Working Paper

The Impact of recombinant bovine Somatotropin on Dairy Farm Profits: A Switching Regression Analysis

Loren Tauer

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Abstract

Production and profit impacts from the use of recombinant Bovine Somatotropin (rbST) on dairy farms were estimated using switching regression, with separate regressions for rbST-using farms and non-rbST-using 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 have larger dairy herds, but age was not a significant determining factor in adoption. RbST was estimated to increase milk production per cow even when correcting for the fact that rbST users would have higher milk production per cow without the use of rbST. However, that greater production per cow from rbST use did not translate into an estimated impact on profits per cow.

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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 levels of this hormone, enhancing milk production, but requiring additional feed and other inputs to achieve increased milk production. It has been commercially available to U.S. dairy producers from the Monsanto Company since February of 1994 under the registered tradename POSILAC.

RbST was subject to years of investigation and testing before approval for commercial sale in the United States. Given the large production response per cow that most of these tests reported, rbST was generally projected to be profitable for dairy farmers, with estimates often exceeding $100 per year per cow (Butler), although some projected little or no profit (Marion and Wills, 1990). Although POSILAC has been available to U.S. dairy farmers for over 5 years and a number of studies have estimated the determinants of rbST adoption, few 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 milk production per cow and return above variable cost per cow. 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 affect, 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 on milk production per cow from the use of rbST, and found the impact of rbST on profits was statistically zero. They suggested that farmers may still be learning how to profitably use rbST, 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. A limitation of these studies was that the intensity of rbST use on these farms was not accurately measured. Farmers were only asked whether or not they used rbST, or were asked to reply to broad ranges of herd usage.

Ott and Rendleman (2000) used actual milk production experienced on U.S. rbST-adopting farms, but since 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

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rbST-using farmers. If better managed, those adopting farms might have experienced a greater production increase per cow even without the use of rbST.

Ex post estimates of actual rbST adoption by dairy farms include Barnham (1996) and Barham, et al. (2000). Results generally show 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 production and profit response per cow 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 endogenous switching regression, sometimes referred to as the Mover/Stayer model since it has been used to 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 farms and non-rbST using farms, with rbST expenditure per cow 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* ≤0,

$\mu \sim N(0,1)$.

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.

Production or profit per cow is estimated by the following regression equations with regime 1 representing rbST use and regime 0 representing non-rbST use:

$$y_1 = \beta_1'x_1 + (\rho_1\sigma_1\sigma_u)\{\phi(\alpha'Z)/\Phi(\alpha'Z)\} + \varepsilon_1 \tag{2}$$

$$y_0 = \beta_0'x_0 + (\rho_0\sigma_0\sigma_u)\{-\phi(\alpha'Z)/1-\Phi(\alpha'Z)\} + \varepsilon_0 \tag{3}$$

where y is production or profit per cow. The vector x_1 represents the explanatory variables for rbST users, and x_0 represents the explanatory variables for non-rbST users, with β representing the corresponding estimated parameter vectors. The remaining terms represent the error structure of each equation, correcting for self-selection bias since rbST using (or non-using) farms may have greater (or lower) production and 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).

The multiplicable 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).

Since 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 non-use 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 or output.

Equations [1], [2] and [3] are estimated using the software LIMDEP. 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 Mill's 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 for $\rho_0\sigma_0$. 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 production or profit impact of rbST for a farm with characteristics

x is then computed as:

$$\delta = (\beta_1' - \beta_0')x \qquad (4)$$

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 and Verbeek).

Data

The data are from the New York Dairy Farm Business Summary Program

(Knoblauch and Putnam). 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 most 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 percent of total farm receipts.

Variable specification is consistent with the annual Dairy Farm Business

Summary Report (DFBS) and is shown in Table 1. Performance variables used are

herd production per cow and 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 income per cow results.

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 percent of the herd; (3) used on 25-75 percent of the herd; or (4) used on more than 75 percent of the herd. Most responses were in categories 0 and 3. Very few farms indicated they used it on more than 75 percent of the herd. Likewise, few farms used it on less than 25 percent 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 non-users if they checked categories 0 or 1. For farms that have adopted it, 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 are 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. 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

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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 production per cow or profit per cow equations. The accuracy of the adoption function estimates are illustrated in Table 3. Of the 171 farms actually using rbST in 1999, 130 farms, or 76 percent, are predicted to be users by the model.

Impact of rbST on production per cow

The impact of rbST on herd production per cow is shown in Table 4. This is herd average production and includes both cows treated with rbST and not treated with rbST during the calendar years. The variables included in the rbST equation are the expenditure of rbST per cow and rbST per cow expenditure squared. The no-rbST equation was estimated with an intercept only. Obviously, there are many determinants of production per cow. Unfortunately, there are a limited number of exogenous variables collected by the New York Farm Business Summary, and past efforts relating these to productivity and profitability of the farm have been disappointing (Tauer and Stefanides). The presumption is that these uncollected determinants are randomly distributed over rbST users and non-users. Those collected but not randomly distributed are included in the adoption equation.

