# Integration of Agriculture and Technological Change

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Market structure has implications for research policies. The public sector reduced its support
for technological change for poultry relative to beef and pork after poultry became integrated.
However, market integration causes private sector research to be below the optimal level from
society's perspective. In order to get the appropriate response from the private sector, the
public sector should not reduce its support for technological change after market integration.
Instead, the public sector should increase its support for research such as basic science that
complements private sector research.

Current trends affecting the structure of agriculture include increasing consolidation of farms and vertical integration among the market stages. Farm numbers declined by 30,000 per year during the mid-1980's, continuing the trend towards fewer and larger farms. Increased vertical coordination results from processors contracting with producers and operating production facilities in order to better meet the demands of discriminating consumers (Council on Food, Agricultural, and Resource Economics). With the increased use of purchased inputs such as pesticides by farmers and increased processing of food products, the agribusiness share of the consumers' food dollar has increased, while the farm share has declined. Smith estimated that the share of agricultural sales contributed by farming dropped from 21 to 5 percent during this century. The process of farm consolidation, vertical coordination, and expansion of agribusiness contributions relative to those of farming can be described as the industrialization of agriculture. This process of industrialization has implications for technological change.

First, the relative importance of public and private research will likely change as a result of the industrialization of agriculture. Public research has traditionally emphasized farm production in which the benefits from the research are widely dispersed and not easily captured by those conducting the research. Benefits from public agricultural research such as abundant supplies and lower prices have accrued largely to society as a whole rather than to individual farmers. As the relative impor-

tance of farming in the overall agricultural sector declines, the share of public sector research may continue to decline. Public and private sector expenditures for agricultural research were both at about the same level in 1950, but private sector expenditures have grown much more rapidly than public sector expenditures since then (Huffman and Evenson). In 1990 private sector expenditures for agricultural research were almost double public sector expenditures. With the industrialization of agriculture, the private sector will play a greater role in funding agricultural research.

Secondly, the industrialization of agriculture will change the research mix. The public sector spends more than the private sector in crop breeding and management and in nutrition and livestock (Pray and Neumeyer). The private sector spends more than the public sector on mechanization, chemicals, and post harvest research. Developments in biotechnology have increased incentives for the private sector to conduct research related to production agriculture. The environment for private sector research has also improved as a result of greater protection for intellectual property rights (Centner and White). The private sector can now capture many of the benefits of improved plant and animal varieties, which has spurred private sector investments in these areas. Huffman and Evenson believe that, in the future, the role of the private sector in research will continue to broaden while the public sector will concentrate on pilot inventions and pre-technology science that facilitate and enhance private sector research.

The objective of this paper is to examine how the integration of agriculture affects the magnitude of public sector and private sector research. First, a case study of livestock and poultry research is examined. Poultry is already integrated and pork

production is rapidly becoming integrated. Poultry experienced a reduction in public support for research relative to beef and pork as it became integrated. Secondly, a market model is developed to explain the economics of technological change. The decision making processes for both the public sector and private sector are examined. Application of the comparative statics model shows the impact of market integration on technological change for the public and private sectors.

## Livestock and Poultry Research

This section examines the impact of integration in poultry on research expenditures in the public sector. Poultry production is already controlled by a few large contractors with no independent access to the market by small or medium growers (USDA, *A Time to Choose: Summary Report on the Structure of Agriculture*). Livestock production is moving more rapidly toward industrialization than grains (Council on Food, Agricultural, and Resource Economics). In particular, hog production is shifting to fewer and larger farms with closer ties to pork processors (Barkema and Cook).

Significant economies of size in selling and processing poultry led to high concentration at the first-handler level (USDA, *A Time to Choose: Summary Report on the Structure of Agriculture*). In turn, processors of poultry increased coordination through contracts and integration. Broilers are produced under contracts, while turkey production has been integrated. Feed suppliers integrated forward into production and processing in order to fully utilize their production capacity. Thus poultry has been industrialized.

An examination of research funding trends for poultry and livestock shows how the public sector has responded to changes in market structure. Cash receipts and research expenditures for beef, pork and poultry are reported in Table 1. Cash receipts and research expenditures reported here were deflated using the GNP implicit price deflator with a 1984 base. The research intensity variable in this table is the ratio of research expenditures to cash receipts converted to a percentage term. Poultry had the highest research intensity in 1969, but between 1969 and 1991, a period in which poultry became fully integrated, there was little change in poultry's research intensity. While poultry's research intensity increased only 39%, research intensity doubled for beef and tripled for pork.

