Ex Ante Evaluation of the Economic Impact of Agricultural Biotechnology: The Case of Porcine Somatotropin

Catharine M. Lemieux and Michael K. Wohlgenant

Introduction of a new growth hormone, porcine somatotropin, will have a significant impact on the U.S. pork industry. *Ex ante* effects are estimated using a linear elasticity model, which accounts for interrelationships between domestic and international markets for hogs and pork, different adoption rates and lengths of run for supply, and consumer demand shifts from leaner pork. The paper shows how to use experimental data to quantify production function and supply shifts. Results indicate that, for a five-year adjustment period, producers' surplus will increase between $250 million and $720 million; consumers' surplus will increase between $900 million and $1.95 billion.

Key words: biotechnology, economic surplus, porcine somatotropin, pork demand, pork supply.

Advances in biotechnology are leading to the creation of products which are expected to have a significant impact on agricultural production. Much discussion in the literature has focused on possible impacts of biotechnology on agriculture (Kalter and Tauer, Hueth and Just, Stallman and Schmid), but few quantitative estimates of the probable impact exist. This paper examines the impact of a new growth hormone, porcine somatotropin (PST), on the U.S. pork industry. Our approach is generally useful for *ex ante* analyses of new biotechnologies where experimental estimates of the impact of the technology are available and where the nature of the commodity produced may be affected by the new biotechnology.

PST is a naturally occurring somatotropin protein produced in the pig's pituitary. Supplemental PST has been shown in experimental research to lead to improvement in average daily gain, improvement in feed efficiency, and change in carcass composition of the pig by converting fat to lean meat. The purpose of this paper is to simulate the likely impact of supplemental PST use on prices and quantities of pork at the retail and farm levels and on net benefits of producers and consumers.

The approach taken here to quantifying the impact of PST is in the spirit of previous *ex ante* approaches to estimating returns to agricultural research (Norton and Davis). This study explicitly takes into account (*a*) interrelationships between the domestic hog and pork markets, (*b*) interrelationships between pork and other meats, (*c*) interrelationships between the domestic and international markets for hogs and pork, (*d*) intertemporal effects through different adoption rates and different lengths of run for supply adjustment, and (*e*) shifts in consumer demand from production of leaner pork. The approach extends and encompasses previous simulation studies on the impact of animal growth hormones (Kalter et al., Meltzer and Kalter, Fallert et al.). The model used—a linear elasticity model—is generally applicable regardless of whether the parameter values are selected through econometric or programming approaches.

One of the main contributions of this paper is to show how experimental research can be

---

Catharine M. Lemieux is an assistant professor of economics, Indiana State University, and Michael K. Wohlgenant is a professor of economics and business, North Carolina State University. Senior authorship is shared.

Paper No. 12050 of the Journal Series of the North Carolina Agricultural Research Service.

Research was in part supported by funds provided by Pitman-Moore, Inc.

Appreciation is expressed to R. K. Perrin, W. N. Thurman, V. K. Smith, and anonymous reviewers for helpful comments. Remaining errors are the sole responsibility of the authors.

used to quantify shifts in the market supply curve. By decomposing technical change into a neutral component and a biased component, shifts in the production function can be identified and estimated from experimental data. In turn, these production function shift parameters can be used as scaling factors for output and factor prices in the econometrically estimated inverse supply function to calculate the reduction in marginal cost from introduction of the new technology.

Modeling the Impact of PST

Figure 1 shows the hypothesized impact of PST on the domestic hog industry. Introduction of PST will cause the market supply curve to shift from S_0 to S_1 and the demand curve to shift from D_0 to D_1. Assuming the horizontal shift in supply is larger than the horizontal shift in demand, price would be expected to fall and quantity would be expected to rise. Clearly, the net effect of a simultaneous increase in demand and supply from introduction of PST is for quantity to increase more and price to fall less, compared to the case when introduction of PST only increases supply.

Assuming the same absolute reduction in costs and increase in demand at all quantities, figure 1 also can be used to indicate gains to producers and consumers from introduction of PST. Area P_1ECD represents the gains to producers, while area ABP_1E represents the gains to consumers. Producers' share of the benefits declines as demand becomes more inelastic and supply becomes more elastic. Also, benefits both to producers and consumers will be greater when introduction of PST causes demand as well as supply to increase.

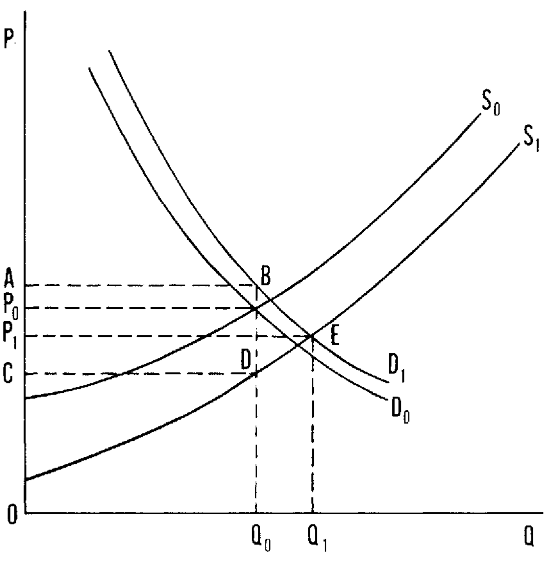

Figure 1. Net effect of increase in demand and supply from PST on U.S. hog industry

For any given length of run, figure 1 illustrates the key parameters in quantifying the impact of PST. These parameters are (*a*) elasticities of supply and demand, (*b*) decreases in production costs at various quantities, and (*c*) increases in demand at various quantities derived from an increase in consumer demand for leaner pork. The remainder of this section shows how to use experimental data to quantify production and supply function shifts. Procedures used to estimate demand and supply elasticity interrelationships and increases in the demand for hogs from producing leaner pork are discussed in the next section.

Experimental results from injection of supplemental PST indicate improvements in average daily gain and feed efficiency (Boyd et al.). This information may be quantified by defining the production function as

$$(1) \qquad Q = A \cdot f(B \cdot F, K),$$

where Q is the quantity of pork produced, F is the quantity of feed consumed, K denotes other inputs, and A and B are scale parameters ($A \geq 1$, $B \geq 1$). Technical change is represented here as a combination of extended Hicks'-neutral change (Blackorby, Lovell, and Thursby) and Hicks' F-saving change for the general case of a nonhomothetic production function.