Coefficients on the linear and quadratic rbST expenditure were not statistically significantly different from zero in either of the years. Lack of statistical significance could result if all farms used identical amounts of rbST, implying little variability in usage, but there is large variability in rbST use with an average expenditure of $61.24, and a standard deviation of $30.70 in 1999.

A Wald test of the equality of the intercepts of the rbST equation and the no-rbST equation produced chi-squared values of 31.42 for 1998 and 42.91 for 1999,

easily rejecting equality for both years. This rejection holds when the equations are re-estimated without the rbST expenditure variables in the rbST equations, producing chi-square values of 102.32 for 1998 and 141.47 for 1999. Thus rbST does increase output per cow. The rbST correlation between the adoption equation error and rbST production regression equation error is 0.73 for 1998 and 0.71 for 1999, both statistically significantly different from zero. The corresponding correlation between the adoption equation error and no-rbST production regression error is –0.59 for 1998 and –0.54 for 1999, both also statistically significantly different from zero. Thus rbST users have higher production per cow regardless of rbST use and non-rbST users have lower production per cow.

Impact of rbST on net farm income per cow

The impact of rbST on profits per cow is shown in Table 5. The rbST expenditure per cow coefficient estimates on the rbST equation are of the expected signs for both years, implying a concave relationship between profit per cow and rbST expenditure, but those coefficients are not statistically different from zero, indicating no relationship between rbST expenditure and profits per cow. The intercepts of the rbST regression and the no-rbST regression equations are not statistically different from zero even when the equation is re-estimated without the rbST expenditure variables, with Wald test chi-squared values then of 0.02 for 1998 and 0.74 for 1999 (Table 6). Thus, it must be concluded that rbST has no impact on measured profit per cow. The rbST correlation between the adoption equation error and rbST profit regression equation error is –0.21 for 1998 and 0.02 for 1999, neither statistically different from zero. The corresponding correlation between the adoption equation error and no-rbST profit regression error is 0.19 for 1998 and 0.09 for 1999, neither

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statistically different from zero. Thus, there appears to be no selection bias when measuring profits per cow, which existed in the production per cow equations.

In 1998 the estimated profit per cow for no-rbST users was $628, the intercept of the no-rbST equation. Inserting their actual rbST expenditures into the rbST use equation, the 1998 estimated profit per cow for the rbST users was an average of $630, with a standard error of the mean of 3.26. This is only $2 more for the rbST users, and a t-test of equality of these expected profits for 1998 was 0.62, failing to reject the null hypothesis that these means are different. The 1999 estimated profit per cow for the no-rbST users was $468 and the mean for the rbST users was $531 with the standard error of this mean being 3.50. This is $63 more for the rbST users, and a t-test of equality of these expected profits was 18.15, permitting rejection of the hypothesis of equal means for 1999. However, since the estimated rbST expenditure coefficients used to compute these returns had large standard errors, it is questionable whether one should accept these results. Since rbST increases milk production and requires more feed, it would be expected that the year for rbST to be profitable would be a year with high milk prices and low feed prices. Yet the average milk price in New York for 1999 at $14.60 per hundredweight was actually lower than the $15.40 milk price received in 1998, although the feed price of $175 a ton for feed in 1999 was lower than the $199 price in 1998 (mixed dairy feed, 16% protein).

Although the rbST expenditure variables on the profit per cow equation were not statistically different from zero, in both years they produce a concave relationship between rbST expenditure and profit per cow. The computed optimum rbST expenditure from the 1998 estimates would be an unreasonable $309 per cow, when

the farms actually used $55.12 per cow.[11] The optimum for 1999 is $61 per cow,

which is identical to the farm average expenditure of $61.21 in 1999.

If a profit impact is not measured it may be because Monsanto is fully

capturing the net return from the use 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 $704 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 $624 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

$596 if they did not have to pay for POSILAC, which is $66 more than when they

paid for POSILAC. The farms not using POSILAC in 1999 earned $467 per cow. A

Wald test of these values produces a chi-square value of 3.32, which allows rejection

of equal means only at the confidence probability of 0.09. It appears that a rbST profit

per cow is not statistically measured even if Monsanto provided rbST free to the

using farmers.

