The Dynamics of Agricultural Biotechnology Adoption: Lessons from rBST use in Wisconsin, 1994-2001

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Abstract:
This paper explores the dynamics of rBST adoption using panel data from Wisconsin dairy farmers that span the period from its commercial introduction in 1994 to 2001. The panel data allow an examination of a broader range of adoption behavior that includes disadoption, early and late adoption, as well as persistent non-adoption. The data also permit attention to endogeneity concerns that arise in cross-sectional analyses of technology adoption, where potential predictors are also choice variables. Differences in both complementary technology use and farm size are identified as key predictors of adoption behavior, as are farmer attitudes toward this controversial technology.

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Economists have long viewed technology adoption as a dynamic process (Griliches; Mansfield) because of the learning, coordination, and investment issues that face potential adopters (Feder and Slade). Yet, until the mid-1990s empirical studies of adoption trends and determinants relied heavily on cross-sectional rather than panel data (Besley and Case), which meant that the underlying dynamics were rarely explored at an empirical level. Recent efforts (Foster and Rosenzweig; Conley and Udry; and Cameron) highlight the value of panel data to help uncover the subtle dynamics of learning, strategic behavior, and coordination among producers faced with decisions about whether to adopt and how to most effectively deploy new technologies.

This paper shifts the focus of attention to two other contributions that panel data have for improving adoption analyses beyond that of explicating information dynamics. One is the endogeneity issue that arises when examining potential predictors of new technology adoption, where the predictors are also "choice variables" (Zepeda, 1994; Foltz and Chang). Examples include the use of other complementary or substitute technologies, management practices, or related investments, where farmers' choices with respect to these predictors might be endogenous to the adoption decision of the new technology. Panel data permit empirical modeling that explicitly evaluates whether the sequencing of farm technology choices do or do not favor the adoption of a specific technology, and thus to a significant extent addresses the endogeneity issue that plagues cross-sectional adoption analyses. The paper also explores how panel data can be used to broaden the adoption analysis beyond the classic contrast of two classes of agents, adopters and non-adopters to a more accurate mix of non-adopters, early adopters, later

adopters, and disadopters. Identifying core differences across these classes of agents, and hence their likely patterns of adoption behavior in the future, offers a more complete picture of the past, present, and future technology diffusion process.

Panel data from Wisconsin dairy farmers are used to explore the dynamics of adoption, disadoption, and future adoption of recombinant somatatropin (rBST), a productivity-enhancing hormone that is injected in cows. The data span the period from the commercial introduction of rBST in 1994 to 2001, offering a comprehensive view of the adoption process of this leading-edge (and controversial) agricultural biotechnology.

A dynamic study of rBST adoption in Wisconsin is quite timely. First, its adoption dynamics are relevant to a whole class of production-oriented agricultural biotechnologies, especially as companies weigh returns and risks to future investments in agricultural biotechnology products. Second, rBST was anticipated in the early 1990s to be a juggernaut technology, one that both opponents and proponents thought would fundamentally alter the organization and structure of U.S. dairy farming (Hallberg; Fallert et al.; and Liebhardt). Understanding the reasons why rBST has actually had a rather muted impact on the organization and performance of the U.S. dairy sector can be enhanced by a dynamic analysis of adoption patterns in Wisconsin, where approximately 25% of U.S. dairy farms are located. Third, rBST has now been commercially available for long enough now that the technology is arguably mature, especially given its long pre-commercialization debate. Indeed, in Wisconsin, at least, the diffusion process has flattened out, with only an incremental change in the adoption rate over the past two years (15 to 16%) and an actual decline in the estimated number of farms using rBST. With the diffusion process well advanced, and marketing debates quieted, rBST adoption

decisions are more likely to be dominated by farm-level factors related to the fit between the technology and other management and technology choices. Resolving endogeneity problems related to those determinants could provide a more robust and reliable analysis of the technology's diffusion process.

