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The Impact of Recombinant Bovine Somatotropin on Dairy Farm Profits: A Switching Regression Analysis

Loren Tauer
Cornell University, Ithaca, NY

Profit impact from the use of recombinant bovine somatotropin (rbST) on dairy farms was estimated using switching regression, with separate regressions for rbST-using and rbST-nonusing farms. To correct for potential self-selection bias, a probit adoption function was estimated and used to correct the error term in each regression equation. Farmers who use rbST were found to have more formal education and to have larger dairy herds; age was not a significant determining factor in adoption. RbST was estimated to not increase per-cow profit.

Key words: dairy, recombinant bovine somatotropin, rbST

Introduction

Bovine somatotropin is a hormone produced by the dairy cow that regulates milk production. The genetic material for this compound has been isolated by genetic engineering and is produced by recombinant biotechnology. This recombinant-produced bovine somatotropin (rbST) can be injected into the dairy cow to augment her naturally produced hormone, enhancing milk production but also requiring additional feed and other inputs to achieve increased production. Under the registered trade name POSILAC, rbST has been commercially available from the Monsanto Company to US dairy producers since February of 1994.

RbST was subject to years of investigation and testing before it was approved for commercial sale in the United States. Given the large production response per cow reported by most of these tests, rbST was generally projected to be profitable for dairy farmers; estimates often exceeded $100 per year per cow (Butler, 1992), although some projected little or no profit (Marion & Wills, 1990). Although POSILAC has been available to US dairy farmers for many years, and a number of studies have estimated the determinants of rbST adoption, fewer studies have assessed actual profitability on dairy farms.

Tauer and Knoblauch (1997) used data from the same 259 New York producers in 1993 and 1994 to estimate the impact of rbST on per-cow milk production and return above variable cost. RbST was not available in 1993, but one third of these farmers used rbST in 1994. The use of rbST had a positive and statistically significant impact on the change in average production per cow between the two years, but the profit change effect, although positive and large, was not statistically different from zero. Stefanides and Tauer (1999) also analyzed the production and profit effects using the same data source, but included data from 1995, resulting in a panel data set of 211 farms. They likewise found a statistically significant positive effect of rbST on per-cow milk production and found the impact of rbST on profits was statistically zero. They suggested that farmers may still be learning how to use rbST profitably, or that such a large number of farmers are using rbST—including those getting a low return—that the average farm is not making a profit from its use. Tauer (2001) used this same data source but included data from 1996 and 1997. Positive profit rbST treatment coefficients were generally estimated, but the standard errors were so large that statistically he concluded the profit impact was zero.

Foltz and Chang (2002) sampled all Connecticut dairy farms for the 1998 production year and likewise found that rbST had a positive and statistically significant effect on milk production, but the impact on profits was statistically zero (although numerically negative). They found that supporting technologies significantly interacted with rbST productivity (output per cow) on these farms. McBride, Short, and El-Osta (2003) used a sample of US dairy farms to analyze the production and financial impact of rbST adoption. They found that adoption behavior varies significantly across the United States. Although a per-cow increase in milk production is associated with rbST adoption, the estimated profitability impact is not statistically significant due to substantial variation in the net return from rbST adoption.

A limitation of these studies was that the intensity of rbST use on these farms was not accurately measured. Farmers were only asked whether they used rbST or to reply to broad ranges of herd usage.

Ott and Rendleman (2000) used actual milk production experienced on US rbST-adopting farms, but because they did not have actual cost changes, they imputed costs and returns in a partial-budget framework. They concluded that rbST would increase profits by \$126 per cow, similar to previous ex ante impact studies. In their analysis, they did not correct for the potential self-selection bias that might occur with rbST-using farmers. If better managed, those adopting farms might have experienced greater production per cow even without the use of rbST.

Estimates of actual rbST adoption by dairy farms include Barham (1996) and Barham, Jackson-Smith, and Moon (2000). Results generally showed that larger farms and farms that use other new technologies are more apt to have adopted rbST. Younger and more formally educated farmers have also adopted rbST to a greater extent.

