The Economic Impact of bGH on the New York State Dairy Sector: Comparative Static Results

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The price and quantity effects of a forthcoming biotechnology product, bovine growth hormone (bGH), are explored in a simple partial equilibrium model. The model is based on previous theoretical work on technological change but is developed in terms of a sector output. A particular output curve is estimated using data from a random sample of New York State dairy farms. Information on the farm level production effects of bGH is used to shift the output curve and to solve for equilibrium levels of price and output. The model projects the bGH may lead to the exit of 5,400 New York dairy farms and a 20 percent reduction in herd size. Consumers will benefit from an approximately 30 percent drop in milk price. The effect on gradual diffusion of bGH on farm numbers is considered. To accommodate this technology policies encouraging an orderly transfer of resources out of the dairy sector should be examined.

Introduction

In this paper we explore the economic consequences of a forthcoming biotechnology product, bovine growth hormone (bGH), on the New York State dairy sector. In the first section we develop a simple partial equilibrium model of the sector that can be used to study the impact of yield increasing technology. In the second section the estimation of the model is discussed. Then the comparative static results of the model under different policy and technology scenarios are presented, along with estimates of the impact of the technology on the New York State dairy sector. We next tentatively consider the time path of farm numbers with gradual adoption of bGH. Finally, we summarize our results and consider the policy issues raised by this new technology.

We focus on bGH because it is widely expected to be among the first commercial application of biotechnology to agriculture (Office of Technology Assessment) and because of the significance of the dairy industry to New York agriculture. Bovine growth hormone is a naturally occurring substance that serves to channel energy in the animal's system. When injected in lactating dairy cows, bGH has been found to be capable of increasing output by forty percent during the period of injection (Bauman, et al.). Recent developments in recombinant DNA technology have made commercial production and application of bGH feasible (Miller et al.). A study by Kalter et al. found that bGH use is profitable and that it will be rapidly adopted by dairy farmers.

At the same time, however, there is great concern over the financial viability of many dairy farms, and over the future of federal dairy policy. It is widely expected that significant declines in employment in the dairy sector, national herd size, output and price will accompany the introduction of more market oriented policies. The effect of the introduction of yield increasing technology in this environment is the subject of this paper.

The Model

Binswanger provides a graphic presentation of partial equilibrium approaches to technical

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change and examines the implications of general equilibrium models. He points out that technical change may be shown to have different implications when more than one factor of production and more than one sector are modeled simultaneously. However, when the sector experiencing technical change is small relative to the rest of the economy, such as the New York State dairy sector, a partial equilibrium approach will be able to capture the most significant consequences of technical change. Hayami and Herdt employ a supply-demand framework, similar to Binswanger, to empirically analyze *ex post* the effects of high yielding rice in Asia.

Assume the output of the dairy sector, Q, is a concave increasing function of n inputs:

$$(1) \qquad Q = Q(X_1, X_2, \ldots X_n) \qquad Q'(X_i) > 0 \quad Q''(X_i) \leq 0$$

where the X_i's are inputs such as land, labor, and capital.

The market for milk is described by a downward sloping demand function

$$(2) \qquad P = P(Q) \qquad P' < 0$$

Inputs are brought into production such that their marginal product is equal to their price (w). If the sector is small relative to the rest of the economy, these prices can be taken as fixed.

$$(3) \qquad \bar{w}_i = \frac{\partial Q}{\partial X_i} P(Q)$$

That is, the effect of a change in input i on total sector revenue will just cover its opportunity cost.

Technological change can be introduced into this model by defining a new sector output function Q^H (for high tech):

$$(4) \qquad Q^H(X_1, X_2, \ldots X_n) \geq Q(X_1, X_2, \ldots X_n)$$

If technological progress is limited to the dairy sector there is no reason to expect $\bar{w}$ to change. Thus the new equilibrium condition is simply:

