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Predicting the Diffusion of Rice Varieties and Hybrids in Texas

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Selected Paper prepared for presentation at the American Agricultural Economics Association Annual Meeting, Denver, Colorado, August 1-4, 2004

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Subject Code 17 – Productivity Analysis

Abstract

This paper examines the diffusion of specific rice varieties, as opposed to variety classes in the previous literature. Using simulation techniques to incorporate risk into the diffusion path, new variety product life cycle diffusion is projected with implications for breeders, researchers, and private companies.

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INTRODUCTION

Rice production in the United States, and around the world, has experienced many changes over the last three centuries. According to the USA Rice Federation (2004), technological advances in the rice industry have allowed the United States to become one of the most innovative rice producers in the world.

Perhaps the most significant innovation in the area of rice production is the development of high yielding varieties and hybrid seed. New varieties and hybrids provide the potential for many changes to the industry, including higher yields and the possibility of price impacts, due to increased supply. Furthermore, modern seeds lead to increased production on less land, which spares additional resources (i.e. water, labor, and land) needed to sustain the world's population (Borlaug 2003).

Research institutions utilize a vast amount of resources during the rice development process, without knowing how quickly a new seed will be adopted. Extension representatives in Beaumont, Texas indicate that breeding programs consume over half of rice research funding as it can take up to ten years to develop a new rice variety, with estimated costs of $7-10 million (Clawson 1999). Therefore, one can pose the simple economic question: Will the benefits outweigh the costs? Or, put another way, how many acres might be planted to a new variety, and will the sales revenue of the new variety outweigh the costs of development? Without an in-depth analysis, the uncertainty inherent in the introduction of a new hybrid or variety makes it difficult to determine the answers to these questions. Prior research has estimated predictive diffusion models, but

researchers have rarely, if ever, incorporated a risk component in their predictive diffusion models.

BACKGROUND

Rice Production in Texas

The Texas rice industry generates approximately $500 million annually, making rice a significant contributor the economic viability of the Gulf Coast (Wilson 2003). Texas ranks fifth among the states in annual production, surpassed by Arkansas, California, and Louisiana, and Mississippi. However, as the overall rice production in the United States has exhibited an upward trend over the past decade, Texas has shown a general downward trend. Figures 1 and 2 illustrate the production trends in the United States and Texas, respectively.

New varieties and efficient production practices have provided farmers with higher yields on fewer acres. Although Texas is planting less land to rice, the state has maintained the highest per acre long grain rice yield in the nation since 1994. Along with better varieties, the current structure of government payments contributes to the decreasing acres planted to rice. Often times, Texas landowners can benefit more by removing their land from rice production, as to prevent sharing the government payment with a tenant (Clawson). Texas rice yield and acre trends are depicted in figures 3 and 4.

Faltering production coupled with "comparatively high costs (Clawson)" present a major obstacle for the Texas rice industry. In the end, current limitations provide further incentive for academic and private breeding institutions to develop lines of rice that will help the Texas rice infrastructure to survive.

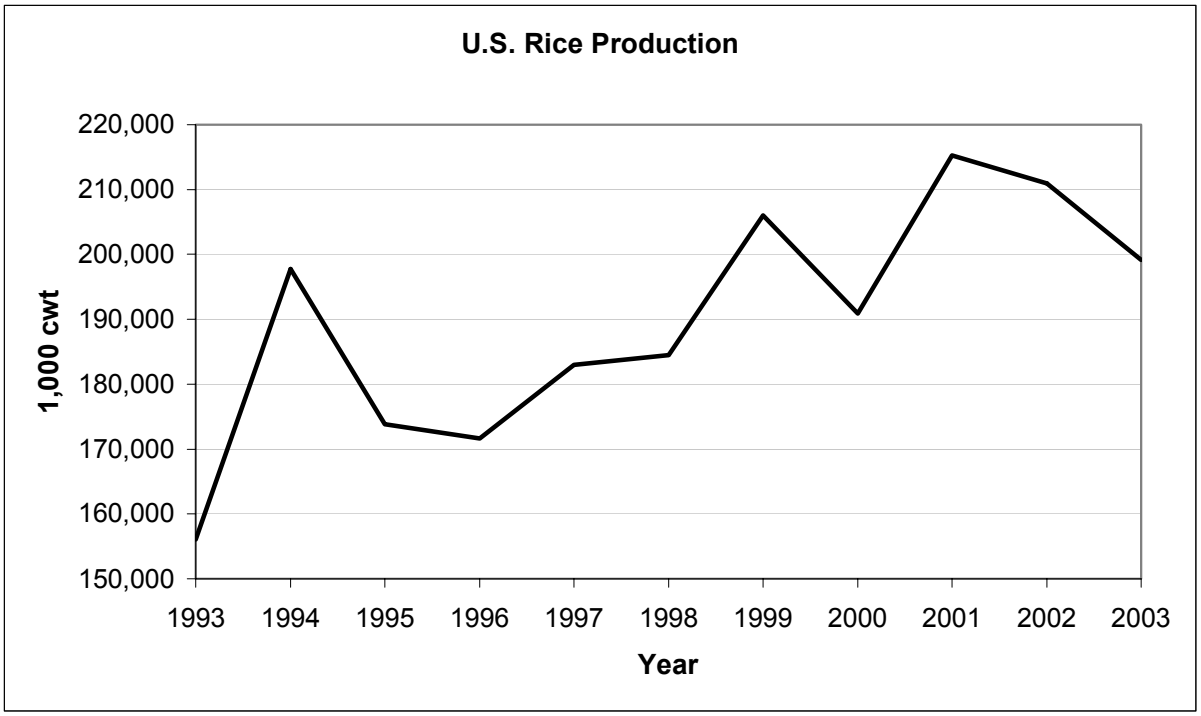

Fig. 1. U.S. Rice Production, 1993-2003.