This paper revisits the New York dairy farms for the production years 1998 and 1999. These years have not been previously analyzed. More importantly, farm expenditure on rbST was first collected in 1998, permitting an examination of the per-cow profit response based upon a measure of the intensity of rbST use on the farm. To accomplish this, a switching regression technique is used.

Methods

The technique used is switching regression—sometimes referred to as the Mover/Stayer model—because it can measure the earnings of individuals moving or staying in a region or industry. Obviously, it can be applied to any situation where it is possible for the decision maker to choose one of two (or more) regimes, in this case either using or not using rbST. Distinct regressions are estimated for rbST-using and rbST-nonusing farms, with per-cow rbST expenditure as an explanatory variable for farms using rbST. To correct for potential self-selection bias, a probit adoption function is estimated and used to correct the error term in each regression equation. These equations are estimated jointly using Maximum Likelihood. A discussion of this and alternative modeling approaches, including instrumental variables, is available in Vella and Verbeek (1999).

The first step is to estimate rbST adoption by a probit function with the specification

$$A^* = \alpha' Z + \mu, \tag{1}$$

where $A = 1$ if $A^* > 0$, $A = 0$ if $A^* \leq 0$, and $\mu \sim N(0,1)$. A^* is an underlying index reflecting the likelihood of choosing to use rbST, given the farmer's assessment, such that when A^* exceeds the threshold value (here 0), we observe the farmer using rbST and $A = 1$. Matrix Z consists of exogenous variables which explain adoption, α is a vector of estimated parameters, and μ is an error term with mean zero and variance σ^2. The adoption equation is a reduced-form equation, since the structural equation determining adoption invariably includes the profit from adoption, which is not observed but is being estimated.

Per-cow profit is estimated by the following regression equations, with regime 1 representing rbST use and regime 0 representing rbST nonuse:

$$y_1 = \beta'_1 \mathbf{x}_1 + (\rho_1 \sigma_1 \sigma_u)\{\phi(\alpha' Z) / \Phi(\alpha' Z)\} + \varepsilon_1 \text{ and} \tag{2}$$

$$y_0 = \beta'_0 \mathbf{x}_0 + (\rho_0 \sigma_0 \sigma_u)\{-\phi(\alpha' Z) / (1 - \Phi(\alpha' Z))\} + \varepsilon_0, \tag{3}$$

where y is profit per cow. The vector $\mathbf{x}_1$ represents the explanatory variables for rbST users, and $\mathbf{x}_0$ represents the explanatory variables for rbST nonusers, with β representing the corresponding estimated parameter vectors. The remaining terms represent the error structure of each equation, correcting for self-selection bias, because rbST-using (or nonusing) farms may have greater (or lower) profit per cow even without the use of rbST. The terms ε_1 and ε_0 are standard normally distributed errors with means of zero. The terms ϕ and Φ are the probability density and cumulative distribution function of the standard normal distribution, respectively. The ratio of ϕ and Φ evaluated at $\alpha' Z$ is the inverse Mills ratio, which reflects the truncation of a normal distribution at $\alpha' Z$ (Greene, 1997).

The multiplicative terms $(\rho_1 \sigma_1 \sigma_u)$ and $(\rho_0 \sigma_0 \sigma_u)$ represent the covariance of the adoption equation (1) and rbST impact equation (2), and the adoption equation (1) and the non-rbST impact equation (3), respectively. These covariances can be broken down into the standard deviations of the appropriate equations (σ_u, σ_1, σ_0) and the correlations ρ_1 and ρ_0. However, given the structure of the model and the nature of the derived data, σ_u cannot be estimated, so it is normalized to 1.0 (Greene, 1997).