The form of (1) implies that, holding A and K constant, the same relative increase in output can be obtained through increasing feed consumption or through changing the scale parameter B by the same proportion. Experimental data for PST show the amount of feed saved, holding all other inputs constant. If we take the biased component of technical change, $\theta = d\ln B$, as the percentage change in feed saved (i.e., $\theta = -d\ln F$), it follows that the neutral component of technical change, $\delta = d\ln A$, equals the observed relative change in output from the experiment since, from the total differential of the logarithm of (1) holding K constant,

$$d\ln Q = (MP_F/AP_F)(d\ln F + \theta) + \delta = \delta,$$

where MP_F is the marginal product of feed and AP_F is the average product of feed.

The procedure for deriving the biased component of technical change, θ, ignores changes in the composition of the ration toward a higher proportion of protein. Quality changes in the ration can be accommodated by assuming the production function is weakly separable with respect to corn (C) and hog supplement (S). That is,

$$Q = A \cdot f(B \cdot F(C, S), K).$$

If $F(C, S)$ is also homogenous of degree 1 then

$$d\ln F = k_c \cdot d\ln C + k_s \cdot d\ln S,$$

where k_c and k_s are the cost shares of corn and supplement in the ration. This specification implies that the adjusted biased technical change component, θ^*, can be quantified as

$$\theta^* = -k_c \cdot d\ln C - k_s \cdot d\ln S.$$

To find the impact of technical change on marginal cost of hog production, we derive the total cost function corresponding to (1) and differentiate with respect to output. This total cost function has the form

$$(2) \qquad TC = C(Q/A, P_F/B),$$

where P_F is the per unit cost of the ration. (For simplicity, prices of other variable factors and quantities of fixed factors are subsumed in the total cost function.) The way in which biased technical change is introduced into (2) is equivalent to that of Binswanger. Formulation (2) extends his approach by incorporating the neutral technical change component as a scaling factor for output.

Differentiating (2) with respect to Q yields the marginal cost function,

$$(3) \quad MC = [\partial C(Q/A, P_f/B)/\partial(Q/A)](1/A).$$

Differentiating (3) with respect to A and B and converting to elasticities gives expressions for the elasticities of the inverse supply function with respect to A and B:

$$(4a) \quad (\partial MC/\partial A)(A/MC) = -(1 + 1/\epsilon), \text{ and}$$

$$(4b) \quad (\partial MC/\partial B)(B/MC) = -\epsilon_f,$$

where ϵ is the elasticity of supply (inverse of the elasticity of marginal cost with respect to Q), and ϵ_f is the elasticity of marginal cost with respect to the feed price. This means that for given values of δ and θ^*, the percentage change in marginal cost of hog production is approximately equal to

$$(5) \quad dMC/MC = -(1 + 1/\epsilon) \cdot \delta - \epsilon_f \cdot \theta^*,$$

where θ^* is the percentage change in feed ration adjusted for changes in protein content as defined above. Adjusting (5) for the cost of the PST treatment produces a formula to estimate net reductions in the supply price from the introduction of PST.

As pointed out by Rose and by Lindner and Jarrett (1980), in *ex ante* analyses of research benefits, information on the reduction in marginal cost generally can be inferred only at the original quantity. However, in the case of *PST*, experimental data indicate that the percentage reduction in marginal cost is dominated by the effects of improvement in average daily gain, which is reflected in the first component of (5). If, as maintained by Hildreth and Jarrett (1978), inframarginal firms are the larger, lower cost firms, and if these larger firms tend to have smaller supply elasticities, then with the first term in (5) predominating the percentage change in marginal cost should decline more as output falls.[1] This effect over the range of output suggests that a vertically parallel supply shift, as assumed in figure 1, is not an unreasonable approximation. To the extent that per unit costs do not decrease as much for low-cost producers as for high-cost producers, assuming a parallel supply shift will cause producer returns to be overstated.

A Model of the Pork Sub-Sector

The model used to quantify the impact of PST on prices and quantities in the pork industry contains a series of equations in log-differential form representing supply, demand, and market clearing relationships. The endogenous variables of the model are proportional changes in quantities of pork sold at the retail level (EQ_{PRD}), pork sold on the export market (EQ_{EXD}), hogs purchased for slaughter (EQ_{HF}), hogs sold by domestic producers (EQ_{HFS}), hogs imported from Canada (EQ_{IMS}), retail pork prices (EP_{PR}), and farm-level hog prices (EP_{HF}). Fixed values are assumed for all input

[1] Using farm record data from the Illinois Farm Business Management Association and survey data compiled by Van Arsdall and Nelson for different size farrow-to-finishing operations, supply elasticities were estimated for different size producing units. These supply elasticities ranged from 0.1 for large farms (2,000–4,999 market hogs per year), 0.3 for medium-size farms (1,000–1,999 market hogs per year), and 0.5 for small farms (500–999 market hogs per year). See Wohlgenant and Lemieux for details.

prices other than market hogs, for market and cost shares, and for elasticities of supply and demand. For changes from the initial market equilibrium hypothesized here, these assumptions seem reasonable and do not impose undue restrictions on the functional forms for supply and demand. Because the model is specified in proportional changes, explanatory variables not affected by the introduction of the growth hormone (PST) do not appear in these equations.

