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The Adoption and Impact of Bovine Somatotropin on U.S. Dairy Farms

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Data from a national survey representative of U.S. dairy operations were used to assess adoption and the production and financial impacts of recombinant bovine somatotropin (rbST). Adoption rates of rbST varied significantly across the nation, but were higher among larger diary operations in all regions. However, the scale bias of rbST adoption was substantially diminished when the influence of location and the use of related technologies were measured. An increase in milk production per cow was associated with rbST adoption, but estimated financial impacts were not statistically significant due to substantial variation in the net returns of rbST adopters.

Recombinant bovine somatotropin (rbST) is a synthetic version of a naturally occurring bovine hormone that is among the first commercial agricultural technologies derived from recombinant DNA technology research. Prior to commercial release in 1994, numerous experimental trials suggested that rbST could increase milk production by up to 30% with profit opportunities as high as $250 per cow (see Caswell, Fuglie, and Klotz for a review of these studies). Since its introduction, however, analysis of rbST use has failed to indicate that adoption has been associated with higher profits for milk producers (Tauer and Knoblauch; Stefanides and Tauer; Tauer; Foltz and Chang). These *ex post* studies of rbST adoption have been conducted on dairy farms in only a few states. The objective of this study is to utilize survey data from a recent national sample representative of U.S. dairy farms to evaluate rbST adoption and its impact on milk production and on farm financial performance.

The profitability of an innovation compared with traditional methods is regarded as a primary reason why producers adopt new technologies. This view suggests that the adoption of rbST will occur if it is perceived to be more profitable than traditional methods. The economics of rbST is based on the premise that its use increases milk production. However, rbST is profitable only if the costs of

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increased milk production are less than the revenue generated by the added milk. The following example, adapted from Butler (1999), illustrates the profitability that producers may expect. If rbST increases milk production by 8 pounds per cow per day and the average price of milk is $12.00 per hundredweight, the additional revenue from using rbST is $0.96 per cow per day. Supplementing with rbST for the recommended 245 days would generate additional revenue of $235.20 per cow per lactation.

rbST costs about $5.50 per 14-day treatment, or about $0.40 per cow per day. Also, extra feed costs of about $0.05 per pound of milk are incurred to achieve the 8 pounds of additional milk, so that the extra feed cost is about $0.40 per cow per day. Therefore, total added costs associated with using rbST are $0.80 per cow per day, or $196.00 per cow per lactation. Subtracting costs from additional revenues in this example, profits increase by $0.16 per cow per day or $39.20 per cow per lactation. Assuming that producers not using rbST are earning $300 profit per cow per year from milk sales ($1.50 net return per hundredweight on 20,000 pounds of milk per cow), then rbST can be expected to increase returns from $300 to $339.20 per cow, an increase of about 13%.[1]

This example suggests that producers would expect a good return from rbST adoption. The example also illustrates the management requirements associated with rbST. Producers need to have the time, skill, and technologies to monitor individual cow milk production and feed intake to accurately measure the profits from rbST use. The response to rbST varies among cows in a herd and it would be difficult to determine the response of each cow without daily monitoring (Butler 1998). This means that even though rbST is a relatively inexpensive technology for producers to adopt and does not require an investment in capital assets, it is a management-intensive activity to determine the profitable use of rbST. A significant investment in human capital and possibly other information technologies may be needed to profitability use rbST.

This study expands on previous *ex post* work by conducting an analysis of rbST adoption using data from a national survey of U.S. dairy producers. Specific research questions addressed in this study are: (*a*) What factors have influenced the rbST adoption decision? and (*b*) How has rbST adoption affected milk production and profitability? Results of this analysis are compared with those of the other *ex post* studies of rbST adoption.

Literature Review

The adoption of rbST has varied among areas of the United States. Monsanto, the only company currently selling rbST (sold as Posilac) reports that approximately one-third of U.S. dairy cows were in herds supplemented with rbST during 2000, and that the average dairy producer treats more than 50% of the herd (Monsanto). Data from a panel of New York dairies suggest that adoption rates reached about 37% by the end of 1996 (Lesser, Bernard, and Billah). Only about 15% of surveyed dairy farms in Wisconsin were using rbST in 1999 (Barham, Jackson-Smith, and Moon). Data from a survey of California diary producers in 1998 indicated that 25% of producers were using rbST, but only 30% of the cows in these herds were treated (Butler 1999). Also, a significant amount of “dis-adoption” of rbST has been reported. Barham et al. reported about 10% of their panel of Wisconsin farmers had tried rbST, but stopped using it by 2001. Similarly, Barham and Foltz reported abandonment rates of rbST from different locations across the nation as high as 20%.

Farm size, operator age and education, and complementary technologies have been the main factors found to influence of the adoption of rbST. Among New York dairies, larger and more productive operations, as well as those using parlor milking, were more likely to adopt rbST (Stefanides and Tauer). In Connecticut, younger and more educated farmers who own larger farms were more likely to use rbST. The number of complementary technologies used on the farm also had a significant and positive relationship with rbST adoption (Foltz and Chang). Similarly, Barham et al. found nonadopters were older, less educated, and operated smaller dairies than rbST adopters in Wisconsin. They also found complementary technologies, such as total mixed ration (TMR) machinery, to be a strong predictor of being among various adopter categories. Barham and Foltz reported data that indicated larger operations were more likely to adopt rbST in each of several areas of the country, but the size bias was relative within the areas and not absolute across the country. The authors suggested that regional differences in the way dairy farms use nonspecialized family labor may contribute to this result.

