial diversity to data on wheat populations in China. Table 2 lists each index used by its name, category, concept, and mathematical construction, with an accompanying explanation.

Table 2. Definition of spatial diversity indices used in this paper

Index	Concept	Mathematical Construction[a]	Explanation	Adaptation in this paper
Margalef	Richness	$D_{mg}=(S-1)/\ln N$ $D_{mg} \geq 0$	number of species S recorded corrected for the total number of individuals N summed over species	S=number of wheat varieties grown in a season N= total hectares of wheat in that season
Berger-Parker	Relative abundance (Dominance)	$D=1/(N_{max}/N)$ $D \geq 1$	the less dominant the most abundant species, the higher the index value	inverse of maximum area share occupied by any single wheat variety
Shannon	Richness and Evenness	$H'=-\Sigma p_i \ln p_I$ $H' \geq 0$	p_i is proportion, or relative abundance, of a species	p_i is area share occupied by ith variety
Pielou	Evenness	$E=H'/\ln S$ $0 \leq E \leq 1$	Shannon corrected by the logarithm of the number of species recorded	S=number of wheat varieties grown in a season
Simpson	Richness and Evenness	$D_s=1-\Sigma p_i^2$ $0 \leq D_s \leq 1$	also represented in the form of $D_s = 1/\Sigma p_i^2$	

Source: Table adapted from Aguirre, Bellon, and Smale, 1998. Mathematical construction as defined by Magurran (1988).
[a]Magurran reports that in species diversity models, the value of the Shannon index is usually found to fall between 1.5 and 3.5, rarely surpassing 4.5. The maximum of the Shannon index is ln S (when all species are equally abundant), so the or Shannon-Evenness index is the Shannon relative to its maximum. The value of this index should therefore range from zero to 1.

Richness, dominance, and evenness indices reflecting the average diversity measured in seven major wheat-producing provinces of China between 1982 and 1997 are presented in Figures 1 and 2.[2] The implications of using different taxonomies to define crop populations are revealed when indices with identical construction, but using populations classified by cultivar name and by morphological characteristics are compared. The level of diversity reflected by morphological group classification is uniformly lower than that reflected by classification using named varieties. The range in index values differs between the two definitions because group may include several varieties. The relative order of the indices also changes between the two classification taxonomies. The Simpson and Pielou indices do not exhibit much variation of the time period, although slightly more variation is evident in the morphologically-based indices than in those of variety names. The Margalef index for named varieties reflects an increase in the level of diversity over time that does not appear when using classification by morphological groups. The Shannon index of morphological groups exhibits a decreasing trend in diversity in the mid 1980s that again is not reflected in the index using named varieties. Finally, the marked increase in diversity observed in the named variety Berger-Parker index in the early 1980s is not evident in its morphological group counterpart. In general, it appears that changes in diversity visible using named varieties are somewhat dampened in the morphological classification.

Indices of richness, dominance, and evenness for each of the seven major wheat-producing provinces of China were also examined. The diversity indices constructed from data on named wheat varieties consistently attribute the provinces of Shanxi, Anhui, and Hebei with a higher level of diversity than other provinces included in the analysis. Both richness and dominance indices concur that Sichuan province is the least diverse of all the provinces included in the analysis. This finding also holds when calculating these indices based on morphological groups, although the indices are not in agreement with respect to the relative order of the other provinces. The contrast between Sichuan and the other provinces recurs in the evenness indices. Sichuan appears to be the least even according to both classification taxonomies which show that the spatial distribution of wheat cultivars and morphology in Sichuan is relatively “poor” and “inequitable.”

The comparison across the richness, dominance, and evenness indices calculated using the

[2] Provinces included in this analysis are Anhui, Hebei, Henan, Jiangsu, Shanxi, Shandong, and Sichuan.

data set of named varieties suggests that Hebei and Shanxi are the most diverse throughout the study period, while Henan and Sichuan provinces almost always rank among the least diverse. However, the relative order of the provinces changes considerably depending on the year as well as the category of spatial diversity being represented. A similar situation holds when using data on morphological groups. Henan and Sichuan provinces stand out as the least diverse regardless of the index of spatial diversity examined, but there is much less consistency in the conclusions regarding the remaining five provinces.