The notation for the shares and elasticities along with the parameter values used in the simulation are reported in table 1. The proportional change operator $E(x) = dx/x = d(\ln x)$ is used throughout. The eight equations characterizing equilibrium displacement of the U.S. pork and hog markets from the introduction of PST are as follows:

Table 1. Elasticities and Shares: Definitions and Values Used in Simulations

Symbol	Definitions	Values
η	Total demand response elasticity for pork	−0.7 or −0.9
η_X	Price elasticity of export demand for pork	−3.0
S_{HF}	Farmers' share of retail dollar	0.52
S_{PRD}	Domestic consumption share of U.S. pork production	0.986
η_{HF}	Output constant own-price elasticity of demand for hogs	0.0 or −0.1
ξ	Price elasticity of U.S. supply of hogs (short run, intermediate run, long run)	0.4, 1.8, ∞
ξ_M	Price elasticity of import supply of hogs (short run, intermediate run, long run)	12.7, 37.7, ∞; or 15.5, 40.5, ∞
S_{HFS}	U.S. production share of hog supply	0.99
k[a]	Percent change in costs due to adoption of PST (short run, intermediate run, long run)	−4.2, −11.4, −11.4; or −19, −19, −19
g[b]	Percent change in consumer demand for pork from adoption of PST (short run, intermediate run, long run)	0.0, 0.0, 0.0; or 0.9, 2.6, 2.6; or 4.3, 4.3, 4.3

[a] For first three values, percent change in costs of −19% is multiplied by adoption rates of 0.22, 0.6, and 0.6 for three lengths of run.

[b] For first set of values no demand shift is assumed. For second set of values, percent change in consumer demand for pork of 4.3% is multiplied by adoption rates of 0.22, 0.6, and 0.6 for three lengths of run.

(6) $EQ_{PRD} = \eta \cdot (EP_{PR} - g)$ (retail pork demand)

(7) $EQ_{EXD} = \eta_X \cdot (EP_{PR} - g)$ (export demand for pork)

(8) $EQ_{PR} = S_{PRD} \cdot EQ_{PRD} + (1 - S_{PRD}) \cdot EQ_{EXD}$ (market-clearing pork market)

(9) $EP_{PR} = S_{HF} \cdot EP_{HF}$ (retail pork-farm price linkage)

(10) $EQ_{HF} = \eta_{HF} \cdot EP_{HF} + EQ_{PR}$ (output-constant hog demand)

(11) $EQ_{HFS} = \xi \cdot (EP_{HF} - k)$ (U.S. hog supply)

(12) $EQ_{IMS} = \xi_M \cdot (EP_{HF} - \eta_T \cdot g/\lambda)$ (import supply of hogs)

(13) $EQ_{HF} = S_{HFS} \cdot EQ_{HFS} + (1 - S_{HFS}) \cdot EQ_{IMS}$ (market-clearing hog market),

where η, η_X, η_{HF}, ξ, and ξ_M are partial elasticities of demand and supply functions; $S_{HF} = P_{HF} \cdot Q_{HF}/P_{PR} \cdot Q_{PRD}$, $S_{PRD} = Q_{PRD}/Q_{PR}$, and $S_{HFS} = Q_{HFS}/Q_{HF}$ are cost and production shares; k is the proportional change in costs (at a given quantity) from introduction of PST; and g is the proportional shift in consumer demand for pork (at a given quantity) from introduction of PST.

Equation (6) represents the proportional change in U.S. pork consumption in response to the introduction of PST. The domestic price elasticity of demand for pork, η, is a total demand response elasticity (Buse), which takes into account substitution with, and possible feedback effects of, prices of other meats (including pork imports) on consumer demand for pork. Equation (7) takes into account the impact of PST on pork exports through changes in the retail price of pork and shift in export demand for pork from changes in product quality. Equation (8) is the log differential form of the market-clearing condition that total pork supply from the domestic market equals the sum of the quantities sold on the domestic and export markets.

Equations (9) and (10) represent retail-to-farm demand linkages for pork. These equations are the log differentials of the (inverse) product supply and output-constant demand functions derived from an aggregate constant returns to scale production function. Wohlgenant has shown this assumption is plausible in the case of the domestic pork industry.

Equations (11) and (12) are specifications of the impact of PST on domestic and import supply functions of hogs. In this specification, only U.S. hog producers are assumed to adopt PST. Sensitivity of the results to relaxation of this assumption is examined below. If adoption of PST leads to an increase in demand for pork, there will be a wedge between the price paid for domestically produced hogs and imported hogs, reflected as an added carcass premium for domestically produced hogs. The term $\eta_T \cdot g/\lambda$ in equation (12) is the added carcass premium as a proportion of the initial hog price. (η_T and λ are total elasticities of retail demand and derived demand, to be explained below.) Equation (13) is the log differential form of the market-clearing condition that total U.S. hog demand equals the sum of the quantities supplied from the domestic and import markets.

Equations (6)–(13), for given values of the demand and supply elasticities and market and cost shares, comprise a complete system and can be solved for proportional changes in prices and quantities as functions of the shift parameters, k and g. The most intuitive and straightforward way to obtain these solutions is first to obtain expressions for changes in industry derived demand and total market supply of hogs (Muth). Given these expressions, a solution for EP_{HF} is obtained by equating the change in derived demand with the change in total hog supply. Solutions for the other endogenous variables are obtained using the original equations (6)–(13).

Derived demand for hogs is obtained by taking EP_{HF} as fixed and solving equations (6)–(10) for EQ_{HF} to obtain

$$(14) \qquad EQ_{HF} = \lambda \cdot EP_{HF} - \eta_T \cdot g,$$

where

$$(15) \qquad \lambda = \eta_{HF} + S_{HF} \cdot \eta_T \text{ and}$$

$$(16) \qquad \eta_T = S_{PRD} \cdot \eta + (1 - S_{PRD}) \cdot \eta_x$$

are, respectively, the industry derived demand elasticity for hogs and the total retail demand elasticity for pork. The derived demand elasticity consists of a substitution effect between hogs and marketing services, η_{NF}, and an output effect, $S_{HF} \cdot \eta_T$, which measures how changes in the price of hogs indirectly affect total demand for pork through changes in the retail price of pork. The total retail demand elasticity is a weighted average of the domestic and export demand elasticities. The maximum additional price processors are willing to pay for leaner hogs treated with PST (i.e., the added carcass merit premium) can be obtained from (14) by setting $EQ_{HF} = 0$ and solving for EP_{HF} to obtain $\eta_T \cdot g/\lambda$.

The total supply of hogs to the United States in percentage terms is obtained by substituting (11) and (12) into (13)

$$(17) \qquad EQ_{HF} = [S_{HF} \cdot \xi + (1 - S_{HFS}) \cdot \xi_M] \cdot EP_{HF} - S_{HFS} \cdot \xi \cdot k - (1 - S_{HFS}) \cdot \xi_M(\eta_T/\lambda) \cdot g.$$

The supply elasticity of hogs to U.S. processors (coefficient of EP_{HF}) is a weighted average of the elasticities of domestic supply and import supply.

