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The Impact of Technological Change on a Competitive Industry

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This study analytically evaluates the impact of technological change on output and input markets in a competitive industry of identical firms. Firm-level technology and technological change are represented parametrically as local approximations to unknown functional forms. The comparative statics analysis solves for changes in equilibrium market prices and quantities as functions of parameters that characterize technological change. The technology-induced shift in industry supply is shown to equal the rate of technological change plus the share-weighted induced change in input prices. The model provides a consistent and systematic framework for evaluating the impact of technological change, either ex ante or ex post.

Key words: comparative statics, competitive industry, technological change

Introduction

Over sixty years ago, John Hicks used log-linear comparative statics to evaluate how technological change would affect labor's share of the cost of production. His basic insights and approach have since been extended in a number of ways to evaluate the market equilibrium implications of technological change. The purpose of this study is to consolidate these efforts into a coherent treatment using a dual approach for n inputs that permits analytical results for a wider range of technologies and technological changes than has heretofore been considered. The technology considered here is explicitly firm level, and the number of firms is endogenous. A set of parameters approximating the technology and the technological change are proposed which simplify expression and interpretation of the equilibrium effects of technological change.

In 1964 Richard Muth extended Hicks's model to include supply schedules and equilibrium in input markets. The Muth model consisted of six equilibrium equations in six endogenous variables (prices and quantities of one output and two inputs), with five exogenous shock variables considered: vertical shifts in input supply and output demand schedules, a neutral technical change shifter, and a biased technical change shifter. Muth was able to solve the logarithmic differentials of the system to show exactly the conditions under which technological change would increase or decrease relative shares of the two inputs, for example, or how input supply shifts would alter shares. The effect of exogenous shocks on endogenous variables was expressed in terms of point elasticities as a result of the logarithmic differentiation. The technology considered in Muth's primal

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analysis embodied constant returns to scale with input substitution relationships characterized in terms of Hicks's elasticity of substitution.

A year later, John Floyd published a study that used essentially the same model as Muth, explicitly to examine the effects of agricultural price policies rather than technological change. Alston and Scobie first applied the Muth-Floyd model to technical change in agriculture to show how previous fixed-coefficient production models could provide misleading estimates of the distribution of research benefits between producers and consumers. Mullen, Wohlgenant, and Farris extended the approach to consider two outputs as well as two inputs by specifying a production function that is strongly separable in outputs and inputs, which can thus be characterized by one elasticity of transformation as well as one elasticity of substitution. They specified technical change to occur only in the input substitution portion of this production function, expressing it in terms of an equivalent vertical shift in one of the input supply functions. In 1989, Lemieux and Wohlgenant used elements of the Muth model as components of their model of the potential economic effects of pST (porcine sematotropin) in the swine markets, and Holloway extended the Alston and Scobie idea to consider the distribution of gains from research when directed at the farm-processing stage versus the distribution stage. More recently, Wohlgenant adapted the Alston-Scobie application of the Muth model to examine the distribution of gains from research directed at the production or processing sectors versus promotional efforts at the retail level.

These developments have shown the usefulness of the Hicks-Muth-Floyd approach in exploring the impacts of technological change. The insights from this approach could be extended if the systematic approach of Muth and Floyd could be extended to the n-input case with more complete and more flexible representation of technology and technological change. That is the objective and the contribution of this study.

Competitive Equilibrium Conditions

Consider a single-output competitive industry consisting of N identical firms, each of which in initial equilibrium is operating at the point of minimum average cost. Let Y and y represent the output of industry and firm, respectively, with price received p. Let $n \times 1$ vectors X and x represent input use by the industry and firm, with $n \times 1$ vector w representing prices paid in these markets. Let t represent an index of the state of technology and $C(w;\ y,\ t)$ represent the cost function representing the technology for each firm. Equilibrium conditions within this industry can then be described by the following set of seven equations:

