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Enhancing Farm Profitability through Portfolio Analysis: The Case of Spatial Rice Variety Selection

Lawton Lanier Nalley, Andrew Barkley, Brad Watkins, and Jeffery Hignight

This study applies portfolio theory to rice varietal selection decisions to find profit maximizing and risk minimizing outcomes. Results based on data from six counties in the Arkansas Delta for the period 1999–2006 suggest that sowing a portfolio of rice varieties could have increased profits from 3 to 26% (depending on the location) for rice producers in the Arkansas Delta. The major implication of this research is that data and statistical tools are available for rice producers to improve the choice of rice varieties to plant each year in specific locations. Specifically, there are large potential gains from combining varieties that are characterized by inverse yield responses to growing conditions such as drought, pest infestation, or the presence of a specific disease.

Key Words: optimal variety selection, portfolio analysis, rice

JEL Classifications: G11, Q15, Q12

Typically, rice producers in Arkansas plant more than one rice variety each year in an attempt to diversify yield risk. However, these variety combinations are typically selected based on variety descriptions, intuition, and average yields, ignoring one of the most important pieces of information, the relationship between varieties. While extension services throughout the Southeast recommend planting multiple rice varieties, they do not provide recommendations or information about the structural interaction between varieties. In the University of Arkansas Extension Service rice production handbook, diversity in seed selection is emphasized. Slaton reports that, "seeding a large percentage of acreage to single variety is not recommended, planting several varieties minimizes the risk of damage from adverse weather and disease epidemics and increases the chance for quality seed with maximum yields" (Slaton, 2001). Extension Agencies in the Southeast do have programs that allow producers to select a specific variety and receive recommendations on optimum seeding rates, seedbed preparation, seeding date range, and drill width. An obvious void in these recommendations may be the most important recommendation of all, which varieties to plant for optimal diversification.

The selection of rice varieties through portfolio theory, similar to the extensive

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literature in the finance world, offers producers the potential to increase yield and decrease yield variability simultaneously. Using location-specific empirical data, portfolio theory can provide producers a tool that is able to recommend a bundle of varieties to meet a specific objective, either maximizing yield around a given variance or minimizing variance around a given yield. This paper uses existing literature on portfolio theory and applies it to rice varietal selection for six counties in the Arkansas Delta. Three scenarios are evaluated. The first scenario holds constant actual historical yield (bu) and develops a portfolio of rice varieties to *minimize the variance* around that yield. The second scenario holds historical yield variance constant and develops a portfolio of rice varieties to *maximize yield* around the given variance. The third scenario develops a portfolio of rice varieties that maximize profit per acre around a specified variance. The final scenario has great appeal given the recent propagation of Clearfield and hybrid varieties. These varieties allow producers greater planting flexibility in more varied environments but also often embody higher production costs. This study takes the rather broad extension recommendation of "diversifying rice varieties to minimize risk" a step further by developing specific portfolios of rice varieties based on spatial costs and production differences to maximize profit and to minimize risk per acre.

Literature Review

Portfolio theory was initially developed by Markowitz (1959) and Tobin (1958), with extensions by Lintner (1965) and Sharpe (1970) focusing on financial investments. A "portfolio" is defined simply as a combination of items: securities, assets, or other objects of interest. Portfolio theory is used to derive efficient outcomes through identification of a set of actions, or choices that minimize variance for a given level of expected returns or maximize expected returns given a level of variance. Decision makers (producers) can then use the efficient outcomes to find expected utility-maximizing solutions to a broad class of problems in investment, finance, and resource allocation (Robison and Brake, 1979). In other words, portfolio theory can be used to maximize profits and minimize risk and can be implemented in a multitude of settings, including selecting rice varieties in Arkansas.

The deep literature on financial portfolio analysis can be applied to agricultural production and can provide producers a tool for implementing variety seed purchase and planting decisions. Like investment choices in the financial sense, rice varieties allow producers to allocate money across investment opportunities (various varieties) with varying relative risks and yields. Since different varieties of rice respond differently to environmental conditions (climatic, pests, and agronomic), risks associated with rice varieties may in some way be correlated. Certain rice varieties will be positively related to other varieties, and some may be negatively correlated with other variety yields. Because of this correlation, there are potential benefits from planting multiple varieties to spread the risk associated with the aforementioned environmental conditions.