$$(5) \qquad \bar{w}_i = \frac{\partial Q^H}{\partial X_i} P(Q^H)$$

Model Estimation

While farm level dairy production functions using current technology have been estimated (Grisley and Gitu; Hogue and Adelaja), and a few farm level linear programming results with bGH are available (Kalter et al.), sector level output functions with bGH are not available. To enable us to predict the price, quantity and employment effects of bGH we developed an estimation procedure based on the concept of a "particular expenses curve" (PEC) (Marshall, pp. 810–812). Marshall presents the PEC as an approximation to a supply curve that can be useful under certain conditions. A PEC is constructed by ordering producers from most to least cost efficient and tracing out cumulative output as an increasing function of per unit costs. Marshall uses his PEC to measure producer's and consumer's surplus, but indicates that these measures may only be valid at a particular level of output. This results from the fact that the structure of production costs may change as the level of output varies. However, Marshall also goes on to state that we may choose to ignore this fact for the sake of any particular argument, and although it may occasionally be convenient to do this, attention should be called to the nature of the special assumptions made.

We can estimate what is essentially the dual to the PEC by knowing only output per firm for a sample of firms. The output marketed by individual firms is assumed to be the profit maximizing output for the particular price and current technology. Sector output is the sum of output by all firms. By ordering firms from largest to smallest in output we can trace out what may be called a particular output curve. A POC thus relates the number of firms in a sector to aggregate output.

In order to estimate a POC, we used cross sectional data gathered from a random sample of New York State dairy farms previously collected by Kalter et al. Data on herd size and production per cow were used to generate output per farm for the 147 farms in the sample.[1] Farms were ordered from the most productive to least productive using milk output, and cumulative output is calculated for each possible sector size. Implicit in this procedure is the assumption that low output farms would leave the industry first if milk price falls.

As an alternative to ordering farms by physical output, we considered and rejected orderings by gross receipts, by return to labor and

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[1] The average herd size on the 147 farms was 68.9 (s.d. 46.3) and milk production per cow averaged 15,855 (s.d. 2475).

management, or by return to labor and management plus an imputed rent payment. Ordering by gross receipts with milk price the same for all farms would not change the ordering. Ordering farms by some net income measure, while preferable from a theoretical standpoint would have required the use of a nonrandom data set that uses accounting rather than economic measures of costs (New York State Farm Business Summary (Smith and Putnam)). Experiments with that data set, however, indicate that the estimated coefficients are highly insensitive to the choice of ordering technique.[2]

A cumulative output function of the form

$$Q = A F^{\alpha} \qquad 0 < \alpha < 1 \tag{6}$$

where α is the elasticity of output with respect to farms F and A is a constant, has the properties of equation 1, where the inputs are nonseparable and are considered a bundle representing a farm. Equation 6 is linear in logarithms and was estimated as

$$\ln Q = \ln A + \alpha \ln F$$

The ordering of observations results in a serially correlated error process which was corrected by the Cochrane-Orcutt procedure.[3] The estimated equation is:

$$\begin{aligned} \ln Q = {} & 11.5303 + 0.5656 \ln F \\ & (750.91) \quad (156.87) \end{aligned}$$

$$R^2 = .998 \qquad \text{Durbin-Watson} = 0.2592$$

(t-statistic in parenthesis)

The function fits the data very well ($R^2 > .99$) and all parameter estimates are highly significant and of the expected sign. The low Durbin-Watson statistic suggests that serial correlation is still a problem, but the high goodness of fit suggests that parameter estimates would not be significantly changed by any further correction. In any case, while serial correlation leads to inefficient estimates, the results can be shown to be unbiased and consistent (Pindyck and Rubinfeld, p. 153).

In order to estimate changes in the dairy herd we modeled cow numbers as a function of sector size. Because marginal farms with small shares of total output tend to have small herds, we also used a Cobb-Douglas functional form. Animal numbers (N) are thus:

$$N = C F^{\beta} \tag{7}$$

Estimated in logarithms equation 7 is:

$$\begin{aligned} \ln N = {} & 6.3256 + 0.5879 \ln F \\ & (468.56) \quad (185.82) \end{aligned}$$

$$R^2 = .999 \qquad \text{Durbin-Watson} = 1.299.$$

(t-statistic in parenthesis)

Sector level empirical demand functions for milk over a large price range that may occur with bGH adoption are unavailable. It is, however, widely accepted that demand is inelastic and ranges between −.1 and −.4 (George and King; Ippolito and Masson; Riley and Blakley). We assume that the current market price and quantity represents a point on the demand curve and that the New York State dairy sector accounts for a constant share of the market. Thus, we can use any given demand elasticity to construct a constant elasticity of demand function:

$$Q = BP^{\epsilon} \tag{8}$$

where ϵ is the constant price elasticity of demand. The parameter B can be calculated given values for any P and Q combination and an estimate of ϵ.