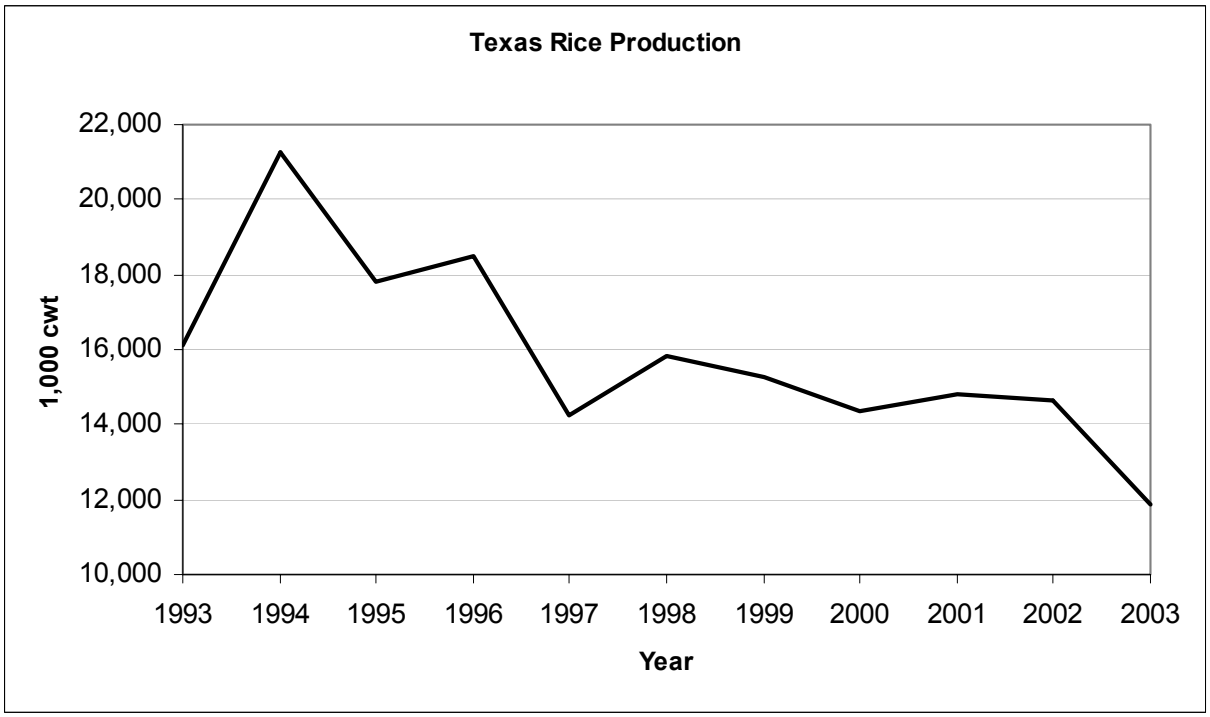

Fig. 2. Texas Rice Production 1993-2003.