During the 1969–91 period, the real value of cash receipts dropped more for beef and pork than for poultry. However the real value of research expenditures for the same period increased much more for beef and pork than for poultry. Research expenditures in 1991 were 28% higher for poultry, 79% higher for beef, and 103% higher for pork than 1969 levels. The public sector's commitment to research in poultry as an integrated industry appears to have fallen in a relative sense as compared to beef and pork, which were not integrated during this period.

## Analytical Framework

This section of the paper develops an analytical framework for optimal technological change as financed by the public and private sectors. First, a comparative statics model of an agricultural product is developed. The production process includes production inputs and manufacturing inputs. Technological change can occur in both production and

**Table 1.  Comparison of Public Research Expenditures for Livestock and Poultry[a]**

| Categories | Units | Beef | Pork | Poultry |
|---|---|---|---|---|
| 1969 | | | | |
| Research Expenditures[b] | Mil$ | 77.4 | 34.5 | 54.7 |
| Cash Receipts[c] | Bil$ | 34.0 | 12.8 | 11.8 |
| Research Intensity | % | .22 | .26 | .46 |
| 1991 | | | | |
| Research Expenditures[d] | Mil$ | 138.8 | 69.9 | 70.0 |
| Cash Receipts[c] | Bil$ | 30.8 | 8.6 | 10.9 |
| Research Intensity | % | .45 | .81 | .64 |
| 1969–91 Growth | | | | |
| Research Expenditures | % | 79.3 | 102.6 | 28.0 |
| Cash Receipts | % | −9.4 | −32.8 | −7.6 |

[a]Constant dollars using GNP implicit price deflator (1984 = 100)
[b]Source: Huffman and Evenson
[c]Source: USDA, ERS, *Economic Indicators of the Farm Sector*
[d]Source: USDA, CSRS, *Inventory of Agricultural Research*

manufacturing. It is assumed that the public sector finances technological change in production and the private sector finances technological change in manufacturing. Secondly, changes in economic surpluses resulting from technological change are quantified. Thirdly, the optimal levels of technological change financed by the public and private sectors are derived.

### Competitive Equilibrium

A comparative statics model of a competitive market for one product and two inputs is developed. This framework follows Diewert's work, which gave explicit consideration to factor markets and production technology. Within this framework it is possible to measure the impacts of technological change. Mullen, Wohlgenant, and Farris applied a related model to the U.S. beef market.

Livestock and manufacturing inputs are combined to produce fresh and processed meat. A general representation of this production process is given by

$$(1) \qquad q = f(x_1, x_2)$$

where $q$ is the final meat product, $x_1$ is the livestock input, and $x_2$ is the manufacturing input. The industry cost function related to this production function can be represented as

$$(2) \qquad C = H(w_1, w_2)q$$

where $C$ is total cost, $w_1$ is the input price for livestock and $w_2$ is the input price for manufacturing inputs. By assuming constant returns to scale, the cost function is separable between input prices and output.

Each livestock market can be described by a system of equations depicting supply and demand relationships:

| | | |
|---|---|---|
| (3) | $q = q(p)$ | Product Demand |
| (4) | $p = H(w_1, w_2)$ | Price Equals Marginal Cost |
| (5) | $x_1 = h_1(w_1, w_2)q$ | Factor Demand |
| (6) | $x_2 = h_2(w_1, w_2)q$ | Factor Demand |
| (7) | $w_1 = w_1(x_1, T_1)$ | Inverse Factor Supply |
| (8) | $w_2 = w_2(x_2, T_2)$ | Inverse Factor Supply |

where $p$ is the retail price of meat. Equation (3) represents retail demand for meat. Equilibrium conditions are specified in equation (4) by equating price and marginal cost. Equations (5) and (6) are output constrained input demand functions, which can be derived by applying Shephard's lemma so $h_1(w_1, w_2) = \partial H / \partial w_1$ and $h_2(w_1, w_2) = \partial H / \partial w_2$. Inverse supply equations for livestock and manu-

facturing inputs are shown by equations (7) and (8), respectively. New technology that reduces the cost of the input is given by $T_1$ for livestock and $T_2$ for manufactured inputs.