The final motivation for taking another look at rBST adoption is the high degree of politicization that occurred especially prior to its commercial release, and then shaped its initial adoption profile (Barham). The durability of the effects of this politicization in shaping farmer adoption choices is pertinent to current and future controversial agricultural technologies (e.g., GMOs). It is made more interesting by the fact that in Wisconsin the voluntary use of labeling to identity "rBST-free" fluid milk products was initially pervasive, but has largely disappeared over the past three years (except for organic products and specialty cheeses). This change means that demand-side concerns are much less likely to be directly influencing current adoption decisions. Thus, if the earlier "attitudes" of farmers toward rBST continue to shape adoption outcomes, then the durability of these politicization effects would be especially noteworthy.

The next section briefly reviews previous rBST adoption studies to set the stage for a discussion in the following section of the empirical approach used in this paper to analyze the dynamics of rBST adoption. The fourth section describes the panel data sets, and presents descriptive statistics that help to motivate the fifth section's econometric analysis of the dynamics of adoption behavior. The final section summarizes the paper's findings on the adoption dynamics of rBST and technology adoption in general.

Previous rBST adoption studies

Three themes have dominated economic research on rBST adoption. Most prevalent, particularly in the years surrounding rBST's commercial release, were efforts to assess the probability and extent of adoption and its potential impact on the performance of the dairy sector (Lesser, Magrath, and Kalter; Larson and Kulcher; Marion and Wills; Zepeda; Saha, Love, and Schwart; Barham). In the US, the most reliable statewide estimates of rBST adoption over the years have come from California and Wisconsin (Butler, 1995; Barham et al.), which are responsible for more than 40% of national milk production. Compared to national forecasts made prior to the commercial release of rBST, adoption levels in these two states at the turn of the century were considerably lower than anticipated, at 25-30% and 15% respectively, versus early 1990s forecasts in the 50-70% range.[1] The most recent U.S. government estimate found in 1996 an adoption rate of 9.4% among farmers nationwide (U.S. Government, APHIS-USDA).

A second and overlapping line of research has focused on the determinants of rBST adoption. Along with the traditional human capital variables, special attention has been paid to the issue of scale or size-bias and the role of complementary technologies in shaping farmer adoption decisions (Stefanides and Tauer; Barham et al.; Foltz and Chang). At issue is why rBST, a technology that is easy to inject, requires no fixed investments, and has minimal start-up costs, has demonstrated a very strong size-bias in adoption. One explanation focuses on the role of complementary technologies and the possibility that the full productivity enhancing effect of rBST may only be realized on farms that have certain management practices and complementary technologies already in

place. These practices are ones found predominantly on larger farms, and so they are the most likely to benefit from the adoption of rBST. Alternatively, there may be personal or organizational goals and objectives that govern the technology adoption decisions of different types of farming operations that are more or less conducive to rBST use. None of the previous studies, however, satisfactorily address the potential endogeneity between complementary technologies and rBST adoption, or between rBST and farm size.

A third and increasingly prevalent theme in the rBST adoption literature is evaluation of its profitability effects. Do the well-demonstrated productivity increases from treated cows generate more revenues than the additional costs of labor, management, feed, medications, and the rBST treatment itself? Spreadsheet simulations by Fetrow and by Butler (1999) show that rBST could indeed be quite profitable on "well-managed farms", but several econometric assessments of actual farm enterprise data from New York (Tauer and Knoblauch; Steffanides and Tauer; Tauer) and Connecticut (Foltz and Chang) show that rBST adoption appears to have no statistically significant impact on profitability (although the coefficient is usually negative), once other factors are incorporated. This result stands up over time where panel data are available (Tauer), under the scrutiny of increasingly sophisticated econometric methods (Foltz and Chang; Tauer) and when the profitability outcomes of a group of disadopters were compared with those of rBST adopters (Foltz and Chang). This profitability result may help to explain both the low level of rBST adoption as compared with *ex ante* forecasts as well as the high levels of disadoption of rBST in Wisconsin found below.

Only Butler (1995) and Foltz and Chang have commented on the role of disadoption in the dynamics of the rBST diffusion process. Neither study, however,

systematically analyzes what factors and experiences might distinguish disadopters from other adopters, nor their views on rBST use in the past and future. The empirical approach described next sets the stage for further analysis of disadoption.