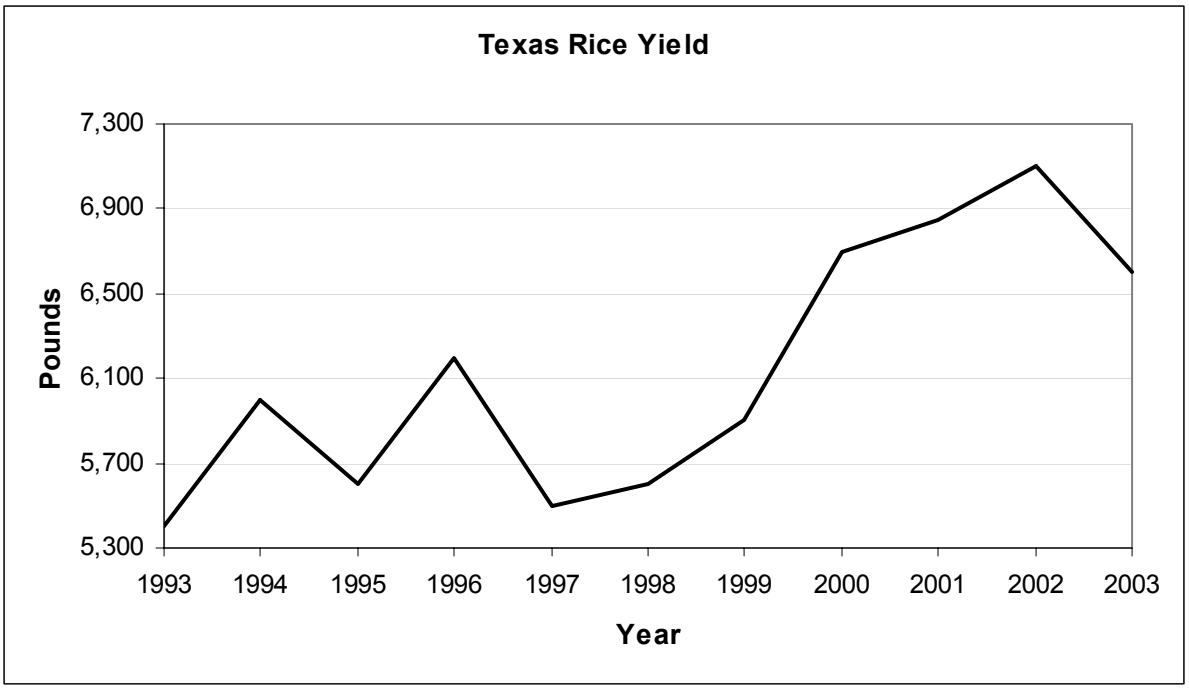

Fig. 3. Texas Rice Yield 1993-2003.

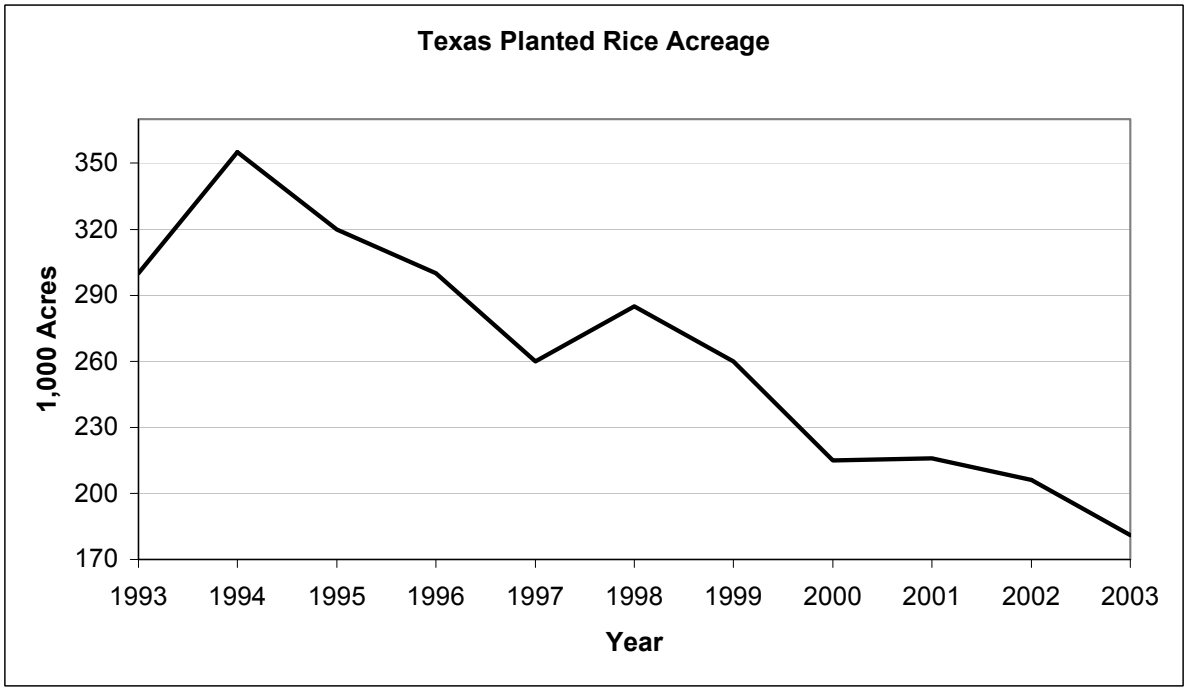

Fig. 4. Texas Planted Rice Acreage 1993-2003.

Popular Rice Varieties

For the last forty years, rice breeders around the world, as well as in the U.S. and Texas, have provided farmers with higher performing seed varieties. Research conducted by the International Rice Research Institute (IRRI) in 1960 began paving the way for breeding research and the formation of better seed varieties (Dethloff 1988). The Institute's goal of resolving Asia's widespread hunger issues provided the rest of the world with indirect benefits. By 1966, the IRRI had made substantial progress, giving the world semi-dwarf rice varieties that were disease resistant and provided higher yields on fewer acres. Professionals in the rice industry fondly referred to the semi-dwarf varieties as a "miracle rice," leading the way towards a "Green Revolution" for crop production (Latham 1998).

While yield potential has traditionally been one of the most preferred rice characteristics to develop, current biotechnology allows scientists to focus on enhancing other traits including, but not limited to, disease and insect resistance, milling quality, plant size, fertilizer responsiveness, and taste characteristics. The most popular varieties in Texas for 2003 included Cocodrie, Cypress, CL161, and Jefferson, which represent 71.7, 10.0, 9.8, and 3.7 percent of planted acreage, respectively (Way 2004). Each of these varieties are early maturing, long-grain semi-dwarfs with high main crop, ratoon crop, and milling yields.

