Adoption and Diffusion of Biotechnology: rbST in California[1]

L.J. Butler
Department of Agricultural and Resource Economics
University of California-Davis

and

Irene Henriques
Schulich School of Business
York University, Toronto

Introduction

The problem of projecting future use patterns of agricultural biotechnology products in order to evaluate their potential for development and commercialization is a challenging proposition for economists. While many have attempted *ex ante* methods of projecting adoption and diffusion rates, very few have tested their *ex ante* results after the fact. In this paper, we use the results of a continuous survey of California dairy producers *ex post* to test the predictions of an *ex ante* study of adoption of recombinant bovine Somatotropin (rbST) carried out using data 4-7 years prior to the availability of the new technology.

Bovine somatotropin (bST) is a naturally occurring (peptide) hormone produced in the pituitary gland of cows. It was discovered in the 1920's, and originally called "bovine growth hormone" or bGH. Experiments in the 1930's revealed that bGH, when extracted from the pituitary gland of a cow and injected into another cow, could increase milk production in the recipient cow. However, using it to increase milk production in an individual cow was neither practical nor feasible. According to Monsanto, it takes the pituitaries of 25 cows to get enough bovine growth hormone to dose one cow for one day. In the late 1970's, Dr. Dale Bauman, an animal scientist at Cornell University, successfully transferred the gene responsible for bGH production (in a cow) to a bacterium. The resulting product was called recombinant Bovine Growth Hormone, or rbGH. Simple multiplication of the bacterium meant that it could easily be produced in commercial quantities at very reasonable cost. Several pharmaceutical and non-pharmaceutical companies became very interested in the product in the early 1980's. Despite the fact that rbGH is a peptide hormone and not a (much-maligned) steroidal hormone, to avoid the stigma associated with hormones, the industry agreed to change its name to Bovine Somatotropin. Thus, it's synthetic analog would be called recombinant Bovine Somatotropin, or rbST. Today, both names (rbGH and rbST) are still used.

Four companies involved in rbST research applied for patents for their particular brand of rbST in the early 1980's, which resulted in many misstatements, exaggerations and misunderstandings. Congressional Hearings were held in June 1986. From these hearings emerged the alleged last word on rbST. The basic findings were:

- rbST, when injected into a cow, could cause a 10 to 25 percent increase in milk production.

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- There was also a 10-15 percent increase in feed efficiency. This means that there is an effective decrease in feed costs per unit of milk produced, and therefore a lower average cost of production.
- rbST appeared to be safe both for human milk consumption and for cows.

It took until November of 1993 to gain U.S. Food and Drug Administration (FDA) approval, and it was not released commercially until February of 1994.

Numerous papers in the animal science literature show that, with a few exceptions, use of rbST increases milk production by 5 – 15 pounds per cow per day of usage. In a recent paper by Bauman, et. al., (1999) 340 Dairy Herd Improvement (DHI) herds were used to compare production responses to rbST. 176 herds were control herds (non-rbST users), and 164 were rbST herds. After correcting for management improvements, feed supply, seasonal variation, etc., in both control and rbST herds, the study concluded that milk, fat, and protein production increased significantly in response to rbST. Over the four years since commercial availability, these cows showed an average of 6+ pounds of milk per cow per day for each cow milking on test day, and 8+ pounds of milk per cow per day for each cow milking on test day over the last two-thirds of lactation (mid and late lactation). These represent at least 1,968 pounds of milk, 59 pounds of fat, and 62 pounds of protein per 305-day lactation. As Bauman et.al. point out, these are presumably minimum responses to rbST treatment, because it was assumed that 100 percent of the cows in each herd were treated with rbST. Since most producers do not treat 100 percent of cows, average response rates are much higher than these results indicate.

These results, along with several hundred other controlled experiments and studies indicate that rbST does appear to significantly increase milk production in treated cows. To really appreciate the results of the Bauman et. al. paper, the reader should understand that this study was carried out on entire herds in the field – as opposed to controlled experimental results on individual cows which often exaggerate the response rate.

Survey and Study Results Prior to rbST Availability (1987-1993)

The controversy surrounding rbST has existed since the 1983 when a report on the economic impacts of the technology on the dairy industry emerged from Cornell University (Kalter et al., 1983). Several subsequent reports on the economic and social impacts of rbST fueled the fires of controversy between 1983 and the present. Specifically, questions were raised about adverse health effects on animals treated with rbST, the appropriateness of the technology for an industry plagued with surpluses, the effects of increased milk production on milk prices, and the plight of the family farm in the U.S. Media hype about the impacts of rbST has been intermittent since 1983, but increased substantially from 1988 - 1993. In 1987, fully 20 percent of our respondents had not heard of rbST. But this number dwindled to zero over the years as increasing media attention focused on the various issues involved.