Dynamics of rBST Adoption: Issues and Approaches

Technology adoption decisions are typically constructed using a random utility formulation, following McFadden, and Domencich and McFadden, where the technology decision hinges on whether the expected utility of farmer (i) under adoption, $E(U_{i1})$, is greater or less than the expected utility under non-adoption, $E(U_{i0})$. The index function denoting this decision, $Y_i = E(U_{i1}) - E(U_{i0})$, is unobservable, but as long as $Y_i > 0$, then the individual farmer *i* will adopt the technology. If $Y_i < 0$, then the individual farmer *i* will not adopt the technology. The standard empirical technique for studying this type of choice is to estimate the index function $Y_i = \mathbf{x}_i\beta + \varepsilon_i$ (Maddala), using farm and farmer characteristics, $\mathbf{x}_i$, as explanatory variables in the case of adoption, and denoting the unobserved error term by ε_i (Maddala). The term $\mathbf{x}_i\beta$ provides an estimate of $E(U_{i1}) - E(U_{i0})$ and usually includes structural variables thought to affect either the real or perceived impacts of rBST adoption on each individual farm. Depending on the distributional assumption made about ε_i, the model can then be estimated using a binary model, such as a standard Probit or Logit function.

Endogeneity issues arise when one or more of the explanatory variables ($\mathbf{x}_i$'s) are also choice variables for the farmer, where a similar calculation of the expected profitability of those choices might also be part of the farmers' decision-making calculus. For adoption decisions in particular, one set of key choice variables can be the use of other technologies and management practices that might shape the profitability of the

new technology, and thus could be viewed as part of an overarching production strategy. Other endogenous choice variables might include farm size, attitudes, and related investments. By way of contrast, demographic and human capital variables, such as age, education, and training, which are also widely studied determinants of adoption decisions, can be treated as exogenous in a given period, because they are not generally choice variables in the same period as the adoption of the technology in question.

Most econometric estimations of the adoption of rBST and other farm technologies for that matter ignore these endogeneity concerns and treat all of the X_i variables as exogenous. These single-equation estimates may provide inconsistent coefficient estimates due to what is, in effect, simultaneous equation bias. With cross-sectional data, two approaches to this bias in technology adoption analyses have been suggested. One is to develop simultaneous equation systems to examine the jointly determined variable choices (Zepeda). The other is to treat certain choices as precursors to the adoption choice in question and then to use a Heckman selection approach to order the intertwined decisions (Foltz and Chang). To date, however, neither of these approaches has been widely deployed in farm technology adoption research, and neither has been deployed at all to examine the rBST adoption choice.[2]

Panel data provide a straightforward way to resolve the endogeneity problem associated with other choice variables and their influence on the adoption of the technology in question. In particular, information from earlier waves of the panel data on the use of specific technologies can be used to predict the adoption of the main technology of interest at a later point in time. Potentially, these panel data models can also be turned around to see whether the use of a new technology has any effects on

expanding the later adoption of these same 'precursor' technologies whose value may have been enhanced by the introduction of the new technology. This exercise is not pursued below.

A second issue that arises in studying the adoption of new technologies is that over time there are more than just adopters and non-adopters of a technology. At a minimum, there are four important categories of adoption behavior: early adopters, later adopters, non-adopters, and one that is often overlooked, disadopters (for an exception, see Carlotto, de Janvry, and Sadoulet). Knowledge of the relative frequencies of these behaviors, and the fundamental differences among farms in each category, reveals more about the dynamics of the diffusion process than a simple binary analysis of adoption allows. Panel data on adoption decisions over time are well suited to identify each of these types of adoption behavior.

A multinomial logit estimation strategy can capture the unique determinants of these distinctive categories of dynamic adoption behavior. Specifically, the determinants associated with each category can be contrasted with those in a benchmark category (McFadden; Zepeda; Barham).[3] Varying the choice of the benchmark category means that comparisons can be developed between, for example, non-adopters and the rest of the adoption categories, or between early adopters and the rest of the adoption categories. Interpretations of these different estimations can expand our understanding of how farm and farmer characteristics affect adoption decisions.