OBJECTIVES

The primary objective of this research is to predict the diffusion of new rice hybrids and varieties in Texas. To achieve this initial objective, the following specific objectives will be addressed:

- Determine factors which can contribute to changes in adoption and affect the diffusion of established varieties;
- Estimate the diffusion of selected, established rice varieties;
- Apply simulation modeling techniques, using the traits desired for hybrids and varieties, to predict the producer acceptance of new seeds.

REVIEW OF LITERATURE

The development of new technologies provides society with the chance to evolve by finding solutions to a variety of problems. The idea of progressing in the future fuels product development and has led to a great deal of research in the technology adoption and diffusion field, as can be seen in the reviews conducted by Feder, Just, and Zilberman (1985), Mahajan and Peterson (1985), and Mahajan, Muller, and Bass (1990).

The adoption of a new product, service, or idea by select individuals does not guarantee that it will be readily diffused throughout an industry or society. Rogers (1995) identifies adoption as a process where an individual moves through a series of decisions to determine if a new technology is worthy of adoption. On the other hand, diffusion is the communication of a technology throughout a social system. Rogers identified the characteristics that determine an innovation's rate of adoption as follows:

1. Relative Advantage – Does the innovation have added benefits when compared to its predecessor?
2. Compatibility – Does the innovation conform to existing values and norms?
3. Complexity – Is the innovation difficult to understand or use?
4. Trialability – Can the innovation be tested or sampled?
5. Observability – Are the results of adopting the innovation visible to other individuals?

According to Rogers, "Innovations that are perceived by individuals as having greater relative advantage, compatibility, trialability, observability, and less complexity will be adopted more rapidly than other innovations (p. 16)." However, when a new technology is introduced, there is a great deal of uncertainty as to how the product will conform to these guidelines. Therefore, as Rogers noted, the innovation must create enough interest to motivate individuals to seek information used to move through the "innovation-decision process" and determine whether the product is worthy of investment, or adoption. Eventually, as information is passed along and individual adoption decisions are made, the new technology will develop a diffusion path over time (usually S-shaped) that is dependent upon the rate of imitation in a specific society.

Diffusion literature is continually exploring the determinants of adoption. Mansfield (1961) asked the question, "Once an innovation is introduced by one firm, how soon do others in the industry come to use it (p. 741)?" In other words, what factors dictate why some firms choose to adopt a new technology quickly and other firms lag behind. Mansfield suggested a technology's rate of imitation is a function of the number of firms currently using the innovation, the profits resulting from adoption, the size of

investment, and "other" determinants. Furthermore, many researchers such as Ryan and Gross (1943), Feder and O'Mara (1982), and Bass (1969) indicate progressive knowledge and experience with a product are key factors in the diffusion process.

However, one of the most important variables to consider when analyzing the effectiveness, or diffusion, of a new technology is profitability. Therefore, it is imperative to discuss the seminal work in the area, that of Griliches (1957). Griliches was the first to utilize the logistic function in conjunction with economic theory to estimate of the diffusion hybrid seed. The results of his study indicated that the diffusion of new corn hybrids depends upon farmers' expected profitability. As economic theory and profit maximization would suggest, the cumulative adoption of any given hybrid will increase as the farmers' potential for profit increases. Ito, Grant, and Rister (1992) obtained similar results in a study replicating the Griliches methodology to assess the condition of the US rice industry. However, despite the widespread knowledge that this method was revolutionary in the field of diffusion economics, there has been some criticism of the logistic function used by Griliches due to curve's inability to adjust to different potential adoption, or "ceiling," levels and non-symmetrical diffusion paths.

Dixon (1980) revisited the Griliches corn study, expressing concern over the validity of the ceiling values and estimation methods utilized in the original diffusion model. Griliches obtained fixed ceiling estimates by a visual inspection of data available in 1957, yielding ceiling values significantly lower than the actual full adoption population revealed by 1960 data. Furthermore, one could argue that the strict logistic function does not sufficiently fit the data for curves that tend to be skewed or non-symmetrical. With these complaints in mind, the Dixon study indicated that a ceiling

value reflecting 100 percent adoption, used in conjunction with a non-symmetrical Gompertz function, results in a more accurate estimate of the diffusion of hybrid corn. Although Dixon utilized a fixed ceiling value (which is reasonable due to the fact that hybrid corn had reached full adoption long before publication), the study allows readers to make an important observation in comparison to the Griliches study. Static diffusion models can lead to misguided results.

Mahajan and Peterson (1978) noted that the ceiling value on the number of potential adopters could be affected by many factors such as population changes, marketing tools, and government action. Therefore, the study recommended diffusion ceilings be a function of important variables that may cause fluctuations in the potential number of adopters. Knudson (1991) incorporated methods from Manahan and Peterson, as well as Metcalfe and Gibbons (1983) that showed diffusion ceilings can be represented as a function of a demand equation, to compare the performance of static and dynamic logistic diffusion models for semi-dwarf wheat varieties. The dynamic Knudson model utilized a semi-dwarf wheat supply function to represent maximum number of adopters in any given wheat-producing region. Results of the study indicated that the dynamic model outperformed the static model, providing a better fit to the data. As Knudson indicated, the superior performance of the dynamic model is logical as it relaxes many assumptions inherent in the static logistic function such as allowing fluctuations in adopter population and adjusting to changes in the technology (i.e. prices) and its surrounding environment over time. With this in mind, dynamic models should be seriously considered when conducting a cumulative adoption study.