The profitability of rbST was evaluated using data from New York dairy farms (Tauer and Knoblauch, Stefanides and Tauer, Tauer). Stefanides and Tauer estimated that production increased an average of about 1,000 pounds per cow per year on farms using rbST on a portion of the herd compared with farms where rbST was not used. Tauer estimated a production response to rbST ranging from 2,700 to nearly 3,500 pounds per cow per year between 1994 and 1997. However, neither of these studies found the adoption of rbST to have a statistically significant impact on farm profits. Ott and Rendleman used 1996 U.S. Department of Agriculture dairy data and measured a herd milk response of nearly 3,000 pounds per cow and an optimal rbST use rate of 73% of the herd. These data did not include cost information, but combining cost budgets with the data, it was estimated that rbST use would increase profits by $126 per cow.

Foltz and Chang estimated three rbST adoption models and used the results to develop instruments for measuring the production and profit impact of rbST on dairy farms in Connecticut. The models included a probit model, and probit and tobit models specified with complementary technology variables. Complementary technologies were specified to test the hypothesis that these technologies account for the scale bias observed in rbST adoption. They found that the specification of complementary technology variables improved the prediction of the adoption model, and thus complementary technologies play an important role in rbST adoption, but they did not account for the scale bias. A production response to rbST adoption of over 4,000 pounds per cow was found in one specification of adoption impact models. None of the models, however, indicated a positive and statistically significant impact of rbST on farm profits.

Empirical Procedure

The empirical approach used in this study follows that used by Stefanides and Tauer, and by Foltz and Chang. The rbST impact is estimated by regressing variables describing farm and operator characteristics on milk production and profitability. Among the explanatory variables is a binary variable indicating whether or not rbST was used on the operation. The potential endogeneity of the rbST variable is acknowledged and corrected using the instrumental variable procedure.

To illustrate the empirical approach consider the following regression equation:

$$Y = \mathbf{X}\boldsymbol{\beta} + R\gamma + \varepsilon, \tag{1}$$

where Y indicates milk production or profitability, $\mathbf{X}$ is a matrix of explanatory variables, R is a binary variable for rbST use (=1 if rbST is used, 0 otherwise), and ε is a random disturbance assumed to be normally distributed. If γ is to measure the impact of rbST adoption, farmers should be randomly assigned among the adopters and nonadopters. However, since farmers themselves decide whether to adopt rbST the assignment is by self-selection. The literature suggests that dairy producers who adopt rbST may be better managers and thus more productive and more profitable than nonadopters even without the use of rbST (Barham, Jackson-Smith, and Moon; Fetrow). Because the differences between rbST adopters and nonadopters are likely to be systematic, treating R as an exogenous variable and applying ordinary least squares to (1) would result in inconsistent parameter estimates.

Most remedies to the self-selection issue involve the estimation of a separate equation explaining the selection decision and then using the prediction from that equation to correct for the bias. In this study, the selection decision is modeled with an adoption-decision equation relating the decision to use rbST to characteristics of the farm operator and operation. Predictions from the adoption-decision equation serve as an instrumental variable for rbST use, R, in the adoption-impact equation shown in (1).

The adoption-decision equation is specified with a binary probit model that can be represented by

$$R^* = \mathbf{Z}\boldsymbol{\delta} + \mu, \tag{2}$$

where R^* is a latent variable describing the profitability of the new technology compared with the old, $\mathbf{Z}$ is a matrix of explanatory variables, and μ is the error term that is assumed to be normally distributed with a zero mean and a variance of 1. R^* is related to the observed decision to adopt R, where $R = 1$ if $R^* > 0$ and $R = 0$ if $R^* \leq 0$. The probability of adoption is $\text{prob}(R = 1) = \text{prob}(R^* > 0) = \text{prob}(\mathbf{Z}\boldsymbol{\delta} + \mu > 0) = \text{prob}(\mu < \mathbf{Z}\boldsymbol{\delta}) = \Phi(\mathbf{Z}\boldsymbol{\delta})$, where Φ is the cumulative distribution function of the standard normal distribution. The predicted probabilities of rbST adoption, $\Phi(\mathbf{Z}\boldsymbol{\delta})$, are used as the instrumental variable for R in equation (1).

