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The Genetic and Economic Impact of the University of Arkansas's Rice Breeding Program: 1983–2007

L. Lanier Nalley, Karen A. Moldenhauer, and Nate Lyman

This study estimates the proportion of rice yield increase in University of Arkansas Division of Agriculture's (UofA) released rice cultivars that are attributable to genetic improvements through the University's breeding program. Test plot data from eight UofA experiment stations were used to quantify the yield increases and potential yield growth decreases over time. In addition to quantifying the yield and yield variance evolution at the UofA, this study also calculates the economic benefits of the UofA rice breeding program. Results indicated that by releasing modern rice cultivars, the UofA rice breeding program increased average producer yield by 0.68 bu/ac annually. During the last decade, 1997–2007, the average annual economic benefits were 34.3 million (2007) dollars. When accounting for the spillover of UofA rice varieties to neighboring states the average annual economic benefit of the breeding program increases to 46.7 million (2007) dollars.

Key Words: economic impact of technological change, Just and Pope, public rice breeding

JEL Classifications: O13, O32, Q16

Public research in rice breeding has resulted in higher yields for Arkansas rice producers over the past three decades. This study measures the genetic and economic impact of the University of Arkansas Division of Agriculture's (U of A) rice breeding program over the last 24 years (1983–2007). Yield increases for rice varieties released by the UofA breeding program were quantified, holding growing conditions, grain length, climatic conditions, and other agronomic improvements in production constant. The yield differential for each rice variety included in the UofA's annual Arkansas Rice Performance Trials (ARPT) was quantified to isolate the percentage of yield enhancement attributable solely to the genetic improvement at the rice breeding program at the University of Arkansas. The main objective of this study was to determine the proportion of the increases in yield of University of Arkansas-released rice cultivars attributable to genetic improvements. Test plot data from eight University run experiment stations were used to quantify the yield increases and potential yield growth decreases over time. Furthermore, this study set out to determine whether modern rice cultivars released by the UofA have influenced yield variability during the same 24-year period. Yield variation may have decreased due to genetic enhancements through improved tolerance to rice blast and other pathogens, resulting in higher levels of yield stability

In addition to quantifying the yield and yield variance evolution at the University of Arkansas'

L. Lanier Nalley is an assistant professor, and Nate Lyman is a graduate student, Department of Agricultural Economics and Agribusiness, University of Arkansas, Fayetteville, AR. Karen A. Moldenhauer is a professor, University of Arkansas Division of Agriculture Rice Research and Extension Center, Stuttgart, AR.

rice breeding program, the third objective of this study was to calculate the economic benefits of the UofA's rice breeding program for rice to local producers in Arkansas and the surrounding states that sow UofA varieties. This is important for formulating future policy decisions, given the recent trend of budget cuts at public institutions.

Measurements of the Benefits of the UofA Rice Breeding Program

The methodology used to calculate the economic benefits of the Arkansas rice breeding program followed an extensive literature on the economic impacts of agricultural research, as summarized by Huffman and Evenson (2006) and Alston, Norton, and Pardey (1995). Previous evaluations of breeding programs have been exemplified in studies by Nalley, Barkley, and Chumley (2008); Nalley et al. (2008); Brennan (1984, 1989a); Byerlee and Traxler (1995); and Barkley (1997). Brennan (1989b) goes further by evaluating the breeding programs at different stages in their lives.

The first step in evaluating the economic impact of the Arkansas rice breeding program was to measure the increase in yields from the genetic improvement of rice, holding all other production parameters constant. This was accomplished by applying the methodology of Feyerherm, Paulsen, and Sebaugh (1984) to calculate the relative yields for each variety with data from the ARPT for rice varieties. Use of relative yield performance data from test plots implicitly assumes that actual producer yields are equivalent to test plot yields in the UofA rice experiments. Although a gap between experimental and actual yields exists, Brennan (1984) wrote, "The only reliable sources of relative yields are variety trials" (p. 182).[1] Annual changes in relative yields are measured with performance test data, which represent ideal management and agronomic conditions, instead of actual rice yield performance.

The genetic contribution of the Arkansas rice-breeding research program was measured by quantifying the increase in yields attributable to genetic enhancements in rice for the period 1983–2007. Yield gains were measured from all varieties released by the UofA, beginning with Newbonnet in 1983. Salmon (1951) reported that tests over many location-years are necessary to detect differences in cultivar yields. Yield data were aggregated over all locations and years to develop a yield ratio for each variety. Following Feyerherm, Paulsen, and Sebaugh (1984), relative yield ratios were derived by calculating the mean yield ratio over all location-years where each rice variety was grown together with the control variety (Newbonnet). For ease in interpretation, yield differences were also calculated by subtracting the mean yield of each variety from the mean yield of the control variety.