To calculate the impact of the introduction of PST on hog prices, (14) is equated with (17) and solved for EP_{HF}, to obtain:

$$(18) \qquad EP_{HF} = \{S_{HFS} \cdot \xi \cdot k - [1 - (1 - S_{HFS}) \cdot (\xi_M/\lambda)] \cdot \eta_T \cdot g\}/(\xi_T - \lambda),$$

where

$$(19) \qquad \xi_T = S_{HFS} \cdot \xi + (1 - S_{HFS}) \cdot \xi_M$$

is the elasticity of total hog supply. Once the effect on the farm price of hogs is determined, the effect PST will have on farm output and prices and quantities of pork at retail is determined through equations (6)–(13).

Formulas to quantify changes in economic surplus of consumers and producers are derived on the assumptions that the supply and demand functions are linear for small changes from the initial equilibrium and that supply and demand shifts from the introduction of PST are parallel. The first assumption seems reasonable in the context of the present application. The assumption of parallel shifts was discussed in the previous section.

All changes in economic surplus are calculated for the domestic hog market. The demand function for hogs, equation (14), is an industry-derived demand curve which takes into account associated price adjustments in the retail pork market. Thus, changes in economic surplus calculated with this demand curve measure net welfare effects on pork consumers (Just, Hueth, and Schmitz, chap. 9).

Another consideration in developing formulas for changes in economic surplus is the time it takes producers to respond to the impact of the new technology. The methodology for estimating welfare changes when the supply function adjusts over several time periods is outlined in Just, Hueth, and Schmitz (chap. 4) and Mullen, Wohlgenant, and Farris. They show that, in this case, the appropriate measure of change in producers' surplus is the change in producers' surplus based on the supply curve which corresponds to the appropriate length of run (as viewed from the initial time period). Changes in producers' surplus and changes in consumers' surplus are calculated for different lengths of run in the present study to show the relative importance of length of time for adjustment to introduction of a new technology.

Given these considerations, changes in producers' and consumers' surplus derived from figure 1 can be quantified as[2]

$$(20) \quad \Delta PS = P_{HF} \cdot Q_{HFS} \cdot (EP_{HF} - k)(1 + 0.5 \cdot EQ_{HFS}),$$

$$(21) \quad \Delta CS = -P_{HF} \cdot Q_{HFD} \cdot (EP_{HF} - h)(1 + 0.5 \cdot EQ_{HFD}),$$

where all variables were defined before except h, which is the carcass merit premium for leaner hogs as a share of the initial price of hogs (i.e., $h = \eta_T \cdot g/\lambda$).

Parameter Values for the Model

This section discusses the procedures used to obtain estimates of parameters in the model presented above. Ranges for the parameter values used in the model are reported in table 1.

Elasticities of Demand

Domestic demand for pork was modeled as part of a complete demand system consisting of pork, beef, poultry, and all other goods. This allows derivation of a price elasticity of total demand response for pork, which requires estimates of cross-elasticities of demand for pork with respect to prices of other meats and cross-elasticities of demand for other meats with respect to the price of pork (Buse). The functional form used is the Rotterdam model (Barten), in which budget-share-weighted changes in logarithms of per capita quantities are linearly related to changes in logarithms of real (CPI-deflated) meat prices and real per capita total consumption expenditures. Sample mean own-price and cross-price elasticities of demand for meats estimated with the Rotterdam model over the time period 1956–83 are reported in table 2. These elasticity values are very similar to those estimated by Huang in the context of a complete demand system of disaggregated food commodities and by Eales and Unnevehr in the context of a five-commodity model for meats.

The own-price elasticity of demand for pork of −0.8 measures the responsiveness of the demand for pork to changes in the price of pork when the prices of other meats are held constant. When the supplies of beef and poultry are taken as perfectly inelastic, this elasticity declines to −0.7. This may be viewed as a lower bound estimate of the total demand response elasticity for pork because this estimate shows the maximum possible change in prices of beef and poultry when their supply curves are perfectly inelastic.

The range of −0.7 to −0.8 for the total demand response elasticity for pork assumes that the price of pork imports moves proportionately with the price of domestically produced pork. If PST is available only to U.S. producers, however, then these elasticities are biased downward because they do not take into account substitution from imports to domestically produced pork resulting from a decrease in the relative price of domestic pork. For this reason, Armington's framework is used to compute an elasticity of demand for

Table 2. Own-Price and Cross-Price Demand Elasticities for Pork, Beef, and Poultry

	Elasticity with Respect to Retail Price of		
Commodity	Pork	Beef	Poultry
Pork	−0.80	0.22	0.10
Beef	0.13	−0.63	0.08
Poultry	0.21	0.30	−0.56

Note: Demand elasticities reported in this table are mean own-price and cross-price elasticities derived from econometric estimation, by method of restricted seemingly unrelated regressions (symmetry and homogeneity imposed), of the absolute price version of the Rotterdam model over the period 1955–83.

[2] The formula used to compute the change in producers' surplus, (20), is equivalent to that derived by Alston and Scobie (p. 355). Also, this formula shows net benefits to producers because it aggregates over adopters and nonadopters. The formula for the change in consumers' surplus, (21), can be shown to be identical to the formula used by Unnevehr in the case of a parallel shift in the demand curve.

pork holding the price of pork imports constant. Using the estimated own-price elasticity of demand for all pork of −0.8 and an estimated elasticity of substitution between imported and domestic pork of 2.5 results in an upper bound estimate for η of −0.9.[3]

The United States also exports pork products, presumably of a different type and/or quality than those imported. No estimates are available for this elasticity, although U.S.-produced pork likely competes closely with pork produced in other countries. We assume a value for the export demand elasticity of −3.0. Because pork exports account for only about 1.4% of total U.S. pork production, the simulation results reported below are insensitive to the specific value assumed for this parameter, including whether or not foreign consumers buy PST-treated pork.

