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Application of an *Ex Ante* Procedure
to Biotechnology Projects**

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ABSTRACT

A procedure for projecting ex ante the adoption rate of new biotechnology products is developed and applied to bovine growth hormone (bGH), a milk production stimulant. Using 1984 New York survey results the projected rate is rapid, up to 90% adoption in three years. This rapid rate indicates the critical need to anticipate and prepare for such products with the proposed procedure providing a seemingly reliable forecast at low cost.

key words: adoption, technology, diffusion, biotechnology

PROJECTING ADOPTION RATES:

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to Biotechnology Products

Following Professor Berg's pioneering work in gene splicing at Stanford University in the early 1970's, the patenting of the first life form in the United States in 1980, and the initial explosive growth of genetic engineering start-up companies in the late 1970's, the United States has been poised for a breakthrough in technology which will fundamentally affect our lives. Early biotechnology research resulted in applications such as human pharmaceuticals, including human insulin in 1982 (1). It was expected that biotechnology developments with agricultural applications would have effects just as far-reaching. Early studies predicted that the first products were likely to be of an animal health and growth-supporting nature (2). Now a number of agriculturally-related products are nearing market readiness, according to industry sources, with the anticipated animal-related products expected first. It will soon be possible to determine firsthand the real production impact of this technology.

The availability of a product is not the only matter to be assessed when evaluating the impacts of a technology; also important is the rate at which that product is adopted by farmers. As many researchers and businessmen have learned, farmers may perceive obstacles to adoption not apparent to outside observers. There is a key need to project adoption rates to facilitate private and public planning for technological change, change which through manipulating the natural biological processes could exceed the scope seen to date. Most research to date on agricultural technology adoption and diffusion has been of an explanatory, rather than predictive, nature. The purpose of this article is the development of an *ex ante* procedure for projecting the farm-level adoption rates of agricultural technologies which are totally new to farmers. The procedure is developed using a case study of a bovine hormone which stimulates milk production. This product is described in section two. Section one is a review of the adoption and diffusion literature to date. Section three extends current research to include an *ex ante* procedure while section four discusses an application of the procedure and a projection of the adoption rates for the study product.

DIFFUSION AND ADOPTION MODELS

Concern about the effects of technological change has led to the description of a number of analytical methods for explaining the rates of adoption and diffusion. According to the generally accepted terminology, adoption refers to individual decisions, while diffusion is the aggregate impact of those individual decisions. The analytic approaches seen in the literature on both adoption and diffusion focus on an *ex post* explanation of the processes. Thus, while providing guidance concerning the diffusion patterns to be expected for a new innovation, the literature offers little in the way of precise formulations to assist in the prediction of future events.

Ex post studies of diffusion over time have shown that cumulative adoption follows an "S" shape or sigmoid distribution. Mathematically, these adoption patterns have been described, with high levels of accuracy, by logistic functions. Logistic functions have the convenient property of tracking growth to some asymptote.[1]

Griliches (3) provided the first major application of the logistic curve to the study of technological change. In his study of hybrid corn, Griliches utilized the logistic function:

$$P = \frac{K}{1 + e^{-(a+bt)}} \qquad (1)$$

where P = the level of diffusion

K = the maximum level of diffusion (asymptote)

a = a constant

b = the rate of "acceptance"

t = time in years.

Equation (1) can be estimated using ordinary least squares by converting to the following form:

$$\log\left(\frac{P}{K-P}\right) = a + bt + \varepsilon \qquad (2)$$

where ε is a randomly distributed error term.

In order to calculate estimates of a and b, Griliches first estimated values for K through visual inspection of plotted data collected from 31 states and 132 crop reporting districts. He then sought to explain differences in the parameters a and b for each region.[2]

Work by Mansfield (4), Fisher and Pry (5), and Blackman (6) has employed similar approaches to the <u>ex post</u> study of innovation diffusion. These models, in which both the level of diffusion and the difference between that level and a ceiling determine the time path of diffusion, have been labeled by Lilien and Kotler (7) as <u>imitation models</u>. The term "imitation" stems from the specific marketing use of this model, where the influence of an already "converted" fraction of the market on the adoption rate is interpreted as the imitation effect. Under this model, then, adopters are assumed to be swayed by word-of-mouth interaction from earlier adopters or by the example those users set.

Lilien and Kotler contrast these imitation models with <u>innovation models</u>. The innovation model postulates that the rate of diffusion is determined only by the proportion of the market not having adopted the product. Under this assumption, adopters are not influenced by prior users, but only by external stimuli such as advertising. Innovation models take the general form

$$\frac{dY_t}{d_t} = p(1 - Y_t) \tag{3}$$

where p is defined as the coefficient of innovation. Innovation models have been estimated by Fourt and Woodlock (8) and others.

A combined innovation-imitation model was used by Bass (9) in the form

$$Y_t = P(1 - Y_t) + q\, Y_t\, (1-Y_t) \tag{4}$$

where q is the coefficient of imitation. Easingwood <u>et al.</u> (10) proposed a "Nonuniform Influence Model," which allows relaxing the implicit assumption that the diffusion curve be symmetrical. Symmetry in the composite model further implies that the adoption rate is maximized when market penetration reaches 50 percent. In practice the adoption rate frequently reaches its maximum level before the 50 percent level is achieved (10, pp. 275, 281).