Perhaps most important, identifying the extent and persistence of disadoption behavior is critical to understanding the long run diffusion of a new technology. Put simply, high rates of permanent disadoption bode poorly for future increases in adoption

of a technology compared to one where this category of adopter is infrequently observed. Thus, evidence on the incidence of, reasons for, and permanence of disadoption are likely to add considerable insights to the overall dynamics of the technology diffusion process.

As mentioned earlier, because of the intense politicized debate that preceded rBST's commercial introduction in the United States, farmers' rBST adoption decisions may have a somewhat unique aspect to them. Previous work (Barham) found that farmer attitudes toward biotechnology and other farm structure issues were significant explanatory factors in adoption decisions in Wisconsin during the year following the technology's release. However, those data were also contemporaneous to the adoption decision, and thus also were subject to the (endogeneity) critique that the "attitudes" may be a justification rather than the reason for what might be viewed as fundamentally an economic decision. The permanence of those attitudinal effects was also subject to question, as one might imagine farmers initially allowing their attitudes toward a controversial technology to affect their adoption decisions, but subsequently focusing on more narrow economic criteria in their adoption choices. The panel structure of the present analysis allows a reconsideration of this question to see whether "attitudinal" factors persist over time in shaping adoption decisions.

Data and Descriptive Statistics

The panel data set used in the analysis spans the years since rBST's commercial introduction, and consists of 404 active dairy farmers who responded to the Program on Agricultural Technology's 2001 Wisconsin Dairy Farm Poll. The baseline observation for these households was either a 1994 survey (n=188) or a 1995 survey (n = 216), both of which were random samples selected from the Wisconsin Dairy Producer List, a

population list of commercially licensed dairy farms maintained by the Wisconsin Department of Agriculture, Trade, and Consumer Protection.[4]

In the data analysis, we merge the two baseline responses (1994 and 1995) into one initial period. This consolidation seems reasonable given the relatively small differences evident across the two periods. For example, rBST adoption rates in the fall of 1994 and the spring of 1995 cross-section samples were, respectively, 5.4% and 6.6%. In addition, comparison of the two baseline samples across other observable variables reveals almost identical values (i.e., average herd size of 56 in 1994 and 58 in 1995, total mixed ration equipment use 25% versus 27%, and DHIA adoption of 68% and 67%).

The panel data include observations on the characteristics of farmers, farm households and the farm enterprises. They do not include detailed information on farm financial performance. That information is difficult to obtain reliably in a mail survey format. As a result, the adoption analysis below does not extend the recent profitability studies of Stefanindes and Tauer, Tauer, and Foltz and Chang. However, based as they are on a large panel of randomly selected Wisconsin dairy farmers, the data allow a much richer picture of the dynamics of rBST adoption than has heretofore been available.

As shown in Table 1, the panel data are used to identify four categories of decisions regarding rBST use. The dominant category, accounting for 73% of the panel data sample, is “Non-Adopters”, i.e. farmers who report never having adopted rBST on their farms. The next category “Disadopters” - accounts for about 10% of the panel respondents. They are farmers who have used rBST on their herds in the past, but are not currently using it in 2001. The third category, “Later Adopters,” account for 11%. They are currently using rBST on their herds but were not using it at the time of the initial

baseline surveys (most of them began use in the 1996-99 period). The fourth category involves "Early or Continuing Adopters" who account for 6% of the sample, and adopted rBST at the beginning of the panel study period and are using it in 2001. If the disadopters are combined with the other two adopter categories, then it is apparent that while more than a quarter of current Wisconsin dairy farmers have tried rBST, 40% of the farms are currently disadopters. This observation confirms the finding in Foltz and Chang in their rBST adoption and profitability study that disadoption represents an important dynamic in the rBST diffusion process.