The elasticity of substitution between the raw product (hogs) and the bundle of marketing inputs, is assumed to be either 0.0 or 0.2. The lower bound estimate of 0.0 reflects the one extreme of fixed input proportions. The value of 0.2 is a geometric mean of estimates obtained by regressing the ratio of farm to retail quantity on the ratio of retail price to net farm value with a linear time trend, and vice versa. These regression results are shown in table 3. Multiplying the two extreme-bound estimates of the elasticity of substitution by a negative of the cost share of marketing inputs in pork production (−0.48) yields the extreme-bound estimates for η_{HF} of 0.0 and −0.1 (table 1).

Elasticities of Supply

The price elasticity of supply of market hogs depends on the length of time producers take to respond to a given price change. For this reason, a dynamic specification was employed to generate supply elasticities for different lengths of runs. The model is similar in structure to that used by Freebairn and Rausser. Two equations were used to estimate price elasticities of U.S. hog supply: hog production as a function of lagged hog price, lagged ration cost, lagged number of sows farrowing, and number of pigs per litter; and change in the number of sows farrowing as a function of lagged hog price and lagged ration cost. Following the recommendation of Veloce and Zellner, these equations were estimated on a per farm basis. This specification resulted in larger and more plausible supply elasticity estimates. These results are reported in table 4.

Supply elasticities for different lengths of run were calculated by lagging the inventory equation one time period, substituting this equation into the production equation, and combining lagged hog prices for different time periods. Supply elasticities for one year (short run), five years (intermediate period), and long run are shown in table 1. Note that this model implies a perfectly elastic supply curve in the long run, which seems plausible given that hog production requires such little land.[4]

[3] The formula used to estimate the elasticity of demand for domestically produced pork is

$$\eta_d = k_d \cdot \eta - (1 - k_d) \cdot \sigma,$$

where η_d is the price elasticity of demand for domestic pork (holding price of imports constant), k_d is the quantity share of domestically produced pork consumed, η is the price elasticity of demand for all pork consumed in the U.S., and σ is the elasticity of substitution between domestically produced pork and pork imports. Values of the parameters are $\sigma = 2.5$, $k_d = .938$, and $\eta = -0.8$, implying $\eta_d = -0.9$. The value for σ was obtained by regressing the ratio of domestic consumption to imports on the ratio of imported to domestic pork prices.

[4] A referee expressed concern about the stability of the supply model. The supply model has an infinite, nonconvergent distributed lag,

Table 3. Econometric Estimates for Elasticity of Substitution between Hogs and Marketing Inputs, 1959–83

Dependent Variable	Explanatory Variables					
	Intercept	$\ln(P_{RP}/P_{FH})$	$\ln(Q_{FH}/Q_{RP})$	T	R^2	DW
$\ln(Q_{FH}/Q_{RP})$	0.193 (0.210)	0.086 (0.033)		−0.008 (0.0004)	0.95	0.53
$\ln(P_{RP}/P_{FH})$	−0.097 (0.271)		2.87 (1.094)	0.025 (0.009)	0.29	1.82

Note: Q_{FH} is U.S. hog slaughter, mil. lb. (USDA, *Livestock and Meat Statistics*), Q_{RP} is U.S. pork production, carcass lb. (USDA, *Livestock and Meat Statistics*), P_{RP} is average retail price of pork, ¢/lb. (USDA, *Livestock and Poultry Outlook and Situation Report*), and P_{FH} is the net farm value of pork, ¢/lb. (USDA, *Livestock and Poultry Outlook and Situation Report*). Values in parentheses are standard errors. Equations estimated by OLS.

Table 4. Econometric Estimates of U.S. Hog Production and Inventory of Farrowing Sows, 1970–83

Dependent Variable	Explanatory Variables						
	Intercept	P_{FH-1}	P_{F-1}	I_{S-1}	PL	R^2	DW
Q_{FHS}	−45.954	0.225	−1.395	1.084	6.249	0.97	2.30
	(7.905)	(0.045)	(0.544)	(0.129)	(2.558)		
ΔI_S	0.201	0.253	−2.160			0.65	2.62
	(1.009)	(0.052)	(0.468)				

Note: Q_{FHS} is U.S. hog production per farm, P_{FH-1} is the one-year lagged price of barrows and gilts in seven markets ($/cwt.), P_{F-1} is the one-year lagged price of feed ration, 14% CP ration ($/bu.), I_S is the end-of-the-year inventory of sows farrowing per farm, and PL is the number of pigs per litter. Price and quantity data come from USDA, *Livestock and Meat Statistics*. Pigs per litter and number of hog farms obtained from USDA, *Hogs and Pigs*. Prices deflated by CPI.

The import supply elasticity of hogs is derived from the excess supply function of hogs from Canada. This elasticity is computed as

$$\xi_M = \xi^*/k_q - \lambda^*/k_c,$$

where ξ^* and λ^* are Canada's domestic supply and demand elasticities for hogs; and where k_q and k_c are Canada's hog exports (to the U.S.) as a share of domestic production and consumption, respectively. Canada's export shares of production and consumption are about 5.6% and 6.9%, respectively. Assuming Canada has the same domestic demand and supply structure as the United States, derived demand and supply elasticity estimates generated for the United States are used to compute import supply elasticities of hogs from Canada. These elasticities have been calculated for both high (when $\eta = -0.9$ and $\eta_{HF} = -0.1$) and low (when $\eta = -0.7$ and $\eta_{HF} = 0.0$) values of the derived demand elasticity. As with the domestic supply elasticity, the two extreme-bound estimates of the import supply elasticity are listed in table 1 for the different lengths of run.

$$Q_t^s = 0.225P_{t-1} + 0.274(P_{t-2} + P_{t-3} + \ldots),$$

which implies a perfectly elastic long-run supply curve. This seems reasonable in the case of U.S. hog production and is consistent with previous findings by Freebairn and Rausser. The relevant question with regard to stability is whether price converges in a stable manner to long-run equilibrium. To see that the system is indeed stable, the demand function (when the derived demand elasticity is −0.6) can be written as

$$Q_t^d = -0.338P_t.$$

Imposing the equilibrium condition, $Q_t^s = Q_t^d$, and solving for P_t yields

$$P_t = -0.666P_{t-1} - 0.811(1 - L)^{-1}P_{t-2},$$

where L is the lag operator. This equation can be reduced to the second-order difference equation,

$$P_t + 0.334P_{t-1} + 0.145P_{t-2} = 0,$$

which is stable because it satisfies the conditions $C^2 < 1$ and $b^2 < (1 + C)^2$ for the quadratic equation $X^2 + bX + C = 0$ (Baumol, pp. 246–48). The second-order difference equation when the derived demand elasticity is −0.4 can also be shown to generate a stable solution.