While all these models have been useful in describing <u>ex post</u> the diffusion of an innovation, they are severely limited with respect to <u>ex ante</u> prediction. When attempted, the new product is generally a close substitute for an existing item and the maximum market share to be taken has been estimated, or the projection is made after a product has been partially adopted, often in excess of 50 percent (9, p. 226; 11, p. 496). Jarvis (11), for example, estimated both the rate of acceptance and the ceiling with data from the early stages of improved pasture diffusion in Uruguay. He repeatedly estimated Equation 2 with various assumed ceilings and selected the equation with the best fit (R^2) to represent the diffusion rate. For a wholly new product, including most biotech innovations, neither of these special cases can be applied.

While diffusion models are useful for understanding the aggregate process of technological change, they provide little ex ante insight into the likely rate of the adoption of particular innovations. For this, it is helpful to draw upon hypotheses from the adoption of innovation literature. Rogers (12), in summarizing this literature, suggests five dimensions (relative advantage, compatibility, complexity, divisibility, communicability) which determine the rate and likelihood of adoption. Rogers' analysis, along with the more quantitative work by Griliches, emphasizes that adoption decisions in aggregate depend on both sociological and economic factors. At the level of personal decision-making, it is generally accepted that there are individual characteristics which make people some more likely to adopt innovations than others (13).

With respect to the features of innovations, Rogers' notion of relative advantage relates to the extent to which a new technique or product is preferred to the existing technology. Generally, the superiority of an innovation is measured by its profitability or risk-reducing potential.

Compatibility is the extent to which a new innovation is consistent with the existing norms, values and prior experience of prospective adopters. Also to be considered is the extent to which it is compatible physically and managerially with existing practices.

Complexity is the extent to which new techniques and their consequences are easy or difficult to understand. In general, researchers such as Kivlin (14) and Graham (15) have found that less complex ideas are more quickly and widely adopted.

Divisibility is the extent to which an innovation can be used on a limited basis. The importance of divisibility stems from the risks potentially involved in trying a new innovation. If trials can be done on a limited basis, earlier adopters, especially, are able to limit their exposure to losses.

Finally, Rogers lists communicability as the ease with which knowledge of an innovation can be passed along to potential users. This concept includes both the complexity of the incorporation as well as the rapidity and tangibility of benefits.

Recent work by Agriculture Canada (16) on the adoption of six production level innovations employed a slightly different taxonomy of how product characteristics influence adoption. According to Agriculture Canada (16, pp. 44-45) important issues are the innovation's age, the initial investment required by the adoption decision and the riskiness of the undertaking. Three other factors, complexity, divisibility, and profitability, are very similar to those described by Rogers.

With this identification of the limitations of applying current analytical procedures to the pending stream of wholly-new biotechnology products, we turn to a suggested ex ante process for projecting farm-level adoption. The procedure is demonstrated by example, using bovine growth hormone (bGH) as the sample case. Before proceeding it is necessary to describe in some detail the characteristics of bGH.

BOVINE GROWTH HORMONE: AN EMERGING PRODUCT

Bovine growth hormone is a naturally occurring protein in cattle. In the 1930's it was discovered that the administration of bGH during lactation led to immediate and substantial increases in milk production. However not until gene splicing techniques were perfected was it feasible to produce the compound economically in commercial quantities (17). When introduced daily into dairy cows on about the 90th day of the lactation cycle, experiments at Cornell University and elsewhere have demonstrated the potential for a 10 to 40 percent increase in milk production per cow (18). Over the entire lactation that increase translates to a maximal advance of 25 percent. Moreover the increase begins within a few days of treatment and is independent of historical production levels.

Recent experimentation suggests that proportional increases can also be achieved during the first 90 days of the cycle. If true, and at this writing there is no definitive published experimental support, then total output per cow could rise by more than the 25 percent accomplished to date.

A detailed evaluation of the profitability of bGH use suggests strong inducements to adoption (19). Production cost for the 44 milligram daily dose is in the neighborhood of 8.5 to 18.6 cents. Computing returns over costs for the "representative farm" involves some judgment as the optimal ration for cows on treatment is not known in detail. Nonetheless, using several scenarios, returns to marginal feed expenses (but excluding the cost of the compound) are in the range of 5 to 25 percent at stable milk prices. On the well-managed farm, bGH is clearly a profitable product at the current price/feed cost ratio.

Despite the impressiveness of the test results there are reasons to believe adoption will not be as rapid as some have projected. Farmers must assess the labor and management costs of compound use while providing for the additional energy requirements of animals on treatment. Use also entails some risks which are not fully documented at this point. Moreover adopters have the option of reducing herd size so as to hold milk production constant or expanding output with constant or larger herds. Each of these decisions will affect aggregate milk production and are matters of public and private concern. We turn now to developing insights into those issues.

APPLYING DIFFUSION MODELS TO bGH

Predicting the rates of adoption and diffusion for an entirely new product such as bGH is necessarily a speculative exercise. The most relevant source of information is the judgment of potential users, in this case dairymen. The problem of obtaining useful indications of an innovation's attractiveness consists both of communicating the innovation's potential advantages and disadvantages as well as eliciting meaningful reactions from potential users. For generating a prediction of dairy farmers' response to bGH, a survey procedure was developed that involved both these elements.

In collaboration with dairy science researchers at Cornell University, a hypothetical Cooperative Extension "Fact Sheet" on bGH and fictitious advertisement for bGH from a well-known dairy publication were prepared. (See Figure 1 for an example of the questionnaire. The more detailed "Fact Sheet" is not shown.) These documents reflected the most up-to-date information

Figure 1: Fictional advertisement included as part of the informational material with the questionnaire-

What would you pay to increase your herd average potential from 14,000 to 15,750 or from 16,000 to 18,000 pounds?