A number of studies have been carried out over the last 10 – 15 years (mostly before rbST was commercially available). Most studies involved asking dairy producers their opinions and attitudes toward rbST, and whether or not, and to what to extent, they plan to adopt rbST. The objectives of these studies were, among other things, to determine the socio-economic characteristics of producers, and relate these to their intentions to adopt. The data were then used to predict aggregate adoption rates, which in turn could be used to asses the potential social and economic impacts of rbST.

It is impossible to neatly summarize, and do justice, to the many studies that have been done on rbST (Centner and Lathrop (1996) report that more than 1,500 articles have been written on rbST). Several articles have attempted to summarize the results of many of these studies (Caswell, Fuglie and Klotz, 1994; Raboy and Simpson, 1993; Lesser, Bernard and Billah, 1999)

Overall, the predicted aggregate adoption rates range from 8% to 41% for early adopters, and from 33% to 92% for eventual adopters. Factors associated with early adoption in most studies identified producers who were younger, better educated, with larger farms and a stronger than average asset base, who were skilled managers and managed herds with higher than average herd productivity. At the same time, most surveys also identified a significant proportion of dairy producers who were committed non-adopters because of the socio-economic issues surrounding rbST. Predicted rates of profitability from rbST use range from negative values on poorly managed dairy farms with low herd productivity, to $250 per cow on farms with higher production bases and elevated response rates (Fallert et. al. 1987; Schmidt 1989; Butler 1992; Marion and Wills, 1990, Jarvis 1996).

In 1987, a survey of California dairy producers was carried out to determine their attitudes and concerns about technology adoption, and particularly about rbST. A sample of 152 dairy producers (about seven percent of total) was drawn from a complete list of all Grade A producers in California. The same producers have been continuously surveyed each year since 1987. In 1990 the original survey sample was increased to represent approximately 10 percent of all California dairy producers. In 1994, after extensive debate and testing, rbST was finally approved for commercial use on US dairy farms. The survey was carried out in 1994 and 1995, but was postponed in 1996. In 1997/98, in addition to surveying the entire panel of dairy producers, an extensive survey was made of almost 50 percent (1,000 producers) of the California dairy industry on adoption or non-use of rbST.

Survey participants were asked whether they would use rbST immediately after it became available, wait to use it, or would not use it at all. Over the 7 years of the survey prior to the commercial availability of rbST, responses to this question varied considerably. Table 1 is a tabulation of responses to this question for the first 7 years of the survey.

TABLE 1.

Milk producers likelihood of using rbST when it becomes commercially available.

	% of Total Respondents						
	1987	1988	1989	1990*	1991*	1992*	1993*
Prospective Users	42.3	55.0	47.7	33.1	32.2	28.4	30.1
Would use immediately	8.5	3.6	2.9	5.9	4.3	6.6	4.1
Would wait	33.8	51.4	44.8	27.2	27.9	21.8	26.0
Would not use	29.2	27.0	44.8	57.4	53.8	56.2	62.3
Uncertain	28.5	18.0	7.6	9.4	14.0	15.4	7.5

*****Larger sample

Note: "Uncertain" category in Table 1 includes those who reported that they would use rbST only if conditions in the dairy industry were such that they felt they could only remain competitive by doing so.

<u>Adoption and Use of rbST after Availability</u>

Very few *ex post* studies of rbST adoption have been carried out. Lesser et. al. (1999), Tauer and Knoblauch (1996) and Lyson, Tauer and Welsh (1995) report on studies carried out on rbST use on New York dairies. Overall adoption rates in New York were 33% - 39% after one year, and 37% by the end of 1996. Barham (1995 and 1996) reports on early adoption rates in Wisconsin. According to these studies, 6.6% of dairy producers had adopted rbST after one year of availability, while 50% of producers reported no planned use, and a further 36% were classified as unlikely users. Butler (1998a) reports on adoption rates in California. By the spring of 1995, one year after commercial availability, about 20% of California producers were using rbST on an average of 25% of their cows. Another 5 percent of producers reported having used it in the past on about 23% of their herd. Thus about 10% of all cows in the sample were treated with rbST within a year of release. By 1996, the percentage of current users had not changed, but the number of past users had increased slightly, the number of prospective users had increased and the number of committed non-users had dropped from 59% in 1994 to 44% in 1996.