Robison and Brake (1979) provide a thorough literature review of portfolio theory, with applications to both agriculture and agricultural finance. More recently, Nyikal and Kosura (2005) used quadratic programming to solve for the efficient mean-variance frontier to better understand farming decisions in Kenyan agriculture. Redmond and Cubbage (1988) applied the capital asset pricing model to timber asset investments in the United States. Figge (2004) summarized the literature on how portfolio theory has been applied to biodiversity, and Sanchirico, Smith, and Lipton (2005) used portfolio theory to develop optimal management of fisheries. Although portfolio analysis is not a new concept to agriculture, its implementation to variety selection is.

Barkley and Porter (1996) analyzed Kansas wheat producer variety selection decisions for the period 1974–1993, and found that variety choice was statistically related to production characteristics, such as disease resistance, and end-use qualities. They concluded, ". . . wheat producers in Kansas take into account end-use quality in varietal selection decisions, but economic considerations lead many farmers to

plant higher-yielding varieties, some of which are characterized by low milling and baking qualities" (p. 209). Barkley and Porter (1996) also found that yield stability was a significant determinant of variety selection decisions, as discussed in Porter and Barkley (1995). A key point the authors found was that farmers often planted the highest yielding varieties, which may be characterized by greater yield variance. A multitude of other studies have been conducted in low-income countries on which variety attributes affect adoption rates (Dixon et al., 2007; Doss et al., 2003; Heisey and Mwangi, 1993; Smale, Just, and Leathers, 1994). Although structural differences exist due to the location differences of the studies, the authors concluded that education through extension plays a significant role in the adoption of specific varieties.

Barkley and Peterson (2008) illustrate how portfolio theory can reduce risk and increase yields for Kansas wheat farmers from historical test plot data. This study goes one step further by incorporating variety specific cost of production so that a profit-maximizing portfolio can be estimated. Most of the existing literature simply suggests a single variety to be sown based on spatial data. Very few, with the exception of Barkley and Peterson (2008), actually recommend a portfolio of varieties based on spatial data to either minimize variance around a target yield or maximize yield. This study builds off the Barkley and Peterson (2008) findings and recommends a portfolio to maximize profit around a target variance. The next section uses the portfolio approach used in aforementioned studies in an attempt to provide rice producers in Arkansas a tool for rice selection.

Methods

The current model uses a framework similar to that of Markowitz (1959) who developed a model to analyze different financial investments. Markowitz (1959) developed portfolio theory as a systematic method of minimizing risk for a given level of expenditure. An efficient portfolio of rice varieties can be elicited with the estimates of expected yield and variance of yields for each variety, combined with all of the pairwise covariances across all rice varieties. The efficient mean-variance frontier for a portfolio of rice varieties is then derived by solving a sequence of quadratic programming problems. Based on a producer's risk aversion preferences, a specific point on the efficiency frontier can be identified as the optimal portfolio of rice varieties.

Apart from yield risk, rice farmers face price risk. Price risk in rice farming is largely a function of world market prices. Roughly 40% of the U.S. rice crop is exported. Consequently, domestic farm prices for rice are strongly related to world prices and reflect strong competition in a global market. Variety selection decisions would likely be less affected by price risk as by yield risk, since price risk is roughly equal across varieties. Also, a large percentage (85–90%) of rice producers in the Arkansas Delta use the futures markets or pool their rice with cooperatives to eliminate price risk. Production expenses also play a major role in rice management decisions. Rice is a high-cost crop relative to other field crops like wheat or soybeans, and volatility in production expenses can significantly impact rice production. Production costs for rice have risen significantly since 2003 due to rapidly increasing fuel and fertilizer prices. Water availability also impacts rice production decisions. Rice has the largest water requirement of any row crop in Arkansas, and water applied to rice accounts for almost 70% of the total volume of water applied to all crops in the state. Most irrigation water is supplied by wells tapping into the Mississippi River Valley alluvial aquifer, which underlies nearly all of eastern Arkansas, and large water withdrawals are placing strong downward pressure on this groundwater source. Thus, water is becoming increasingly limiting in many areas of eastern Arkansas. Higher fuel and fertilizer expenses and declining water availability would likely compel rice producers to select varieties that utilize fertilizer more efficiently, select varieties that are more cold tolerant (allowing them to take better advantage of early spring rainfall), or select varieties that are more early maturing (allowing them to depend less on irrigation in late summer). Rice producers would also likely plant varieties that

are more disease tolerant, because such varieties require a lower flood level (and thus less irrigation water) to control diseases like blast than varieties that are more disease susceptible.