The yield ratio and yield differential provide comparisons of variety performance (Table 1). While the Feyerherm, Paulsen, and Sebaugh (1984) method allows for estimation of relative yield differences, it does not account for differences in breeding objectives; that is, if a variety is bred for blast resistance, lodging resistance, or bred for not only maximum yield but yield stability as well. To incorporate the objective of yield stability the Just and Pope (1979) method is implemented.

The Just-Pope Model

A Just-Pope (1979) production function was selected for its ability to offer flexibility in describing stochastic technological processes. This method provides a straightforward procedure for testing the relationships between increased yield and yield stability. The Just-Pope production function allows inputs to affect both the mean and variance of outputs. The production function is as follows:

$$(1) \qquad Yi = f(\mathbf{X}i, \beta) + g(\mathbf{X}, \alpha)\varepsilon_i,$$

where Y_i is yield of the ith cultivar, the $\mathbf{X}_i$ are explanatory variables, β and α are parameter

[1] In 2007 the United States Department of Agriculture reported an average yield of 160 (bu/ac) for the entire state of Arkansas compared with the Arkansas Rice Performance Trials (ARPT) average of 168 (bu/ac), a 5% difference (University of Arkansas, CES, 2007). That being said, experimental test plot yields should be viewed as a yield "ceiling" for producers to analyze varieties by. An overestimation of a breeding program can result given the size of the yield "gap" between test plots and on-farm results.

Table 1. Relative Yield Advantages of University of Arkansas Rice Varieties, 1983–2007

Variety	Average Yield	Yield Ratio[a]	Yield Difference (bu/acre)[b]	Year Released to Public	Number of Observations	Long Grain
			Traditional			
Taggart*	201.03	1.35	52.21	2009	28	Yes
Templeton*	192.38	1.29	43.56	2008	61	Yes
Spring	150.00	1.01	1.18	2005	45	Yes
Banks	191.00	1.28	42.18	2004	62	Yes
Francis	196.00	1.32	47.18	2002	96	Yes
Ahrent	163.00	1.09	14.03	2001	140	Yes
Wells	191.00	1.28	42.18	1999	133	Yes
Drew	172.00	1.16	23.18	1996	149	Yes
Kaybonnet	159.93	1.07	11.11	1994	103	Yes
LaGrue	181.00	1.22	32.18	1993	228	Yes
Orin	161.80	1.09	12.98	1991	15	No
Alan	128.07	0.86	−20.75	1990	15	Yes
Millie	134.03	0.90	−14.79	1990	27	Yes
Katy	138.22	0.93	−10.60	1989	53	Yes
Semidwarf						
Cybonnet	181.00	1.22	32.18	2004	63	Yes
Medark	175.00	1.18	26.18	2004	63	No

[a] Mean values of the ratio of the yield of each variety to the yield of the control variety (Newbonnet) for all location years. A larger value indicates a higher yield relative to the control variety.
[b] Calculated by subtracting the mean yield of each variety from the mean yield of the control variety (Newbonnet). The control variety is Newbonnet, control yield = 148.82 bu/acre.
** Although Taggart and Templeton were released to the public in 2009 and 2008, respectively, they had test trials that that fall into the period analyzed in this study (1986–2007).

vectors, and ε_i is a random variable with a mean of zero. The first component of the production function $f(\mathbf{X}_i, \beta)$ relates the explanatory variables to mean output. The function $g(\mathbf{X}_i, \alpha)\varepsilon_i$ relates the explanatory variables to the variance in output. Since the basis of the Just-Pope production function is that the error term of the production function depends on some or all of the explanatory variables, it can be viewed as a multiplicative heteroscedasticity model, which can be estimated using a three-stage procedure. If variance is an exponential function of K explanatory variables, the general model with heteroscedastic errors can be written as:

$$(2) \qquad Y_i = X_i'\beta + e_i, i = 1, 2, \ldots, N$$

$$(3) \qquad E(e_i^2) = \sigma_i^2 = \exp[X_i'\alpha],$$

where $X_i' = (x_{1i}, x_{2i}, \ldots, x_{ki})$ is a row vector of observations on the K independent variables. The vector $\alpha = (\alpha_1, \alpha_2, \ldots, \alpha_k)$ is of the dimension (K x 1) and represents the unknown coefficients. $E(e_i) = 0$ and $E(e_i e_s) = 0$ for $i \neq s$. Equation (3) can be rewritten as

$$(4) \qquad \ln \sigma_i^2 = X_i'\alpha,$$

where the σ_i^2 is unknown, but using the least square residuals from Equation (2) the marginal effects of the explanatory variables on the variance of production can be estimated such that:

$$(5) \qquad \ln e_i^{*2} = X_i'\alpha^* + u_i,$$

where e_i^* is the predicted values of e_i and where the error term is defined as:

$$(6) \qquad u_i = \ln (e_i^{*2}/\sigma_i^2).$$

The predicted values from Equation (5) are used as weights for estimating generalized least squares coefficients for the mean output Equation (2). That is, the estimates from Equation (5) can be viewed as the effects of the independent variables on yield variability. The predicted values

from Equation (5) are then used as weights when re-estimating Equation (2). The results from the re-estimation of Equation (2) with the weights from Equation (5) provide the effects of the independent variables on yield.