With the FDA approval of rbST in November of 1993, and its commercial availability in February 1994, the survey of California dairy producers was modified to solicit responses to the following questions:

a. Are you currently using rbST? If so, when did you start using it?
b. Have you ever used rbST? If so, why did you stop using it?
c. Are you considering using rbST in the future? If so, what factors would play a major role in your decision to use it?

Table 2 is a tabulation of the adoption and use of rbST in 1994 and 1997/98

Table 2
Adoption and Use of rbST in 1994 and 1997/98

	1994	**1997/98**
Current Users	18.2	27.7
Past Users	5.1	17.8
Prospective Future Users	17.6	8.6
Non Users	59.1	45.9
Total number of cases	183	584

Between 1994, when the survey was administered about 6-9 months after the commercial release of rbST, and 1997/98, adoption rates climbed from about 23 percent (current and past users) to almost 46 percent. However, it is clear that many producers had tried rbST and decided to discontinue its use. The 1997/98 survey yielded over 50 different reasons why producers who had previously used rbST but stopped using it. For many, it just didn't work or the results were disappointing. Many felt that it was not cost effective, and many also had problems like mastitis, lameness, loss of condition and lowered immune system functions which they attributed to rbST use. Regardless of the reason for stopping the use of rbST however, the question these responses raise is; what constitutes "adoption"? Clearly, current use is one definition, but it does not take into account the fact that producers may use rbST at different times and for different management reasons. If we restrict the definition of adoption to current use, then we are ignoring the responses of those who were not using it at the time of the survey, but have used rbST in the past and may continue to use it in the future. Therefore, in this paper, we define "adoption" as all producers who have used or are currently using rbST.

The Role of Information in Technology Adoption

In 1994, just as rbST was becoming commercially available, we used data collected over a 4-year period from 1987 – 1990 to analyze the potential adoption of rbST by California dairy producers. (Klotz, Saha and Butler, 1995). This study developed an analytical framework to explain producers adoption decisions in an environment where a new technology is relatively unknown and producers have the choice of adopting immediately or waiting until further information about the technology becomes available.

The following explanation of the model is quite cursory because there is simply not space here to explain all the details. The interested reader can review the full model in Klotz, at. al., 1995. However, there are several aspects to the model that need to be understood. When we carry out a survey of dairy producers intentions regarding a new technology that is not yet commercially available (and still requires FDA clearance and approval), and where information about the technology is incomplete, we are faced with several possible reactions.

1. Producers may not have heard about the new technology.

2. Dairy producers may have heard about the new technology, but may not know whether they would adopt it or not.

3. Even though producers may consider adoption a strong possibility, they may also know that they have a choice of postponing that decision if, at the time of commercial availability, it is not profitable to do so.

4. Producers may change their mind about their initial decision as time passes. In fact it is possible that producers may change their mind several times before the technology becomes available or before time to make a decision is imminent.

5. The producers decision *ex ante* is based on the *perceived* benefits and/or costs of the technology. Since the benefits and costs of rbST are dependent on external, unknown factors such as the price of milk, the cost of feed, the profitability of rbST, and these are unknowable *a priori*, then the "perception" is based on the producers acquired level of information. This *ex ante decision to adopt is*, in turn, highly dependent on a number of socio-economic variables or socio-demographic attributes that are also likely to influence the actual adoption process.

6. It is possible that a producer could have gathered sufficient information in the pre-approval stage (prior to commercial availability) to be certain about whether or not to adopt the new technology.

7. The problem of a repeated survey over the years is that the survey itself may introduce a bias. Asking producers whether they "have heard" about rbST can only be answered honestly with a "no" the first time it is asked. After asking the

question for a second and subsequent time, awareness of the new technology becomes not a factor of education, age, etc, but of being surveyed.

Thus, the producer is faced with the following alternatives:

A. The *ex ante* choice – decide now whether or not to adopt rbST based on expected profit from adoption; or
B. The *ex post* choice – wait until the technology is commercially available and adopt rbST *only* if it is profitable to do so, and profits are high.