Data

Data for the analysis came from a detailed survey of U.S. dairy operations conducted in 2000 as part of USDA's annual Agricultural Resource Management Survey (ARMS). Each farm in the ARMS sample represents a known number of farms with similar attributes so that weighting the data for each farm by the number of farms it represents provides a basis for calculating estimates for the target population. The target population in the dairy survey was operations milking 10

Table 1. Estimated adoption rates of rbST on U.S. dairy operations in 2000

Group	Farms Adopting	Cows on Adopting Farms	Cows Treated on Adopting Farms	Increase in Production from Treatment
	Percent			
U.S. region[a]	17	32	47	11
Northeast	20	34	55	12
Upper Midwest	17	35	37	9
Corn Belt	14	20	66	11
Appalachian	8	12	42	10
Southeast	30	44	52	11
Southwest	20	42	47	21
Pacific	19	32	44	12
Size of operation				
Fewer than 50 cows	11	13	64	12
50–99 cows	16	17	53	10
100–499 cows	25	27	52	11
500–999 cows	40	41	55	11
1,000 or more cows	65	64	34	15

Notes: Farms adopting are those treating any cows with rbST. “Cows on adopting farms” are the entire herd on farms treating with rbST, including treated and untreated cows. “Cows treated on adopting farms” is the proportion of the herd treated on adopting farms. The increase in production from treatment is that reported by the survey respondents.
[a]The regions are defined as: Northeast—VT, NY, and PA; Upper Midwest—MN, WI, and MI; Corn Belt—IA, IL, MO, IN, and OH; Appalachian—KY, TN, and VA; Southeast—GA and FL; Southwest—TX, NM, and AZ; Pacific—CA, WA, and ID.

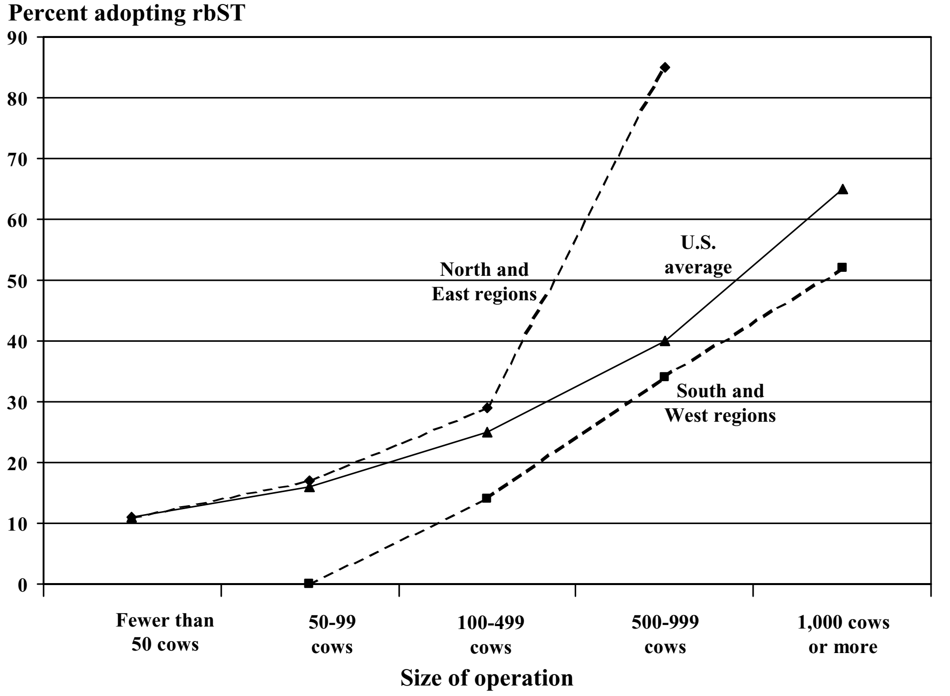
or more cows at any time during 2000. The survey collected information about dairy production practices and input use, farm financial status, and operator human capital and demographic characteristics. The survey also collected specific data about rbST use on the dairy operation. The data include information from 872 dairy operations in 22 states that represented 90% of U.S. milk production in 2000 (U.S. Department of Agriculture). All operations were used to examine adoption rates, but only dairy operations that reported being in business during all of 2000 were used in the empirical analysis. Also, 13 observations were deleted because of missing data. This left data from 820 dairy operations available for the empirical analysis.[2]

An estimated 17% of U.S. dairy operations used rbST in 2000 (table 1). Operations treating with rbST included about 32% of U.S. dairy cows, very similar to Monsanto’s report of rbST use (Monsanto). Producers treating with rbST treated an average of 47% of their herd and report an average increase in production of 11%, also very similar to the figures reported by Monsanto. Barham, Jackson-Smith, and Moon report that at the recommended use of rbST, a farm would be near full adoption if approximately 66% of the herd was under treatment at any given time. This means that the 47% estimated from the survey translates to just over 70% of what may be considered as full adoption.

Regional adoption estimates show that the highest rbST adoption rate was in the Southeast (30% of farms) while the lowest was in the Appalachian region (8% of farms). The farm adoption estimate for the Upper Midwest, at 17%, is in line with the 15% reported for Wisconsin in 1999 (Barham, Jackson-Smith, and Moon). Farm adoption estimates in the Northeast and Pacific regions, however, are somewhat lower than those reported in New York (Lesser, Bernard, and Billah) and California (Butler 1999). Also, rbST adoption was more common on larger farms in all regions, particularly in the Upper Midwest and Southwest. Adoption rates by size of operation indicate a significant size bias in the adoption of rbST (table 1). Adoption rates increase across all of the size groups, ranging from only 11% of operations with fewer than 50 cows to 65% of operations with 1,000 or more cows.