Although recent research has shown that the potential ceiling of diffusion can vary in response to many factors, no studies have incorporated the fact that uncertainty in marketing a new technology can cause the rate of diffusion to become an uncertain path. The simulation literature is replete with applications to problems of risk and uncertainty, yet has not been applied to the projection of technology diffusion. This research pulls together the diffusion literature and simulation to explore the dynamic diffusion path under uncertainty.

METHODOLOGY

Predicting the acceptance of specific rice varieties in Texas was initially approached with the goal of incorporating prior diffusion methods, namely Griliches and Knudson, and simulation techniques to provide a more robust estimate of diffusion. The Griliches model below provides a sufficient starting point for the formulation of a cumulative adoption equation,

$$(1) \qquad \log_e [P/(K- P)] = a + bt$$

where P represents the percentage of acres planted with a new variety or hybrid, K indicates the ceiling, t is the time variable, a is the constant, and b the rate of diffusion. Furthermore, equation (1) can be modified to account for a dynamic ceiling. Applying a technique similar to the method of Knudson, the fixed ceiling from equation (1) could be made flexible by utilizing the acreage planted to rice in Texas as a proxy for the maximum level of adoption,

$$(2) \qquad A_t = a + b_1A_{t-1} + b_2Y_{t-1} + b_3PC_{t-1} + b_4P_{t-1} + b_5ARP$$

where A_t is total acres of rice planted, A_{t-1} is the acres of rice planted in t-1, Y is total rice yield in t-1, PC_{t-1} is the cost of production per acre in t-1, P_{t-1} is the farm price in t-1, and ARP represents the percentage of land the government requires to be set aside for the Acreage Reduction Program.

Replacing K from equation (1) with A_t from equation (2) provides a flexible diffusion model (3), which can adjust to the fluctuating number of acres available to plant to a new seed variety.

$$(3) \qquad \log_e [N^A / (A_t - N^A)] = a + b_1 t$$

Similar to the Griliches model, equation (3) can be estimated using least squares regression, providing a base diffusion equation to which simulation techniques can be applied.

However, upon inspection of acreage data specific to the complete diffusion individual varieties, it became apparent that prior methods used in the estimation of seed diffusion are deficient in an important area, the disadoption of technology. In the case of Griliches' and Knudson's work, they examined a whole class of varieties – hybrid corn and semi-dwarf wheat varieties, respectively. Specific varieties within those classes can exhibit the classic S-shaped diffusion pattern throughout the cumulative adoption period, but then exhibit a decline as the variety's life cycle is completed. Figure 5 displays the life cycle the Lemont variety in Texas from its introduction in 1983 to 2001. Acres planted to Lemont increased for the first six years of its life on the market, then declined as better varieties were introduced. It is this rapid life cycle that becomes of interest for this study, as the economic success of any given variety is dependent upon both the adoption and abandonment processes.

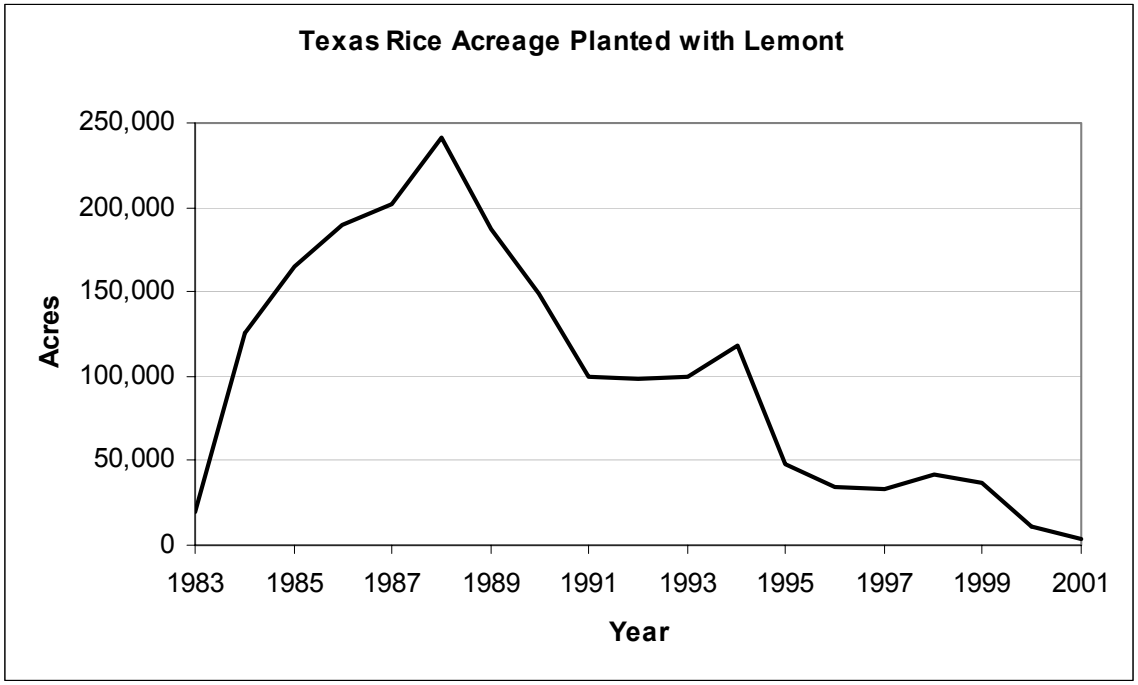

Fig. 5. Texas Rice Acreage Planted with Lemont 1983-2001.