(1a) $$Y = f(p) \quad \text{(product demand)},$$

(1b) $$Y = Ny \quad \text{(output aggregation)},$$

(1c) $$C(w;\ y,\ t)/y = p \quad \text{(zero profit condition)},$$

(1d) $$C_y(w;\ y,\ t) = p \quad \text{(marginal cost equals price)},$$

(1e) $$C_w(w;\ y,\ t) = x \quad \text{(optimal input use—Shephard's lemma)},$$

(1f) $$X = Nx \quad \text{(input aggregation), and}$$

(1g) $$X = g(w) \quad \text{(input supply).}$$

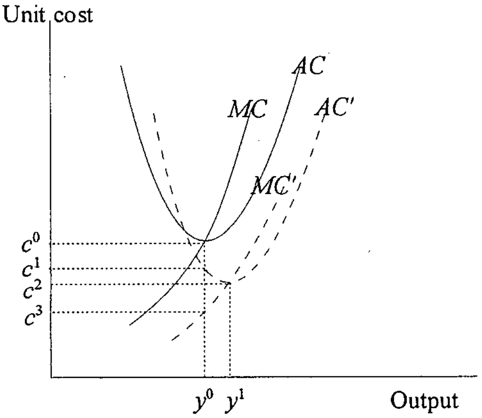

Figure 1. Rate and size bias of technological change

The endogenous variables in this set of equations are *Y, y, p, N, X, x,* and *w*. The only exogenous variable for this analysis is *t*, the index of technology. The logarithmic total differentials of these equations can be used to establish the effect of a change in technology (t), expressed in terms of percentage change in equilibrium levels of the endogenous variables.

Parametric Approximation of the Technology and Technological Change

An unknown technology can be locally approximated (at the equilibrium point represented by w, y, and t) in terms of parameters representing slopes and curvatures, including slopes and curvatures representing a change in technology. The comparative statics analysis of the effect of a technological change on industry equilibrium can then be conveniently represented in terms of these parameters. Here, the basic technology is approximated in terms of four parameters to be defined shortly: returns to size θ, the elasticity of marginal cost μ, the compensated input demand elasticity matrix H, and the input expansion bias vector φ. The nature of the technological change is similarly approximated in terms of three parameters to be defined below: the rate of technological change δ, its size bias σ, and a vector of its input biases B.

Let the degree of returns to size for the initial technology be represented by cost elasticity with respect to output, or the ratio of marginal cost to average cost:

$$(2) \qquad \theta(w; y, t) \equiv \frac{\partial \ln C}{\partial \ln y} = yC^{-1}C_y \quad \text{(returns to size)},$$

which is the reciprocal of traditional measures of returns to size measure (for example, Nadiri; Chambers; Baumol, Panzar, and Willig). A value of $\theta = 1$ indicates locally constant returns to size, $\theta > 1$ indicates decreasing returns, and $\theta < 1$ indicates increasing returns. If the industry described by equation (1) involves a technology with a U-shaped cost curve such as that depicted by the solid lines in figure 1, then $\theta = 1$ at the equilibrium point y^0, $\theta < 1$ to the left of y^0, and $\theta > 1$ to the right of y^0 (Chambers, ch. 2). It will also prove useful to approximate the curvature of the cost function with the parameter:

$$(3) \qquad \mu(w; y, t) \equiv \frac{\partial \ln C_y}{\partial \ln y} = yC_y^{-1}C_{yy} \quad \text{(elasticity of marginal cost)},$$

and to approximate the isoquant curvatures with the compensated input demand elasticity matrix:

$$(4) \qquad H(w; y, t) = \chi^{-1}C_{ww}W \text{ (output-constant input demand elasticity matrix)},$$

where χ is an $n \times n$ matrix with x on the diagonal, and W is an $n \times n$ matix with w on the diagonal. Finally, approximate the curvature of the expansion path of the technology in terms of the elasticities of input shares with respect to output change:

$$(5) \qquad \varphi_i(w; y, t) \equiv \frac{\partial \ln k_i}{\partial \ln y} = \frac{\partial \ln x_i(w; y, t)}{\partial \ln y} - \theta(w; y, t), \quad \text{or}$$

$$\varphi(w; y, t) = y\chi^{-1}C_{wy} - \theta(w; y, t)\iota, \quad \text{(the size bias vector)},$$

where k_i is the cost share of input i, and ι is a vector of 1s. If all values φ_i are zero, then at the point of approximation the expansion path follows along a ray from the origin (this property will later be referred to as local homotheticity). It is easy to demonstrate that the share-weighted sum of φ_is is zero ($\Sigma_i k_i\varphi_i = 0$), and that if constant returns to size holds at the point of approximation (as at y^0 in fig. 1), the unweighted sum of φ_is equals zero.

We now turn to the parametric representation of technological change. The primal rate of technological change has generally been defined as the percentage increase in output while inputs are held constant; whereas, the dual rate of technological change (also referred to as the rate of cost diminution by Berndt; Chambers; Antle and Capalbo; and others) has been defined as the percentage downward shift in the cost function while output and input prices are held constant. Here, for simplicity, we define the rate of technological change as the percentage downward shift in cost or average cost (AC):

$$(6) \qquad \delta(w; y, t) \equiv -\frac{\partial}{\partial t}\ln C = -\frac{\partial}{\partial t}\ln AC,$$

$$= -C^{-1}C_t \quad \text{(the rate of technological change)}.$$

This parameter is equivalent to the rate of cost diminution. Ohta showed that this dual rate of change is equal to the primal rate multiplied by the dual rate of returns to size, θ. Further, it is easily demonstrated that the rate of cost diminution δ can also be expressed as the share-weighted change in optimal input use for a given level of output, that is, $\delta = \Sigma_i k_i \text{d}\ln x_i(w; y, t)/\text{d}t$.

Other characteristics of technological change are significant in determining its impacts on the industry. The first is size bias. At a competitive equilibrium, all firms will be operating at the minimum point on the average cost curve (y^0 in fig. 1), with average and marginal costs equal. If at the current level of output, marginal cost shifts downward by more than average costs, as is depicted in figure 1, the new point of minimum average cost will occur at a larger output than before, and the technological change can be characterized as having a positive size bias. Therefore an appropriate parametric measure approximating the size bias of technological change is the difference between the shift in average and marginal costs:[1]

$$\text{(7)} \qquad \sigma(w;\, y,\, t) \equiv -\left(\frac{\partial}{\partial t}\ln MC - \frac{\partial}{\partial t}\ln AC\right)$$

$$= -C_y^{-1}C_{yt} - \delta(w;\, y,\, t), \quad \text{(size bias of technological change).}$$

If $\sigma > 0$, the technological change will increase the equilibrium size of firms, while if $\sigma < 0$, it will decrease firm size. At a given level of output, the technological change shifts average costs down by fraction δ, and marginal costs down by fraction $(\delta + \sigma)$. In terms of figure 1, the rate of technological change is the ratio $(c^0 - c^1)/c^0$, while the size bias of technological change is the ratio $(c^1 - c^3)/c^0$.

The final characteristic of significance is the input bias of technological change. Since Hicks first noted that a technological change can lead to changes in factor shares, a number of notions of the input bias (or, alternatively, of input neutrality) of technological change have been offered. Antle and Capalbo (pp. 36–48) have offered an illuminating discussion and comparison of these definitions. For our purposes here, we follow Hicks's original instincts and use the Binswanger definition of the overall bias related to input i as the percentage change in optimal input share, holding input prices and output constant. This measure of bias may thus be defined as:

$$\text{(8)} \qquad \beta_i(w;\, y,\, t) \equiv \frac{\partial \ln k_i}{\partial t} = \frac{\partial \ln x_i(w;\, y,\, t)}{\partial t} - \delta(w;\, y,\, t), \quad \text{or}$$

$$B(w;\, y,\, t) = \chi^{-1}C_{wt} + \delta(w;\, y,\, t)\iota \quad \text{(the input bias of technological change).}$$

A neutral technological change is defined in this context as one for which B is a vector of zeros, though of course factor shares may be changed by the adoption of such a technological change if output per firm is changed, or if the equilibrium levels of input prices are affected. It is easily established that the share-weighted sum of β_is must equal zero ($\Sigma_i\, k_i\beta_i = 0$), that is, that if there is a bias toward any input, there must be biases against one or more others.