Barham and Foltz used farm data to indicate that the size bias in rbST adoption was relative within areas, rather than uniform nationally. They found that in areas where the average herd size was smaller, such as in New York or Wisconsin, the probability of adoption rises faster with herd size than in areas where the average herd size is larger, such as in Texas or Utah. To investigate their findings, the ARMS data on rbST adoption rates were summarized by size for the North and East regions (including the Northeast, Upper Midwest, Corn Belt, and Appalachia) and the South and West regions (including the Southeast, Southwest, and Pacific).[3] Figure 1 shows findings from the ARMS data that support those reported by

Figure 1. Farms adopting rbST by size of dairy operation, 2000



Note: North and East regions include the Northeast, Upper Midwest, Corn Belt, and Appalachia. South and West regions include the Southeast, Southwest, and Pacific.

Barham and Foltz. That is, adoption rates increased much more rapidly with herd size in the North and East regions where herd sizes averaged between 60 and 90 cows than in the South and West regions with average herds of about 400 to 500 cows.

Table 2 shows farm and operator characteristics and the production practices used by adopters and nonadopters. rbST adopters tended to be younger and better educated than nonadopters, and also had a longer planning horizon for the dairy operation. The difference in education may reflect differences in management strategies and a familiarity with and preference for more recent technological options. Dairy producers with a longer planning horizon may be more willing to invest in the human capital and other technologies that support the efficient use of rbST. Adopters were also more specialized in dairy production and more likely to be organized as a corporation.

The dairy operations of rbST adopters were, on average, significantly larger than the dairy operations of nonadopters (220 vs. 95 cows). Average milk production on adopting farms was nearly 2,300 pounds per cow higher than on nonadopting farms, but this difference was not statistically significant. The reason these means were not significantly different is the substantial variation on the production estimate of adopters compared with that for nonadopters.[4] The average return above operating costs per hundredweight of milk was lower on adopting farms. Much of this difference can be attributed to the greater hired labor costs incurred by the larger adopting farms whereas the smaller nonadopting farms used more unpaid labor. rbST adopters earned significantly more per hour of unpaid labor than nonadopters ($32 vs. $14 per hour). However, like the variation in milk production, variation in the net returns of rbST adopters was substantially higher than variation in the net returns of nonadopters.[5]

The adoption of rbST was also associated with the use of other productivity-oriented dairy practices (table 2). A higher percentage of adopters used a parlor milking system, a computerized milking system, and milked cows more than two times per day. Adopters were also more likely to be participants in the Dairy Herd Improvement Association (DHIA), and in genetic and breeding programs. Feeding practices used by rbST adopters more often included a computerized system, a nutritional consultant, and the monitoring of forage quality. Adopters were less likely to be using a rotational grazing system, which may be expected since this is a low-input strategy to minimize feed costs that might not be compatible with rbST use. The strong correlation between these practices and rbST use suggests that management and production systems oriented with these technologies were critical in shaping rbST adoption decisions.

Model Specification and Estimation

The impact of rbST adoption on milk production and farm financial performance was assessed by statistically controlling for several other factors that may also affect these variables, such as economic and environmental conditions, management practices, and operator characteristics. To control for factors other than rbST adoption, multiple regression was used in a two-stage econometric model of the adoption decision and impact. The first stage was an adoption-decision model describing factors that influence the likelihood of adopting rbST. Predictions from

Table 2. Characteristics and production practices of rbST adopters and nonadopters, 2000

Item	Adopters	Nonadopters	All Farms
Farm operator			
Age (years)	45**	50	49
Experience (years operating)	20	22	21
Education			
Formal school (years)	12.7**	12.1	12.2
Completing college (percent)	17**	8	10
Planning horizon (percent)			
Out of business by 2005	15**	32	29
In business in 2010 and beyond	61**	43	46
Farm business			
Milk cows (head)	220**	95	116
Milk production (pounds per cow)	18,179	15,909	16,640
Dairy specialization (percent of value)	88*	84	86
Business organization (percent)			
Individual	73*	81	80
Partnership	16	14	14
Corporation	11*	5	6
Operating margin (dollars per unit)[a]			
Per hundredweight of milk	4.84	5.58	5.29
Per hour of unpaid labor	32.67**	14.06	17.09
Dairy production practices (percent)[b]			
Parlor milking system	49**	37	39
Computerized milking system	15**	5	6
Milking more than two times per day	14**	1	4
DHIA program	78**	39	45
Genetic and breeding program	83**	61	65
Computerized feeding system	17**	7	9
Consulting nutritionist	96**	61	67
Monitoring forage quality	80**	51	56
Rotational grazing system	14*	24	22

Notes: * and ** denote that estimate is significantly different from the estimate for nonadopters at the 10% and 5% levels, respectively.

[a]Operating margin is defined as the gross cash income (commodity sales, government payments, and other farm-related income) less variable input costs. Variable input costs include costs for feed, other livestock-related costs (e.g., veterinary and medicine), seed, fertilizers and chemicals, hired labor, fuels and oils, repairs and maintenance, custom work, and utilities. The operating margin is expressed on an accrual basis by adjusting for the annual change in accounts receivable, and changes in commodity and production input inventories.