Now from CORBIO(R) for only 17¢ (plus feed) a day you can do just that.

How does it work?

Without CORBIO(R), production declines steadily during the latter period of the lactation cycle.

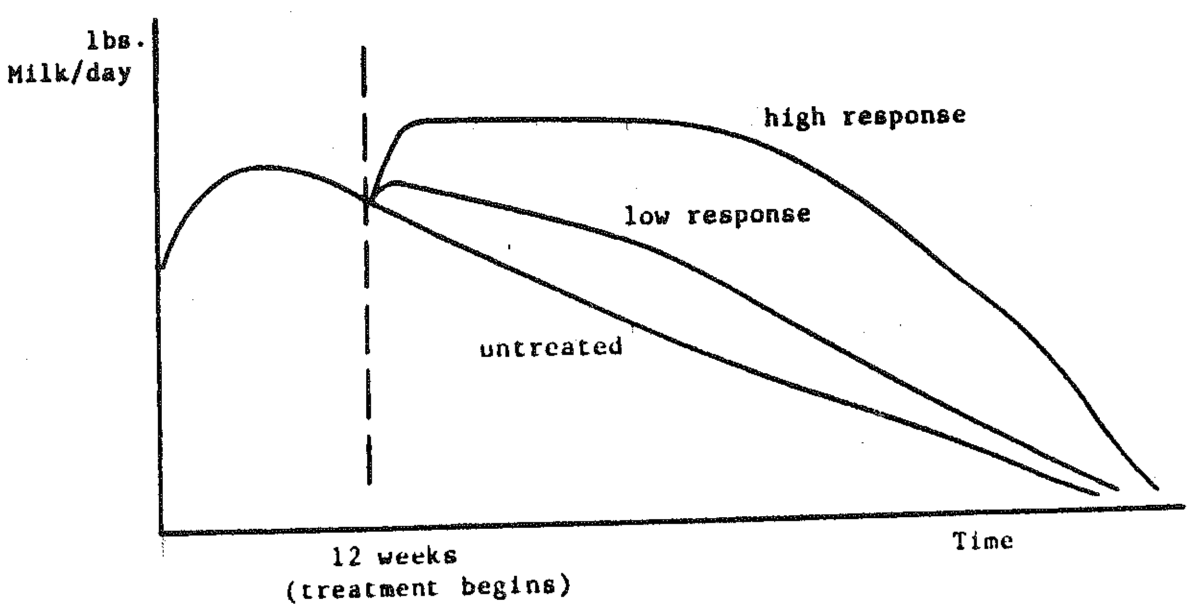
With CORBIO(R), production is 10 to 40 percent higher over that period than in the untreated cow.*

Yet CORBIO is a complete, safe, naturally occurring compound that is already present in your lactating animals. You are simply adding more to stimulate increased production. And the increase starts only a few days after treatment is begun in the 13th week of lactation.

For further information see your dealer.

* Must be injected daily. CORBIO is a registered trademark.

Production responses based on data from experiments at Cornell and other universities.



CORBIO(R) breaks the production ceiling every time!

available on bGH including production responses, costs, and overall effects on animal health. An attempt was made to present the material in a format similar to what might actually be used when bGH is first marketed and one which was brief but interesting.

Responses from farmers were collected using a questionnaire supplied to a randomly selected sample of New York State dairy farmers. Because of the speculative nature of the questions being asked, we were particularly concerned with the consistency and thoughtfulness of an individual's responses. To ensure that the responses used in projecting diffusion were the best that could be obtained, we used an approach based on "decision calculus" to design the survey instrument. Decision calculus, developed to assist in strategic decisionmaking situations (20; 21), specifically utilizes replications to lead decisionmakers to evaluate and refine their subjective judgments. Applications of decision calculus typically involve the use of an interactive computer program. Decisionmakers specify their estimates of outcomes from making relatively extreme decisions. The computer interpolates and offers an estimate of the outcome of less extreme decisions. The decisionmaker compares the model-based outcome with his subjective estimate and revises the midpoint estimate or his own extreme values appropriately. As the procedure continues iteratively, the decisionmaker is led to a precisely stated version of his subjective impression of a decision situation.

In the current study, it was impractical to rely upon a computer-based procedure because of the need to obtain a large sample of respondents. Instead, the questionnaire used here was designed to request repeatedly, in slightly different forms, the farmer's judgment about bGH. For example, early questions requested the respondent to assess the feasibility of bGH for his/her operation and then to estimate the length of time necessary before he/she would first try the product. Subsequent questions probed the farmer's opinions and, intentionally, promoted reconsideration of initial opinions. These questions included the farmer's reaction to various price levels of bGH and possible changes in farm operations and resources necessary for the successful administration of bGH. Finally, the questioning returned to requesting specific estimates of the number of cows to be treated with bGH at specific times in the future.

DATA COLLECTION PROCEDURES AND SURVEY RESULTS

The complexity of the data collection procedure necessitated that respondents' reactions were thoroughly understood. This was especially important because the production responses expected from bGH use are beyond the levels previously experienced. This evaluation was done through a personal interview procedure conducted in seven New York counties in July and August, 1984. The counties were chosen by dairy extension specialists as representative of the diverse farming environment across New York State.[3] Ten randomly selected dairymen in each county were contacted and an interview schedule set. Copies of the information materials and questionnaire were sent a week prior to the interview and subsequently completed by the enumerator. Additional information and comments were collected at the same time. Time and scheduling problems limited the number of interviews in each county to between five and seven for a total of 40 personal interviews.