Because estimates of ρ_1 and ρ_0 show the correlation of the "unobservables" of the adoption equation with the "unobservables" of the rbST use and nonuse regression equations, respectively, a test of whether ρ_1 and ρ_0 are statistically different from zero measures the endogeneity of the rbST adoption decision. If ρ_1 and ρ_0 are zero, then rbST adoption is exogenous, and it would not be necessary to model and include an adoption equation in estimating the treatment impact of rbST on profits.

Equations (1), (2), and (3) are estimated using the software LIMDEP (1998). The probit function (1) is first estimated by maximum likelihood using OLS estimated starting values. The predicted values from the probit function are then used to calculate the inverse Mills ratio, which is subsequently included as an explanatory variable when estimating equations (2) and (3) by OLS. Given the linear structure of these equations, a single parameter is estimated for $\rho_1\sigma_1$ and $\rho_0\sigma_0$. Finally, equations (1), (2), and (3) are estimated jointly by maximum likelihood using previous estimates of β_1, β_0, and α for starting values. Given the structure of the MLE equation, separate estimates for ρ_1 and σ_1, and then ρ_0 and σ_0, are possible.

The average profit impact of rbST for a farm with characteristics **x** is then computed as $\delta = (\beta'_1 - \beta'_0)\mathbf{x}$. This is typically referred to in the literature as the *average treatment effect*, which is the average treatment effect of a farm using rbST randomly assigned to the treatment. Although treatment was not randomly assigned, this terminology expresses the idea that the unobservables capturing the treatment decision that are correlated with the rbST response have been controlled for (Vella & Verbeek, 1999).

Data

The data are from the New York Dairy Farm Business Summary Program (Knoblauch & Putnam, 1998). This is a record collection and analysis project primarily meant to assist dairy farmers in managing their operations. Farmers receive a business analysis of their farm and benchmark performance measures from combined participants. This is not a random sample. It represents a population of farmers that actively participate in agricultural extension and research programs. The farms in this sample are larger on average than New York dairy farms, and they experience higher levels of production per cow. To be included in this data set, milk receipts must constitute at least 90% of total farm receipts. In addition, farms coded as irregular using a set of metrics (and thus classified as outliers) were not included in the analysis.

Variable specification is consistent with the annual Dairy Farm Business Summary Report (DFBS) and is shown in Table 1. A limited number of exogenous variables are collected including age, education, and in the short run, the number of cows and milking system. The performance variable used is net farm income per cow. Technology adoption is typically assessed by farmers based upon the impact it has on net farm income. Although not reported in this article, the total cost of production per hundredweight of milk produced was also used as a performance variable, with results similar to the reported net farm per-cow income results.

Table 1. Definition of variables.

Variable	Definition	1999 average value (SD)
Education	Years of formal education	13.56 (1.80)
Age	Years	47.65 (9.47)
Log cows	Natural log of average number of cows in herd	4.96 (0.90)
Milking system	1 if parlor; 0 otherwise	0.61
rbST use	1 if used on farm; 0 otherwise	0.53
Profit per cow	Net farm income per cow	472 (418)
Milk price	Milk price per hundredweight of milk sold	14.85 (0.85)
rbST per cow in 1999	Expenditure on POSILAC per cow for 171 using farms in 1999	61.24 (30.70)
rbST per cow in 1998	Expenditure on POSILAC per cow for 169 using farms in 1998	55.12 (30.93)

The DFBS surveys for each year asked farmers to indicate their use of rbST in one of five categories, as follows: (0) not used at all; (1) stopped using it during the year; (2) used on less than 25% of the herd; (3) used on 25–75% of the herd; or (4) used on more than 75% of the herd. Most responses were in categories 0 and 3. Very few farms indicated they used it on more than 75% of the herd; likewise, few farms used it on less than 25% of the herd. These groups pertain to the percentage of cows that were treated during lactation. The usage categories are not concisely defined, so farms were simply sorted as rbST users if they checked categories 2, 3, or 4 and nonusers if they checked categories 0 or 1. Intensity of rbST use for adopting farms is measured by the expenditure on POSILAC during the year divided by the average number of cows during the year.