[b]DHIA indicates participation in the dairy herd improvement association. Genetic selection and breeding programs include such practices as embryo transplants and artificial insemination to improve herd quality.

the adoption-decision model were included as an explanatory variable in regressions relating farm and operator characteristics to measures of milk production and financial performance. This specification was used as a means of correcting for potential self-selection bias.

The probit model used to examine the adoption decision was specified with several farm and operator variables generally found to be related to technology choice (Feder, Just, and Zilberman; Feder and Umali), and those more specific to rbST choice (Stefanides and Tauer; Foltz and Chang). Adopters were those who reported rbST use on any portion of the herd during 2000. Farm operator variables regressed against the decision to adopt included age (*AGE*), experience (*EXPERIENCE*), education (*EDUCATION*), and planning horizon (*PHORIZON*). Farm operation variables were herd size (*COWS*) and size squared (*COWSSQ*), specialization in milk production (*SPECIALIZE*), business organization (*BUSORG*), and geographic location. Whether the farm operator had a long planning horizon was indicated if the operator expected to be in the dairy business for more than 10 years. Business organization was specified by an indicator that the operation was organized as a corporation. Variables for geographic location were also included in the model to account for the impact that regional differences in climate, production systems, and cultural perceptions of rbST have on adoption.[6] Location in the Upper Midwest was specified as the basis for comparison so coefficients on variables for the other regions indicate the difference between the region and the Upper Midwest.

One might expect rbST to be scale neutral because of its ease of use, small startup costs, and lack of a significant capital investment. However, the data indicate that the rate of rbST adoption has been significantly higher on larger operations. It has been suggested that technologies complementary with rbST may account for this scale bias as larger farms are more likely to be using these technologies (Foltz and Chang).[7] Thus, including complementary technologies among the explanatory variables may account for the size bias observed in rbST adoption. The adoption-decision model was estimated with and without the inclusion of variables indicating the use of technologies that are potentially related with rbST. This was to test whether the inclusion of these technologies could account for the scale bias observed in the data.

Technologies specified in the model included the use of a milking parlor (*PARLOR*), a computerized feeding system (*COMPFSYS*), and a computerized milking system (*COMPMSYS*). These technologies are useful for maintaining individual cow records that can be used to evaluate the efficiency of using rbST. The use of rotational grazing (*ROTGRAZE*) was added as an indicator of a low-input system that might discourage the use of rbST. Participation in the dairy herd improvement association (*DHIA*) and an indicator if cows were milked more than two times per day (*TIMES*) were also included as productivity-oriented technologies whose use may indicate producers more inclined to use rbST. This set of technologies was specified in the model because they were introduced to the dairy business long before rbST and likely adopted prior to the choice of rbST. More than 80% of the surveyed dairy operations had been in business at least 20 years, while rbST was introduced only 6 years prior to the survey. Thus, the adoption of these technologies is unlikely to be endogenous to the rbST adoption decision.[8]

An adoption-impact model was then estimated for milk production and alternative measures of financial performance. Milk production was measured as the average pounds of milk produced per cow, including milk from both treated and untreated cows. The farm's operating margin, defined as gross income less variable input costs including rbST, was used as the measure of financial performance.[9] The operating margin was examined because rbST adoption mainly impacts variable input costs, including feed and other livestock expenses.[10] The operating margin was measured per hundredweight of milk production and per hour of unpaid labor used on the operation. Dairy operations use a significant amount of labor in milk production, including a mix of both hired and unpaid labor that varies mainly by size of the dairy operation. Hired labor was charged as a variable cost, whereas the net returns are a residual payment to the unpaid labor.

Regressors specified in the adoption-impact models included operator and farm characteristics, and production technologies and practices likely to affect milk production and net returns. Operator experience and education were included in the adoption-impact models, along with variables to account for herd size and geographic differences among farms. Production technologies and practices specified in the model included use of a parlor milking system (*PARLOR*), participation in the DHIA (*DHIA*), use of genetic selection and breeding programs (*GENSELECT*), monitoring of forage quality (*MFORQ*), and an indicator if the cows were milked more than two times per day (*TIMES*). Milk price (*MPRICE*), calculated implicitly for each farm as milk receipts divided by pounds of milk sold, was also included in the financial impact models. The predicted probability of using rbST (*PrbST*), estimated from the probit adoption model that included complementary technologies, was specified as the instrument for rbST adoption in the impact models.

A two-step procedure was used to estimate the model, along with weighted-regression procedures (Heckman). A variance estimator designed for the ARMS data was used to estimate parameter variances. The ARMS uses a multiphase sampling scheme that places barriers on the development of classical variance formulas. Instead, a structured resampling method, the delete-a-group jackknife variance estimator was applied. In the application of the delete-a-group jackknife variance estimator provided by the National Agricultural Statistics Service, the sample is divided into 15 nearly equal and mutually exclusive parts. Fifteen parameter estimates, called "replicates," are created with one of the 15 parts deleted in turn for each replicate estimate. The jackknife variance estimate measures how much the replicate estimates differ from the full sample estimate.[11] More information about the jackknife variance estimator can be found in Dubman and in Kott.