Characteristics of the 2001 survey respondents in each of the rBST adoption categories are compared in Table 1 (with pairwise significance results offered comparing non-adopters with the other categories and early adopters with the other categories). Consider the following observations:

- There are few differences in the age and education profile of the three groups who have used rBST (early adopters, late adopters, or disadopters). On the other hand, non-adopters have higher average age and lower formal educational levels relative to the other three categories;
- Non-adopters had significantly smaller herds, averaging 54 cows compared to 135 for disadopters, 131 for later adopters and 233 for early adopters;
- Current rolling herd averages across the four groups are significantly different. The 7% gap between the non-adopters and the disadopters is consistent with the notion introduced by Larson and Kuchler that higher productivity farms would be more likely to adopt rBST. Then, the 10-16% gap between the disadopters and the other two categories of adopters is

consistent with the expected 10% increase in production associated with rBST use (Zinn and Bravo-Ureta; Foltz and Chang). Finally, the 6% difference between early and later adopters could be reflective of differences in management ability or experience with the technology;

- Adoption rates of complementary technologies (regular veterinarian services, balanced feed rationing, total mixed ration equipment (TMR), and dairy herd record keeping practices) are significantly higher among adopter categories than they are in the non-adopter category. Use of these technologies is almost universal among early adopters and very high among disadopters and later adopters. Yet, early adopters do have significantly higher rates of adoption of TMR, three-times-a-day milking, and DHIA record keeping than do disadopters and later adopters.
- Adoption of a potentially non-complementary technology, management intensive rotational grazing is more than twice as likely among the non-adopters than current adopters.

These statistics confirm previous findings that show non-adopters, on average, to be distinct from adopters in terms of size and complementary technology use (Barham, Zepeda, Foltz and Chang, Barham et al.). They also show that the differences among the three "adopter" categories (including disadopters) are much smaller, although early adopters have larger herds and are more likely to use complementary technologies.

While the 2001 data illustrate the contemporary characteristics of farms in each of the four adoption categories, the panel design of our study also enables us to look at what these same groups of farms looked like at the beginning of the panel study period. Table

2 provides a similar profile of their farm characteristics in 1994/1995. In general, farms in all four adoption-groups milked fewer cows, had lower levels of productivity, and used fewer production-enhancing dairy technologies or management practices than in 2001. However, most of the significant differences between groups were evident at both the beginning and the end of the panel study. Two notable exceptions are:

- Early adopters expanded their herds much more rapidly than the other adopter categories. For example, early adopters had an average herd size of 92 cows in the baseline period and 233 in 2001, while disadopters went from 82 to 135 and later adopters from 76 to 131.
- The adoption of management intensive rotational grazing among disadopters in 1994-95 was lower than it was among other categories of adopters, while in 2001 it was considerably higher. This change suggests that some disadopters may have made a switch in production strategies during the span of the panel.

The econometric analysis (discussed below) examines the differences in farmer and farm structure characteristics more systematically in order to identify the key factors associated with rBST adoption.

Before elaborating the dynamics of adoption, it is worth considering the perceived risks and benefits that producers associate with rBST. Table 3a presents response data from the 2001 survey on non-adopters reasons for not using rBST, adopters' reasons for using rBST, and disadopters' reasons for stopping use of rBSTAlmost three-fourths of the non-adopters cited concerns about herd health, while over 60 percent listed concerns about milk safety, potential consumer reactions, and milk surpluses as reasons for avoiding rBST. By contrast, most of those using rBST in 2001 reported interest in

extending the lactation of certain cows, increasing milk production, and expected increases in profits from rBST use.[5] Finally, disadopters reported that they ceased rBST use mainly because they felt it was not cost-effective (82.1%), a finding that is consistent with recent profitability studies (Stefanides and Tauer; Foltz and Chang). Herd health problems (51.3%) were the second most common reason for disadoption, and consumer concerns (38.5%) ranked third.

One of the unique features of panel data is that it allows the analyst to empirically assess the reliability of behavioral intention questions. The future rBST use intentions of panel respondents (measured in 1994) are reported for producers in each of the major rBST adoption categories. For the most part, rBST use intentions correspond nicely to actual future behavior. Not surprisingly, almost all of the persistent non-adopters reported that they were unlikely to ever use rBST in the future, with most indicating they would not use rBST under any circumstance. Interestingly, a majority of the eventual disadopters and later adopters also suggested in 1994 that they were unlikely to use rBST in the future. Nevertheless, compared to the non-adopters, much larger fractions of these two groups expressed ambivalence toward the technology, and far fewer planned to never use rBST "under any circumstance." The early adopters (by definition) all were currently or on the verge of using rBST in the initial survey. Finally, between 1994 and 2001, 95% of the panel respondents who reported in 1994 that they would "definitely not use rBST" did not use it on their farms. Of the remaining 5%, half tried rBST and have stopped using it and half are currently using it on their farms.