Results

Adoption Results

The probit adoption functions for 1998 and 1999, estimated by maximum likelihood, are shown in Table 2. The education of the farmer and the size of the farm appear to be the determining factors influencing adoption. Farmers who have more years of formal education and those who have larger farms are more apt to adopt rbST. Age appears not to be a determining factor.

Table 2. RbST adoption function estimates for 1998 and 1999 from probit maximum likelihood estimation (test statistics in parentheses).

	1998	1999
Intercept	-5.25 (-3.06)***	-3.99 (-2.41)**
Education	0.111 (2.46)***	0.135 (2.85)***
Age	0.003 (0.36)	-0.004 (-0.48)
Log cows	0.763 (5.48)***	0.925 (6.21)***
Parlor	0.399 (1.94)**	0.327 (1.51)
Milk price	-0.017 (-0.19)	-0.154 (-1.50)
Log likelihood value	-171	-157
Number of observations	324[a]	324[a]

[a] 249 farms overlap.
$*\rho < .10$. $**\rho < .05$. $***\rho < .01$.

Table 3. Frequencies of actual and predicted outcomes for rbST adoption in 1999 (adoption = 1).

		Predicted		
		0	**1**	**Total**
	0	120	33	153
Actual	**1**	41	130	171
	Total	161	163	324

Whether the farm milks with a parlor was a determinant in 1998 (the correlation between the number of cows and milking in a parlor is only 0.45) but not in 1999. The price of milk was not a determinant for adoption, although variation of price was spatial and not temporal in these data. These results carry through when the adoption function is later estimated jointly with the per-cow profit equation. The accuracy of the adoption function estimates are illustrated in Table 3. Of the 171 farms actually using rbST in 1999, 130 farms (76%) are predicted to be users by the model.

Impact of rbST on Per-Cow Profit

The impact of rbST on estimated profit per cow is shown in Table 4. This is herd average profit per cow, and includes both cows treated and not treated with rbST during the calendar years. The same variables as used in the adoption equation were used in both the rbST and non-rbST profit-per-cow equations. Because these variables were transformed in the probit adoption equation, singularity was not a problem. Also included in the rbST equation are the per-cow rbST expenditure and per-cow rbST expenditure squared. These are herd average expenditures and not expenditures per treated cow.

Table 4. Impact of rbST on net farm income per cow in 1998 and 1999, estimated by maximum likelihood switching regression (test statistics in parentheses).

	1998	1999
Probit selection equation		
Intercept	-5.06 (-2.79)***	-3.75 (-1.81)*
Education	0.108 (2.30)**	0.139 (2.76)***
Age	0.003 (0.32)	-0.004 (-0.38)
Log cows	0.778 (5.53)***	0.916 (5.97)***
Parlor	0.407 (1.96)*	0.351 (1.60)
Milk price	-0.030 (-0.31)	-0.175 (-1.36)
rbST regression equation		
Intercept	-207 (-0.12)	-388 (-0.47)
Education	-14.27 (-0.46)	0.332 (0.02)
Age	-5.26 (-1.76)*	-5.72 (-2.10)**
Log cows	-10.70 (-0.06)	48.51 (0.44)
Parlor	-127 (-0.65)	-237 (-1.64)*
Milk price	91 (2.27)**	77 (1.88)*
rbST expenditure	1.20 (0.36)	1.50 (0.50)
rbST expenditure squared	0.0036 (0.11)	-0.0224 (-0.82)
No rbST regression equation		
Intercept	-2,093 (-3.07)***	-2,977 (-4.64)***
Education	28.36 (1.29)	56.86 (2.51)***
Age	-2.08 (-0.53)	-0.236 (-0.06)
Log cows	153 (1.81)*	278 (3.36)***
Parlor	8.81 (0.08)	-119 (-1.15)
Milk price	121 (4.40)***	117 (3.00)***
Variance estimates		
σ_{rbST}	469 (10.32)***	464 (10.70)***
r_{rbST}	-0.71 (-4.75)***	-0.83 (-8.48)***
$\sigma_{no\ rbST}$	353 (11.55)***	298 (18.41)***
$r_{no\ rbST}$	-0.12 (-0.09)	-0.01 (-0.01)
Log likelihood value	-2550	-2496
Number of observations	324[a]	324[a]

[a] 249 farms overlap.
$*\rho < .10$. $**\rho < .05$. $***\rho < .01$.