Totally differentiating the system of equations (3) through (8) and converting to elasticities shows how technological change affects the industry equilibrium:

$$(9) \quad \hat{q} = \eta \hat{p}$$
$$(10) \quad \hat{p} = k_1 \hat{w}_1 + k_2 \hat{w}_2$$
$$(11) \quad \hat{x}_1 = -k_2 \sigma \hat{w}_1 + k_2 \sigma \hat{w}_2 + \hat{q}$$
$$(12) \quad \hat{x}_2 = k_1 \sigma \hat{w}_1 - k_1 \sigma \hat{w}_2 + \hat{q}$$
$$(13) \quad \hat{w}_1 = (1/\epsilon_1)\hat{x}_1 + \gamma_1$$
$$(14) \quad \hat{w}_2 = (1/\epsilon_2)\hat{x}_2 + \gamma_2$$

where $\hat{}$ over a variable indicates relative change ($\hat{a} = d \log a = da/a$), $\eta$ is the own price elasticity of demand, $k_i$ is the input share of total cost ($k_1$ is livestock production as a share of total cost and $k_2$ is manufacturing as a share of total cost), $\sigma$ is the elasticity of substitution between the two inputs, $\epsilon_i$ is the input supply elasticity, and $\gamma_i$ is the relative price change resulting from technological change. The shift in the supply of inputs ($\gamma_i$) is proportional to a shift in input demand resulting form biased technical change (Mullen, Wohlgenant, and Farris).

The system of equations (9) through (14) can be solved by forming the Jacobian matrix, which is the matrix of partial derivatives of the endogenous variables. Analytically inverting the Jacobian matrix and post multiplying it by the vector of exogenous shifters $(0 0 0 0 \gamma_1 \gamma_2)'$ yields the following solutions.

$$(15) \quad \begin{aligned} \hat{q} &= \bar{q}_1 \gamma_1 + \bar{q}_2 \gamma_2 \\ &= [-\eta k_1(\epsilon_2 + \sigma)\epsilon_1/D]\gamma_1 + [-\eta k_2(\epsilon_1 \\ &\quad + \sigma)\epsilon_2/D]\gamma_2 \end{aligned}$$

$$(16) \quad \begin{aligned} \hat{p} &= \bar{p}_1 \gamma_1 + \bar{p}_2 \gamma_2 \\ &= [-k_1(\epsilon_2 + \sigma)\epsilon_1/D]\gamma_1 + [-k_2(\epsilon_1 \\ &\quad + \sigma)\epsilon_2/D]\gamma_2 \end{aligned}$$

$$(17) \quad \begin{aligned} \hat{x}_1 &= \bar{x}_{11}\gamma_1 + \bar{x}_{12}\gamma_2 \\ &\quad [(k_2\sigma\epsilon_2 - k_1\eta\epsilon_2 - \eta\sigma)\epsilon_1/D]\gamma_1 \\ &\quad + [-k_2(\sigma + \eta)\epsilon_1\epsilon_2/D]\gamma_2 \end{aligned}$$

$$(18) \quad \begin{aligned} \hat{x}_2 &= \bar{x}_{21}\gamma_1 + \bar{x}_{12}\gamma_2 \\ &= [-k_1(\sigma + \eta)\epsilon_1\epsilon_2/D]\gamma_1 + [k_1\sigma\epsilon_1 \\ &\quad - k_2\eta\epsilon_1 - \eta\sigma)\epsilon_2/D]\gamma_2 \end{aligned}$$

$$(19) \quad \begin{aligned} \hat{w}_1 &= \bar{w}_{11}\gamma_1 + \bar{w}_{12}\gamma_2 \\ &= [-(\epsilon_2 + k_1\sigma - k_2\eta)\epsilon_1/D]\gamma_1 \\ &\quad + [-k_2(\sigma + \eta)\epsilon_2/D]\gamma_2 \end{aligned}$$

$$(20) \quad \begin{aligned} \hat{w}_2 &= \bar{w}_{21}\gamma_1 + \bar{w}_{22}\gamma_2 \\ &= [-k_1(\sigma + \eta)\epsilon_1/D]\gamma_1 + [-(\epsilon_1 + \\ &\quad k_2\sigma - k_1\eta)\epsilon_2/D]\gamma_2 \end{aligned}$$

$$(21) \quad \begin{aligned} D &= -\epsilon_1\epsilon_2 - k_1\epsilon_1\sigma - k_2\epsilon_2\sigma + k_1\eta\epsilon_2 \\ &\quad + k_2\eta\epsilon_1 + \eta\sigma \end{aligned}$$

where the determinant of the Jacobian matrix is $D/\epsilon_1\epsilon_2$. The only reason to introduce $D$ is to simplify equations (15) through (20) where the same variables are repeated several times. The tilde ( ˜ ) over a variable indicates a derivative with respect to $\gamma_i$. For example, $\tilde{q}_1 = d\hat{q}/d\gamma_1$ and $\tilde{x}_{11} = d\hat{x}_1/d\gamma_1$. These derivatives, which are the bracketed terms before $\gamma_1$ and $\gamma_2$, will be used to simplify subsequent notation.