Results

Table 3 presents probit parameter estimates for the rbST adoption-decision models, excluding and including related technologies. Several variables were statistically significant in both models with signs that are consistent with prior expectations. The pseudo R^2 improved considerably (0.13–0.21) when the technology variables were added to the model, indicating their importance to adoption behavior.

The results indicate that younger milk producers were more likely to adopt rbST. The coefficient on operator age was negative and significant in both model specifications, as found in previous studies. Operator education and experience with the dairy operation also had a positive impact on adoption in the model

Table 3. Probit estimates of the rbST adoption-decision model, 2000

	Excluding Related Technologies		Including Related Technologies	
Variables	Coefficient	Std. Error	Coefficient	Std. Error
INTERCEPT	−0.8292	0.6217	−0.7004	0.7458
AGE	−0.0308**	0.0073	−0.0318**	0.0086
EXPERIENCE	0.0126**	0.0055	0.0105	0.0062
EDUCATION	0.0567*	0.0293	0.0259	0.0382
PHORIZON	0.1364	0.1304	0.0703	0.1645
SPECIALIZE	−0.0003	0.0064	−0.0003	0.0071
BUSORG	0.1648	0.3200	0.0665	0.3294
COWS[a]	0.3871**	0.0975	0.2180*	0.1179
COWSSQ	−0.0133**	0.0052	−0.0068	0.0049
NORTHEAST	0.1726	0.2801	0.0774	0.3174
CORNBELT	−0.1832	0.1505	−0.1339	0.2249
APPALACHIAN	−0.5432**	0.2506	−0.3919	0.3436
SOUTHEAST	−0.5479	0.3283	−0.3253	0.4029
SOUTHWEST	−1.1286**	0.3096	−0.8523*	0.4418
PACIFIC	−1.0692**	0.3176	−0.7984**	0.3578
PARLOR	–	–	0.1128	0.1559
COMPMSYS	–	–	0.3794	0.3566
COMPFSYS	–	–	0.2455	0.2512
ROTGRAZE	–	–	−0.2797	0.2622
DHIA	–	–	0.8156**	0.1877
TIMES	–	–	0.6335**	0.2858
Log-likelihood	−26,429		−24,034	
Pseudo R^2	0.13		0.21	
Sample size	820		820	

Notes: * and ** denote significance at the 10% and 5% levels, respectively. Critical t-values are 2.145 at the 5% level and 1.761 and the 10% level using the jackknife variance estimator with 15 replicates. Coefficients on location variables are interpreted relative to the deleted group, Upper Midwest. The regions are defined as: Northeast—VT, NY, and PA; Upper Midwest—MN, WI, and MI; Corn Belt—IA, IL, MO, IN, and OH; Appalachian—KY, TN, and VA; Southeast—GA and FL; Southwest—TX, NM, and AZ; Pacific—CA, WA, and ID.
[a]Measured as hundreds of cows.

excluding related technologies, but were not significant when they were added. Coefficients on herd size in both models indicated that larger producers were more likely to adopt rbST and the negative sign on the quadratic term indicates that the size impact on adoption increased at a decreasing rate. However, the impact of herd size on adoption was substantially less (about 44%) when the related technology variables were added to the model. This result differs from that reported by Foltz and Chang who found little change in the impact of herd size on adoption when technology differences were measured.

Estimated coefficients on the geographic variables indicate that location in the Appalachian region was associated with a lower adoption probability than in the Upper Midwest, consistent with the mean adoption rates found in these regions.

Negative coefficients were also found on the variables indicating location in the western regions (i.e., Southwest and Pacific) in both model specifications. This means that once the difference between size and other characteristics of dairy operations in the Upper Midwest and western regions were statistically controlled, the probability of adopting rbST was estimated to be higher among Upper Midwest producers. Coefficients on variables for the related technologies that require capital investments, including a milking parlor, and computerized feed and milking systems, were not statistically significant. However, coefficients on variables indicating use of productivity-oriented practices likely to be complementary with rbST were positive and statistically significant. Producers participating in the DHIA program and milking more than twice a day were more likely to use rbST. This result is similar to that reported by Foltz and Chang.

Table 4 shows results of the adoption-impact models. The estimated model for milk production per cow indicates that more educated producers and more specialized operations had a higher output per cow. Estimated coefficients on the size of operation and location variables were not statistically significant in the production-impact model. Productivity-oriented practices, including participation in the DHIA program and use of genetic selection and breeding, had a statistically significant and positive correlation with production per cow. Accounting for these impacts, treatment of some portion of the herd with rbST had a statistically significant impact that added almost 2,700 pounds of annual milk production per cow. This is close to the impact estimated by Ott and Rendleman, at the lower end of the 2,700–3,500 pounds per cow range reported by Tauer, but much less than the 4,142 pounds per cow estimated in a similar model specified by Foltz and Chang.