The choice between these two alternatives is a strategy – and the deciding factor is the present discounted value (PDV) of rbST-induced profit. Thus:

$$PDV_A = R – C + R/(1-r)$$

Where PDV_A = present discounted value of the *ex ante* choice
R = expected profit = $p.R^H + (1-p)R^L$
p = the probability of high profit, R^H
$1-p$ = the probability of low profit, R^L
C = the fixed cost per cow of rbST adoption
r = discount rate

And:

$$PDV_P = 0 + p(R^H – C)/(1-r)$$

Where PDV_P = present discounted value of the *ex post* choice

Thus the producer will choose the *ex post* choice only if:

$$PDV_P > PDV_A$$

This decision can be viewed as choosing the *ex post* choice when the “net value of information” is positive. The larger the net value of information becomes, the more likely the possibility the producer will choose the *ex post* alternative. But when the net value of information is negative and $PDV_A > 0$, immediate adoption will be chosen. Immediate adoption may not be optimal however, because even if the expected net present value of adoption is positive, the NPV of waiting and adopting if profitability is positive may be higher.

Differentiation of the above functions yields the following further, and quite intuitive implications of the model:

1. The producer will wait for more information if the cost of adoption, C, is high.
2. If the probability of higher profits from adopting rbST increases, the value of information will decrease, thus making PDV_A (the *ex ante* choice) more attractive.
3. Because per-cow fixed adoption costs are primarily information-acquisition costs, larger producers will tend to have lower per cow fixed adoption costs, C, and thus induce the *ex ante* choice. That is, larger producers will tend to be earlier adopters.

A probit adoption model, using data collected from 1987-1990, that explicitly accounts for the above (sample selection arising from incomplete information) was developed. The results showed that:

1. Failure to address the sample selection problem can introduce considerable bias
2. The socio-economic profile of a dairy producer most likely to adopt is as follows:
    a. Large, productive herd
    b. More years of education
    c. Prior success in adopting new technologies

   Operating experience and use of a computer did not have significant effects.
3. As information about rbST became available, dairy producer attitudes has become more negative, since the number producers who said they would adopt rbST decreased from 1997 to 1990.
4. The model predicts that approximately 63 percent of the sample of producers will adopt rbST. (Failure to address the sample selection problem indicates that only 53 percent of producers will adopt rbST).

One of the unique things about this model is that we were able to model the changing attitudes of dairy producers over time, as the results in 3 above suggest. For example, the number of producers who said they would adopt rbST after FDA approval declined steadily from 1987 to 1990. This trend is not usually observed in other studies because they are usually based on data from a single year, whereas this model was based on data collected over a number of years.

The Importance of Feed Management Technologies

Administering rbST to dairy cows has two distinct effects upon the lactation curve. First, there is an immediate increase in milk production causing the lactation curve to shift upward a few days following administration, and second, the use of rbST increases the persistency of lactation causing higher levels of milk production to be maintained for a longer period. The action of rbST is to mobilize body energy stores to increase milk production. As a consequence, the cow needs more and continuous feed, or else her body condition rapidly deteriorates. The consequence of these effects is that the producers ability to keep sufficient amounts of a well-balanced ration available at all times is critical to the success or failure of rbST use. In other words, feed management practices such as Total Mixed Rations (TMR) and feed buffers, in addition to innovativeness and technical ability (proxied through the use of computers in the operation of the dairy) may be important determinants of continued rbST adoption.

We used data collected in the 1997/98 survey of California dairy producers to examine whether:

1. The adoption of certain feed management technologies is an important explanatory variable influencing the adoption of rbST.
2. Feed management technologies (or the lack thereof) are important explanatory variables for dairy producers who no longer used rbST but had adopted it in the past,
3. The adoption of rbST and feed management technologies are interrelated and, if so, how.

Results of the study are reported in Henriques and Butler (2000). Using bivariate and multivariate probit analysis, we concluded that feed management technologies are important determinants of current and continuing adoption of rbST. However, use of feed buffers had a significantly larger impact in current adoption decisions than TMR, which appeared to have little significant impact. Our results also suggest that the non-adoption of feed buffers may have contributed to a dairy producers decision to discontinue using rbST. Additionally, we found that rbST adoption decisions are <u>not</u> interrelated with the decision to adopt TMR. But, a bivariate probit model of the rbST adoption decision and the feed buffer adoption decision supported our original hypothesis that the adoption of feed buffers can be viewed as an interrelated technology. This study provided a useful precursor to our discriminant function analysis.