An additional mailing to 1,025 New York dairymen (out of 17,236 total) was made in September, 1984. The random sample, which constitutes a rate of six percent for the State, was drawn from the "Ring List" maintained by the New

York State Department of Agriculture and Markets. By law, ring tests must be made on all milk cows four times annually and the results recorded. The Ring List thus represents a virtually complete and up-to-date mailing list for sampling purposes. Dairy farms are listed by county, but no record is available on herd size or production level. Thus only a simple random sampling procedure could be used.

Of the 1,025 questionnaires set, 14 were returned as undeliverable along with 133 usable returns (13 percent). The combined sample is then 173, or one percent of New York dairy farms in 1984. This response rate, while not unusually low, does raise questions about the possible selectiveness of the respondents. We analyzed this question by comparing mail and in-person samples using two t-tests. No significant difference (at the five percent level) was recorded among age, barn type and herd average. Moreover, there was no significant difference between the two groups in when they would first try bGH or in judgments about the feasibility of the innovation (Table 1). As a further comparison, a recent (1984) survey of dairy housing and milking systems throughout the Northeast was used (22). The Heslop survey results with respect to housing and milking systems closely matched those obtained for this research. Based on these factors, we consider the survey results to be reflective of the attitudes of dairymen in New York State.

<u>Survey Responses</u>

Responses to the principal survey question are summarized below.

<u>Feasibility</u>. Respondents were asked to assess the feasibility of bGH for their herds as "very", "somewhat", "possible", "questionable", or "other". A plurality (61 percent) was at least somewhat favorably inclined to adoption.

<u>Date to First Trial</u>. Respondents were asked how soon after commercial avail-

Table 1

COMPARISON OF IN-PERSON AND MAIL SURVEY RESPONSES[1]

	Number	Age (years)	(Mean) Product Per Cow (lbs)	Herd Size	Assessment of Feasibility (1 = extremely feasible 5 = questionable)	Time of First Trial (yrs. from availability)
In-Person	40	45.2 (10.6)	15,445 (2,702)	68.4 (41.7)	2.7 (1.2)	1.16 (1.6)
Mail	133	46.9 (10.92)	16,052 (2,388)	67.8 (46.7)	2.9 (1.3)	0.82 (1.09)
Total	173	46.6 (10.92)	15,885 (2,474)	67.9 (45.4)	2.8 (1.3)	.91 (1.24)
All New York Dairy Farms[2]	17,236	n.a.	n.a.	n.a.	n.a.	n.a.
All New York State Farms[2]	42,207	50.1	n.a.	n.a.	n.a.	n.a.

[1]Number in parenthesis is standard deviation.

[2]Stanton and Knoblauch, 1984.

Source: Survey data, unless otherwise specified.

ability they first expected to use bGH. Two-thirds anticipated initiating treatment within the first year with over a quarter planning immediate adoption. Conversely, one-eighth of the sample has no expectation of ever using the compound (Table 2).

Of those who would try bGH in their herds, the majority (73 percent) said they would experiment first by treating only a portion of their herd. Farmers would generally select test cows randomly and would not favor high or low producers. The gradual introduction is related to the individual operator's wish to gauge the impact of bGH on his/her operation prior to beginning full-scale use. The ability to test bGH on a portion of a herd is an example of the way in which the divisibility of the innovation facilitates adoption. Correlation of date to first trial and assessment of feasibility suggested high levels of consistency across the questionnaire. In fact, 21 percent of respondents rated compound use as very feasible while 27 percent planned to adopt immediately.

Price Response. In the material presented to farmers, the expected price of bGH was pegged at $0.17 per daily dose. Also provided was an indication of the range of incremental milk production that could be expected based on available experimental results. At all production levels and at all recent historical milk prices, the value of additional milk output far outweighed direct product cost. Nonetheless, when asked if an increase in the price of bGH to $0.25 per dose would affect their adoption decision, 47 percent responded that they would be less likely to try the product. A decrease to $0.10 per dose would increase the likelihood of trial for 40 percent of the respondents. Considering profitability of compound use this price sensitivity of farmers is quite surprising and appears to be related to a keen sense of cost control.

Table 2

EXPECTED TIME TO FIRST bGH TRIAL BY
NEW YORK DAIRYMEN, 1984

Initiation Date	Percent/Respondents
Immediately upon availability	27
3 months after availability	12
6 months after availability	10
1 year after availability	17
2 years after availability	5
3 years after availability	5
4 years after availability	4
Later than 5 years	5
Never	13
Other, No Response	2

Source: Survey results.

Herd Size. As a means of gauging the impact of bGH on herd expansion plans, respondents were asked, for the next one and five years, their (a) present plans for expansion or contraction and (b) additional changes which might be made as a result of bGH use. Without bGH the average planned increase in cow numbers was reported as 19.6 over the next five years. Since many farmers have in recent years expanded their milking herd to maintain cash flow with declining prices, farmers could use the higher output-per-cow potential of bGH as an opportunity for adjusting herd numbers. However, no significant impact was recorded, and we are unable to reject the null hypothesis that herd adjustment plans will be unaffected by the availability of bGH.