Table 4 also shows the estimated models for the rbST impact on operating margin per hundredweight of milk and per hour of unpaid labor. Coefficients on education and specialization indicate an unexpected negative relationship between these variables and the operating margin per hundredweight. Geographic variables were also significant in this estimated equation showing higher returns for producers in the Upper Midwest compared with producers in most other regions. Size of operation had a positive impact on the operating margin per unpaid labor hour mainly because larger operations hire more labor for production activities and spread their unpaid managerial labor over more units of production. Milk price had a positive and statistically significant impact on both measures of financial performance. None of the coefficients on the technology variables specified in these models were statistically significant.

The coefficient on rbST use was positive and substantial in both financial performance models, but not statistically significant at conventional significance levels (table 4). Since rbST use increases milk production, this means that the costs of additional inputs used to generate the production response offset the additional milk revenue. However, the magnitude of the estimated profit response ($3.61 per hundredweight and $9.90 per hour) suggests that rbST generated a substantial increase in net returns on some operations. The lack of statistical significance implies that the variation in net returns among operations using rbST was also substantial. These results coincide with the other *ex post* studies of rbST adoption impacts that also showed positive production impacts but a profit response that was not statistically significant (Stefanides and Tauer; Tauer; Tauer and Knoblauch; Foltz and Chang).

Table 4. Regression estimates of the rbST adoption-impact models, 2000

	Milk Production per Cow (lbs)		Operating Margin per Hundred Weight ($)		Operating Margin per Unpaid Hour ($)	
Variables	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
INTERCEPT	5633.58*	2868.20	15.906**	4.967	−7.002	37.297
EXPERIENCE	1.72	20.64	0.017	0.018	0.291	0.191
EDUCATION	231.15**	80.96	−0.217**	0.093	−1.605	1.420
SPECIALIZE	58.61**	23.53	−0.189**	0.041	−0.305	0.196
COWS[a]	−72.65	325.54	−0.325	0.266	13.303*	6.656
COWSSQ	−1.55	9.98	0.010	0.010	0.020	0.328
MPRICE[b]	—	—	0.818**	0.116	4.295**	1.751
NORTHEAST	33.62	914.46	−2.209**	0.638	−11.886**	3.376
CORNBELT	−292.33	854.21	−1.591*	0.900	−8.002	5.806
APPALACHIAN	−326.21	901.18	−2.044**	0.799	−8.264	10.999
SOUTHEAST	−1016.37	1852.35	−3.060**	1.072	25.004	24.893
SOUTHWEST	−608.99	1412.54	−1.858	1.481	7.731	20.814
PACIFIC	1107.96	1455.95	−0.758	0.823	18.240	17.201
PARLOR	−300.33	924.65	−0.474	0.639	5.241	7.323
DHIA	1763.56**	605.14	−0.534	0.527	−1.125	3.469
GENSELECT	726.32*	389.89	0.113	0.627	−1.086	3.401
MFORQ	999.91	605.23	0.162	0.774	4.383	3.210
TIMES	1965.40	1267.07	−1.522	1.077	11.907	14.647
PrbST[c]	2666.38*	1411.12	3.614	3.212	9.904	38.490
R^2	0.22		0.29		0.34	
Sample size	820		820		820	

Notes: * and ** denote significance at the 10% and 5% levels, respectively. Critical *t*-values are 2.145 at the 5% level and 1.761 and the 10% level using the jackknife variance estimator with 15 replicates. Coefficients on location variables are interpreted relative to the deleted group, Upper Midwest. The regions are defined as: Northeast—VT, NY, and PA; Upper Midwest—MN, WI, and MI; Corn Belt—IA, IL, MO, IN, and OH; Appalachian—KY, TN, and VA; Southeast—GA and FL; Southwest—TX, NM, and AZ; Pacific—CA, WA, and ID.
[a]Measured as 100's of cows.
[b]Milk price was not included in the production model.
[c]The predicted probability of adopting rbST estimated from the adoption-decision model.

Table 5 includes a summary of the adoption impacts measured by the difference in adopter and nonadopter sample means, and regression results with and without the sample selection correction. The comparison of means did not yield a statistically significant production response to rbST, but by statistically controlling for other factors in the regression analysis the response was significant. However, it appears that the production response to rbST would have been significantly overstated had the selection bias not been corrected. Another point is that the regression results corrected for selection bias were greater in magnitude than the uncorrected results in both models of the net returns to rbST (although none are statistically significant). This implies that, contrary to prior expectations, there may have been a negative self-selection bias associated with the profitability of rbST adoption.

Table 5. Comparison of the rbST adoption impact using different measurement methods, 2000

Measurement Method	Impact of Adoption on: Milk Production per Cow (lbs)	Operating Margin per Hundred Weight ($)	Operating Margin per Unpaid Hour ($)
Difference in adopter and nonadopter means	2,270	−0.74	18.61**
Regression without sample selection correction[a]	3,124**	−0.79	6.52
Regression with sample selection correction[b]	2,666*	3.61	9.90

Notes: * and ** denote significance at the 10% and 5% levels, respectively.
[a]Estimated impact by using a binary (0,1) variable for rbST adoption.
[b]Estimated impact by using the predicted probability of adopting rbST estimated from the adoption-decision model.