***Ex Post* Discriminant Function Analysis**

To test the validity of the *ex ante* model estimated in 1993 using data from 1987-1990, we used a relatively straightforward discriminant function analysis. Discriminant function analysis can be used to determine which variables discriminate between two or more naturally occurring groups. In this case, we are simply attempting to define the difference between rbST users and non-users, and in particular, to test if the differentiating characteristics of users and non-users of rbST, found in the *ex ante* analysis, are good predictors of adoption.

Applying and interpreting discriminant analysis is similar to regression analysis, where linear combinations of measurement for two or more independent variables describes or predicts the behavior of one or more dependent variables. The most significant difference is that discriminant analysis is most useful where the dependent variable is categorical.

We have used a Full Information Maximum Likelihood (FIML) method to determine the linear discriminant function:

$$Y = a + b_1X_1 + b_2X_2 \ldots\ldots\ldots b_mX_m$$

Where Y= the categorized dependent variable (y=1 if a user, 0 otherwise)
X_{ij} = a matrix of independent variables 1……m

The observed values $X_1 \ldots\ldots\ldots X_m$ (may be either categorical or metric) from two multivariate normal populations π_1 and π_2 have means μ_1 and μ_2 and covariance matrices Σ_1 and Σ_2. It is usually assumed that the covariance matrices are equal, and the costs of misclassification and prior probabilities of membership are also equal for the two populations. However, in this case we set the prior probabilities proportional to the observed cases. Using a Mahalanobis distance function, we can define two classification functions, S_0 and S_1, where:

$$S_i = c_i + w_{i1}X_1 + w_{i2}X_2 \ldots\ldots\ldots w_{im}X_m$$

where S_i = the classification score, S_0 or S_1
W_{ij} = the weight for the jth variable for the ith group
X_j = a matrix of independent variables 1…….m

We define a discriminant function with the dependent variable BSTUSER, which is a categorical variable equal to 1 for all observations <u>who have used or are currently using rbST</u>, and 0 otherwise. We use the same independent variables as those used in the *ex ante* model. These are described in Table 3

Table 3
Variable Descriptions and Statistics
(all estimates based on non-missing observations)

Variable	**Explanation**	**Means**		
		Total	**Users**	**Nonuser**
		473 cases	228 cases	245 cases
NUMCOWS	Number of cows in herd	909	1250	592
MILKPROD	Average milk production/cow/year	19099	20593	17709
YROPER	Years of experience in dairying	23.5	21.0	25.8
EDUC	Index of education level	3.06	3.27	2.87
PCRECORD	Use of a personal computer =1	0.74	0.91	0.58
AD_FB	Use of feed buffers =1	0.70	0.82	0.59

The results of the discriminant function analysis are reported in Table 4.

Table 4
FIML Estimates of Parameters
(all estimates based on non-missing observations)

Variable	*Ex Ante* Analysis (1987 – 1990 data)	*Ex Post* Analysis (1997/98 data)	Standardized *ex post* Coefficients
Constant	-2.0508***	-1.96112***	
NUMCOWS	0.0003435***	0.000538*	0.50405
MILKPROD	0.00005973**	0.00003368***	0.21451
YROPER	-0.006717*	-0.0229099*	-0.30924
EDUC	0.06605***	0.0147525***	0.021272
PCRECORD	0.1643*	1.2359***	0.5049
AD_FB	0.3031**	0.57858***	0.25594

Levels of significance are denoted by the asymptotic t-ratio where *** denotes significance at the 1% level; ** denotes significance at the 5% level; * denotes significance at the 10% level.

The Wilks Lambda test of association for the *ex post* analysis is 0.7668, and the Chi-Square value is 124.27 with a ρ-value of 0.0000, which means that the two distributions of users and non-users are statistically significantly different at the 1% level.

Comparing the *ex post* unstandardized coefficients with the results of the *ex ante* model, we find that the coefficients are of similar magnitude and have the same signs. The standardized coefficients of the discriminating function show how the independent variables are used to discriminate amongst the two groups. NUMCOWS and PCRECORD are the two most significant variables, followed by YROPER, AD_FB and MILKPROD. EDUC has the least effect, but is clearly highly significant in both the *ex ante* and *ex post* analyses.

The two classification functions derived from the discriminant function are shown in Table 5 and the Classification Table is shown in Table 6.