*Economic Surplus*

The distributional consequences of technological change will be addressed in this section. The change in consumer surplus is the area under the demand curve and between the two equilibrium prices, with and without technological change (Just, et al.). Lindner and Jarrett reported that the type of supply shift, which results from an innovation, would influence the magnitude of the benefit estimates. However, Rose argued that it would be virtually impossible to predict the type of supply shift that would result from a particular innovation. Rose concluded that the only realistic strategy is to assume the supply shift is parallel, which makes a minor adjustment for price response. The change in consumer surplus ($dCS$) is given by the following equation.

$$(22) \qquad dCS = pq(-\hat{p})(1 + \tfrac{1}{2}\hat{q})$$

The change in producer surplus for livestock producers ($dPS_1$) and manufacturing ($dPS_2$) are given by the following equations.[1]

$$(23)\ dPS_1 = w_1 x_1(\hat{w}_1 - \gamma_1)(1 + \tfrac{1}{2}\hat{x}_1)$$
$$(24)\ dPS_2 = w_2 x_2(\hat{w}_2 - \gamma_2)(1 + \tfrac{1}{2}\hat{x}_2)$$

Relative measures of economic surpluses can be calculated by dividing by market receipts, $pq$. For example $\hat{CS} = dCS/pq$ and $\hat{PS}_i = dPS_i/pq$.

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[1] In a linear model, producer surplus (*PS*) can be calculated as follows:

$$PS = \tfrac{1}{2}\ (\text{slope})\ x^2$$

where slope is the slope of the supply curve and x is the quantity of input used. The change in producer surplus from technological change can be calculated by subtracting the initial *PS* (without technological change) from the new *PS* (with technological change).

$$dPS = \tfrac{1}{2}\ \text{slope}\ [(x + dx)^2 - x^2]$$

For the comparative statics model used in this study, the expression for slope is as follows:

$$\text{slope} = (-\gamma w + dw)/dx$$

where w is input price and $\gamma$ is technological change. Substituting this definition of slope into the equation for dPS and simplifying yields:

$$dPS = -\gamma wx + xdw - \tfrac{1}{2}\ \gamma wdx + \tfrac{1}{2}\ dwdx.$$

Replace dw and dx with these relationships: $dw = \hat{w}w$ and $dx = \hat{x}x$. With these substitutions, this relationship for dPS can be re-written to conform to equations (23) and (24).

$$(22a)\ \hat{CS} = -\hat{p} + \tfrac{1}{2}\hat{p}\hat{q}$$
$$(23a)\ \hat{PS}_1 = k_1(\hat{w}_1 - \gamma_1 + \tfrac{1}{2}\hat{w}_1\hat{x}_1 - \tfrac{1}{2}\hat{x}_1\gamma_1)$$
$$(24a)\ \hat{PS}_2 = k_2(\hat{w}_2 - \gamma_2 + \tfrac{1}{2}\hat{w}_2\hat{x}_2 - \tfrac{1}{2}\hat{x}_2\gamma_2)$$

An expression for social welfare is formulated to determine optimal rates of technological change. This formulation of social welfare will allow for varying welfare weights for the economic surpluses. The welfare function with weights is adopted because public support of poultry research declined relative to beef and pork after poultry became integrated. This evidence indicates the possibility of lower welfare weights for agribusinesses relative to some other groups in the market.

A relative measure of social welfare resulting from technological change can be determined by summing economic surpluses and subtracting the costs of technological change.

$$(25) \qquad \hat{SW} = \hat{CS} + \theta_1\hat{PS}_1 + \theta_2\hat{PS}_2 \\ - \hat{C}_1(\gamma_1) - \theta_2\hat{C}_2(\gamma_2)$$

where $\hat{SW} = dSW/pq$ is a relative measure of social welfare, $\hat{C}_i$ is a relative measure of cost for technological change, and $\theta_i$ are the welfare weights, indicating the relative importance of each group in the public sector's decision-making process. The welfare weights for consumers and taxpayers are normalized at 1.0 for both groups. The welfare weight for livestock producers ($\theta_1$) can be varied depending upon the degree of market integration. The welfare weight for manufacturing ($\theta_2$) is applied to both the manufacturers' producer surplus, $\hat{PS}_2$, and the cost of technological change financed by the manufacturing sector, $\hat{C}_2(\gamma_2)$. To make the model of social welfare fully operational, a particular functional form has to be specified for the cost relationships for technological change. A quadratic functional form is assumed. The quadratic form indicates that the cost of technological change is increasing at an increasing rate, but marginal cost is a linear function of technological change, which will be convenient in subsequent analysis. The operational model of social welfare is given by the following relationship.