Life Cycle Model

As can be seen in figure 5, the number of acres planted can be plotted, providing a distinctive picture of a seed's life cycle. Therefore, the following model (4), which estimates the acreage planted to a specific variety, is proposed to deal with the cumulative adoption and disadoption of rice seed,

$$(4) \qquad A_t = a + \underset{(+)}{b_1 t} + \underset{(-)}{b_2 t^2} + \underset{(+)}{b_3 t^3} + \underset{(+)}{b_4 A_{t-1}} + \underset{(+)}{b_5 Y_{t-1}} + \underset{(-)}{b_6 PC_{t-1}} + \underset{(+)}{b_7 P_{t-1}} + \underset{(+)}{b_5 ARP} + e$$

where A is total acres of rice planted, t is a trend variable, Y is total rice yield, PC is the cost of production per acre, P is the farm price, and ARP represents the percentage of land the government requires to be set aside for the Acreage Reduction Program. Each of the variables, save ARP and t, have been lagged one time period due to the fact that most crop production decisions for the current year depend upon last year's prices, yields, acres, and costs. Trend squared, production costs, and the ARP percentage are expected

to have a negative relationship with the number of acres planted. Alternatively, trend, trend cubed, number of acres planted in *t*-1, yield, and farm price are hypothesized to positively influence the number of acres planted.

Equation (4), and its parameters, can be estimated using least squares regression, providing a base life cycle equation to which simulation techniques can be applied.

Simulation Model

As mentioned before, there is a great deal of risk and uncertainty in the involved in the life cycle of a new technology. Basic diffusion models and point forecasts provide merely one of many potential outcomes. On the other hand, simulation can be used to statistically represent the possible combinations of random variables in a system (Richardson 2004). Thus, incorporating a risk component into a diffusion equation can provide a probability distribution about one's forecast, creating a more robust prediction of the diffusion path.

Inherent in the basic, or deterministic, life cycle equation (4), is an error term that defines the probability distribution about the diffusion path. Under the assumption that the residuals, captured within the error term, are normally distributed in equation (4), the basic life cycle could be made stochastic and simulated. Because many individuals consider Lemont to be one of the most popular rice varieties to be introduced in Texas, it will be used as the base situation variety, providing a probability distribution for simulation

Simulation Distribution

One can hypothesize that the variability in the number of acres planted to a specific variety has the potential to increase over time. At a minimum, the distant future is more uncertain than the near future. Therefore, a GRKS distribution, developed by Gray, Richardson, Klose, and Schumann (Richardson 2004), will be used in conjunction with the lower and upper confidence interval about the estimated acreage planted in each year to create a stochastic product life cycle. As each year's distribution is separate from every other year, this method does not assume a constant variation in acres over the course of a variety's adoption and disadoption. Instead, the acreage planted will be allowed to fluctuate independently in each year, providing a more realistic representation of the product life cycle.

Out of Sample Modeling

One of the most popular varieties to recently enter rice Production in Texas is Cocodrie. This variety has performed well for the first six years of its life on the market, exhibiting the traditional diffusion path, seen in figure 6. However, the diffusion of any variety is uncertain. It is interesting to not that this variety has already peaked in use. Incorporating the probability distribution from Lemont, which displayed similar initial diffusion patterns, will further illustrate the risk that research and development institutions assume when marketing a new seed.