Multiplicative Heteroscedasticity

An advantage of the Just-Pope production function is its correction for multiplicative heteroscedasticity, which is important for varietal traits because of the variations in both the species and breeding goals across cultivars. Since cultivars are intended to be grown statewide and are specifically bred for resistance to different pathogens and adaptation to various agronomic conditions, the error terms across cultivars may be heteroscedastic in nature.[2] The Just-Pope production function accounts for these variations and corrects the associated multiplicative heteroscedasticity in the error terms.

Data Collection

Data were collected from the ARPT test plots throughout the Delta of Arkansas from 1986–2007. The ARPT data consisted of six university-run experiment stations: Pine Tree (St. Francis County), Stuttgart (Arkansas County), Rowher (Desha County), Keiser (Mississippi County), Cotton Branch (Lee County), an experiment station in Missouri, and two test plots conducted on farmer's fields in Jackson (Ruteldge Farm) and Clay (Ahrent Farm) counties. Cultural practices varied somewhat across the ARPT locations, but overall the rice variety trials were conducted under conditions for high yield. Nitrogen was applied to ARPT tests located on experiment stations in a two-way split application of 100 lb Nitrogen at preflood followed by a single mid-season application of 30–60 lb Nitrogen (depending on the experiment station location). Phosphorus and potassium fertilizers were applied before seeding at the Stuttgart, Jackson County, and Clay County locations. A total of 17 varieties were tested from 1986–2007; however some of the varieties were released before 1986 but were still sown in farmer's fields and thus included in the test plots. That is, even though the test period for this data set was 1986–2007, cultivars released prior to 1986 were also included. The oldest variety in the study was Newbonnet released in 1983, and the most recent was Taggart released in 2009.[3]

Rice Varieties

Long grain rice grown in the southern United States has cooking qualities that can be described as typical (Moldenhauer, Gibbons, and McKenzie, 2004 and Slaton, 2001) and produces rice that is dry and fluffy (non-sticky) when cooked. Long grain rice varieties grown in Arkansas are typically milled, parboiled, quick cooked, or used in processed rice products. Medium grain rice varieties grown in Arkansas produce moist sticky rice when cooked and are used in breakfast cereals, soups, baby food, and in alcoholic brewing processes. Approximately 93% of the observations in the data set were of the long grain variety with the remaining 7% being medium grain.

Semidwarf rice varieties are those who have been bred with a dwarfing gene that allows the plant to mitigate some lodging issues associated with high yielding varieties. In other words, a shorter variety often has a reduced chance of falling over under the weight of its own grain. The traditional "standard stature" varieties produce more biomass and have the potential for an increased market as a bioenergy source. Approximately 12% of the observations in the data set are semidwarf varieties with the remaining 88% being traditional varieties.

Empirical Model

The mean and variance of yield are specified as a function of the release year (*RLYR*) of each cultivar, which can be interpreted as the "vintage" of the rice breeding technology (Arrow,

[2] Breusch-Pagan test, significant at the 1% level, indicated the presence of heteroscedasticity.

[3] Two varieties, Taggart and Templeton, were released to the public after 2007 but had test plot observations before 2007.

1962; Traxler et al., 1995). *RLYR* captures the progression of rice breeding technology across time, and is the main variable for measurement and analysis of the impact of the UofA's rice breeding program on rice yield. That is, the coefficient of *RLYR* represents the increases in yield due to genetic enhancement attributable to the UofA's rice breeding program. Following previous work (Traxler et al., 1995), a distinction should be emphasized between release year (*RLYR*), which varies from 1989–2009, and the trial date, which varies from 1983–2007. Each cultivar has a single *RLYR*, the date that the cultivar is made available for planting and the embodied breeding technology for that specific year. In the multiple regression model estimated here, the coefficient on *RLY*R captures only the effect of rice seed technology at the year of release. Thus, each cultivar is represented by only one *RLYR*. A typical newly released cultivar has relatively higher yields than previously-released cultivars in the early years of adoption, followed by replacement by higher-yielding releases later. Release year is not a time trend variable, but is modeled similar to the way that Arrow's (1962) growth model denoted embodied technology (Traxler et al., 1995). Arrow (1962) assigned "serial numbers" of ordinal magnitude to the embodied technology in capital. In this model, the variable *RLYR* represents the embodied technology for a given year of release by the UofA breeding program. An *RLYR* squared term allows the model to capture curvature in the estimated relationship between yield and *RLYR*. Moreover, curvature provides breeders, administrators, and policy makers the ability to monitor not only yield increase, but also whether it is increasing at an increasing or decreasing rate.