$$(25a) \qquad \hat{SW} = \hat{CS} + \theta_1\hat{PS}_1 + \theta_2\hat{PS}_2 - \\ c_1\gamma_1{}^2 - \theta_2 c_2\gamma_2{}^2$$

A relative measure for change in profits for manufacturing is determined by subtracting costs of technological change from the relative measure of producer surplus:

$$(26) \qquad \hat{\pi}_2 = \hat{PS}_2 - \hat{C}_2(\gamma_2)$$

where $\pi_2$ is d(profits)/pq, with no change in fixed

costs. Assuming a quadratic functional form for the cost of technological change, the relative change in manufacturing profits is given by the following equation.

$$(26a) \qquad \hat{\pi}_2 = \hat{P}S_2 - c_2\gamma_2^2$$

Equation (26a) can also be thought of as a measure of agribusiness profits without integration of the two input sectors. With vertical integration of manufacturing and livestock production, the concept of agribusiness profits would be extended to include all producer surpluses:

$$(26b) \qquad \hat{\pi} = \hat{P}S_1 + \hat{P}S_2 - c_2\gamma_2^2$$

where $\hat{\pi}$ is a relative measure of combined profits for manufacturing and livestock producers.

## Optimal Technological Change

Using the framework presented in the previous section, research policy choices are considered as endogenous. It is assumed that the public sector funds technological change in production, and the private sector funds research in manufacturing. Optimal solutions involve decisions by both the public and private sectors. A game theoretic framework is used to consider alternative strategies of the public and private sectors. First, it is assumed that the public and private sectors cooperate to maximize global welfare. Secondly, it is assumed that the public and private sectors determine optimal research policies in a non-cooperative Nash game, assuming optimal policies by the other sector.

The optimal level of technological change to maximize global welfare can be found by taking the derivatives of $\hat{S}W$, equation (25a), with respect to $\gamma_1$ and $\gamma_2$. Setting these derivatives equal to zero gives the following set of equations.

$$(27a) \quad d\hat{S}W/d\gamma_1 = \alpha_{10} + \alpha_{11}\gamma_1 + \alpha_{12}\gamma_2 = 0$$

$$(27b) \quad d\hat{S}W/d\gamma_2 = \alpha_{20} + \alpha_{21}\gamma_1 + \alpha_{22}\gamma_2 = 0$$

where the $\alpha_{ij}$ are reported in Table 2. Solving these equations simultaneously yields the optimal values for $\gamma_1$ and $\gamma_2$ to maximize social welfare.

$$(28a) \quad \gamma_1^a = (\alpha_{22}\alpha_{10} - \alpha_{12}\alpha_{20})/(\alpha_{11}\alpha_{22} - \alpha_{12}\alpha_{21})$$

$$(28b) \quad \gamma_2^a = (\alpha_{11}\alpha_{20} - \alpha_{21}\alpha_{10})/(\alpha_{11}\alpha_{22} - \alpha_{12}\alpha_{21})$$

where $\gamma_i^a$ is a cooperative game solution maximizing global welfare (25a). We are interested in the derivatives of $\gamma_i^a$ with respect to $\eta$, $\sigma$, $\kappa_i$, $\epsilon_i$, and $\theta_i$. However, these expressions are too complicated to sign the derivatives by inspection, so sensitivity

analysis will be used to determine the impact of these parameters on the optimal level of technological change.

There are two non-cooperative games with a Nash equilibrium that are also of interest. First, the private sector would determine the optimal level of technological change in manufacturing ($\gamma_2$), while the public sector determines the optimal level of technological change in production ($\gamma_1$). This scenario does not include the integration of manufacturing and livestock production. The appropriate derivatives for this solution are given below.

$$(29a) \quad d\hat{S}W/d\gamma_1 = \alpha_{10} + \alpha_{11}\gamma_1 + \alpha_{12}\gamma_2 = 0$$

$$(29b) \quad d\hat{\pi}_2/d\gamma_2 = \beta_{10} + \beta_{11}\gamma_1 + \beta_{12}\gamma_2 = 0$$

where the $\alpha_{ij}$ and $\beta_{ij}$ are shown in Table 2. The first equation is the same as the earlier cooperative game, but the second equation is different. The optimal solutions for this alternative are reported below:

$$(30a) \quad \gamma_1^b = (\beta_{12}\alpha_{10} - \alpha_{12}\beta_{10})/(\alpha_{11}\beta_{12} - \alpha_{12}\beta_{11})$$

$$(30b) \quad \gamma_2^b = (\alpha_{11}\beta_{10} - \beta_{11}\alpha_{10})/(\alpha_{11}\beta_{12} - \alpha_{12}\beta_{11})$$

where $\gamma_i^b$ is the Nash equilibrium prior to integration.