Productivity in Chinese Agriculture

The structure of agricultural production and productivity growth in Chinese agriculture has been the subject of many studies (McMillan et al, 1989; Fan, 1991, 1997; Lin, 1988, 1992; Fan and Pardey, 1997; Rozelle and Huang, 1997; Huang and Rozelle, 1996; Huang et al., 1996). The consistently observed growth rates in agricultural production, exceeding even the growth in population, have been recognized as one of the country's major policy accomplishments (Rozelle and Huang, 1997). In the last 43 years, grain production has increased by an average of 3% per year (Fan and Pardey, 1997). A specific examination of wheat production shows that wheat has not been an exception; its production and yield growth rates surpassed those of both rice and maize from the 1970's through the mid 1980's (Rozelle and Huang, 1997).

Much discussion has also taken place regarding the factors contributing to the productivity growth in Chinese agriculture. Technological advances, particularly in the form of improved varieties, have played a key role in grain production (Lin, 1991; Rozelle and Huang, 1997). The institutional and market reforms implemented in the late 1970's and continuing into the mid 1980's have also been credited with a major role in agricultural productivity growth (Lin, 1992; Wen, 1993). Government investment in research and in infrastructural development has been identified another major factor (Fan and Pardey, 1997). Rozelle and Huang (1997) single out investment in irrigation, particularly in the North China Plain wheat-maize region, as an important factor specifically for wheat production. Finally, Huang and Rozelle (1996) also draw attention to the role of environmental factors in detrimentally affecting grain output.

Most previous studies examining productivity growth and efficiency in Chinese agriculture have approached the analysis from the primal side largely for data-related reasons. Two recent studies have taken the dual approach to examine production efficiency. Wang, Cramer and Wailes (1996) use household data to estimate a shadow frontier profit function to separate the effects of technical and allocative efficiency. Because of market distortions caused by sociopolitical and institutional constraints, they question the appropriateness of assuming profit-maximizing behavior in China. Fan (1999) argues that while the assumption of cost minimization may be appropriate, rice farmers in Jiangsu allocate inputs (fertilizers, pesticides, labor, and machinery) according to their shadow prices.

In this paper we assume that wheat farmers minimize costs, and as a preliminary approach, we use Fan's (1999) estimates of distortion ratios to convert observed input prices to shadow prices. We test the hypothesis that the spatial diversity of wheat affects the total cost of wheat production and input allocations in the major wheat-producing provinces of China. By so doing, we estimate the marginal cost of promoting a more "equitable" distribution of wheat varieties in terms of the economic efficiency of wheat production. We use the Shannon index of evenness in morphological groups of wheat varieties as our index of crop genetic diversity. Since spatial diversity indices are constructed from data on the area shares planted to varieties, they are therefore endogenous to input use decisions. Furthermore, since provinces are the unit of analysis rather than farmers, and farmers are unable to observe the effects of crop genetic diversity on risk, a risk-neutral decision-making framework is employed. The next section presents the specification of the regression model and data.

Model Specification and Data

The model is specified as Cobb-Douglas, and in general form may be written as:

(1) $$C = C(y^{\circ}, \mathbf{r} \mid \mathbf{v}, \delta, \mathbf{z}, t)$$

(2) $$s_i = s_i(\delta, \mathbf{v}, \mathbf{z}, t)$$

(3) $$\delta = \delta(\delta_m, \delta_b, \mathbf{v}, R, \mathbf{z}, \mathbf{d})$$

Subscripts for year and province have been suppressed. Total wheat costs per hectare (C) are determined by the predicted level of wheat output (y^{o}) and a vector of shadow input prices ($\boldsymbol{r}$), conditioned on genetic diversity (δ), experimental yield potential of cultivated wheat varieties and age of wheat cultivars grown ($\mathbf{v}$), and a vector of policy and environmental variables ($\boldsymbol{z}$). The latter vector includes a shifter variable for each of 3 policy regimes from 1982-84, 1985-90, and 1991-95; a multiple cropping index, and variables measuring the arable land identified as prone erosion, drought, and flooding. A separate variable for the overall level of government investment in research is also included. This variable does not vary across provinces and incorporates expenditures on extension and breeding research, among others.

Shares for *i* inputs (labor, fertilizer, pesticide, and machinery) are specified as "constant" in the Cobb-Douglas function, but are also conditioned on the shifter variables specified in the cost function. A time trend and squared time trend are included in cost and share equations in order to estimate neutral technological change.