It is assumed that a producer's objective is to choose the optimal allocation of rice varieties to plant, and has X total acres dedicated solely to rice.[1] Therefore, the decision variable is x_i, the percentage of total acres planted to variety *i*, where $i = 1, \ldots, n$, and $\Sigma_i x_i = X$. Quadratic programming is used to solve for the efficiency frontier of mean-variance (MV) combinations. This frontier is defined as the maximum yield mean for a given (or target) level of variance, or conversely, the minimum variation for a given (or target) mean yield using a portfolio of rice varieties. If the mean yield of variety *i* is equivalent to y_i, then the total is the weighted average yield, equal to: $\Sigma_i x_i y_i$.

The total farm variety yield variance (V) is defined in Equation (1),

$$(1) \qquad V = \Sigma_j \ \Sigma_k \ x_j x_k \sigma_{jk}$$

where x_j is the percentage of total acres planted to variety j, σ_{jk} is the covariance of variety yields between the j^{th} and k^{th} rice varieties, and σ_{jk} is the variance when $j = k$. The inclusion of the covariances across rice varieties is imperative for efficient diversification as a means of hedging against risk (Heady, 1952; Markowitz, 1959).

Hazell and Norton (1986) explained that the intuition of Equation (1) is the total farm variance for all wheat varieties planted, (V) is an aggregate of the variability of individual varieties and covariance relationships between the varieties. The authors drew two important conclusions on crop variety selection: First, "combinations of varieties that have negative covariate yields will result in a more stable aggregate yield for the entire farm than specialized strategies of planting single varieties," and second "a variety that is risky in terms of its own yield variance may still be attractive if its returns are negatively covariate with yields of other varieties planted."

[1] It is assumed that all of these acres are homogenous in production.

The mean-variance efficiency frontier is calculated by minimizing total farm variance (V) for each possible level of mean yields (y_i), as given in Equation (2).

$$(2) \qquad \text{Min } V = \Sigma_j \ \Sigma_k \ x_j x_k \sigma_{jk},$$

subject to:

$$(3) \qquad \Sigma_j \ x_j y_j = \lambda \quad \text{and}$$
$$(4) \qquad x_j \geq 0 \quad \text{for all j.}$$

The sum of the mean variety yields in Equation (3) is set equal to the parameter λ, defined as the target yield level, which is varied over the feasible range to obtain a sequence of solutions of increasing farm-level mean yield and variance, until the maximum possible mean yield is obtained. Equation (2) is quadratic in x_j, resulting in the use of the Excel Solver program to solve the nonlinear equation.

Since production costs differ across rice types (hybrid and conventional) the profit maximization portfolio of varieties can be calculated as:

$$(5) \qquad \text{Max}\Pi = \sum_{X=1}^{X} x_i(PY_i - C_i)$$

subject to:

$$(6) \qquad \Sigma_j x_i y_j = \phi \quad \text{and}$$
$$(7) \qquad x_i \geq 0 \quad \text{for all i}$$
$$(8) \qquad \Sigma x_i = 1$$

where x_i is the percentage of variety *i*, P is the constant price per bushel of rice, and C_i is the cost of production per acre of rice for variety *i*, and Y_i is the estimated yield of variety *i*. The sum of the mean variety variance in Equation (6) is set equal to the parameter φ, defined as the target variance level (in our case the actual 2007 observed variance), which is varied over the feasible range to obtain a sequence of solutions of increasing farm-level mean yield and variance, until the maximum possible profit is obtained.

Data

Data were collected from the Arkansas Rice Performance Trials (ARPT) test plots throughout

the Delta of Arkansas from 1997 to 2007. The ARPT data consist of four university-run experiment stations: Pine Tree (St. Francis County), Stuttgart (Arkansas County), Rohwer (Desha County), and Keiser (Mississippi County), and two test plots conducted by farmers in Jackson (Ahrent Farm) and Clay (Rutledge Farm) counties. Since different locations are characterized by different growing conditions, the quantitative analyses conducted here are all for a given test plot at a given location. Although a gap between experimental and actual yields exists, Brennan (1984) wrote, "The only reliable sources of relative yields are variety trials" (p. 182).[2] Therefore, annual changes in relative yields are measured with performance test data. 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 not available (N/A) at preflood followed by a single midseason application of 30–60 lb N/A. Phosphorus and potassium fertilizers were applied before seeding at the Stuttgart, Jackson County, and Clay County locations. A total of 51 varieties were tested from 1997 to 2007, but only 18 varieties were included in the portfolio analysis. The other 33 lines were left because those varieties are no longer available to farmers to sow. The varieties included in the portfolio analysis included nine released by Louisiana State University, four by the University of Arkansas, three hybrid varieties released by Rice-Tec, two by University of Texas, and one by Mississippi State. Hybrid seeds are released by private industry (Rice-Tec), whereas conventional seeds are released by public institutions (University of Arkansas, Louisiana State University, etc).