Other Factors

Concerns about the respondents' comprehension of the survey were minimized by the written comments included on the mailed forms. These comments indicated a high level of understanding of the survey purpose and of the product. One frequent comment received was an expressed concern about the acceptability of bGH to DHIC (Dairy Herd Improvement Coop) and related testing programs. This factor seems to have an impact on adoption rates and could have important policy implications.

Farmers also questioned the practicality and desirability of daily injections. This is also reflected (see below) in a more positive response to an implant method of administration. Concern over injections is based on the operational difficulties of managing the injection of animals as well as its humaneness.

Farmers expressed an acute awareness of the potential of increased milk output to depress further milk prices. Some farmers, in fact, questioned the desirability of bGH being made available given market conditions, one farmer writing, "It should be outlawed." Others noted that if many other farmers used bGH they would, practically, have no option but to adopt as well.

Identifying Fast Adopters

We attempted to relate characteristics of farmers and their farms with their interest in adopting bGH. The characteristics studied were barn type, milking system, herd size, average herd production and age of operator. Farmers were classified as early, middle and late adopters, according to the length of time they would wait before trying bGH. Of the total sample, 89 percent provided sufficient information on both farm characteristics and adoption expectations to use for this analysis. Early adopters were classified as those who would try bGH within one year of availability. Middle adopters would try bGH between 1 and 5 years after its availability, and late adopters would wait more than 5 years or said they would never try bGH. About two-thirds of the sample was classified as early adopters with the rest split between middle and late adopters.

We used analysis of variance to test for differences among the adopter categories with respect to ages of the operator, herd size and average production. We expected that younger farmers would appear more innovative. This could result from inexperience, need, or looser bonds of tradition. Early adopters in the sample are slightly younger than both middle and late adopters (mean age of 45.5 years versus 49.1 and 48.0 years, respectively). However, the statistical evidence is not strong, with significance at only the 25 percent level. Average production per cow also varies among adopter categories. Early and late adopters tend to have higher levels of output per animal than middle adopters but the differences are not statistically significant.

Giving reasonable significance (10 percent) is average herd size. Larger herds are indicative of better managers, who can be expected to be more innovative and greater risk takers. The expected pattern developed with early and middle adopters having significantly larger herds than late adopters (mean herd size of 72 and 70 for early and middle adopters versus 49 for late adopters).[4 5]

Analysis of variance could not be used to test for differences among adopter categories on the basis of geography, barn type or milking system because of the categorical nature of the variables. Instead, we conducted chi-square tests for association. We anticipated that increased requirements for energy in the ration of treated cows would make bGH relatively more attractive to farmers in the west central region as compared to farmers in the heavy, poorly drained soils of Northeastern New York. However, this was not supported by survey results. Similarly, milking system did not provide a statistically significant means of distinguishing among adopter categories.

Barn type, however, is significantly associated with adopter category. Early adopters were significantly more likely to have free stall or combination barns than stanchion systems.[6] Seventy-five percent of farmers having free stalls or combinations were early adopters versus only 62 percent of stanchion barn owners. There is some question whether this variable reflects innovativeness of farmers or greater ease of administration (compatibility). According to dairy extension specialists there is no clear advantage for one system over the other in administering the daily injections. The general feeling is that barn type reflects the innovativeness of the operator with more progressive farmers using free stall systems.

The two statistically significant factors, average herd size and barn type, provide a basis for projecting adoption decisions to populations other than New York State dairy farmers. However, further analysis is required before such a projection can be made with confidence.

PROJECTION OF DIFFUSION RATES

Potential diffusion rates are projected based on responses to the question, "Overall, how many cows in your herd would you expect to be using the hormone in: .... ". Respondents were then given a list beginning with six months and progressing to 10 years. The mail survey asked for separate responses for injections and implants as administrative methods. The in-person survey was limited to injections only as an administration technique. Otherwise the surveys were identical.

A number of approaches can be taken to analyzing the response to this question depending on how the surveys were completed. In several cases, respondents did not provide information on planned bGH use in all the time periods indicated. This required dropping the response from the sample altogether or imputing some rate of change in cows on treatment for the excluded years. Additionally, while most respondents increased the number of cows on treatment over time up to their entire herd size, some indicated that they would level off, with only a portion on treatment by the tenth year. Based on available information on the bGH program, it seems highly unlikely that only portions of a herd would be treated, except during a trial period.

Consequently, we have calculated diffusion rates in three ways:

* All Responses: include all responses, and when necessary extrapolate use of the highest indicated level (e.g. if use was placed at 50 percent in year 5 then it was assumed to be 50 percent in year 10 if no other figure was given.

* Complete Responses: all responses that did not completely specify treatment rates for the entire time period, six months through 10 years, were deleted.
* Excluding Partial Adopters: only responses which showed non-adoption or reached 100 percent herd treatment by the tenth year were included.

The procedure was applied twice, once for injections and once for implants.[7]

The first data treatment described above is questionable and is not expected to relate well to actual adoption rates and levels. The second and third treatments differ by the validity of the judgment that dairymen will not, in the long term, maintain only a portion of the herd on treatment. Rather than attempting to justify one choice or another, we present both with the expectation that they will bracket the actual experience. The appendix contains the data values for injections and implants, respectively, and are summarized in Figures 2 and 3 for administration by injections and implants, respectively. As can be seen, the availability of implants would both accelerate the adoption process and raise the long term penetration level.