Given the apparent reliability of "intention" data in predicting future behavior, the bottom half of Table 3b reveals the future rBST adoption intentions of these same

farmers as of the spring of 2001. Overall, the panel respondents anticipate making very little change in their current adoption behavior over the next three years. For example, only 3% of disadopters report being very likely to start using rBST, 11% report of the disadopters being somewhat likely to start using rBST, while 83% report being in the categories of not very likely to start or definitely will not start using rBST. Of the two current adopter categories, 16% of later adopters report being likely to stop using rBST, while none of early adopters plan to stop using it.[6] Finally, 98% of the non-adopters report that they are not very likely to start or that they will definitely not use rBST.[7]

The Dynamics of rBST Adoption in Wisconsin

In this section, the dynamics of rBST adoption are examined using an unordered multinomial logit specification (McFadden, Greene). The underlying behavioral structure of the model is identical to the adoption choice model presented above in the issues and approaches section. Using the same notation regarding technology adoption choice Y_i and the explanatory factors, $\mathbf{x_i}$, when there are multiple outcome choices, the standard approach relies on the Weibull distribution for the various disturbance terms. Then, the J+1 unordered outcomes occur with a probability determined by the following equation:

$$P(Y_i = j) = \frac{\exp(\beta_j' x_i)}{\sum_j \exp(\beta_j' x_i)} \quad , j = 0,1,...,J. \qquad (1)$$

In order to identify the J+1 possible unordered outcomes in this model, and the model's parameters, a standard normalization is to assign a benchmark outcome to have the parameter matrix $\beta_0 = 0$. This technique allows the rest of the coefficients in the

estimation of the different technology choices to be identified relative to the benchmark outcome. Once this is done, the adoption probabilities to estimate become:

$$P(Y = j) = \frac{\exp(\beta_j' x_i)}{1 + \sum_{k=1}^{J} \exp(\beta_j' x_i)} \quad for\ j = 1, \ldots, J. \tag{2}$$

$$P(Y = 0) = \frac{1}{1 + \sum_{k=1}^{J} \exp(\beta_j' x_i)} \ . \tag{3}$$

In the current specification, we use the four adoption categories from Tables 1 and 2 to study changes in rBST adoption behavior among respondents between 1994/1995 and 2001. The benchmark outcome in the first model estimated below is the non-adopters, while in the second it is the early adopters. Each of these models offers a distinctive perspective. The first helps to highlight the differences between non-adopters and all three adopter categories, while the second brings out the additional contrasts between the early adopters and the later adopters and disadopters.

The explanatory variables ($\mathbf{x_i}$'s) used in the multinomial logit represent farm and farmer characteristics in 1994 or 1995. Use of the baseline panel characteristics to explain the changes in rBST adoption status over the ensuing 6-7 years helps to overcome the endogeneity problems mentioned above. Consistent with previous studies, we focus on the influence of age, education, herd size, use of other dairy technologies, and the attitudes of farmers to predict adoption behavior.[8] A regional measure is also included to capture the geographical experience that dairy farmers in the East-Central region of Wisconsin are more likely to be early adopters of emerging technologies.

The multinomial logit regression results are reported in Tables 4 and 5. In the first model, the signs of the coefficient estimates on the regressors are all consistent with predicted differences between the three adopter-groups on the one hand and the non-adopter group on the other. In terms of farmer characteristics, non-adopters have significantly lower education levels than disadopters and early adopters ($p< .1$) and are significantly older than the later adopters ($p<.01$). The other coefficient estimates on education and age have similar signs and magnitudes to the significant results but are in the 80-90% confidence interval.