The data set is panel in nature across both time and experiment stations. Since not all rice varieties are planted at each station, an efficiency frontier and subsequent portfolios are calculated for each experiment station resulting in a time series data set. The variance-covariance matrices were calculated using a Just-Pope regression technique (Just and Pope, 1979) that accounts for multiplicative heteroskedasticity across varieties. A regression, and subsequent variance-covariance matrix, was estimated for each experiment station to hold climatic, agronomic, and other production conditions constant.

Conventional, Clearfield, and Hybrid Rice

A persistent problem for rice producers in the Southeast is the presence of red rice (a weed) throughout their fields. Red rice was estimated to be present in approximately 20% of all rice acreage in Arkansas in 2002 (Annu et al., 2001). Because of its nearly identical genetic structure to commercial rice, there is no existing herbicide developed that can adequately control red rice without also injuring or killing conventional rice. Louisiana State University searched for an individual rice cultivar that had undergone a slight alteration in its natural inventory of genetic information to hopefully result in a variety that was naturally resistant to the red rice herbicide. Over 10 years of searching through approximately one billion rice seeds and plants, an individual plant resistant to imidazolinone herbicides was found. Cross breeding this plant resulted in varieties that became known as the Clearfield lines. If producers adopt Clearfield lines, they typically improve yield and quality through the mitigation of red rice (red rice can contribute up to a 20% docking loss in milled rice, Annu et al., 2001). That being said, Clearfield seed carries a premium relative to conventional rice (an average of 4.5 times more expensive in 2008), which leaves a producer with a rather ambiguous cost-benefit decision to make.

Recently farmers in Arkansas have begun to adopt hybrid rice varieties, with the state acreage increasing from 0.8% in 2002 to 20% in 2007. The costs of production of Clearfield and hybrid rice also differ due to differences in fungicide and other input applications. Location-specific costs of production for conventional, Clearfield, and hybrid rice varieties were obtained from the University of Arkansas

[2] In 2007 the USDA reported an average yield of 160 (bu/ac) for the entire state of Arkansas compared with the Arkansas Rice Performance Trials average of 168 (bu/ac), a 5% difference (University of Arkansas Cooperative Extension Service, 1996–2007).

Table 1. 2007 Rice Varietal Distribution for Counties with Arkansas Rice Performance Trial Test Plots

		Varieties (%)									
					CL	XL	CL	XL			XL
Station	County	Bengal	Jupiter	CL161*	729*		730*	Cocodrie	Francis	Wells	723** Others
Stuttgart	Arkansas	4.0	1.4	7.1	0.3		2.1	11.5	27.9	30.3	7.7 7.7
Rohwer	Desha	8.0	0.3	0.0	6.6		1.6	17.4	6.7	28.9	15.1 15.4
Pine tree	St. Francis	18.2	5.4	1.0	0.0		0.9	9.0	8.5	54.6	1.2 1.3
Keiser	Mississippi	0.0	0.0	0.6	0.0		0.0	0.0	14.3	72.0	12.4 0.2
Ahrent farm	Jackson	12.3	10.2	12.2	3.4		4.0	2.2	2.1	38.1	8.2 7.4
Rutledge farm	Clay	6.1	2.4	5.2	4.6		5.3	1.2	15.0	36.7	15.4 8.1

* Denotes a Clearfield variety.

** Denotes a Hybrid variety.

Cooperative Extension Service. Costs include fertilizer, fungicides, herbicides, insecticides, seed, labor fuel, etc. The average cost of planting an acre of conventional rice in 2007 was calculated to be $569, Clearfield at $645, and hybrids at $609.[3] The average 2007 price of $5.40 per bushel was used as an output price. Since there is not a premium or discount given to a specific rice variety, all varieties (conventional and hybrid) were priced equally.