Estimating Diffusion Functions

As indicated above, previous research suggests that the diffusion of bGH can be expected to follow an "S" pattern. This is confirmed by visual examination of Figures 2 and 3. Of particular interest for this research is the rate of innovation and the ultimate level of adoption. Unfortunately, the conventional estimating form of the logistic (equation 1) requires an a priori estimate of that ceiling level. Jarvis, as noted, employed sensitivity analysis to select the ceiling level most consistent with existing data. In this research we employed an alternative formulation of the logistic function suggested by Pindyck and Rubinfeld (23, p. 477).

Figure 2 EXPECTED bGH ADOPTION WITH INJECTIONS

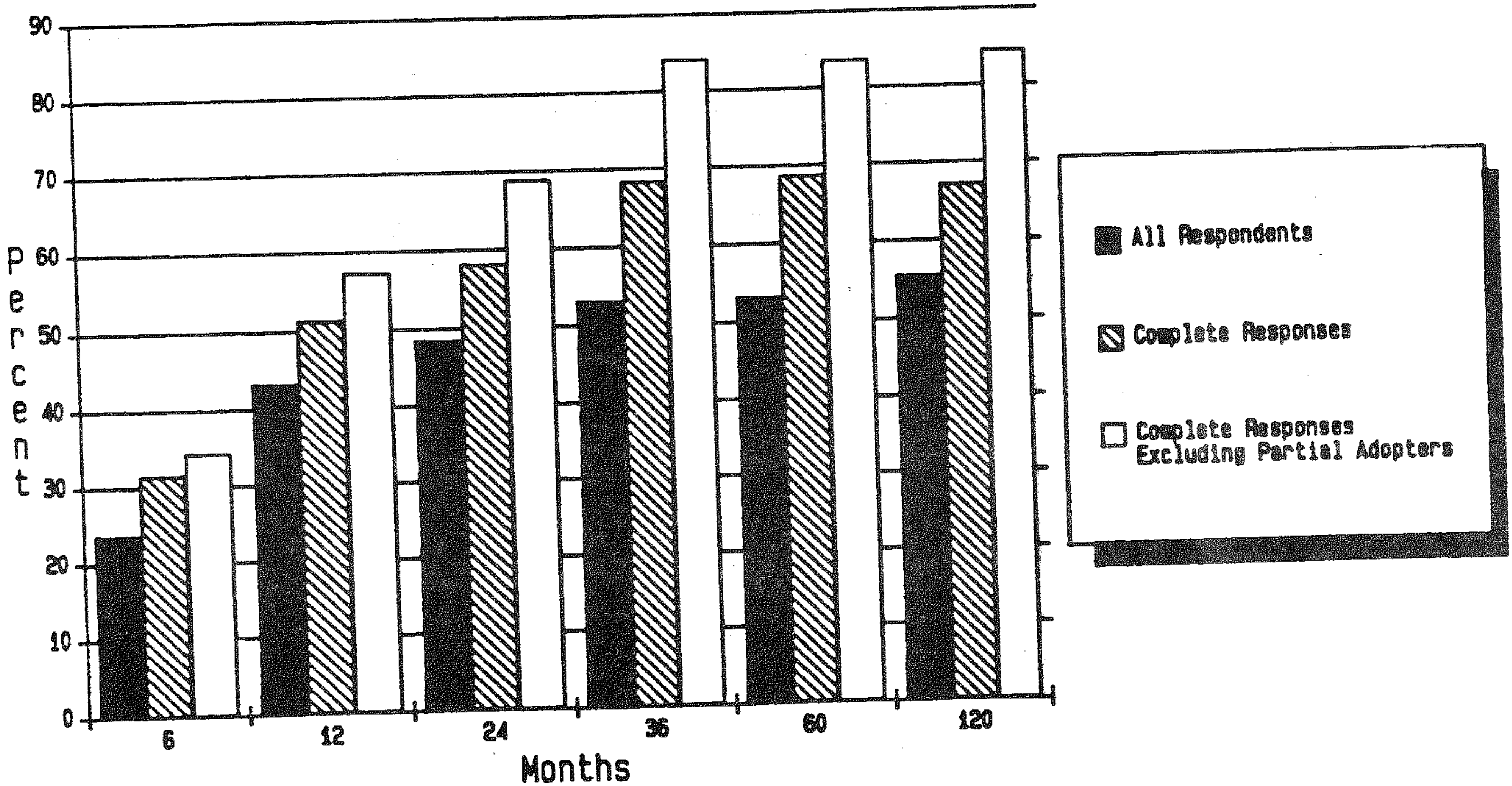
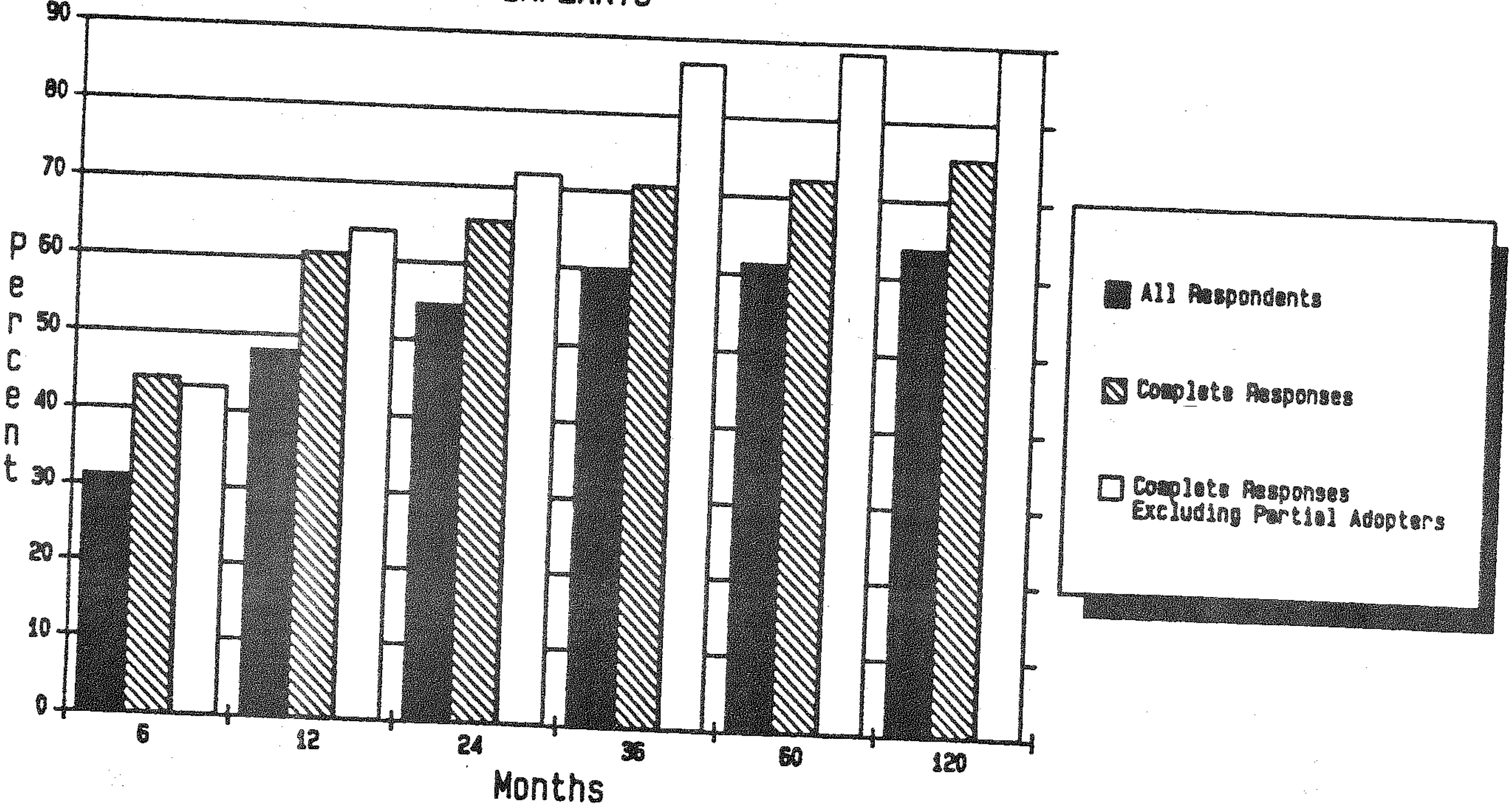