Mean and variance of yield were also modeled as a function of rice grain length: medium and long grain. A distinction between the two needed to be made given the fact they are used/bred for different purposes. While there is no *a priori* expectation of a yield difference between grain lengths, given the fact they are bred for different end use purposes, grain length needed to be held constant. Long grain was selected as the default because it was the most common grain length planted during the study. The University of Arkansas has released both tradition (standard statured varieties) and semidwarf varieties. Although given a normal growing year, standard and semidwarf varieties in Arkansas yield approximately the same, *ceteris paribus*, given the higher probability of lodging and thus yield loss in standard varieties during a wet/windy growing season, a distinction needs to be made between the two. The standard saturated varieties were chosen as the default since the majority of the varieties released by the UofA are of standard stature.

Yield is not the only selection criteria in the rice breeding program at the University of Arkansas. Therefore, a complete analysis of returns on investment should include yield growth and other traits such as yield stability, disease resistance, and end-use quality. While the most obvious tangible improvements of a breeding program are increased yields, the substantial economic benefits achieved as a result of yield losses avoided through disease (biotic) resistance (blast, sheath blight, smut, and stem rot) should be taken into consideration. Other economic benefits of a breeding program can be in the form of abiotic improvements such as decreased water needs (number of days on flood), improved heat stress, and cold tolerance (for early season rice). Improvements in biotic resistance/tolerance and abiotic stress can lead to higher yields and reduced yield variability. Or, it could leave both mean yields and variability constant, but it still has value as rice yields might otherwise have deteriorated as pathogens evolve to overcome resistance genes. Traits other than yield growth are difficult to measure and assess, and are therefore beyond the scope of the present study.

A dummy variable was included to represent each growing year from 1983–2007 with 2007 being the base year. The *year* variable was included to hold growing season anomalies constant. That is, if early rains delay planting, hurricane winds cause excessive lodging (2007), abnormally dry or wet growing seasons result in yield reductions, etc. By holding these growing season anomalies constant with the *year* dummies, these yield reductions can be accounted for and statistically correct yield estimates can be obtained for each growing year.

A dummy variable was also included for each ARPT experiment station. The station variable is

the cross-sectional component of the panel data, and plays a pivotal role in holding growing conditions constant across the growing regions. Growing conditions, climatic and agronomic, vary by location throughout the state. Rainfall and other growing conditions in Northeast Arkansas diverge from the Southeast Arkansas experiment stations. Another spatial difference would be the presence of blast, smut, sheath blight, or any other diseases, which may vary across locations. By including the station variable the model can hold these spatial variances constant across experiment stations. Where the *year* variable can determine if a given growing season is abnormally wet or dry for the state as whole, the station variable can determine within a year if a specific location is abnormally wet or dry and can isolate spatially specific disease outbreaks. These differences in growing conditions across experiment field locations, or stations, are accounted for by inclusion of the station variable in the regression model.

The estimated equations for yield (Y_i) in kg/ha and the log variance of yield (e_i^2) were modeled as in Equations (7) and (8).

$$Y_{ijt} = \beta_1 RLYR_i + \beta_2 RLYR_i^2 + \beta_3 Medium + \beta_4 Semidwarf + \delta_t + \varphi_i + \varepsilon_i \tag{7}$$

$$\ln(e_{ijt})^2 = \lambda_1 RLYR_i + \lambda_2 RLYR_i^2 + \lambda_3 Medium + \lambda_4 Semidwarf + \delta_t + \varphi_i + \varepsilon_i \tag{8}$$

where Y_{ijt} is the yield in bushels per acre for variety i, at station j, in time period t. *Medium* and *Semidwarf* are qualitative variables (0–1) for variety i. $RLYR_i$ is the release year for variety i. The term δ_t represents a vector of qualitative variables for each year (t), from t = 1983 to t = 2007, with t = 2007 being omitted as the base (default) year. The term φ_i is a vector of qualitative variables for each of the eight locations, or experiment stations, where the variety test performance experiments are conducted.[4] The Rice Research and Extension Center in Stuttgart is the omitted, representing the base category.

Model Results

Table 1 illustrates the average yield and release year for each variety in the study, and the results from the Just-Pope model. Both the effects on yield and on yield variance and the ordinary least squares (OLS) estimates are shown in Table 2 and Table 3 presents the fixed effects regression coefficients. Using the estimated *RLYR* and $RLYR^2$, while holding constant all other variables at their means, partial derivatives of the function with respect to release year were calculated and illustrated on the bottom of Table 2. More than 39 percent of the variation in rice yields was explained by the regression model for the 1983–2007 period. The medium grain varieties released by the UofA yielded 9.71 bushels per acre more than the long grain varieties, holding all else constant. Semidwarf varieties were shown to yield approximately 15.98 bushels per acre less than the traditional (standard) varieties released by UofA. This was expected since the majority of varieties released by the UofA breeding program were of standard height (93%), inferring that the majority of its time, effort, and money were spent on standard statured varieties.