Actual 2007 on-farm planting data were obtained for each of the counties where the six experiment stations were located (United States Department of Agriculture National Agricultural Statistics Service 2008). Table 1 illustrates the distributional breakdown of each of the six counties by the percentage of total rice acreage in each respective county planted with the various rice varieties in 2007. The most popular variety in each of the six counties in 2007 was the conventional University of Arkansas variety "Wells." Hybrids and Clearfield varieties had the largest percentage of acreage in Clay and Jackson Counties at 31% and 28%, respectively, and the lowest percentage of total acreage in St. Francis County at 3%.

Results

From the actual varietal distribution that farmers selected in 2007, the model allows for the calculation of actual variance, yield, and profit per acre by county.[4] Since 2007 empirical data exists by variety in each location, the model can calculate the "actual" variance, yield, and profit per acre in 2007 and use these estimates as a type of baseline. From these data, three iterations of the model were run. First, holding the actual 2007 variance constant and using the variance-covariance matrix, the model could maximize *yield* per acre by using portfolio theory.[5] Second, by holding the actual 2007 variance constant and using the var-covar matrix, the model can maximize *profit* by using portfolio theory. The reason a divergence between maximizing profit and yield exists is because the costs associated with different seed varieties (conventional, Clearfield, and hybrid) varies. Third, by holding actual 2007 yield constant and using the var-covar matrix, the model could minimize *yield variance* per acre by using portfolio theory. The results are reported as follows.

Maximizing Profit

Table 2 shows the profit-maximizing varietal distribution for each county, holding the actual 2007 estimated variance constant as well as the

[3] Due to different growing conditions (silt loam soils instead of clay) the cost of production for conventional seed in Stuttgart (Arkansas County) was estimated at $565 per acre.

[4] In what follows, the definition of the "actual 2007 varietal selection" is the percentage breakdown by variety that Arkansas farmers actually planted in 2007 by each location, respectively.

[5] The variance-covariance matrices for each experiment station are available upon request from the authors.

Table 2. Comparison of Actual 2007 Rice Distributions versus Model Derived Profit Maximizing Distributions

		Profit Maximizing Percentage Holding 2007 Actual Variance Constant Varieties (%)								
Station	County	Bengal	Jupiter	CL161	CL XL 729	CL XL 730	Cocodrie	Francis	Wells	XL 723
Stuttgart	Arkansas	0	65	0	0	0	13	21	0	0
Rohwer	Desha	23.01	0	0	0	0	20.5	6.4	0	50.1
Pine tree	St. Francis	31.4	1.4	0	0	0	11.8	55.4	0	0
Keiser	Mississippi	9.7	0	0	0	0	0	4.5	85.8	0
Ahrent farm	Jackson	0	0	0	37.1	18	22.3	0	0	22.6
Rutledge farm	Clay	0	0	0	0	0	15	0	28	57
		Difference from 2007 Actual Percent Planted to Profit Maximizing Percentage								
Stuttgart	Arkansas	−4	63.6	−7.1	−0.3	−2.1	1.5	−6.9	−30.3	−7.7
Rohwer	Desha	15	−0.27	0	−6.6	−1.6	3.1	−0.4	−28.9	35
Pine tree	St. Francis	13.2	−4.1	−1	0	−0.9	2.8	46.9	−54.6	−1.2
Keiser	Mississippi	9.7	0	−0.6	0	0	0	−9.8	13.8	−12.4
Ahrent farm	Jackson	−12.2	−10.2	−12.2	33.8	14	20.1	−2.1	−38.1	14.4
Rutledge farm	Clay	−6.1	−2.4	−5.2	−4.6	−5.3	13.8	−15	−8.7	41.6

percent deviations in actual versus optimal planting.[6,7] Desha, Jackson, and Clay Counties all experienced a large shift from conventional varieties to the more expensive hybrid varieties. Conversely, Mississippi, Arkansas, and St. Francis Counties shifted completely out of hybrid and Clearfield varieties to a mix of all conventional varieties. This is explained by the large yield increases hybrid varieties exhibited in Desha, Jackson, and Clay and the relatively small increases in Mississippi, Arkansas, and St. Francis counties. Interestingly, on average the hybrid varieties yielded higher than the conventional varieties in Mississippi, Arkansas, and St. Francis counties, but their increased seed costs made the less expensive conventional varieties more attractive.