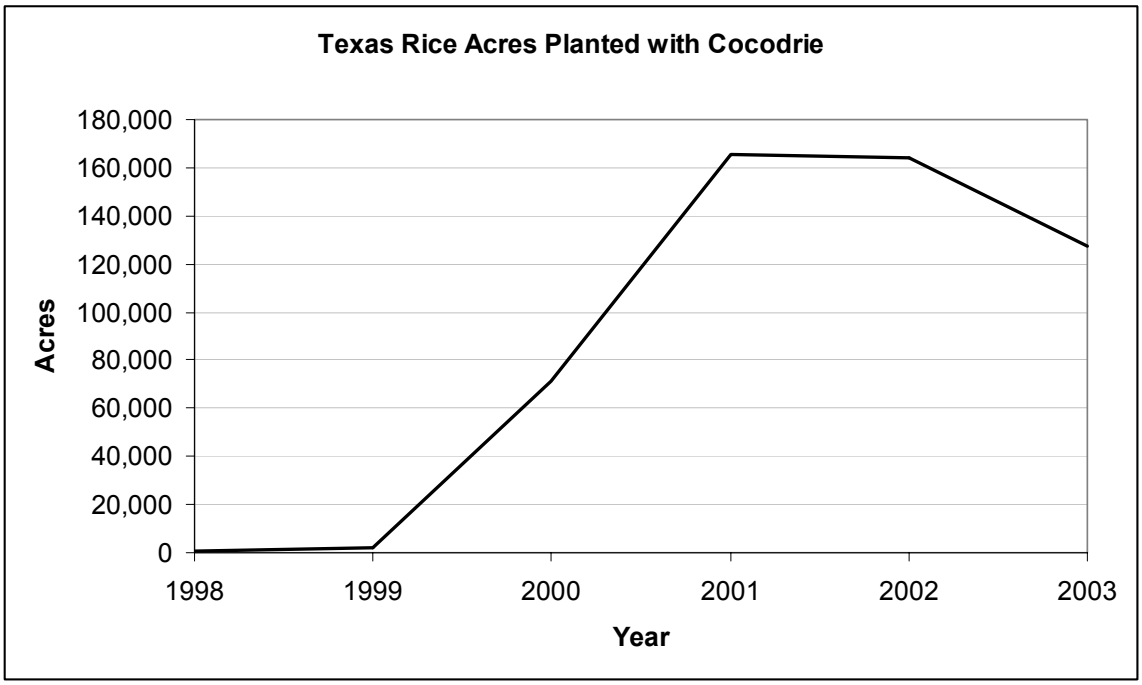

Figure 6. Texas Rice Acreage Planted with Cocodrie 1998-2003.

Data

The data to estimate the model are from two sources, the United States Department of Agriculture (USDA) and the Texas Agricultural Experiment Station (TAES). USDA data, specific to Texas, are used for Yield (*Y*), production cost (*PC*), farm price (*P*), and Acreage Reduction Program (*ARP*). Individual variety data is taken from annual acreage surveys, performed by TAES personnel, to estimate acres planted to a specific variety (*A*).

RESULTS AND DISCUSSION

Base Life Cycle

Table 1 displays the results from the estimation of the base life cycle model using the Lemont variety. The model returned the expected signs on all variables, except yield.

This may be due, in part, to the high performance of Lemont and its ability to produce higher yields on fewer acres. Production costs appear to have the largest impact on the number of acres planted, returning an elasticity of –4.2 at the mean. The regression indicates that there is a great deal of risk involved in the product life cycle, as indicated by a large standard deviation on the residuals equal to 13,572. This lends support to using a separate prediction interval around each year to account for risk, as opposed to forcing one probability distribution for the entire life cycle. Overall, the model provided a good fit to the data, with an R^2 of 0.964.

Table 1. Parameter Estimates for Base Life Cycle Model

Variable	Estimate
Constant	425,751*
	(136,342)[a]
T	35,622
	(-14,765)
t^2	-1,597
	(953)
t^3	0.003
	(0.002)
A_{t-1}	0.210
	(0.198)
Y_{t-1}	-26.4
	(16.6)
PC_{t-1}	-946*
	(253)
P_{t-1}	11,941*
	(4,127)
ARP	2,929*
	(1,008)
R^2	0.964

*Denotes significance at the 0.05 level.

[a]Numbers in parentheses are standard errors.

Simulations

The base model for Lemont and was made stochastic and simulated for 100 iterations over the life of the variety. As can be seen in figure 7, average acreage planted is similar to the deterministic representation of Lemont's life cycle, as estimated with equation (3). The application of simulation allows the decision maker to view the wide range of possibilities for s return on investment. While Lemont clearly remained in production until 2001, the probability of reaching zero acres planted increases as time progresses. In fact, the simulation indicated that there was a chance of witnessing zero acres planted in Lemont's first year on the market and, toward the end of the variety's life cycle, as early as 1997.