The "release year" variable, or the year in which each respective rice variety was released to the public, was positively associated with yield, and on average was equal to 0.68 (Table 2).[5] This result would indicate that each year the UofA breeding program increased average yield for their varieties by 0.68 bushels per acre annually, equivalent to a 0.42 percent annual yield increase (0.68/162.39, where 162.39 is the average yield for all UofA varieties over the time period under investigation). During the 1983–2007 period, the UofA rice breeding program contributed 16.42 bu/ac cumulatively to rice yields (0.68 × 24). This equates to a 10.11% (16.42/162.39) increase to producer

[4] The Hausman test, for fixed versus random effects, indicated random effects were appropriate. That being said, the t-ratio for fixed effects were larger, in absolute value, and the coefficient differences between the two models were negligible. Thus the fixed effects model was implemented.

[5] The regression included a squared term ($RLYR^2$) meaning that 0.68 bu/acre is not a constant but rather the average increase in annual yield over the time period. The average *RLYR* term was calculated from regression results on Table 2, $RLYR = \beta_1 + 2(\beta_2 * \overline{RLYR})$.

Table 2. Regression Results from OLS and Just-Pope Production Functions

Variable	OLS Yield[a] Coefficient	Just-Pope Yield[b] Coefficient	Just-Pope Variance[c] Coefficient
Constant	178389.69	177242.12	4600.23
	(4.47)*	(−4.35)*	(1.48)
RLYR	−179.57	−178.38	−4.60
	(−4.48)*	(−4.36)*	(−1.47)
$RLYR^2$	0.05	0.04	0.001
	(4.50)*	(4.75)*	(1.41)
Medium	9.96	9.72	−0.25
	(4.50)*	(4.10)*	(−1.44)
Semidwarf	−16.22	−15.98	−0.63
	(−5.73)*	(−5.43)*	(−2.85)*
Adj. R^2	0.40	0.40	0.05
Akaike Info. Criteria	6.70	6.76	1.60
F-Test	55.77*	55.90*	5.47*

Notes: () represents t-statistic.
Mean of RLYR = 1993.055
[a] Partial derivative with respect to RLYR ($RLYR = \beta_1 + 2(\beta_2 * \overline{RLYR}) = 0.71$
[b] Partial derivative of RLYR = 0.68
[c] Partial derivative of RLYR = −0.16
* Denotes statistical significance at the 1% level

yields per acre attributed to genetic enhancement from the UofA breeding program over the entire time period.

Another important aspect of the UofA breeding program is the decrease in yield variability over the same time period. More specifically, between 1983 and 2007, the varieties released by the UofA breeding program experienced an increase in annual yield, and a decrease in yield variance. The average yearly variance decreased 0.016 (bu/acre)^2 (Table 2).[6] The UofA breeding program continually breeds for pathogen resistance in all of its cultivars. Improvements in blast tolerance and other pathogen resistance, so called maintenance breeding, can lead to lower yield variability and higher mean yields. If the yield variance decreases, as is the case in the results above, there is an economic value to this in the form of yield loss prevention. Without the UofA breeding program rice yields may otherwise have deteriorated as pathogens like blast and sheath blight may have lessened yield and increased variability as they overcame earlier sources of resistance through breeding.

Table 4 presents the estimates of the genetic and economic benefits of the UofA rice breeding program for rice producers in Arkansas, assuming a perfectly elastic demand for rice.[7] The genetic gains on Table 4 are calculated from the results (*RLYR* and $RLYR^2$) of the regression model on Table 2. An important feature of the calculation of genetic gains associated with a breeding program is to take into account the cumulative effects of the program over the entire period. That is, the yields gains attributable to the breeding program in 2007 are those observed in 2007 plus those seen in 2006. So, the genetic gains for 2007 would be the sum of the year specific genetic gain from 1983–2007. The annual and cumulative genetic gains for the UofA rice breeding program are listed in Table 4. Rice producers in Arkansas have received an average

[6] Since the variance regression included a squared term ($RLYR^2$) this would indicate that 0.0162 (bu/acre)^2 is not a constant but rather the average decrease in annual yield variation over the time period.

[7] This assumes that the increased Arkansas rice production due to genetic improvement does not influence the global price of rice. This is a realistic assumption, since Arkansas produces such a small portion of the global rice supply, and the yield increase is a relatively small shift in the total world supply of rice.

Table 3. Fixed Effects Regression Results from OLS and Just-Pope Production Functions