The second Nash equilibrium assumes full integration of manufacturing and livestock production. In this scenario, agribusiness considers changes in producer surpluses in manufacturing and livestock production in determining the optimal level of technological change financed by the private sector. The appropriate derivatives for this scenario are given below.

**Table 2. Parameter Expressions for Social Welfare and Agribusiness Profits**

| | | |
|---|---|---|
| $\alpha_{10}$ | = | $-\bar{p}_1 + \theta_1(k_1\bar{w}_{11} - k_1) + \theta_2(k_2\bar{w}_{21})$ |
| $\alpha_{11}$ | = | $-\bar{p}_1\bar{q}_1 + \theta_1(k_1\bar{w}_{11}\bar{x}_{11} - k_1\bar{x}_{11}) + \theta_2(k_2\bar{w}_{21}\bar{x}_{21})$ $- 2c_1$ |
| $\alpha_{12}$ | = | $-\frac{1}{2}\bar{p}_1\bar{q}_2 - \frac{1}{2}k_1\bar{w}_{11}\bar{x}_{12} + \frac{1}{2}k_1\bar{w}_{12}\bar{x}_{11}$ $+ \theta_2(\frac{1}{2}k_2\bar{w}_{21}\bar{x}_{22} + \frac{1}{2}k_2\bar{w}_{22}\bar{x}_{21} - \frac{1}{2}k_2\bar{x}_{21})$ |
| $\alpha_{20}$ | = | $-\bar{p}_2 + \theta_1(k_1\bar{w}_{12}) + \theta_2(k_2\bar{w}_{22} - k_2)$ |
| $\alpha_{21}$ | = | $-\frac{1}{2}\bar{p}_2\bar{q}_1 - \frac{1}{2}\bar{p}_1\bar{q}_2 + \theta_1(\frac{1}{2}k_1\bar{w}_{12}\bar{x}_{11} +$ $\frac{1}{2}k_1\bar{w}_{11}\bar{x}_{12} - \frac{1}{2}k_1\bar{x}_{12}) + \theta_2(\frac{1}{2}k_2\bar{w}_{22}\bar{x}_{21} +$ $\frac{1}{2}k_2\bar{w}_{21}\bar{x}_{22} - \frac{1}{2}k_2\bar{x}_{21})$ |
| $\alpha_{22}$ | = | $\bar{p}_2\bar{q}_2 + \theta_1(k_1\bar{w}_{12}\bar{x}_{12}) + \theta_2(k_2\bar{w}_{22}\bar{x}_{22} - k_2\bar{x}_{22} -$ $2c_2)$ |
| $\beta_{10}$ | = | $\theta_2(k_2\bar{w}_{22} - k_2)$ |
| $\beta_{11}$ | = | $\theta_2(\frac{1}{2}k_2\bar{w}_{22}\bar{x}_{21} + \frac{1}{2}k_2\bar{w}_{21}\bar{x}_{22} - \frac{1}{2}k_2\bar{x}_{21})$ |
| $\beta_{12}$ | = | $\theta_2(k_2\bar{w}_{22}\bar{x}_{22} - k_2\bar{w}_{22} - 2c_2)$ |
| $\beta_{20}$ | = | $\beta_{10} + \theta_1(k_1\bar{w}_{12})$ |
| $\beta_{21}$ | = | $\beta_{11} + \theta_1(\frac{1}{2}k_1\bar{w}_{12}\bar{x}_{11} + \frac{1}{2}k_1\bar{w}_{11}\bar{x}_{12} - \frac{1}{2}k_1\bar{x}_{12})$ |
| $\beta_{22}$ | = | $\beta_{12} \varpi \theta_1(k_1\bar{w}_{12}\bar{x}_{12})$ |

(31a)   $d\hat{SW}/d\gamma_1 = \alpha_{10} + \alpha_{11}\gamma_1 + \alpha_{12}\gamma_2 = 0$

(31b)   $d\hat{\pi}/d\gamma_2 = \beta_{20} + \beta_{21}\gamma_1 + \beta_{22}\gamma_2 = 0$

where the $\alpha_{ij}$ and $\beta ij$ are shown in Table 2. The first equation is still the same as the cooperative game, but the second equation relates to the producer surplus for livestock producers and manufacturers. The optimal solutions for this alternative are reported below.