Because current government milk price support programs shift the quantity demanded outward it was necessary to estimate a free market clearing price and quantity. Data for the entire U.S. dairy industry shows that government purchases in 1984 amounted to roughly 13 percent of output. To estimate a market clearing price we calculated equation 8 such that it included the 1984 average New York price of $13.45 and 87 percent of the output of our sample. Using this demand curve and the estimated output function, a long run equilibrium milk price of between $12.33 and $12.39 is obtained depending on elasticity assumption. This range is higher than most estimates of equilibrium milk prices. The high equilibrium price predicted by this model, vis-a-vis, for example Novakovic, and Dahlgren, is in part due to the complete and instantaneous adjustment implied by this model. Without price supports the model predicts quantity falling by approximately 11 percent, farm numbers by about 17

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[2] When regression coefficients obtained by ordering Farm Business Summary farms by a net income measure are compared with those obtained by ordering farms by output, elasticity of output varies by less than 8% and the technology coefficient by 3.8%, both well within the level of accuracy that can be expected with this general procedure.

[3] The Cochrane-Orcutt procedure uses correlation between adjacent residuals to perform a generalized differencing transformation process. The procedure is repeated until the value of the adjustment variable is less than 0.01.

Table 1. Employment and Output with Alternative Assumed Free Market Prices (no bGH effect)

Price $	Output (% of 1984)	Farms (% of 1984)	Cows (% of 1984)
13.45	100.0	100.0	100.0
13.00	95.7	92.5	95.5
12.00	86.0	77.0	86.7
11.00	77.0	63.0	76.2
10.00	68.0	50.5	67.0

percent and herd size by about 11 percent. To facilitate comparisons with models indicating lower equilibrium prices and quantities, we constructed demand curves around a range of prices that includes most estimates of free market equilibrium prices. Quantities associated with various assumed free market equilibrium prices are shown in Table 1.

The equilibrium condition (equation 4) was used to estimate the "wage" of farms. Using the estimated sector output function, the 1984 average New York milk price of $13.45 per cwt, and assuming that this represents a long run equilibrium, an implicit wage of $88,571.35 per farm was calculated. This value appears plausible based on estimated total revenues of farms in the sample. Average gross receipts for this sample were $149,101. The relatively low imputed "wage" may be consistent with economic rents earned by farms endowed with high quality resources.

The sector wide effects of bGH on productivity are not known. It is known that in experimental situations bGH can raise output of a fixed size herd by 25.6 percent on an annual basis (Bauman et al.). Further development may increase this yield enhancement. In practice, however, such gains may be achieved only by the most well managed operations. We model technical change in two ways to cover the range of possible sector wide effects.

The simplest approach is to increase the constant term of the Cobb-Douglas output function by a percent value. This represents a constant percent increase in output for all farms, i.e. the marginal output function shifts upward by the chosen percentage. This is similar to the approach used by Akino and Hayami to shift a rice supply curve due to improved varieties. We evaluated effects of 10, 20, 30 percent changes in technology. This approach assumes that the use of bGH has no effect on input use or on the prices of variable inputs, but merely generates more output at each farm level. This is generally consistent with the findings of Kalter et al. They find that bGH increases farm output by essentially transforming low producing cows into high producing cows, necessitating the use of additional inputs that high producing cows require, primarily more feed. However, this analysis entirely neglects the cost of the hormone itself, which is unknown at this time, but could amount to a substantial percentage of the value of additional milk generated.