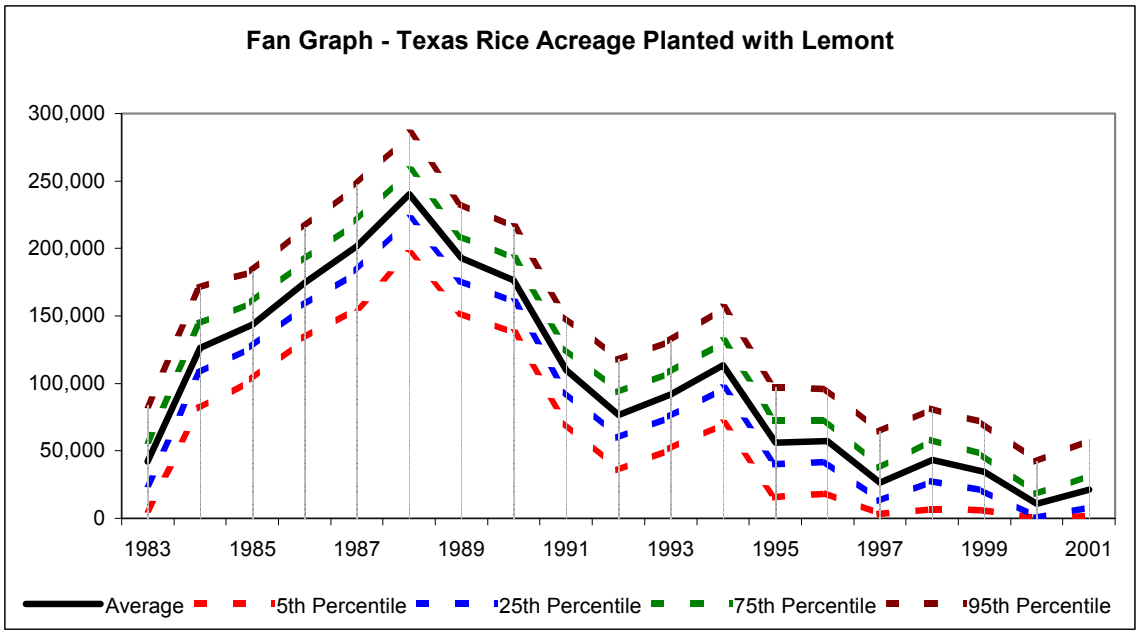

Figure 7. Simulated Acreage Planted with Lemont

The GRKS distribution from Lemont was applied to the acres planted with Cocodrie over the years 1998 to 2003. Despite Cocodrie's excellent performance over the past six years, simulations indicate that there is the potential for a significant increase in the variation of acres planted in the latter years. Similar to Lemont, the variety has gone through the adoption stage fairly quickly, and is currently experiencing its first year of decreasing acres planted. Thus, the speed with which any given variety begins to be disadopted becomes vital, as research institutions are trying to realize the greatest returns possible over the life of the product. Figure 8 indicates that there is enough risk in the product life cycle to push acreage planted with Cocodrie significantly lower than initial estimates would show. Therefore, a business leader who has access to a probabilistic forecast could make better marketing decisions and account for the numerous possibilities in product sales.

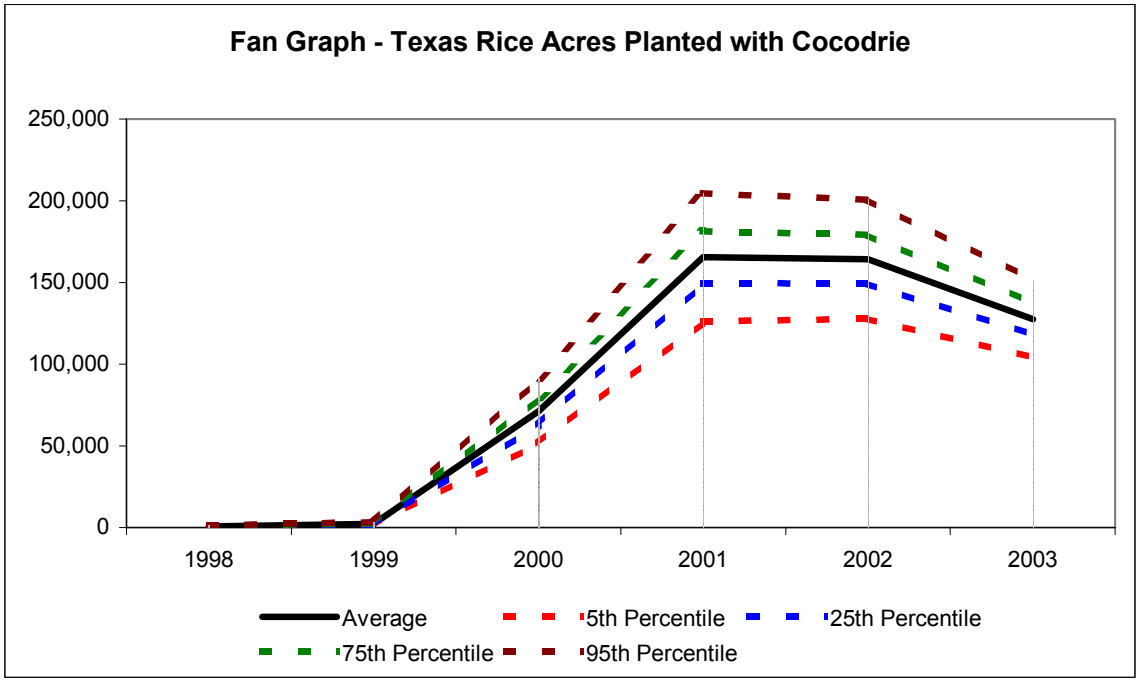

Figure 8. Simulated Acreage Planted with Cocodrie

CONCLUSIONS

Not considering the wide array of sales possibilities, represented by the varying number of acres planted, can cause development companies to severely overestimate, or underestimate, revenue opportunities. Research is currently underway to improve the model's simulation capabilities, allowing for out of sample estimations that will predict a variety or hybrid's entire product life cycle. It is also important to note that, while the parameter for the Acreage Reduction Program was significant in explaining variability in the number of acres planted in the base model, for more current varieties, this variable drops out due to the lack of ARP in current farm programs. But, it is interesting to note, in a slippage related argument, that the diffusion of a new variety may be significantly enhanced by supply control programs that reduce acres planted. The continuation of this study will incorporate additional variables to compensate for current farm programs that have decoupled payments from production and may have a significant impact on acreage planted.

In the end, the proposed model and methodology can provide a research and development institutions the ability to preview the wide range adoption and disadoption paths. While deterministic, or point, estimates have little to no chance of occurring, stochastic estimates, such as those presented in this paper, provide an window of occurrences that allow for better planning, decreasing the potential for poor investments.

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