Summary and Conclusions

Data from a sample of milk producers in 22 states were used to estimate an adoption function for rbST and to measure the impact of adoption on milk production and measures of farm financial performance. Factors found to influence the adoption of rbST include many of the same factors shown to influence the adoption of other agricultural technologies. Younger, more educated, and more experienced milk producers were more likely to use rbST. Despite the inherent scale-neutral nature of rbST, adoption was much greater on larger farms. rbST is a management-intensive technology associated with the use of other productivity-oriented technologies and management practices that have been adopted more often on larger farms. The scale bias measured from survey data was considerably reduced by accounting for differences in the use of some of these technologies, but was not totally eliminated.

The use of rbST was found to significantly increase milk production per cow, an average of about 2,700 pounds, after statistically controlling for other factors that would affect milk production and the potential self-selection bias from survey data. The impact on financial performance, however, was not statistically significant. Estimated coefficients measuring the financial impacts were substantial, but large standard errors prevented the estimates from being statistically significant. These results suggest that there are probably dairy operations where rbST use substantially improved financial performance, and that there are probably situations where rbST was unprofitable. Wide variation in the financial performance of operations using rbST means that statistical tests about the average impacts were not conclusive.

Why is there such a wide variation in financial performance among U.S. dairy operations using rbST? An interesting finding of this study is a negative self-selection bias associated with the profitable use of rbST, suggesting that many rbST users were possibly less profitable than nonusers before adoption. If so, this would contribute to the wide variation in net returns among rbST users. rbST use will not substitute for good management, but rather requires good management to be successful. Also, rbST has been on the market only since 1994 and there may be a significant learning process associated with using the technology profitably. Early adopters may be earning significant profits from rbST, whereas later adopters may still be learning how to use the technology profitably. The close tie between the level of management and the production and profits obtained from rbST may be a major reason why rbST is associated with such substantial variation in farm performance.

Findings of this study conform with much of the *ex post* literature on rbST adoption, but provide a national perspective on the issue. Adoption rates estimated from the national data are similar to those reported by most states. Findings about the relationship between size and rbST adoption also support previous findings on the regional nature of the size bias. This study was able to explain more of the size bias from the use of technologies complementary with rbST than other work has, but the size bias remained. Other factors not accounted for in the model, such as other fixed costs associated with the acquisition of information about herd response and profits, may explain the remaining size bias. Finally, despite having measures of profit that are probably superior to those used in prior work, conclusions about the impacts of rbST use on profits were the same as those found in previous studies.

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Endnotes

[1]This example does not include the cost of additional labor required for production and management activities associated with using rbST.

[2]Of the 39 operations that were not in business during all of 2000, 35 operations exited the dairy industry. Six of these operations reported using rbST.

[3]The ARMS data were aggregated into the two broad areas because of insufficient data to report rbST adoption by size of operation for each separate region. Adoption estimates could not be reported for operations with 1,000 or more cows in the North and East regions and for operations with less than 50 cows in the South and West regions due to insufficient data in these groups.

[4]The coefficient of variation (i.e., standard error relative to the mean) on the estimate of production per cow for rbST adopters is nearly 10%, compared with only about 2% for nonadopters. A 95% confidence interval around the mean production among rbST adopters ranges from about 14,300 to 22,000 pounds per cow.

[5]Coefficients of variation on the estimates of net returns for rbST adopters are twice those on the estimates for nonadopters.

[6]For example, Wisconsin enacted a voluntary labeling law in April 1994 that allows processors to package milk products as free of rbST as long as the label included a disclaimer that no health differences have been shown between milk from treated and untreated cows. This effectively constrained rbST adoption in Wisconsin (Barham).

[7]Complementary technologies such as ration formulation equipment, and computerized feeding and milking systems require a significant capital investment and thus are scale biased toward larger farms. Their use with rbST may, therefore, account for the size bias associated with rbST.

[8]The variables for times milked and computerized milking system could be endogenous for some farms. Since rbST makes cows more productive, producers may need to milk more often. Also, computerized milking systems are an innovation that was introduced during the same period as rbST.

[9]Gross income comprises commodity sales, government payments, and other farm-related income. Variable input costs include costs for feed, other livestock-related costs (e.g., veterinary and medicine), seed, fertilizers and chemicals, hired labor, fuels and oils, repairs and maintenance, custom work, and utilities. The operating margin is expressed on an accrual basis by adding the annual change in accounts receivable, and annual inventory changes in farm commodities and production inputs (Farm Financial Standards Council).

[10]Due to data issues, Foltz and Chang deducted depreciation expense, in addition to variable costs, in their measure of net returns. They indicated that this could have made rbST adoption appear less profitable if rbST adopters had a higher depreciation expense due to the adoption of capital-intensive complementary technologies, among other reasons. However, because of the aggregation of their data, they could not test for a correlation between depreciation expense and rbST use. Analysis of the ARMS data did not find a statistically significant difference between the depreciation expense of rbST adopters and other dairy farms.

[11]Parameters estimated with the two-step procedure are consistent, but not as efficient as those estimated with the maximum likelihood approach. However, this method was used because of the difficulties in obtaining convergence with the maximum likelihood method for each of the jackknife replicates.

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