Coefficients on the linear and quadratic rbST expenditure variables were not statistically significantly different from zero in 1998 or 1998. Lack of statistical significance could occur if all farms used identical amounts of rbST, implying little variability in usage, but there is large variability in per-cow rbST use, with an average expenditure of $61.24 and a standard deviation of $30.70 in 1999.[1]

Age has a negative and statistically significant impact on net farm income per cow for rbST users in both 1998 and 1999, and although age also had a negative impact on net farm income per cow for rbST nonusers, that impact was not statistically significant. The existence of a parlor for milking also negatively impacted income for rbST users in 1999. As expected, in all years and impact equations, a higher milk price has a positive and statistically significant impact on net farm income per cow.

In the non-rbST equation, besides the price of milk, the number of cows in both 1998 and 1999, and education in 1999, had statistically significant impacts on net farm income per cow. A greater number of cows lead to greater net farm income per cow, and more education increased net farm income.

The correlation between the adoption equation error and rbST profit regression equation error is -0.71 for 1998 and -0.82 for 1999—both statistically different from zero—and the corresponding correlation between the adoption equation error and non-rbST profit regression error is -0.12 for 1998 and -0.01 for 1999—neither statistically different from zero. These signs and statistical significances are contrary to most expectations that rbST users have higher profits per cow regardless of rbST use.

A Wald test of whether the estimated coefficients as a group are different between the rbST use and rbST nonuse equations, except for the intercept and rbST quantity use variables, produced a χ^2 value of 2.00 (α = 0.84) for 1998 and a χ^2 value of 11.19 (α = 0.05) for 1999, concluding that statistically the coefficients are not different for 1998 but may be different for 1999.

Given these results, the per-cow profit equations were re-estimated using only intercepts for the rbST-using and rbST-nonusing farms. Modeling two equations (rather than one equation with a dummy rbST-use variable) allows the error terms on the two equations to differ. Results are shown in Table 5. The probit selection (adoption) equation results are similar to previous models. The estimated net farm per-cow income return to rbST is statistically zero (but numerically negative), as summarized in Table 6.

Table 5. Impact of rbST on net farm income per cow in 1998 and 1999, reduced model, estimated by maximum likelihood switching regression (test statistics in parentheses).

	1998	1999
Probit selection equation		
Intercept	-3.98 (-2.30)**	-2.79 (-1.58)
Education	0.103 (2.37)**	0.123 (2.61)***
Age	0.004 (0.52)	-0.003 (-0.39)
Log cows	0.728 (5.28)***	0.873 (5.72)***
Parlor	0.442 (2.19)**	0.431 (1.95)**
Milk price	-0.087 (-0.93)	-0.214 (-1.86)*
rbST regression equation		
Intercept	636 (10.94)***	517 (11.94)***
No rbST regression equation		
Intercept	667 (11.11)***	536 (9.95)***
Variance estimates		
σ_{rbST}	437 (19.91)***	421 (20.08)***
r_{rbST}	-0.35 (-1.85)*	-0.26 (-1.23)
$\sigma_{no\ rbST}$	367 (21.42)***	319 (18.79)***
$r_{no\ rbST}$	0.16 (0.79)	0.18 (0.91)
Log likelihood value	-2566	-2524
Number of observations	324[a]	324[a]

[a] 249 farms overlap.
ρ < .10. **ρ < .05. *ρ < .01.*

The correlation between the adoption equation error and the rbST net income equation error is still negative in both years as estimated in the full model, but the magnitude is less negative, and only weakly statistically different from zero for 1998. The corresponding correlation between the adoption equation error and the non-rbST net income regression error is statistically zero in both years. These results imply that although rbST adopting and nonadopting farms may have different characteristics, neither may be inherently more or less profitable before adoption, and it appears that rbST does not make the adopting farms more profitable as a group.