As expected, larger herds were more likely to adopt rBST during the study period. In addition, adoption of the TMR feeding systems in 1994/95 increased the chances of later rBST adoption over the ensuing 7 years. Coefficient estimates for both herd size and the use of TMR (Table 4) are statistically significant at the $p<.01$ levels. Thus, as suggested by the descriptive data and previous studies where endogeneity concerns were not addressed, both herd size **and** complementary technology use are important predictors of rBST adoption. While rBST technology itself is quite arguably scale neutral, these findings confirm the notable size-bias found in previous rBST adoption studies, and suggest that it is real and not solely an artifact of the size bias associated with the adoption of complementary technologies. While not explored formally here, the size bias in rBST use may well be associated with the greater degree of managerial specialization that occurs on larger farms and the lower costs associated with monitoring and managing rBST use in the herd.

The coefficient estimate on the Anti-Biotech attitudinal variable distinguishes non-adopters from the early adopters, with the early adopters being more likely to have a

positive view of the technology than the other groups ($p<0.01$). This suggests that negative views of the technology may have had significant impacts on the initial adoption choices of many dairy farmers. Similarly, early adopters were more likely to live in the eastern region of the state than non-adopters. ($p<0.10$).

The multivariate logit results for our second model (Table 5) uses early adopters as the baseline category. This model identifies important differences between early adopters and the other two categories of adopters. The most noteworthy result is that there are very few statistically significant differences between the early adopters and farmers in the other two adopter categories. For example, while initial herd size distinguishes the adopters from the non-adopters, it is not a significant predictor for the timing or persistence of rBST use among adopters. Neither are education, age, or region significant predictors of differences in adoption.

Only two variables are significant in distinguishing the early adopters from the other adopter categories. One is the use of TMR, with the early rBST adopters being more likely than disadopters to have had TMR in place in the baseline period (94-95). The coefficient estimate for later adopters is only slightly below the 0.01 significance threshold and has the same sign and magnitude. It is noteworthy that differential adoption of TMR across these three groups persists over time, with early adopters having a 96% adoption rate of TMR in 2001 , disadopters a 68% adoption rate, and later adopters a 69% rate. This persistent gap in TMR use (as well as in the use of computers and dairy herd production record keeping) suggests that the timing of rBST adoption as well as some disadoption behavior may be linked to farmers not having put in place complementary technologies or management practices.

The other coefficient estimate that is significant in distinguishing early adopters from disadopters and later adopters is the attitudinal variable, with early adopters being more likely than the others to have had a positive view of rBST at the outset of the process ($p<.05$). The significance of this coefficient estimate reconfirms that, indeed, attitudinal differences may have been one of the main factors behind the distinctive adoption behavior of these other adopter groups, particularly in terms of how it influenced the timing of their adoption decisions. (Comparing table 4 and 5, we may argue that attitudinal differences have had significant impacts on the initial adoption choice, but do not appear to be a strong determinant of longer-term adoption choices. However, this argument does not capture the possibility that farmers' view on rBST may have changed over time from baseline period to 2001.)

Conclusion

This paper uses panel data from Wisconsin dairy farmers to explore the dynamics of rBST adoption. One of the principal objectives of the paper was to address endogeneity concerns that arise in cross-sectional analyses of technology adoption, especially when considering the impacts of other choice variables, such as technologies or farm size, on the adoption of the technology in question. This was done by using baseline data on these features to explain the changes in adoption behavior over seven years spanning the period from the introduction of rBST in 1994 to 2001. The four adoption categories explored were non-adopters, disadopters, later adopters, and early (continuing) adopters. The other objective was to use the adoption data and some additional questions about

experience with the technology and intention data to explicate the dynamics of rBST adoption in Wisconsin.

Overall, the empirical analysis of these four adoption categories leads us to the following conclusions about the adoption process of rBST in Wisconsin. First, the persistent rBST non-adopters looked and continue to look very distinct from the other categories of adopters. They tend to milk fewer cows, use fewer complementary dairy production technologies, and hold more negative views towards rBST, at least relative to the early adopters. Despite an obvious and persistent scale bias in rBST adoption among Wisconsin farmers, there is evidence that the impacts of farm size on rBST adoption is distinct from that of the use of complementary dairy production technologies. Looking ahead, our non-adopters seem very unlikely to adopt rBST, and sensitivity analyses show that they would have to make major changes in their operations before we would expect them to become rBST users.[9]