Conclusions

Dairy farm record data for 1998 and 1999 from New York were used to

estimate the production and profit response from the use of rbST. The compound

rbST has been commercially available in the United States since 1994, so farmers

have had four years of observation and experience. An endogenous switching

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[1] Monsanto sold POSILAC during these years at $5.80 per 14-day dose, with discounts as 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.

regression model was estimated with self-selection of whether to use rbST or not 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. The use of rbST was estimated to increase milk production per cow even when correcting for the fact that rbST users would have higher milk production per cow without the use of rbST. However, that greater production per cow from rbST did not translate into an estimated impact on net income per cow. There was no statistical difference in net income per cow between rbST using and non-using 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, since 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 also true that it is notoriously difficult to quantify and estimate the determining factors of farm level profitability. There is so much noise in any profit equation that most models explain a very small part of the variability in profit across farms.

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Table 1. Definition of Variables

Variable	Definition	*1999 Average Value (Standard Deviation)*
Education	Years of formal education	13.56 (1.80)
Age	Years	47.65 (9.47)
Log Cows	Natural log of number of average 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)
Production per Cow	Milk sold divided by reported average number of cows (lbs.)	19,502 (3,728)
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)

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	324
	(249 farms overlap)	

*Statistically significant at $\rho = 0.10$.
**Statistically significant at $\rho = 0.05$.
***Statistically significant at $\rho = 0.01$.

Table 3. Frequencies of Actual and Predicted Outcomes for rbST Adoption in 1999 (Adoption = 1)

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

Table 4. Impact of rbST on Herd Production per Cow for 1998 and 1999, Estimated by Maximum Likelihood Switching Regression (Test statistics in parentheses)

	1998	*1999*
- - - - - - - - - Probit Selection Equation - - - - - - - - -		
Intercept	-5.68	-5.99
	(-6.93)***	(-6.77)***
Education	0.123	0.136
	(3.18)***	3.14)***
Age	0.0002	-0.012
	(0.03)	(-1.42)
Log Cows	0.784	0.960
	(5.89)***	(6.86)***
Parlor	0.406	0.154
	(2.20)**	(0.80)
-------- rbST Regression Equation --------		
Intercept	19,724	20,682
	(33.28)***	(33.75)***
rbST Expenditure	16.56	39.27
	(0.83)	(1.92)*
rbST Expenditure Squared	0.231	-0.161
	(1.24)	(-0.83)
---------- No-rbST Regression Equation ----------		
Intercept	15,411	15,672
	(32.67)***	(38.54)***
---------- Variance Estimates ----------		
σ_{rbST}	3,881	3,638
	(11.94)***	(14.19)***
r_{rbST}	0.73	0.71
	(5.79)***	(5.79)***
$\sigma_{no\ rbST}$	2,534	2,616
	(14.40)***	(15.32)***
$r_{no\ rbST}$	-0.59	-0.54
	(-4.23)***	(-3.84)***
Log Likelihood Value	-3,190	-3,182
Number of Observations	324	324
	(249 overlap)	

*Statistically significant at $\rho = 0.10$.
**Statistically significant at $\rho = 0.05$.
***Statistically significant at $\rho = 0.01$.

Table 5. 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	-5.49	-5.98
	(-6.03)***	(-6.24)***
Education	0.111	0.126
	(2.51)**	(2.60)**
Age	0.004	-0.005
	(0.54)	(-0.57)
Log Cows	0.737	0.893
	(5.31)***	(6.00)***
Parlor	0.441	0.355
	(2.16)*	(1.57)
-------- rbST Regression Equation --------		
Intercept	539	554
	(6.21)***	(6.59)***
rbST Expenditure	2.10	1.46
	(0.62)	(0.56)
rbST Expenditure Squared	-0.0068	-0.0238
	(-0.20)	(-1.01)
-------- No rbST Regression Equation --------		
Intercept	628	468
	(10.18)***	(8.38)***
--------- Variance Estimates --------		
σ_{bST}	430	416
	(22.46)***	(21.91)***
r_{rbST}	-0.21	0.02
	(-1.00)	(0.08)
$\sigma_{no\ rbST}$	366	315
	(20.26)***	(19.04)***
$r_{no\ rbST}$	0.19	0.09
	(0.97)	(0.42)
Log Likelihood Value	-2565	-2524
Number of Observations	324	324
	(249 overlap)	

*Statistically significant at $\rho = 0.10$.
**Statistically significant at $\rho = 0.05$.
***Statistically significant at $\rho = 0.01$.

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)	$641	$530
No rbST (Intercept)	$627	$468
Wald Test (Chi-Squared Value)	0.02	0.74
--------- rbST Regression Equation with Cost of rbST Removed from NFI ----------		
rbST (Intercept)	$704	$596
No rbST (Intercept)#	$624	$467
Wald Test (Chi-Squared Value)	0.88	3.32**

\# Estimates change slightly because of estimation of equations as a system
*Statistically significant at $\rho = 0.10$.
**Statistically significant at $\rho = 0.05$.
***Statistically significant at $\rho = 0.01$.

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