Station	OLS Yield Coefficient	Just-Pope Yield Coefficient	Just-Pope Variance Coefficient	Year	OLS Yield Coefficient	Just-Pope Yield Coefficient	Just-Pope Variance Coefficient
Missouri	−16.36	−15.75	0.91	2007	default	default	default
	(−4.21)*	(−3.82)*	(2.99)*	2006	16.44	15.50	−0.70
Cotton Branch	−16.65	−15.61	0.82		(4.96)*	(−4.75)*	(−2.69)*
	(−6.08)*	(−5.38)*	(−3.84)*	2005	23.94	22.65	−0.29
Kaiser	−6.86	−7.27	0.52		(6.99)*	(−6.77)*	(−1.10)
	(−3.30)*	(−3.29)*	(3.20)*	2004	−4.88	−5.62	−0.45
Jackson County	13.97	13.76	1.11		(−1.55)	(−1.83)***	(−1.83)***
	(−5.89)*	(−5.09)*	(5.29)*	2003	16.72	16.07	−1.09
Clay County	3.81	4.25	1.12		(4.61)*	(−4.41)*	(−3.85)*
	(1.69)**	(−1.75)**	(6.08)*	2002	14.92	13.30	−0.24
Rohwer	−10.28	−9.98	0.88		(4.08)*	(−3.77)*	(0.84)
	(−4.89)*	(−4.54)*	(5.38)*	2001	5.14	3.62	−1.09
Pine Tree	−1.51	−1.27	0.73		(1.40)	(−1.01)	(−3.81)*
	(−0.74)	(−0.60)	(4.60)	2000	−7.72	−9.31	−0.64
Stuttgart	default	default	default		(−1.72)***	(−2.09)**	(−1.82)***
				1999	−4.56	−5.57	−0.32
					(−1.07)	(−1.33)	(−0.92)
				1998	−19.04	−21.40	−0.15
					(−4.38)*	(−5.10)*	(−0.45)
				1997	−35.37	−36.84	−0.79
					(−5.05)*	(−4.94)*	(−1.44)
				1991	−14.04	−16.13	−1.34
					(−3.75)*	(−4.26)*	(−4.57)*
				1990	−7.93	−10.28	−1.48
					(−2.09)**	(−2.68)*	(−5.01)*
				1989	−11.60	−13.73	−1.40
					(−2.97)*	(−3.48)*	(−4.60)*
				1988	−3.97	−5.83	−1.05
					(−0.91)	(−1.31)	(−3.07)*
				1987	−5.22	−7.32	−1.09
					(−1.11)	(−1.54)	(−2.99)*
				1986	−51.42	−53.93	−1.02
					(−10.91)*	(−11.30)*	(−2.78)*

*, **, *** Denotes statistical significance at the 1%, 5%, and 10% level, respectively.

annual economic benefit of $19.5 million (2007) in United States dollars (USD) from the UofA rice breeding program from 1986–2007. These benefits are a function of several exogenous factors (acreage, rice price, and adoption rate) and the endogenous factor of genetic gains attributed to the breeding program. The average economic benefits Arkansas producers have received this decade (2000–2007) are estimated at $34.3 million (2007) USD annually (Table 4).

There are substantial "spillover" benefits outside the state of Arkansas from the UofA rice breeding program. That is, out of the total 817,240 acres sown to UofA rice varieties in 2007, 141,490 (17.31%) were sown outside of the state of Arkansas. To fully account for the "total" economic benefits of the UofA breeding program the summation of yield enhancements from the other states that sow UofA varieties must be accounted for.

Table 5 is constructed using the total rice acreage in Mississippi, Louisiana, Missouri, and Texas that were sown to UofA rice varieties, as well as the average annual long grain rice price

Table 4. Benefits of the Arkansas Rice Breeding Program to Arkansas Producers, 1986–2007

Year	Genetic Gain (bu/ac)	Cumulative Genetic Gain (bu/ac)	Acres of Rice in AR	Proportion of Rice that are UofA Rice Varieties	Additional Bushels	Rice Price ($/cwt)	Additional $ Gains Due to UofA Breeding Program
1986	0.01	0.01	1,020,000	0.87	4,902	$3.68	$8,117
1987	0.10	0.10	1,010,000	0.8	81,519	$7.60	$278,795
1988	0.19	0.29	1,210,000	0.66	228,478	$6.90	$709,423
1989	0.28	0.56	1,140,000	0.8	511,767	$7.46	$1,718,001
1990	0.36	0.93	1,200,000	0.66	733,424	$6.75	$2,227,774
1991	0.45	1.38	1,260,000	0.69	1,200,445	$7.69	$4,154,140
1992	0.54	1.93	1,380,000	0.76	2,019,308	$5.39	$4,897,831
1993	0.63	2.56	1,230,000	0.76	2,392,872	$7.97	$8,582,036
1994	0.72	3.28	1,420,000	0.55	2,564,827	$6.52	$7,525,202
1995	0.81	4.10	1,340,000	0.42	2,306,429	$9.14	$9,486,341
1996	0.90	5.00	1,170,000	0.46	2,692,118	$10.20	$12,356,820
1997	0.99	6.00	1,370,000	0.5	4,107,166	$9.87	$18,241,980
1998	1.08	7.08	1,525,000	0.57	6,153,849	$8.87	$24,563,087
1999	1.17	8.25	1,645,000	0.51	6,923,823	$5.71	$17,790,764
2000	1.26	9.52	1,440,000	0.44	6,029,512	$5.60	$15,194,371
2001	1.35	10.87	1,621,000	0.5	8,809,674	$3.93	$15,579,908
2002	1.44	12.31	1,503,000	0.52	9,622,901	$4.16	$18,014,071
2003	1.53	13.85	1,455,000	0.57	11,482,572	$7.70	$39,787,114
2004	1.62	15.47	1,555,000	0.54	12,988,436	$7.13	$41,673,398
2005	1.71	17.18	1,641,000	0.57	16,070,098	$7.27	$52,573,326
2006	1.80	18.98	1,435,000	0.44	11,985,764	$9.30	$50,160,420
2007	1.89	20.88	1,325,000	0.51	14,106,312	$13.21	$83,854,969