Figure 3 EXPECTED bGH ADOPTION WITH IMPLANTS



They note that the solution to the differential equation:

$$\frac{d_Y}{d_t} = \alpha Y(\beta - Y) \tag{5}$$

has the form of equation (1). The discrete approximation to equation (5):

$$\Delta \frac{Y_t}{Y_{t-1}} = \nu + \delta Y_{t-1} + \varepsilon \tag{6}$$

can be estimated using ordinary least squares. In addition equation (6) provides a simple method of estimating the ceiling level of diffusion. Setting ΔY_t in equation (6) equal to zero the asymptote is simply:[8]

$$-\frac{\hat{\nu}}{\hat{\delta}} = Y_{t-1} \tag{7}$$

Least squares estimate of equations (6) and (7) is given in Table 3[9]. As shown, the goodness of fit of estimated equations is good and coefficients are all statistically significant.[10] As might be expected, rates of diffusion and maximum levels of use are higher for implants than with injection application. Estimated asymptotes show levels in excess of 50 percent for all subsamples. Rejecting the All Responses data treatment as unrealistic leaves a minimum projected penetration of 63 percent.

SUMMARY AND CONCLUSIONS

This paper develops a procedure for projecting adoption rates of farm inputs not presently available on the market. The focus on ex ante estimates makes a significant departure from the accepted literature on adoption and diffusion. Yet a forward-directed analysis is essential if transitions to genetic engineering-based technologies are to be as smooth and painless

Table 3

LOGISTIC DIFFUSION CURVE FITS TO bGH ADOPTION DATA
NEW YORK DAIRYMEN, 1984[a]

Data Treatment	Intercept	Coefficient	R^2	Computed Asymptote
		Injection		
All Respondents	2.85 (6.89)	-5.59 (6.16)	90.2	51.2
Complete Responses	2.27 (5.79)	-3.61 (5.15)	86.4	62.9
Complete Responses Excluding Partial Adopters	1.97 (4.75)	-2.47 (4.06)	79.5	79.8
		Implant		
All Respondents	2.06 (5.82)	-3.51 (5.18)	86.6	58.7
Complete Responses	1.88 (5.91)	-2.70 (5.39)	90.6	69.6
Complete Responses Excluding Partial Adopters	1.65 (4.34)	-1.96 (3.75)	76.5	84.7

[a]Note: t-statistics are in parentheses

Source: data from Appendix

as such potentially fundamental transitions can be.