(32a)   $\gamma_1^c = (\beta_{22}\alpha_{10} - \alpha_{12}\beta_{20})/(\alpha_{11}\beta_{22} - \alpha_{12}\beta_{21})$

(32b)   $\gamma_2^c = (\alpha_{11}\beta_{20} - \beta_{21}\alpha_{10})/(\alpha_{11}\beta_{22} - \alpha_{12}\beta_{21})$

where $\gamma_i^c$ is a Nash equilibrium after integration. These analytical solutions are applied in the following section.

## Sensitivity Analysis

The optimal levels of technological change for livestock production and manufacturing are analyzed for a set of base market parameters and for selected changes in these parameters. The analysis for each set of parameters is repeated for a nonintegrated and an integrated market. A comparison of the results for the nonintegrated market and the integrated market shows the impact of market integration on technological change.

The model is applied to a hypothetical livestock market, with livestock production and manufacturing equally important. The base parameters are presented in Table 3. Parameters in the base solution include the elasticity of demand ($\eta = -.7$), the elasticity of substitution between livestock production and manufacturing ($\sigma = .5$); the elasticities of supply for livestock production ($\epsilon_1 = .2$) and manufacturing ($\epsilon_2 = .2$); and factor shares ($k_1 = k_2 = .5$). A related model for the beef sector is given by Mullen, Wohlgenant, and Farris. Particular attention needs to be focused on $c_i$, which were chosen to yield a 1% optimal rate of technological change for the base solution under global optimization and $\theta_1 = \theta_2 = 1$. Research costs by the public sector [$C_1\gamma_1^2 = 25 (.01)^2 = .0025 = .25\%$] would be .25% of aggregate retail value to produce a 1% technological change in livestock production. Likewise, research costs by the private sector would be .25% of aggregate retail value to produce a 1% technological change in manufacturing.

Agribusiness welfare weights include only manufacturing in the nonintegrated market, but they include livestock production and manufacturing in the integrated market. Welfare weights are normalized for consumers and taxpayers at 1.0 in all sit-

## Table 3.    Sensitivity Analysis

| Optimization Procedure | Agribusiness Welfare Weights | Before Integration $\theta_A = (\theta_2)$ | | After Integration $\theta_A = (\theta_1, \theta_2)$ | |
| --- | --- | --- | --- | --- | --- |
| | | $|\gamma_1*|$ | $|\gamma_2*|$ | $|\gamma_1*|$ | $|\gamma_2*|$ |
| | | ------------------------ Percent ------------------------- | | | |
| (1) Base Parameters: $\eta = -.7$, $\sigma = .5$, $\epsilon_1 = .2$, $\epsilon_2 = .2$, $k_1 = .5$, $k_2 = .5$, $c_1 = 25.$, $c_2 = 25.$ | | | | | |
| Nash Equilibrium | 1.0 | 1.00 | .75 | 1.00 | .78 |
| Nash Equilibrium | .5 | .98 | .75 | .61 | .78 |
| Global Optimization | .5 | .98 | 1.26 | .61 | 1.22 |
| (2)[b] $\eta = -1.4$ | | | | | |
| Nash Equilibrium | 1.0 | 1.00 | .80 | 1.00 | .88 |
| Nash Equilibrium | .5 | .96 | .80 | .56 | .88 |
| Global Optimization | .5 | .96 | 1.21 | .56 | 1.13 |
| (3)[b] $\sigma = 1.0$ | | | | | |
| Nash Equilibrium | 1.0 | 1.00 | .81 | 1.00 | .78 |
| Nash Equilibrium | .5 | 1.01 | .81 | .61 | .78 |
| Global Optimization | .5 | 1.01 | 1.20 | .61 | 1.22 |
| (4)[b] $\epsilon_1 = .4$ | | | | | |
| Nash Equilibrium | 1.0 | 1.00 | .75 | 1.00 | .78 |
| Nash Equilibrium | .5 | .98 | .75 | .68 | .78 |
| Global Optimization | .5 | .98 | 1.25 | .68 | 1.23 |
| (5)[b] $\epsilon_2 = .4$ | | | | | |
| Nash Equilibrium | 1.0 | 1.00 | .60 | 1.00 | .65 |
| Nash Equilibrium | .5 | .99 | .60 | .61 | .65 |
| Global Optimization | .5 | .99 | 1.41 | .61 | 1.36 |