Second, the regression analysis did not reveal many distinguishing characteristics among the early adopters, later adopters, and disadopters. Attitudes and to a lesser extent use of complementary technologies were the only significant explanatory variables that distinguished early adopters from the other two groups. In addition, recognizing that the current use of complementary technologies is actually quite high among the disadopters, we feel that practices such as TMR use, ration balancing, and herd production record keeping serve as critical conditioning factors that enhance the benefits of rBST adoption but certainly do not eliminate all of the perceived disadvantages. Since most disadopters cited a lack of cost effectiveness, herd health problems, perceived consumer concerns, and farm labor shortages as reasons for ceasing rBST use, increases in herd size or in the

use of these technologies do not appear likely to move many disadopters back into the adopter category.

The diffusion of rBST in Wisconsin hit a plateau in recent years. While adoption rates rose from 15% to 16% between 1999 and 2001, the actual number of users of rBST in the state fell for the first time. The empirical analysis offered above suggests that a significant increase in rBST use among Wisconsin dairy farmers is unlikely in the near future. Few non-adopters or disadopters intend to begin using rBST in the next three years, and a small minority of later adopters reported they are likely to stop rBST use. If anything, the attitudes toward rBST use have hardened since 1994, and a smaller proportion of the industry remains undecided about the technology. Adoption rates may gradually increase (because rBST adopters may be more likely to survive than non-adopters), but there does not appear to be a significant proportion of new (or return) adopters waiting in the wings.

Further work on rBST adoption could usefully explore the potential sensitivity of adoption rates to price-cost environment changes, especially reductions in the price of Posilac™, the only commercially available rBST product. Such an undertaking could also explore the potential impacts of monopoly pricing of the technology on its diffusion path. It may be that the high rates of disadoption and hence lower diffusion are directly related to the pricing of the technology. Use of panel data combined with more detailed farm financial information could allow this type of analysis.

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[1] This difference reflects both the heightened level of politicization of rBST adoption in Wisconsin, and the much larger size of California dairies. Elsewhere, Foltz and Chang report a 30% adoption rate in 2000 among Connecticut dairy farmers.

[2] Foltz and Chang use this approach to analyze the profitability and productivity effects of rBST adoption but not the effects of other technology choices on rBST.

[3] More complicated panel models using lagged endogenous variables are not pursued below, mostly because of data limitations, but they remain a largely unexplored option for studying adoption dynamics.

[4] Respondents to the 1994 and 1995 surveys were resurveyed in 2001. 404 responses were obtained from the 621 original respondents who were still involved in dairy (65%). An additional 217 farmers had ceased dairying between 1994/95 and 2001. Only data from active farmers are used to analyze the dynamics of rBST adoption. Exiters are not included in the analysis, though it is the case that baseline non-adopters were more likely to exit (32.2%) than baseline adopters (25.0%).

[5] Respondents were asked to check all reasons that were important to them, and then indicate the most important reason. Overall, extending the lactation of certain cows is the most commonly mentioned reason (89.7%).

[6] Thus, early adopters are all continuing rBST users, while later adopters represent some who may become future disadopters.

[7] Between 1994 and 2001, 95% of the panel respondents who reported in 1994 that they would definitely not use rBST did not use it on their farms. Of the remaining 5%, half tried rBST and have stopped using it, and half are currently using it on their farms.

[8] While most of the independent variables in the model are fairly self-explanatory, the attitudinal term requires some elaboration. In the 1994 and 1995 surveys, dairy farmers were asked how Wisconsin dairy farmers would be affected by FDA approval of rBGH. For those who gave a somewhat negative or strongly negative response, they were assigned a value of 1. If they responded with a neutral or positive response, they were assigned a value of 0. The attitudinal measures used in Barham (1996) were only available for the 1994 respondents. Econometric models using those measures were similar to those reported below for the attitudinal measure that was common to both the 1994 and 1995 surveys. It is also worth noting that use of dairy herd production records had to be dropped as an independent variable from the regressions because 100% of the early adopters used that technology in the baseline period.

[9] The sensitivity analyses are not included in the paper, but the results show that rBST adoption in Wisconsin is not likely to increase much in the future.