The diversity equation expresses the evenness in the spatial diversity of wheat morphological groups in China as driven in part by the same environmental factors that affect the cost of wheat production ($\boldsymbol{z}$) and the weighted average yield potential and weighted average age of cultivars accounting for 80% of the sown wheat area ($\mathbf{v}$). Instruments in the equation are the Margalef and Berger-Parker indices calculated from area shares of named cultivars (δ_m, δ_b), the total level of research expenditures (R), and provincial fixed effects ($\mathbf{d}$). This equation states that environmental factors and provincial effects held constant, the morphological evenness of a wheat crop in any given year and province is determined by the availability of germplasm in the wheat research system, the richness of named cultivars grown by farmers in that year and their relative abundance, and parameters related to the past diffusion of cultivars. Farmers choose to allocate their land among the wheat varieties that are available to them. In the aggregate, their choices determine the distribution over space of morphological traits. We hypothesize that the evenness of this distribution in terms of morphological traits in turn affects wheat productivity and therefore the cost of and input allocation in wheat production.

The simultaneous system was estimated using three-stage least squares in LIMDEP, and the approach follows closely that employed by Antle and Pingali (1994) to analyze the effects of pesticide use on health and the cost of rice production in the Philippines. Restrictions on input prices within the cost function as well as cross-equation restrictions were imposed, and the cost share equation for machinery was dropped. Wheat output is predicted in a single equation ordinary least squares regression with sown area, lagged output price, a variable representing irrigation infrastructure, variety-specific (**v**) factors, and the vector of policy and environmental variables (***z***).[3] [4]

Results

The estimated coefficients of the system are presented in Table 3. Overall, the conventional variables in the cost system (input prices, output) are significant and of the expected sign. The estimated coefficient on the time trend in the cost function suggests that per hectare costs of wheat production have been declining over this time period. The level of environmental degradation increases costs as does the area weighted experimental yield potential of varieties cultivated, perhaps due to farmer perception that these varieties require a higher level of inputs. Its significance in the fertilizer cost share equation can be interpreted as reinforcing this conclusion.

Estimation results show that the diversity index has a positive and significant effect on total per hectare costs of wheat production and the cost share of fertilizer. The interpretation underlying these results is not immediately clear. The diversity index, however, has a negative and significant effect on cost shares for labor and pesticides. Recall that diversity as it is defined here measures the evenness of morphological groups in farmers' fields. A more

[3] With LIMDEP, computational constraints were encountered when this equation was estimated simultaneously with equations (1) to (3).

[4] Panel data for the provinces of Anhui, Hebei, Henan, Jiangsu, Shanxi, Shandong, and Sichuan from 1982 to 1995 on costs, input and output prices, environmental conditions, and government investments are used in the estimation. Data are calculated from information obtained by the Ministry of Agriculture (Financial Division and Science and Technology Division), the Ministry of Finance, State Statistical Bureau, and various issues of China's statistical and agricultural yearbooks.

equitable distribution of morphological traits may provide a natural means of defense against pests and thus reduce the expenditure share of pesticides.

Table 3. Results of 3SLS estimation of cost and share equations with endogenous genetic diversity

Explanatory Variable	Cost	Labor	Fertilizer	Pesticide	Genetic Diversity
Constant	7.279*	.369*	.432*	.112	-41.2*
Time	-.0836*	.0131+	-.0334*	.00486*	
Time^2	.00449*	-.000423	.000360	-.000163*	
Erosion	.0418*	.0547*	-.0244	-.00298*	7.975*
Flood	.169*	-.0108	-.00690	.00426	1.171
Drought	.180*	-.0243	.0189	-.0128	.189
Multiple Cropping index	-.311*	.165*	-.00189	.00604*	-4.92*
Variety yield potential	.00189*	-.000892*	.000635*	-.000246*	.0306*
Variety age	-.00854	.00265	.0205*	-.00483*	1.542*
Policy regime 1	-.0333	.0291+	-.0446*	.00469	
Policy regime 3	-.0593+	-.0274+	.0000192	.00294	
Wheat output	.0000938*				
Wage	.369*				
Fertilizer price	.432*				
Pesticide price	.112*				
Machinery price	.0874*				
Genetic diversity	.000167*	-.000101*	.0000932*	-.0000210*	
Variety richness					1.07*
Inverse variety dominance					-.063
Research investment					-.738*
Anhui					22.3*
Hebei					18.47*
Henan					21.1*
Jiangsu					28.6*
Shandong					22.6*
Shanxi					3.17*
n = 98					
F-significance	.00	.00	.00	.02	.00
Wald significance	.00	.00	.00	.00	.00