An alternative approach is necessary to represent the effect on sector productivity of bGH if, as is expected by some, it is biased in favor of more proficient operations. As noted, while experiment station results show that annual output can increase through the use of bGH by 25.6 percent, its impact on less efficient farms is more speculative. By assuming various levels of overall output change a biased sector output function can be calculated.[4] If the experiment station represents the most efficient farm, it would in our model appear as the first farm in the sector. Thus, its marginal product is, from equation 6:

$$\text{(9)} \quad \frac{dQ}{dF_{F=1}} = A\alpha F^{\alpha-1} = A\alpha 1^{\alpha-1} = A\alpha$$

If output (marginal product) of the most efficient farm will increase 25.6 percent because of bGH then:

$$\text{(10)} \quad \left(\frac{dQ}{dF_{F=1}}\right)1.256 = \hat{A}\,\hat{\alpha}$$

where ^ indicates a parameter of the improved output function. If, however, the output of the entire sector will increase by T percent then:

$$\text{(11)} \quad Q_{F=147}\,(1 + T) = \hat{A}(147)^{\hat{\alpha}}$$

This leaves two equations (10 and 11) in two unknowns ($\hat{A}$ and $\hat{\alpha}$). Using the original dQ/dL, Q and F, and using various estimates of T, we solved for $\hat{A}$ and $\hat{\alpha}$.

These values representing the technological effects of bGH, and the imputed wage of $88,571 per farm and any assumed demand elasticity, allow us to find the sector size that satisfies the equilibrium condition, equation 5. This also yields price and quantity data which

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[4] The term bias is generally used to describe the effect of a technological change on relative factor returns. Here we use biased technical change to refer to the extent to which the shift in sector output derives from increases in output by some or all farms.

Table 2. Effect of bGH and a Free Market Policy on Price, Output, Employment and Cow Numbers in the New York State Dairy Sector

Technical Change	Milk Price ($/cwt.)	Output[a] (mill. lbs.)	Farm Numbers	Cow Numbers (000)
		Current (1984)		
—	13.45	11,691	18,000	943
		$\epsilon = -.1$		
0	12.19	10,276	14,328	824
10	10.41	10,440	12,439	759
20	9.02	10,580	10,944	703
30	7.91	10,721	9,720	656
		$\epsilon = -.2$		
0	12.25	10,358	14,544	832
10	10.60	10,674	12,942	777
20	9.27	10,954	11,628	729
30	8.20	11,223	10,548	688
		$\epsilon = -.3$		
0	12.33	10,440	14,742	838
10	10.76	10,873	13,392	792
20	9.48	11,294	12,258	753
30	8.46	11,691	11,322	718
		$\epsilon = -.4$		
0	12.39	10,510	14,904	844
10	10.89	11,071	13,806	806
20	9.68	11,597	12,852	774
30	8.69	12,112	12,042	745

[a] 1983, most recent year available.

we can express as percentage changes (assuming constant market shares for our sample and state and national populations). We then utilize the relation between farm numbers and animal numbers to estimate the effect of bGH on state herd size. The vertical intercept of the tangent wage/price line also can be used to project the change in share of output to fixed or high quality factors of production.

Results

If markets are allowed to clear, the introduction of bGH will exacerbate downward pressure on milk prices and lead to a reduction in farm and animal numbers. Output will fall as a consequence of free markets but bGH will serve to lessen the decline. The combined effect of a free market dairy policy and a 20 percent shift in technology would be a drop in farm numbers of about 30 percent and for cow numbers to fall by 20 percent. Equilibrium output would fall by less than 4 percent and the farmgate price of milk would drop by about 30 percent. Roughly half of these changes can be attributed to the relaxation of price support programs in the model. If the aggregate output response to bGH is greater than 20 percent, milk price, farm and cow numbers fall more, while equilibrium output falls by less or remains unchanged.

In terms of the New York State dairy sector these percentage changes translate into a milk price of $9.49/cwt, a fall in farm numbers from 18,000 to 12,600, a decline in cow numbers from 943,000 to fewer than 745,000 and a decrease in milk production from 11,691 million pounds to about 11,500 million pounds.[5] Table 2 show these effects by level of technical change and by elasticity of demand.

As noted, this model projects a higher free market price and quantity than given by many other analysts. For purpose of comparison, the effects of assuming lower long run equilibrium prices with and without bGH were analyzed. However, a consequence of the use of constant elasticity functional forms is that percentage changes in output, price and employment from any assumed equilibrium are constant. Thus, differences in quantity projections were due to the use of different

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[5] Data on New York State dairy sector are from New York State Department of Agriculture and Markets (1984).

initial free market prices, while percentage changes were the same.[6]

Isolating the effect of bGH from the relaxation of dairy price supports shows that bGH will increase equilibrium output, but by only roughly half the percentage gain in technology. Cow numbers fall by about half to three quarters of the change in technology. Both milk price and employment will decline by almost the same percentage as the increase in technology.