Table 3 illustrates both the actual 2007 profits per acre as well as the portfolio maximized profit, holding the actual 2007 variance constant. By implementing portfolio theory, farmers could have increased their profits by an estimated 3–26% depending on their location throughout Arkansas. The largest gains were estimated for Jackson County where actual 2007 profits were estimated to be $566 per acre compared with the optimal portfolio mix of $712 per acre, a 26% increase. Even the smallest gain of 3.19%, in Mississippi County, would account for an additional $467,000 in total profits for farmers in that county.[8] The average increase in profit per acre was $63 per acre or approximately 13%. If these numbers are extrapolated to the entire state of Arkansas where in 2007 there were 1.325 million rice acres, there could be an approximate gain in

[6] It should be noted that some farmers prefer to plant medium over long grain rice or visa-versa, this and the following calculations assume that farmers are indifferent between grain lengths.

[7] It is often recommended that farmers plant specific varieties for specific field conditions. That is, some varieties are susceptible to blast (a disease) and thus should be planted to a field with a low history of blast occurrence. This analysis assumes that all fields within a county are homogenous.

[8] These profit results assume that every rice farmer in a given county abides by the optimal portfolio mix, and as importantly for the use of hybrid varieties, enough seed is available to plant the prescribed amount.

Table 3. Potential Gains from Using Portfolio Theory in Maximizing Profit per Acre

County	Actual 2007 Variance	Portfolio Variance	2007 Actual Profit Per Acre	Portfolio Profit Per Acre	Additional Profit Per Acre	% Difference	2007 Rice Acres Planted	Gain from Portfolio[a]
Clay	6,650.38	6,650.38	$594.03	$672.99	$78.96	13.29%	73,500	$5,803,881
Jackson	4,502.91	4,502.91	$566.57	$712.49	$145.92	25.75%	91,500	$13,351,724
Mississippi	5,375.82	5,375.82	$391.50	$403.97	$12.48	3.19%	37500	$467,975
St. Francis	4,162.49	4,162.49	$429.17	$460.40	$31.23	7.28%	34,300	$1,071,271
Desha	1,556.02	1,556.02	$351.83	$407.61	$55.78	15.86%	27,500	$1,534,027
Arkansas	3,304.49	3,304.49	$389.38	$444.96	$55.57	14.27%	105,000	$5,835,174

[a] Assumes that growing conditions are homogenous across entire county and that all rice acres are planted to the optimal portfolio mix.

profit of 83.9 million dollars (1,325,000 × $63) to Arkansas rice farmers. Again, an important aspect of this is that because the prescribed portfolio mix holds the variance constant at the actual 2007 rate, farmers can experience increased profits per acre without taking more risk on.[9]

The Efficient Mean-Variance Frontier

While the above analysis held variance constant and maximizing profit, what if the farmer was willing to take on slightly more risk for a higher profit or reduce risk for a lower profit? This tradeoff is identified on the efficiency frontier, or the line connecting the efficient mean/variance pairs, which are the optimal portfolios derived from the quadratic programming model. The efficiency frontier in Figure 1 demonstrates how variety yield risk can be reduced by planting a portfolio of varieties: portfolios located on the efficiency frontier are characterized by: (1) higher yields, (2) lower yield variance, or (3) both. Anything not located on the frontier can be considered inefficient in the sense that producers could either maintain yield and lower variance or maintain variance and increase yield.

The estimated profit from actual planted varietal distribution by farmers in Jackson County in 2007 (listed on Table 3) was $566.57, with a variance of 4,502.91 (bu/ac).[2] In comparison, if all of Jackson County was planted to its most popular variety in 2007, "Wells," the estimated profit per acre would be slightly less at $562.43 but the variance would be much higher at 8062.09 (bu/ac).[2] Figure 1 shows a portfolio of varieties (32% CL729, 15% CL730, 7% Wells, and 16% XP723) that both increases profit from the 2007 actual planting varietal distribution (listed on Table 1) by $110 per acre and also lowers the variance by 1,502 (bu/ac).[2] Table 3 illustrates the 2007 opportunity cost to Jackson county producers between the efficient frontier (holding variance constant) and those varieties actually planted. The opportunity cost was estimated at $145.92 ($712.49–$566.57) per acre.

[9] Individual farmers within a county may be taking more risk on, but the county average as a whole is not.