The procedure involves providing a sample of producers with facts about the effects of the product in the familiar forms of a simulated advertisement and Cooperative Extension "Fact Sheet". Respondents are then asked a series of specific questions about their own plans based on the provided information.

As a test case a milk-producing stimulant, bovine growth hormone, or bGH, was used. Bovine growth hormone, which is expected to be commercialized in the late 1980's, has the potential for dramatic impacts on milk production with increases per cow of 25 percent and above possible. The results from a sample of New york dairymen contacted in person and through mail questionnaires during the summer and fall of 1984 suggest a moderate-to-rapid adoption rate with a projected adoption ceiling of 63 to 85 percent with the variation attributed to how the survey responses are interpreted. These levels are achieved within three years of commercialization. In the longer term widespread compound use will likely lead to the lowering of real milk prices to the point that its use will become virtually mandatory and hence diffusion near universal. All of this says that planning needs to begin now for an innovation which is expected to have dramatic effects on the dairy sector before the end of the decade.

More generally, the results support the use of the proposed procedure as a means of projecting adoption rates of pending major new technological advances which affect production agriculture. Respondents appeared to have had no problems comprehending factual information of a hypothetical nature and responding to it in a meaningful way. Indeed confidential industry sources acknowledged that the results presented above for bGH are similar to those derived from the more cumbersome and expensive focus group procedure. While further tests are needed before this procedure may be broadly accepted there is no apparent reason why it will not be widely applicable to the score of biotechnology advances which will be approaching market readiness over the next decade and beyond.

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ENDNOTES

1. In these formulations, if the percentage level of adoption at time t is given by Y_t, explanatory variables include a value for the maximum level of diffusion, K, and either Y_{t-1}, $1 - Y_{t-1}$ or both Y_{t-1} and $1 - Y_{t-1}$.

2. Griliches (3) arbitrarily defines the "date of origin" of the hybrid corn innovation as the year (relative to 1940) when 10 percent of the corn acreage in a particular region was planted with hybrid seed. This is calculated by assuming a ceiling of approximately 100 percent so that:

$$\log (.10 / 1.00 - .10) = \hat{a} + \hat{b}t\ (.10)$$

Solving for t (.10);

$$(-2.2-\hat{a}) / \hat{b} = t\ (.10)$$

where ^ indicates a least squares estimate. While the 10 percent level was arbitrary it is used merely as a means of ordering regions by date of adoption. Griliches found that he was able to explain, with a high degree of confidence, both the "date of origin" and the rate of acceptance.

3. The counties are Madison, Washington, St. Lawrence, Jefferson, Wyoming, Ontario and Delaware.

4. For a discussion of the relationship between farm size and the acquisition of new technology see Feder and Slade (4).

5. The computed F value for the ANOVA is 2.67 with 2 and 151 degrees of freedom. When testing the hypothesis that the average herd size of early adopters is greater than that of late adopters, rather than the simple hypothesis that all herd size averages are unequal, a single t-test can be used. With only a single comparison to be made the t-statistic gives a shorter confidence interval than the q-statistic. Testing the hypothesis $\overline{X}_1 = \overline{X}_2$ against the alternative, $\overline{X}_1 > \overline{X}_2$, where the 1 and 2 refer to mean herd sizes

for early and late adopters, respectively, gives a computed t value of 2.40. This is larger than the 99 percent t-distribution for 130 degrees of freedom and the null hypothesis of equal means may be rejected.

6. The computed X^2'd is 6.84 which is substantially larger than the tabulated value for 150 degrees of freedom.

7. Examples of the three data treatment procedures are as follows:

Respondent/Year						Included in Data Set Treatment		
6 mo	1 yr	2 yr	3 yr	5 yr	10 yr	all respondents	complete responses	partial adoption excluded
10	20	30				X		
10	20	30	50	50	50	X	X	
10	20	30	50	80	100	X	X	X
0	0	0	0	0	0	X	X	X

8. The level of diffusion at any point in time must then be calculated backward from the asymptote. Choose some Y_t approximately equal to the asymptote. Rewriting equation (6) we have:

$$0 = \hat{\varepsilon} \, Y_{t-1} \, 2 + (1+\hat{\nu}) Y_{t-1} - Y_t \qquad (8)$$

Equation (8) can be solved iteratively using the quadratic formula to give a value for the level of diffusion in any previous periods.

In fact, this yields two solution for Y_{t-1}, one approached the asymptote from above and another from below. Only the value approaching the asymptote from below has significance in this context.

9. The results are actually from a weighted OLS analysis where the variables are adjusted for the number of adopters in each period as a means of controlling for heteroskedasticity.

10. Note that the parameters are not directly comparable to those of Griliches (3).

APPENDIX

PROJECTIONS OF bGH USE OVER TIME
(percent dairy herd/sample averages)

Data Treatment	Time Period						Sample Size
	6 mo	1 yr	2 yr	3 yr	5 yr	10 yr	
Injections							
All Respondents	23.7	43.2	48.5	53.1	53.2	55.5	119
Complete Responses	31.5	51.4	58.2	65.9	65.4	67.2	54
Complete Responses Excluding Partial Adopters	34.4	57.3	68.9	84.2	83.7	84.6	35
Implants							
All Respondents	31.3	48.0	54.7	59.8	61.4	63.8	85
Complete Responses	44.1	60.9	65.7	70.9	72.3	75.5	41
Complete Responses Excluding Partial Adopters	43.1	64.0	71.9	86.9	88.8	90.0	26

Source: Sample results