The elasticity of demand assumed clearly affect results. The effect is greater for employment and output than for price, and is most pronounced when high levels of technological change are considered. For example, with a 30 percent bGH response the model predicts about a 38 percent fall in price and farms and a 4.4 percent increase in output when an elasticity of demand of −.1 is assumed. If, instead, an elasticity of −.4 is used, farm numbers fall by 20 percent, price declines by 30 percent and output increases by almost 15 percent. The magnitude of the impact of the elasticity assumption varies positively with the level of bGH response.

The economic effects of unbiased and biased technical change are illustrated in Figure 1. If the advantages of bGH are realized to a greater extent by farms that are already the most proficient, the principal consequence is to exaggerate the fall in equilibrium farm numbers. For example, with a biased technical change but an overall change of 10 percent, equilibrium farm numbers drop by 14 percent. With unbiased technical change the decline in farms is only 9 percent.

With biased technical change the equilibrium output increases by somewhat less than with unbiased change and prices fall by slightly less. As effective bias decreases (at overall levels of technical change of 25.6 percent) the differences between biased and unbiased outcomes essentially disappear.

The share of output attributable to fixed or high quality factors (43 percent) is unchanged by unbiased technical change. However, with biased technical change, high quality factors account for a higher percentage of output. With 20 percent technical change, the output share of limited factors rises to 45 percent (this is independent of price elasticity). This suggests that bGH may have significant effects on the price of high quality land and other fixed assets.

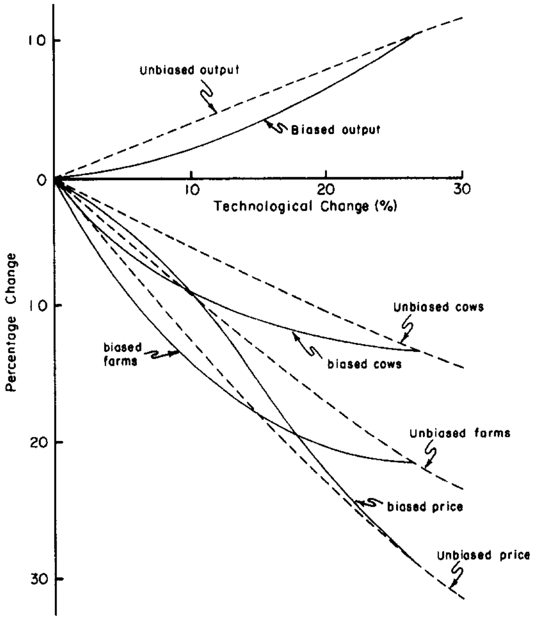

Figure 1. Percent Changes in Output, Price and Employment under Biased and Unbiased Technological Changes (evaluated from free market equilibrium) (ϵ = −.3)

Gross revenue per farm is also essentially unaffected by unbiased change. Without bGH average gross receipts per farm are $156,597 per year. With bGH the range of average gross receipts is $156,545 to $156,650 and does not reveal any significant pattern. Biased technical change, however, raises gross revenue substantially. When the most advantaged farms increase output by 25.6 percent but the sector overall gains only 10 percent, average gross revenue per farm rises by 8 percent to about $169,900. As effective bias disappears the difference in gross revenue also fades.

Diffusion

Research reported by Kalter et al. indicates that the adoption of bGH will not be instantaneous. We used their estimate of the rate of diffusion to follow the changes in prices, quan-

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[6] The interested reader can further explore the sector level effect of bGH by applying the percentage changes implied in Table 2 to the alternative free market prices and quantities shown in Table 1.

tity and employment over time. Their best estimate of the path of diffusion of bGH is