If a profit impact is not measured, it may be because Monsanto is fully capturing the net return from the use

1. *Monsanto sold POSILAC during these years at $5.80 per 14-day dose, with discounts if a higher percentage of a farmer's herd is treated. Cows are not treated in early lactation or during dry periods, but ignoring that, the most a farmer could pay would be $150.80 a year per cow.*

Table 6. Impact of rbST on net farm income per cow in 1998 and 1999 without rbST expenditure explanatory variables, estimated by maximum likelihood switching regression.

	1998	1999
rbST regression without expenditure coefficients estimated		
rbST (intercept)	$636	$517
No rbST (intercept)	$667	$536
Wald Test (χ^2 value)	0.14	0.07
rbST regression equation with cost of rbST removed from NFI		
rbST (intercept)	$699	$585
No rbST (intercept)[a]	$659	$533
Wald Test (χ^2 value)	0.23	0.55

[a] *Estimates change slightly because of estimation of equations as a system.*
$^*\rho < .10$. $^{**}\rho < .05$. $^{***}\rho < .01$.

of rbST by charging a high price for POSILAC. That hypothesis is tested by adding individual farm expenditures on rbST back into net farm income, and re-estimating the equations without the rbST expenditure explanatory variables. Results are summarized in Table 6. The farms using rbST in 1998 earned $699 per cow if they did not have to pay for POSILAC, which is $63 more than the return when they paid for POSILAC. The farms not using POSILAC in 1998 earned $659 per cow. A Wald test of these values did not allow rejection of the null hypothesis that these means are equal. Farms using POSILAC in 1999 earned $585 if they did not have to pay for POSILAC, which is $68 more than when they paid for POSILAC. The farms not using POSILAC in 1999 earned $533 per cow. A Wald test of these values produces a χ^2 value of 0.55, which does not allow rejection of equal means. It appears that rbST profit per cow is not statistically measured in either 1998 or 1999, even if Monsanto provided rbST free to the using farmers. This implies that expenditures on other inputs necessary to effectively use rbST, such as additional feed and labor, may be the reason rbST is not profitable on these farms.

Conclusions

Dairy farm record data for 1998 and 1999 from New York were used to estimate the profit response from the use of rbST. The compound rbST has been commercially available in the United States since 1994, so farmers had four years of observation and experience. An endogenous switching regression model was estimated with self-selection of whether to use rbST corrected by a probit adoption function. Slightly over half of the farmers used rbST.

Farmers who used rbST were found to be more apt to have formal education beyond high school and have larger dairy herds. Age was not a significant determining factor in adoption. In a reduced model, rbST was estimated to have no statistical significant impact on per-cow profit even when correcting for the fact that rbST users might have higher milk profits per cow without the use of rbST. There was no statistical difference in net income per cow between rbST-using and nonusing farms.

Why do these dairy farmers use rbST when it does not appear to generate a profit? The foregoing results cannot give a clear answer, because the estimates represent an average group response. Within that group, there may be farmers that are experiencing a positive profit response. The implicit assumption, then, is that other farmers may be experiencing a negative profit response. It is notoriously difficult to quantify and estimate the determining factors of farm-level profitability. Most past efforts at estimating the profit impact of rbST on these New York dairy farms resulted in positive numerical profit responses, although the standard errors on those estimates where so large that statistically it was concluded that the response was zero (Stefanides & Tauer, 1999; Tauer, 2001). Additional years of data are now available on these farms; more farm observations over more years may permit a clearer picture of the impact of rbST on these farms.

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