Table 5
Classification Function Coefficients for BSTUSER
(all estimates based on non-missing observations)

Variable	**Non-User**	**User**
Constant	-8.12841	-10.31
NUMCOWS	0.000458311	0.00105087
MILKPROD	0.000366367	0.000403461
YROPER	0.156873	0.131642
EDUC	1.07025	1.0865
PCRECORD	1.48312	2.8443
AD_FB	0.225638	0.86284

Table 6
Classification Table

		PREDICTED		
ACTUAL	**Size**	**NON-USER**	**USER**	**Totals**
NON-USER	245	154	91	
		62.9%	37.1%	100%
		32.6%	19.2%	51.8%
USER	228	42	186	
		18.4%	81.6%	100%
		8.8%	39.3%	48.1%
Totals	473	196	277	
		41.4%	58.6%	100%

71.88% of the cases were correctly identified.

The Classification Table presented in Table 6 shows that 58.6 percent of the sample population are predicted to adopt rbST. This compares to 63 percent found in the *ex ante* study. Apart from the fact that these figures are quite close, their slight difference may be explained by the finding in the *ex ante* study (and supported by the survey results reported in Table 1) that the controversial nature of the technology may have lead many dairy producers to view rbST negatively, and thus not to adopt it, even if it was profitable to do so. This is also supported by the fact that only 72% of the cases were correctly classified. That is, 19.2% of those who have not used or are currently not using rbST are predicted to use it, while 8.8% of those who are current or past users will eventually become non-users. Put in another way, 63% of current non-users are confirmed non-users, while 82% of past or current users are projected to continue to use it.

Finally, although not shown here, the covariance matrix and correlation matrix reveal that there are no close correlations between the independent variables. The highest correlation is 29% between MILKPROD and AD_FB.

Concluding Comments

This study uses data collected from California dairy producers 4-5 years *after* the commercial release of rbST to test the validity of predictions made using data collected from the same source 4-7 years *prior* to the commercial availability of rbST. A relatively straightforward discriminant function analysis, using exactly the same variables as the *ex ante* model shows that our abilities to project adoption rates, at least in this case, are fairly accurate. Our relatively simple model shows that the variables selected *prior* to the commercial availability of rbST were indeed relatively accurate predictors of the actual adoption rate 4-5 years after the commercial release of the new technology. Our model, however, does not do a "perfect" job in projecting the actual adoption rates of rbST in California. While the parameters of the *ex post* analysis are relatively similar and of the same sign as the *ex ante* analysis, there are still discrepancies that need to be explained.

There are a number of reasons, some of which have already been suggested in this, and other papers, why dairy producers may have changed their mind about adopting rbST between the *ex ante* and the *ex post* analyses. First, rbST does not require much in the way of large expenditures to be made in order to adopt it. Therefore, there is little cost associated with "unadopting" it if it does not work for a particular situation. Additionally, a number of studies are finding that while rbST is an effective technology for increasing milk production, it is not clear whether there is any significant increase in profitability from using rbST (Tauer and Knoblauch, 1997; Stephanides and Tauer, 1999; Tauer, 2000; Folz, 1999; Butler, 2000)

Second, there are several reasons why we might expect to find differences between the *ex ante* projections and the *ex post* rates of adoption. The farm level characteristics that we have used here are not the only things that impact the adoption of new technologies. External economic conditions such as the price of milk and feed costs are important determinants of the feasibility of adopting rbST, and are probably important determinants of the discrepancies in our analysis. For example, when feed costs are high and milk prices are low, rbST is feasible for a much lower proportion of dairy producers than when feed costs are low and milk prices are high (Butler and Carter, 1988, Butler, 1999). In addition, the peculiarities or unique characteristics of a new technology are also important factors that must be taken into account. Often these peculiarities may only become obvious after the technology becomes available and is tested for a time. rbST may also be used on a highly selective basis both in time and extent. Prior to its commercial availability it was assumed that dairy producers would use rbST on all or most of their cows for a sustained length of time. Our survey results show that most producers are using rbST on a widely varying proportion of their cows, and may often use it for a select time ranging from a few weeks to 5 or 6 months of a 10 month lactation. Therefore, a truer measure of "adoption" and whether we can predict it, may well be the total amount of *extra* milk that is produced as a result of using the new technology.

Nevertheless, despite these shortcomings, in our opinion, it is safe to say that our predictive abilities of adoption rates have certainly improved as econometric techniques have improved, and as we have learned from other *ex post* analyses. We would like to think that they will continue to improve as we understand more about the factors that drive the adoption of new technologies, and as our statistical techniques improve.

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