* significant at .05 level with Z test + significant at .10 level with Z test

Increasing the equity of distribution in morphological traits may also alleviate labor bottlenecks and inefficiencies during key periods of wheat planting and harvesting. Recall also that one of the traits determining morphological groups is duration, an important consideration for farmers in multiple-cropping systems.

Estimation results from the diversity equation suggest a positive relationship between richness in named varieties and evenness in groups differentiated by morphological traits. Expenditures for research decrease the evenness. These expenditures include costs of extension and a possible explanation may involve the nature of extension efforts with respect to varietal choice. These often consist of the selection and recommendation by agricultural and government officials of limited number of varieties. Indicator variables for the provinces also show that controlling for policy and environmental variables, all provinces still exhibit a higher level of diversity in evenness than Sichuan, the default province.

Policy Implications

In response to the importance placed on grain production and food security by the central government, one of the top priorities in Chinese wheat research is the development of new varieties that will advance the yield frontier. Increases in yield potential are achieved not only through the general influx of new genetic materials, but also through the targeted inclusion of genetic materials that reinforce or bring in new sources of resistance to existing and new diseases and pests. Yield gains can also be obtained by developing varieties that are adaptable to less than optimal environmental conditions. Genetic diversity thus may play an indirect role in more technically efficient wheat production by advancing scientific gains in breeding, depending on whether or not it is utilized in achieving these gains.

Although these preliminary results indicate that evenness in morphological groups is a positive factor in overall costs per hectare of wheat production, the relationship of genetic diversity with specific input use remains a factor to consider. If the influx of new genetic sources for pest and disease resistance have simultaneously resulted in increased levels of measured diversity, interaction with other required production inputs may have also changed. Genetic diversity may thus contribute to a more efficient use of inputs, such as pesticides, which otherwise would have been required for a similar level of production stability. Specific policy conclusions based on these preliminary results are most likely not warranted. Ongoing work, including the estimation of shadow input prices based on data from wheat production in these provinces, will refine the results. Future work will also further investigate the relationship of crop genetic diversity to economic efficiency and policies.

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Figure 1. Seven Province Average of Spatial Diversity Indices for Named Wheat Cultivars in China, 1982-1995

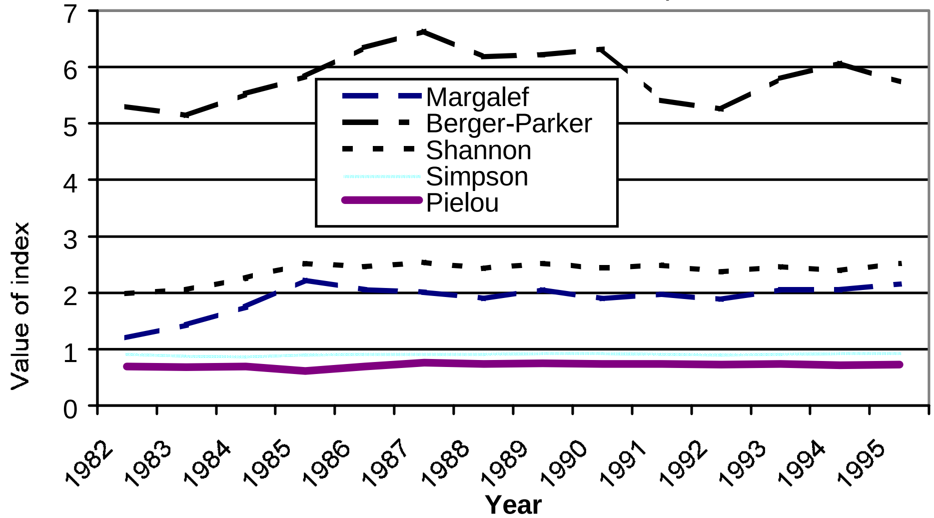

Figure 2. Seven Province Average of Spatial Diversity Indices for Wheat Morphological Groups in China, 1982-1985