from National Agricultural Statistics Service from 1990–2007. Missouri and Louisiana had the largest percentage of their total rice acreage sown to UofA varieties over the 1990–2007 period at 40 and 9%, respectively. Table 6 shows the total benefits, both the benefits in Arkansas and the spillover benefits in the surrounding states, of the UofA rice breeding program using the cumulative genetic gain calculated in Table 4. The average annual benefits of the UofA breeding program from 1990–2007 was 28.04 million (2007 USD). That number increases to 46.7 million (2007 USD) when you analyze the annual benefits for this decade, 2000–2007. Again, these benefits are partially by price, which is exogenous to the breeding program but driven by acreage (adoption rate) and genetic gain, which is endogenous to the breeding program.

Another way of interpreting these results is the counterfactual case. That is, what would have happened if the UofA had not invested in rice breeding from 1983–2007? The implicit counterfactual is that Arkansas and producers would have continued to grow varieties of the vintage and yield of Newbonnet and would have forfeited the benefits estimated above. However, it is more likely that Arkansas producers would have adopted rice varieties developed by other breeding programs (Louisiana State University and Texas A&M for example). In that sense these estimates would *overestimate* the total benefits estimated above.

Often overlooked in breeding programs is the importance of breeding for pathogen and disease resistance, so called "maintenance breeding". While this paper captures the genetic gain attributed to the UofA rice breeding program it fails to account for the significant yield losses that would unfold overtime without UofA breeding. Previous studies (Marasas, Smale, and Singh, 2003) on breeding programs have estimated that the economic impact of a breeding programs pathogen resistance breeding efforts can be as large, if not larger than the impact of increased yields. Therefore, these

Table 5. Total Acreage of University of Arkansas Varieties Sown by State: 1990–2007

Year	Acres of Rice in MO	% of MO. Acres that are UofA Rice Varieties	Acres of Rice in MS	% of MS Acres that are UofA Rice Varieties	Acres of Rice in LA	% of LA Acres that are UofA Rice Varieties	Acres of Rice in TX	% of TX Acres that are UofA Rice Varieties	Total Acreage Sown to UofA Varieties
1990	92,000	5.3	255,000	26.1	555,000	28.9	345,175	0.6	1,025,897
1991	97,000	21.1	225,000	16.3	560,000	27.0	339,192	0.8	1,080,456
1992	117,000	38.0	280,000	14.0	630,000	16.0	346,245	1.9	1,239,839
1993	105,000	42.0	250,000	13.6	545,000	24.4	295,421	2.9	1,154,447
1994	131,000	31.9	315,000	7.2	625,000	13.0	351,735	0.8	929,533
1995	119,000	27.1	290,000	5.0	575,000	3.2	312,108	0.8	630,446
1996	97,000	21.1	210,000	9.0	535,000	12.1	263,407	9.8	668,116
1997	122,000	20.7	240,000	4.6	585,000	5.9	258,934	10.0	781,716
1998	145,000	49.8	270,000	7.3	625,000	1.1	271,989	25.8	1,037,958
1999	186,000	50.0	325,000	3.0	620,000	5.6	246,228	14.8	1,012,519
2000	170,000	34.9	220,000	2.1	485,000	2.4	212,113	7.4	724,758
2001	211,000	29.6	255,000	4.9	548,000	7.3	213,704	7.2	940,571
2002	190,000	39.1	255,000	5.0	540,000	9.1	205,748	7.2	932,386
2003	176,000	64.6	235,000	4.7	455,000	3.4	178,028	4.9	978,330
2004	196,000	68.3	235,000	7.7	538,000	1.4	216,810	5.5	1,011,281
2005	216,000	56.0	265,000	7.8	530,000	2.0	200,937	5.3	1,098,091
2006	216,000	50.5	190,000	0.0	350,000	0.8	147,549	3.0	747,833
2007	180,000	67.6	190,000	7.6	380,000	0.6	143,299	2.0	817,240