Shifts in Supply and Demand

Boyd et al. summarized several studies involving supplemental use of PST. They found improvements in feed efficiency ranging from 13% to 29% and improvements in average daily gain ranging from 16% to 28%. For the present study, PST is assumed to increase feed efficiency by 24% (from a base of 3.87) and increase average daily gain by 15% (from a base of 1.70). Holding the number of days on feed constant at fifty-nine days results in a 15-pound increase in the market weight of a PST-treated pig. The control pig gains 100 pounds and consumes 387 pounds of feed, while the PST pig consumes 338 pounds of feed. The base feed ration is assumed to be 14% crude protein, implying consumption of 317 pounds of corn and 70 pounds of supplement. The PST pig is fed with a 16% ration, implying 261.6 pounds of corn and 76.4 pounds of supplement. Assuming cost shares for corn and supplement of 0.54 and 0.46, these data indicate approximately a 5.2% reduction in feed intake, adjusted for changes in the composition of the ration. Multiplying this number by 0.5, to reflect the approximate proportion of feed costs in the finishing stage, yields an estimate of θ^*, the adjusted biased technical change parameter, of 2.6%.

For a 240-pound market hog, 15 pounds of weight gain through injection with supplemental PST implies an increase in production of 6.3%. Thus, δ = 6.3%. Injection costs are assumed to equal $6.57 per pig, the sum of $6.00 for daily injections of PST and labor costs of $0.57 per pig (Lemieux and Richardson). With a market hog selling for $52 per hundredweight (approximately the average for 1987), injection costs as a share of the value of a market hog are 5.3%. Using the parameter values for technical change of $\theta^* = 2.6\%$ and $\delta = 6.3\%$, the short-run elasticity of supply of 0.4, and the short-run elasticity of marginal cost of 0.75, the net percentage change in marginal cost from equation (5) is

$$(22)\quad k = (-(1 + 2.5)(6.3) - (0.75)(2.6) + 5.3) \cdot \alpha = -19 \cdot \alpha,$$

where α is the adoption rate corresponding to the given length of run. As claimed above, the effect of an increase in weight gain, the first component of (22), dominates the effect of feed savings.

Boyd et al. indicate that PST will increase the amount of lean pork by at least 10%. A value for the increase in consumer demand for leaner pork due to introduction of PST was derived from the value of mean consumers' willingness to pay for 10% leaner pork estimated from market survey data (Lemieux and Wohlgenant). Mean willingness to pay expressed as a percentage of the initial price of pork was estimated to be 4.3%. This suggests an estimate of g of $4.3 \cdot \alpha$. (This percentage is multiplied by the adoption rate to reflect the proportion of the pork supply affected by PST in each length of run.) This suggests values for h (percentage carcass merit premium) ranging from 6.5% (when $\eta = -0.9$ and $\lambda = -0.6$) to 7.5% (when $\eta = -0.7$ and $\lambda = -0.4$).

Adoption rates of PST are the most elusive parameters because they are endogenous, depending on the profitability of the new technology. Two sets of estimates are used in the simulation of the impact of PST. The first set of adoption rates were based on estimates made by Annexstad and the U.S. Congressional Office of Technology Assessment for similar types of technologies. These studies suggest an initial adoption rate of about 0.1 and a ceiling adoption rate at the end of five years of about 0.6. Using the logistics growth function, values were interpolated for intervening years of 0.22, 0.39, and 0.53. For comparison, simulation results are also presented for the case assuming full adoption ($\alpha = 1$) for all lengths of run.

Results

Changes in prices and quantities in the hog industry were estimated for three different lengths of run: short run (1-year adjustment), intermediate run (5-year adjustment), and long run (when the supply elasticity of hogs is infinite). For each length of run, equation (18) is used to estimate the effect on hog prices from shifts in supply and/or demand through introduction of PST. The price elasticity of derived demand for hogs, equation (15), for each time period is either -0.4 (when $\eta = -0.7$, $\eta_{HF} = 0.0$) or -0.6 (when $\eta = -0.9$, $\eta_{HF} = -0.096$). This is in the range of estimates obtained by Wohlgenant through direct estimation of a partially reduced-form derived demand equation for hogs. Given estimated changes in the price of hogs for each year, changes in quantities, other prices, and economic surplus measures for each year are calculated through use of equations (6)–(13) and equations (20)–(21). Parameter values used in the simulations are reported in table 1. For each set of adoption rates assumed (60% ceiling and full adoption), both pessimistic (lower-bound derived demand elasticity and no demand shift) and optimistic (upper-bound derived demand elasticity and demand shift) results are generated.

Effects of the introduction of PST on the various prices and quantities for the four simulations are shown in table 5. Unconstrained estimates of the impact of PST on hog imports, equation (12), frequently declined by less than 100%. In these cases, imports were restricted to fall by 100% by replacing equation (12) with this restriction. The effects all have the expected signs: hog and pork prices fall, domestic quantities of hogs and pork rise, pork exports rise and hog imports fall. The absolute magnitudes of the effects show a tendency to rise over time, as expected. Overall, price and quantity changes appear quite sensitive to adoption rates and length of time for adjustment. To a lesser extent, the relative magnitudes of the changes are also affected by differences in the derived demand elasticity for hogs and whether demand for pork shifts in response to the impact of PST. Hog imports, without spillover of PST technology into Canada, fall dramatically in all lengths of run. Recall that substitution away from pork imports to domestic pork consumption is reflected in the upper-bound estimate of the derived demand elasticity for hogs.