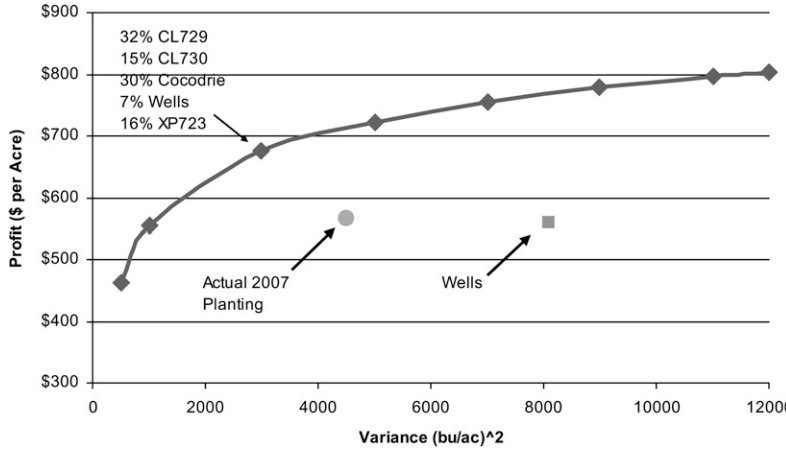

Figure 1. The Efficient Mean-Variance Frontier and Actual 2007 Varietal Distribution for Jackson County

Figure 2 shows the efficient mean profit-variance frontier for St. Francis County. The first noticeable difference is the lower profit potential for St. Francis County as compared with Jackson County. This difference may be attributed to the fact that the ARPT data shows higher yield potential for hybrid and Clearfield varieties in Jackson County and thus has a larger percentage of any given portfolio (as listed on Table 2). Second, yield variability, and thus profit, among the various locations represent different environments, but also susceptibility to various diseases present at specific locations.

The actual profit given the planted varietal distribution by farmers in St. Francis County in 2007 (listed on Table 3) was $429.17, with a variance of 4162.49 (bu/ac).[2] Again, if farmers planted all of St. Francis's acreage to its most popular variety in 2007, "Wells," the profit per acre would have actually increased by $7.46 per acre but variance would have increased by over 100% to 8,451.13(bu/ac).[2] Creating a portfolio of 27% Bengal, 21% Cocodrie, 49% Francis, and 3% Jupiter results in a profit per acre of $448 and a variance of 3,000, as shown on Figure 2. This portfolio mix increases profit per acre from the 2007 actual varietal distribution by $18.83 (4.4%) and reduces variance by 1162.49 (bu/ac)^2 (38%). Table 3 shows the 2007 opportunity cost for St. Francis producers of the actual planted versus the efficient frontier (holding variance constant) was $31.23 per acre ($460.40–$429.17). This highlights the fact that by using portfolio theory to select rice varieties you can simultaneously increase profit and decrease yield variance.

Minimizing Variance Given a Specific Yield Level

Some farmers are risk averse and would rather obtain a guaranteed yield level, say breakeven or another specific amount, and minimize the variance around that yield rather than simply attempting to maximize their yield for a given farm. Portfolio analysis allows for this possibility by holding yield constant and minimizing variance through the selection of different varieties (essentially, this is the opposite of what was done above in the profit maximizing iterations). So, by holding the estimated yields acquired from actual planting data in 2007 (shown on Table 1) the model allows for selection of varieties that will maintain that yield but minimize the yield variance. Table 4 highlights that, by implementation of portfolio theory to select rice varieties, the variation of yield can be reduced up to 71% holding yield constant. Jackson County experienced the largest estimated decrease in variance at 71% with 5 out of the 6 counties experiencing at least a 50% reduction in variance. While this analysis was focused on the actual 2007 yield, any amount could be used and the yield variance minimized around it. This could be advantageous for firms

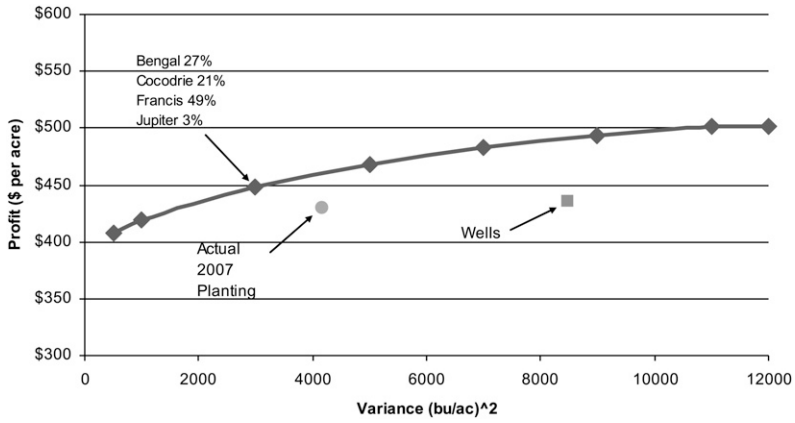

Figure 2. The Efficient Mean-Variance Frontier and Actual 2007 Varietal Distribution for St. Francis County