Table 6. Total Benefits of the Arkansas Rice Breeding Program: 1990–2007

Year	Genetic Gain (bu/ac)	Cumulative Genetic Gain (bu/ac)	Total UofA Acres[a]	Total Additional Bushels	Rice Price (2007 $/cwt)	Additional lbs	Total Gains Attibuted to U of A Breeding Program
1990	0.36	0.93	1,025,897	950,022	$6.75	42,750,977	$2,885,691
1991	0.45	1.38	1,080,456	1,491,865	$7.69	67,133,933	$5,162,599
1992	0.54	1.93	1,239,839	2,387,124	$5.39	107,420,582	$5,789,969
1993	0.63	2.56	1,154,447	2,955,118	$7.97	132,980,316	$10,598,531
1994	0.72	3.28	929,533	3,052,613	$6.52	137,367,600	$8,956,368
1995	0.81	4.10	630,446	2,583,650	$9.14	116,264,267	$10,626,554
1996	0.90	5.00	668,116	3,341,967	$10.20	150,388,509	$15,339,628
1997	0.99	6.00	781,716	4,687,062	$9.87	210,917,778	$20,817,585
1998	1.08	7.08	1,037,958	7,348,217	$8.87	330,669,750	$29,330,407
1999	1.17	8.25	1,012,519	8,356,284	$5.71	376,032,775	$21,471,471
2000	1.26	9.52	724,758	6,897,001	$5.60	310,365,027	$17,380,442
2001	1.35	10.87	940,571	10,223,477	$3.93	460,056,462	$18,080,219
2002	1.44	12.31	932,386	11,479,934	$4.16	516,597,024	$21,490,436
2003	1.53	13.85	978,330	13,545,239	$7.70	609,535,739	$46,934,252
2004	1.62	15.47	1,011,281	15,642,442	$7.13	703,909,881	$50,188,775
2005	1.71	17.18	1,098,091	18,865,716	$7.27	848,957,213	$61,719,189
2006	1.80	18.98	747,833	14,195,994	$9.30	638,819,712	$59,410,233
2007	1.89	20.88	817,240	17,059,921	$12.80	767,696,460	$98,265,147

[a] Acreage is equivalent to summation of state acreage from Table 5.

estimates would *underestimate* the total benefit associated with the UofA rice breeding program.

Implications and Conclusions

Arkansas producers sowing UofA varieties during the period from 1983–2007 experienced a 10.11% yield increase that can be attributed to the genetic advancement of cultivars through the UofA breeding program alone. These estimates result in Arkansas producers receiving an average annual economic benefit of $19.5 million (2007) USD from 1986–2007. When you account for the spillover benefits, neighboring states that sow UofA varieties, the average annual economic benefits increase. That is, in 2007, approximately 17% of all of the UofA varieties sown were sown outside the state of Arkansas. The average total, in Arkansas and surrounding states, economic benefits of the UofA breeding program from 1990–2007 was $28.02 million (2007) annually.

Using a discount rate of 4% to calculate the discounted costs and benefits, and accounting for the 10 year lag between the initial cross and releasing a variety to the public, the benefit cost ratio was estimated to be 17.7:1.[8] That is, for each dollar of public funds invested in the University of Arkansas rice breeding research, nearly $18 of benefits result. Using the same assumptions but with a new discount rate of 10% the estimated benefit cost ratio decreases to 8.75:1. To put these benefits in perspective, the internal rate of return (IRR), which is computed as the discount rate that results in a value of zero for the net present value, was estimated to be 30.9% for the time period.[9] The benefit-cost ratio and IRR provide evidence that the economic rate of return to the University of Arkansas rice breeding program is high, although assessing these measures further is difficult without comparable values for other public investments (the opportunity cost of funds).

[8] The benefit-cost ratio as defined by Tassey (2003) is calculated as a measure of gross research benefits: $\frac{\sum_t \frac{B_t}{(1+r)^t}}{\sum_t \frac{C_t}{(1+r)^t}}$ where B_t is the total economic benefit in year t, C_{t-10} represents annual program costs 10 years prior, and r is the assumed rate of discount of 4%.

[9] The internal rate of return was calculated as: $0 = \Sigma_t[(B_t - C_t)/(1 + IRR)^t]$.

The most tangible improvements of a breeding program are in the form of increased yields, but the substantial economic benefits should be recognized by valuing the yield losses avoided through sheath blight, blast, and other pathogen resistance, so called "maintenance breeding". This study also found that over the 1983–2007 period that UofA varieties had reduced yield variability. This study only valued yield increases and did not attempt to quantify the value of the maintenance breeding nor attempted to monetize the value of decreased yield variability, thus the benefits estimated to producers in this study are on the conservative side. That is, without the breeding program, rice yields could have deteriorated and become more unstable as pathogens such as blast and sheath blight may have drastically reduced yield and increased yield variation as they overcame earlier resistance genes.

Holding all climatic and agronomic conditions constant, the annual genetic gain attributed to the UofA rice breeding program has increased, and the returns to the UofA rice breeding program continue to play a large role for Arkansas producers through both increasing and stabilizing rice yields. Given the estimates found in this research, the benefits of the rice breeding program outweigh the costs by a large multiple, demonstrating that investments in the UofA rice breeding program have provided large and sustained economic benefits to rice producers, consumers, and millers in Arkansas.

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