The expected impact of PST on producers' and consumers' surplus is shown in table 6. As

Table 5. Expected Percentage Changes in Prices and Quantities of Pork from Introduction of PST

Variable	Length of Run	60% Ceiling Adoption		Full Adoption	
		Pessimistic	Optimistic	Pessimistic	Optimistic
Hog price (P_{HF})	SR	−1.8	−0.5	−8.4	−2.6
	IR	−8.9	−7.1	−15.0	−12.0
	LR	−11.0	−11.0	−19.0	−19.0
U.S. hog production (Q_{HFS})	SR	0.9	1.3	4.2	6.6
	IR	4.4	7.6	6.9	12.2
	LR	5.4	10.1	8.3	16.2
Hog Imports (Q_{IMS})	SR	−23.0	−31.0	−100.0	−100.0
	IR	−100.0	−100.0	−100.0	−100.0
	LR	−100.0	−100.0	−100.0	−100.0
U.S. hog slaughter (Q_{HF})	SR	0.7	1.0	3.2	5.5
	IR	3.4	6.5	5.8	11.0
	LR	4.3	9.0	7.2	15.0
Retail price (P_{PR})	SR	−0.9	−0.3	−4.4	−1.3
	IR	−4.6	−3.7	−7.9	−6.4
	LR	−5.9	−5.9	−9.9	−9.9
U.S. pork consumption (Q_{PRD})	SR	0.7	1.1	3.2	5.2
	IR	3.4	5.9	5.8	9.9
	LR	4.1	7.6	6.9	13.0
Pork exports (Q_{EXD})	SR	2.9	3.6	13.0	17.0
	IR	14.0	19.0	24.0	32.0
	LR	18.0	25.0	30.0	42.0

Note: SR denotes short run (1-year adjustment), IR denotes intermediate run (5-year adjustment), and LR denotes long run. Pessimistic results assume no increase in demand and the lower-bound derived demand elasticity of −0.4. Optimistic results assume an increase in demand of 4.3% (weighted by the adoption rate) and the upper-bound derived demand elasticity of −0.6.

Overall, these results suggest that the impact of PST on producers and consumers is likely to be quite significant—even for the intermediate adjustment period of five years. In 1987, the total value of hog production was about $10 billion. In the fifth year, net benefits to producers would range between $250 million and $720 million; net benefits to consumers would range between $900 million and $1.95 billion.[5] Of course, in the long run, when the supply curve of hogs becomes perfectly elastic, consumers receive the full benefits of the new technology. However, it would probably take a number of years before the rents to producers are dissipated.

The results in table 6 indicate that benefits both to producers and consumers are quite sensitive to different adoption rates, length of time for adjustment, and whether demand for pork increases in response to introduction of PST. While aggregate benefits to producers are larger with full adoption than with partial adoption of the technology, the typical producer who adopts will receive more benefits than when all producers adopt. For example, in year 5 a typical producer could increase its per unit profit between 10.1% (19% cost decrease less 8.9% price decrease, table 5) and 11.9% (19% cost decrease less 7.1% price decrease) if only 60% of the industry adopts PST. This compares with increases in per unit profits when all firms adopt between 4% (19%–15%) and 7% (19%–12%). Even in this extreme case of full adoption after five years, individual producers have the potential to earn significant returns. With a 240-pound market hog selling for $50 per hundredweight, returns per pig would increase between about $4.80 and $8.40, which is a return on investment for the assumed injection cost per pig of $6.57 of between 70% and 128%.

The final set of simulations assumed full spillovers of the PST into Canada. These simulations were performed through deleting the term $\eta_T \cdot g/\lambda$ from equation (12), and adding $-\xi \cdot k/0.056$ and $\eta_T \cdot g/0.069$ to the equation to account for the impact of PST on production and demand shifts, respectively. (Recall

[5] These estimates of net benefits to producers and consumers are undiscounted. These values should be discounted when technology adoption is viewed from the initial time period. For example, if the real interest rate is 4%, then the discount factor for year 5 would be 0.85. Discounted net benefits to producers in year 5 would then range between $212.5 million and $612 million; discounted net benefits to consumers in year 5 would range between $765 million and $1.66 billion.

Table 6. Expected Changes in Producers' and Consumers' Surplus (as a Percentage of Total Value of Hog Production) from Introduction of PST

Surplus Change	Length of Run	60% Ceiling Adoption		Full Adoption	
		Pessimistic	Optimistic	Pessimistic	Optimistic
Producers'	SR	2.4	4.4	10.8	16.9
	IR	2.5	4.4	3.9	7.2
	LR	0.0	0.0	0.0	0.0
Consumers'	SR	1.8	1.3	8.5	9.7
	IR	9.0	11.5	15.3	19.5
	LR	11.6	16.2	19.7	27.8

Note: See table 5.

that 0.056 and 0.069 are Canada's export share of production and consumption, respectively.) The results of these simulations were virtually the same as those reported in tables 5 and 6, except that hog imports would be expected to rise rather than decline as indicated previously. Under this alternative, hog imports would rise as much as 34%. U.S. hog prices and quantities would likely not be affected significantly with technology spillovers into Canada because hog imports, even at their peak, accounted for only 1% or less of the total supply of hogs slaughtered in the United States. With a countervailing duty on hog imports from Canada currently in place, the effects of adoption of PST by Canadian producers on U.S. imports and hog prices would be expected to be even smaller.

Conclusions

In this paper, a conceptual and empirical framework for quantifying *ex ante* effects of agricultural biotechnology on industry prices, quantities, and economic surplus measures was presented. The modeling approach is quite flexible in that extreme-bound estimates of the important parameters can be incorporated into the model to check the sensitivity of the simulation results. The approach is also flexible in its ability to account for market interrelationships between the raw material and final product, interrelationships between the domestic and international markets, lagged adoption and supply response of producers, and changes in product quality induced through introduction of the technology. Application of the framework to analysis of the impact of the pork growth hormone, porcine somatotropin (PST), demonstrates the flexibility of the modeling approach in capturing the essential characteristics of the economic impact of such a technology.

Another contribution of this paper has been to demonstrate how experimental data can be quantified as a production function shift. Furthermore, it shows how the production function shift parameters can be used to estimate decreases in cost due to a new technology. This fills a significant gap in the literature on *ex ante* returns to research.

With respect to the economic impact of PST on the hog and pork industries, significant effects can be expected on prices, quantities, and benefits to producers and consumers. Expected benefits to producers appear particularly sensitive to lagged adjustment of producers (through both adoption rates and lagged supply response) and changes in product quality through introduction of PST. Still, substantial benefits can be expected to accrue to producers over a number of time periods using the most conservative estimates of the impact.