such as Kellogg's, which require a specific amount of medium grain rice to fill its orders. Kellogg's, who contracts with farmers, could suggest a portfolio of medium grain rice varieties to ensure its order is filled.

Conclusions

Portfolios take advantage of differences in how rice varieties respond under different growing conditions. Since climatic, pest, and other environmental factors are not known prior to planting, variety diversification can result in positive economic benefits to rice producers. Specifically, there are large potential gains from combining varieties that are characterized by inverse yield responses to growing conditions such as drought, pest infestation, or the presence of a specific disease. Currently, it is not uncommon for rice farmers in Arkansas to seed multiple varieties of rice on their farms. The University of Arkansas rice production handbook states "seeding a large percent of acreage in a single variety is not recommended, by planting several varieties you minimize the risk of damage from adverse weather and disease epidemics and increase the chance of obtaining good quality seed with good yields." Traditionally when farmers decide to seed multiple varieties they choose these combinations based on varietal descriptions, intuition, and average yields, ignoring information on variances and covariances. This study created varietal combinations through the use of portfolio analysis that incorporates the variance-covariance matrix. Several issues were analyzed, maximizing profit per acre while holding variance at its observed 2007 rate and minimizing variance while holding yields constant at their 2007 observed rate.

Using Arkansas Rice Performance Trial data from 1997 to 2007 for 18 rice varieties, the

Table 4. Reduction in Yield Variation by Implementing Portfolio Theory, Holding Yield Constant At 2007 Observed Levels

County	2007 Actual Yield Variance	Portfolio Yield Variance	2007 Actual Yield bu/Acre	Portfolio Yield bu/Acre	2007 Actual CV	Portfolio CV
Clay County	6650.38	2997.26	218.42	218.42	0.37	0.25
Jackson	4500.84	1290.00	214.46	214.46	0.31	0.17
Mississippi	5375.82	4471.98	179.07	179.07	0.41	0.37
St. Francis	4162.49	1626.06	185.91	185.91	0.35	0.22
Desha	1556.02	762.60	173.22	173.22	0.23	0.16
Arkansas	3304.49	1110.23	179.56	179.56	0.19	5.39

model estimates indicate that by using a portfolio theory, profit per acre could have increased between 3 and 26% (depending on the location within Arkansas), while holding yield variance constant at their 2007 levels. Extrapolating the average increase in profit for those counties with an ARPT station to the total rice acreage in the state would result in an increase in profits of 83.9 million dollars to Arkansas rice farmers in 2007. These results show that farmers have a tool that would allow them to increase profitability not at the expense of increasing risk. The portfolio analysis also indicated that there are large potential profits to be had in some counties (Clay, Jackson, and Desha) from the widespread adoption of hybrid and Clearfield varieties where other counties (Arkansas, Mississippi, and St. Francis) maximize their profits from the use of conventional varieties. The model was also capable of selecting varieties to minimize the variance around the actual 2007 yield per acre. These results showed that farmers, through the use of portfolio theory, could have reduced their yield variance between 16 and 71% (dependent on location), while maintaining their actual 2007 yield.

How realistic is it to recommend rice variety portfolios for adoption by Arkansas rice farmers? While it is unlikely that a farmer would adopt a profit-maximizing portfolio of multiple varieties at detailed percentage shares, this research provides new information that can be timely, useful, and important. The innovation is the relationship between varieties, summarized by the covariances across all rice varieties at a given location. This information could be used to derive risk-reducing combinations of varieties, leading to enhanced profit and reduced risk. The major implication of this research is that data and statistical tools are available to improve the choice of rice varieties to plant each year in specific locations within Arkansas. Current producer variety decisions are typically not based on the complete set of information available. Efficient variety portfolios, if adopted, would enhance rice yields in Arkansas, where the economic gains have been shown to be large.

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