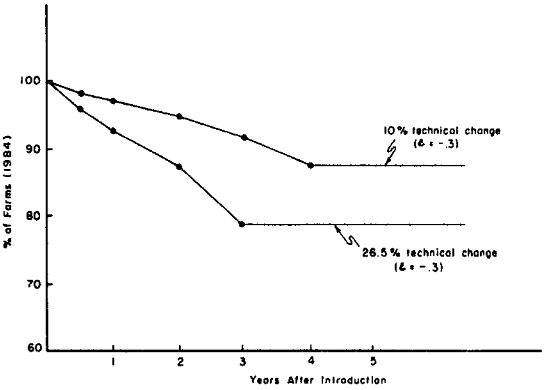
$$\frac{\Delta Y_t}{Y_{t-1}} = 1.97 - 2.47\, Y_{t-1} \tag{12}$$

where Y_t equals the percent level of bGH use at time t, measured from the time of commercial availability.[7] Solving for the level of diffusion following the introduction of the hormone gives the following time path:

6 months	1.9 percent of farms;
1 year	5.4 percent of farms;
2 years	15.3 percent of farms;
3 years	39.7 percent of farms;
4 years	79.0 percent of farms.

The calculation of equilibrium prices and quantities with partial diffusion follows essentially the same procedures as with the previous 100 percent instantaneous adoption. However, output is now calculated as the sum of production by adopters and nonadopters. New adopters in any year are the highest output farms that have not yet adopted but have survived. It is assumed that the contraction of employment that accompanies falling prices first affect nonadopters (i.e. only after all nonadopters have been forced out are adopters removed).

Of greatest interest in the context of gradual diffusion is the adjustment of farm numbers over time. The time path of equilibrium employment taking diffusion as given is illustrated in Figure 2. The consequences of resource immobility make the predicted time paths of price and quantity with gradual diffusion more tenuous than the estimates of the prices and quantities given above. While the complete diffusion results discussed above also involve the assumption of complete market adjustment, we have specified no time dimension or adjustment path. The results indicate that at relatively low levels of technical change and with relatively elastic demand it will be possible for nonadopters to remain in the industry. However, if the actual rates of technical change are high or if demand for milk is highly inelastic, adoption will be necessary, but not sufficient, for economic survival.



[a] Diffusion rate based on Kalter et al., p. 89

Figure 2. Diffusion and the Employment Consequences of bGH[a] (farms as % of free market equilibrium)

Conclusions and Policy Implications

In this paper we have described a simple partial equilibrium model of the New York State dairy sector that allows us to project the effects of a biotechnology product. The model is based on previous theoretical work on technological change but is developed in terms of output. This enables us to use data on the farm level production effects of bGH. We estimated the model using data collected from a random sample of New York dairy farms in 1984. Technical change was modeled in two ways to capture the range of possible sector wide output effects. We also present tentative time paths for resource use based on the predicted rate of bGH diffusion.

The availability of bGH will have significant economic impact on the national and New York State dairy sectors. Our model projects that bGH may lead to the exit of 5400 New York dairy farms. At diffusion rates projected by Kalter et al. this contraction could occur within five years. To put this decline in perspective, the effect of conventional technological change and ongoing structural change has resulted in the exit of 4000 dairy farms over the last ten years (New York State Department of Agriculture and Markets, p. 43).

The comparison of equilibrium farm numbers does not fully convey the implications of bGH. While the number of New York dairy farms has fallen over the last ten years, the consolidation of agricultural resources, as indicated by a constant state herd of roughly 920,000 cows, has meant a relatively stable

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[7] Equation 12 was estimated to predict the percent of cows per herd receiving treatment. However, it may be unlikely that farmers would treat only a portion of their herd (beyond a short trial period). We are using it to predict the percentage of farms adopting bGH.

dairy sector. In terms of cow numbers, our model predicts a reduction of about 20% or some 189,000 animals. This suggests that policies encouraging an orderly transfer of dairy resources to other sectors should be examined.

On net bGH and a free market dairy policy will leave total output essentially unchanged. The primary beneficiaries of bGH will be consumers who stand to gain from substantially lower dairy prices. With output levels holding fairly constant, processors will be largely unaffected by bGH and a free market policy.

Our results indicate that a major question is the extent to which the benefits of bGH are biased in favor of large, high output farms. If this bias occurs, there will be substantial changes in gross receipts per farm and in the share of output attributable to fixed or high quality inputs. Over time, these benefits will be capitalized into land and asset prices, to the benefit of their owners. Thus, to the extent that the distribution of benefits from bGH among dairy farmers is a concern, future public sector research on bGH should address delivery systems, extension and feeding programs that will decrease any bias in the technology.

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