[*Received January 1988; final revision received February 1989.*]

References

Alston, J. M., and G. M. Scobie. "Distribution of Research Gains in Multistage Production Systems: Comment." *Amer. J. Agr. Econ.* 65(1983):353–56.

Annexstad, J. "Survey Says You'll Use Somatotropin, Have Concerns." *Dairy Herd Manage.* Oct. 1986, pp. 12–15.

Armington, P. S. "A Theory of Demand for Products Distinguished by Place of Production." *IMF Staff Pap.* 16(1969):159–78.

Barten, A. P. "The Systems of Consumer Demand Functions Approach: A Review." *Econometrica* 45 (1977):23–51.

Baumol, E. J. *Economic Dynamics*. New York: Macmillan Co., 1970.

Binswanger, H. P. "The Measurement of Technical Change Biases with Many Factors of Production." *Amer. Econ. Rev.* 64(1974):964–76.

Blackorby, C., C. A. Lovell, and M. C. Thursby. "Extended Hicks Neutral Technical Change." *Econ. J.* 86(1976):845–52.

Boyd, R. D., M. Harkins, D. E. Bauman, and W. R. Butler. "Impact of Somatotropin on Growth Performance and Carcass Composition of Growing Swine." Minnesota Nutrition Conference, Bloomington MN, Sep. 1987, pp. 161–72.

Buse, R. C. "Total Elasticities: A Predictive Device." *J. Farm Econ.* 40(1958):881–91.

Eales, J. S., and L. J. Unnevehr. "Demand for Beef and Chicken Products: Separability and Structural Change." *Amer. J. Agr. Econ.* 70(1988):521–32.

Fallert, R., T. McGuckin, C. Betts, and G. Bruner. *BST and the Dairy Industry*. Washington DC: U.S. Department of Agriculture, Agr. Econ. Rep. No. 579, Oct. 1987.

Freebairn, J. W., and G. C. Rausser. "Effects of Changes in the Level of U.S. Beef Imports." *Amer. J. Agr. Econ.* 57(1975):676–88.

Huang, K. *U.S. Demand for Food: A Complete System of Price and Income Effects*. Washington DC: U.S. Department of Agriculture Tech. Bull. No. 1714, Dec. 1985.

Hueth, D. L., and R. E. Just. "Policy Implications of Agricultural Biotechnology." *Amer. J. Agr. Econ.* 69(1987):426–31.

Just, R. E., D. L. Hueth, and A. Schmitz. *Applied Welfare Economics*. Englewood Cliffs NJ: Prentice-Hall, 1982.

Kalter, R. J., R. Milligan, W. Lesser, W. Magrath, L. Tauer, and D. Bauman. *Biotechnology and the Dairy Industry: Production Costs, Commercial Potential, and the Economic Impact of the Bovine Growth Hormone*. Dep. Agr. Econ. A. E. Res. 85-20, Cornell University, Dec. 1985.

Kalter, R. J., and L. W. Tauer. "Potential Economic Impacts of Agricultural Biotechnology." *Amer. J. Agr. Econ.* 69(1987):420–25.

Lemieux, C. M., and J. R. Richardson. "Economic Impacts of Porcine Somatotropin on Midwest Hog Farmers." *N. Cent. J. Agr. Econ.*, in press.

Lemieux, C. M., and M. K. Wohlgenant. "Consumer Acceptance and Demand for Lean Pork." Symposium presented at AAEA annual meeting, Knoxville TN, Aug. 1988.

Lindner, R. K., and F. G. Jarrett. "Supply Shifts and the Size of Research Benefits." *Amer. J. Agr. Econ.* 60(1978):48–56.

———. "Supply Shifts and the Size of Research Benefits: Reply." *Amer. J. Agr. Econ.* 62(1980):841–44.

Meltzer, M. I., and R. J. Kalter. "Porcine Growth Hormone: Implications for Hog Producers and the Swine Industry." Selected paper presented at AAEA annual meeting, East Lansing MI, Aug. 1987.

Mullen, J. D., M. K. Wohlgenant, and D. E. Farris. "Input Substitution and the Distribution of Surplus Gains from Lower U.S. Beef Processing Costs." *Amer. J. Agr. Econ.* 70(1988):245–54.

Muth, R. F. "The Derived Demand Curve for a Productive Factor and the Industry Supply Curve." *Oxford Econ. Pap.* 16(1964):221–34.

Norton, G. W., and J. S. Davis. "Evaluating Returns to Agricultural Research: A Review." *Amer. J. Agr. Econ.* 63(1981):685–99.

Rose, R. "Supply Shifts and Research Benefits: Comment." *Amer. J. Agr. Econ.* 62(1980):834–37.

Stallman, J. I., and A. A. Schmid. "Property Rights in Plants: Implications for Biotechnology Research and Extension." *Amer. J. Agr. Econ.* 69(1987):432–37.

Unnevehr, L. J. "Consumer Demand for Rice Grain Quality and Returns to Research for Quality Improvement in Southeast Asia." *Amer. J. Agr. Econ.* 68(1986):634–41.

U.S. Department of Agriculture. *Agricultural Outlook*. Washington DC, Oct. 1987.

———. *Hogs and Pigs*. Washington DC, various issues.

———. *Livestock and Meat Statistics*. Washington DC, various issues.

———. *Livestock and Poultry Outlook and Situation Report*. Washington DC, various issues.

U.S. Congress, Office of Technology Assessment. *Technology, Public Policy, and the Changing Structure of American Agriculture*. OTA-F-285, Washington DC, 1986.

Van Arsdall, R. N., and K. E. Nelson. *Economies of Size in Hog Production*. Washington DC: U.S. Department of Agriculture Tech. Bull. No. 1712, 1985.

Veloce, W., and A. Zellner. "Entry and Empirical Demand and Supply Analysis for Competitive Industries." *J. Econometrics* 30(1985):459–71.

Wohlgenant, M. K. "Demand for Farm Output in a Complete System of Demand Functions." *Amer. J. Agr. Econ.* 71(1989):241–52.

Wohlgenant, M. K., and C. M. Lemieux. "Effects of Introduction of Porcine Somatotropin on the U.S. Pork Industry." Symposium presented at AAEA annual meeting, Knoxville TN, Aug. 1988.