[a]$\theta_A$ is a vector of weights on social welfare for agribusiness firms. Before integration agribusinesses include only manufacturing (input 2). After integration agribusinesses include commodity producers (input 1), as well as manufacturing.
[b]Scenarios (2)–(5) have all base parameters with the exception of one parameter that has been changed as indicated.

uations. Considering the information on livestock and poultry, which was presented earlier in the paper, it appears that the public sector may place a lower welfare weight on the agribusiness sector. That information indicated that the public sector support for poultry research declined in a relative sense after market integration. To reflect the possibility of the public sector holding a lower welfare weight for agribusinesses, the sensitivity analysis uses two alternative agribusiness welfare weights: $\theta_A = 1$ and $\theta_A = .5$ where $(\theta_1, \theta_2) = (1, \theta_A)$ prior to integration and $(\theta_1, \theta_2) = (\theta_A, \theta_A)$ after integration.

With the base set of parameters and $\theta_A = 1$, global optimization would yield 1% technological change in both livestock production and manufacturing; (this standardized solution is not reported in the table). A non-cooperative Nash equilibrium with these weights and $\theta_A = 1$ would reduce manufacturing technological change, $|\gamma_2|$, from 1.0 to .75 without market integration. Market integration would have increased manufacturing technological change, $|\gamma_2|$, from .75 to .78. The more interesting and more realistic scenario is $\theta_A = .5$. In this case, the global optima differ between pre- and post-integration scenarios, because in the post-integration scenario the agribusiness welfare weight applies to livestock producer surplus, as well as manufacturing producer surplus. Without integration, the public sector desires (global optimization) a sizable increase in manufacturing technological change, $|\gamma_2|$, of 1.26%, but the private sector would increase $|\gamma_2|$ only .75% under a Nash equilibrium. After integration the public sector's contribution to livestock production technological change, $|\gamma_1|$, would be only .61%, but it would want the private sector to support $|\gamma_2|$ at 1.22%. However, the private sector would most likely operate as a Nash equilibrium with $|\gamma_2| = .78\%$. First, these results indicate that market integration results in a lower level of technological change supported by the public sector than without integration. Secondly, the private sector supports less technological change than what would be desirable from society's perspective.

If demand is more elastic, $\eta = -1.4$, the private sector would support more technological change, $|\gamma_2| = .80\%$ compared to .75% under the base scenario. However, the public sector would support a lower level of technological change with market integration, $|\gamma_1| = .56\%$ compared to .61% under the base scenario.

If the elasticity of substitution is higher, $\sigma = 1.0$, there is a reversal in the impact of integration on the private sector support for technological change. In this case, market integration would cause a reduction in private sector support for tech-

nological change. Under a Nash equilibrium, $|\gamma_2| = .81\%$ without integration and $|\gamma_2| = .78\%$ with integration.

Changing the supply elasticity for livestock production did not have much impact on the results, but changing the supply elasticity for manufacturing, $\epsilon_2 = .4$, makes a big difference. The private sector's support of technological change would drop $|\gamma_2| = .65\%$ relative to the base scenario $|\gamma_2| = .78\%$. However, society would want more private sector support, $|\gamma_2| = 1.36\%$ compared to 1.22% under the base scenario. These results indicate the more elastic the supply of manufacturing inputs, the greater divergence between what the private sector does (Nash equilibrium) and what society wants the private sector to do (global optimization).

## Conclusions

Poultry is heavily integrated and pork is rapidly becoming integrated. Other livestock sectors may be integrated in the near future. This type of integration or industrialization has important implications for technological change. The public sector reduced its support for poultry research relative to beef and pork after the integration of poultry. It appears likely that the public sector will reduce its support for technological change in integrated markets. On the surface, this strategy appears to be rational if society values the welfare of consumers, taxpayers, and/or producers higher than the profits of agribusinesses.

Optimal rates of technological change were identified under a cooperative game with global optimization. This approach identifies the best strategy for technological change from society's perspective. However, the most likely private sector behavior would be consistent with a noncooperative game, Nash equilibrium. Results from the sensitivity analysis indicated that the private sector's support of technological change is often quite different than what would be best from society's perspective.

Society does not get the optimal results in technological change that it would desire by reducing its level of research funding after market integration. Left alone the private sector will not adequately support technological change from society's perspective. The public sector will need to encourage more private sector support for technological change with industrialization of agriculture. The public sector might emphasize research such as basic science that complements and supports private sector research.

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