Biases for the case of two inputs are represented in figure 2, where the solid curve from the origin represents the original expansion path and dashed curve represents the expansion path after the technological change. The initial equilibrium is at point A and the new equilibrium (the same output level, with unchanged input prices) is at point B. The bias as defined above is represented by the arc β'_{12}, reflecting an increase in the share of x_1 and a decrease in the share of x_2. This is in contrast to an alternative measure of bias commonly used, represented by the arc β_{12}, which is the change in price ratio necessary to induce the producer to choose the original input bundle (see Antle and Capalbo).

[1] The author is unaware of other references to such a concept in the literature. However, a size bias is implied by any cost function model for which $C_{yt} \neq 0$.

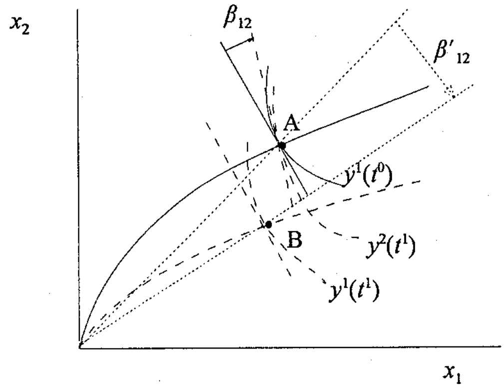

Figure 2. Input bias of technological change

Comparative Statics of Technological Change

The comparative statics effects of a technological change can be derived by total differentiation of the equilibrium equations (1), then solving for the changes in endogenous variables (Y, y, p, N, X, x, and w) as functions of the exogenous variable t. The logarithmic differentials of the equilibrium equations can be expressed compactly as follows:

(9a) $$d \ln p - 1/\eta d \ln Y = -d\rho,$$

(9b) $$d \ln Y - d \ln N - d \ln y = 0,$$

(9c) $$d \ln p - k' d \ln w + (1 - \theta) d \ln y = -\delta dt,$$

(9d) $$d \ln p - (\varphi' + \theta\iota')K d \ln w - \mu d \ln y = -(\delta + \sigma)dt,$$

(9e) $$d \ln x - H d \ln w - (\varphi + \theta\iota) d \ln y = (B - \delta\iota)dt,$$

(9f) $$d \ln X - \iota d \ln N - d \ln x = 0, \quad \text{and}$$

(9g) $$d \ln w - S^{-1} d \ln X = d\omega,$$

where η is product demand elasticity, k is an $n \times 1$ vector of cost shares, K is an $n \times n$ matrix with vector k on the diagonal, and S is an $n \times n$ matrix of input supply elasticities.

Here, following Muth's original analysis, two additional exogenous variables have been added, ρ which represents an exogenous vertical shift in the effective demand facing the industry, and ω which represents a vector of vertical shifts in the input supplies. The comparative statics results of such exogenous shifts are readily determined from the analysis to follow, but they will not be discussed further.

These differentiated equilibrium equations have some interesting interpretations in themselves. The average cost condition (9c) specifies that the equilibrium product price will fall by the same percentage as the rate of technical change δ, plus the share-weighted average of any induced input price changes, plus an adjustment for size changes (none if $\theta = 1$, i.e., locally constant returns to size.) The marginal cost condition (9d) specifies that product price will also change by the same percentage as the shift in marginal costs ($\delta + \sigma$), plus additional adjustments if input prices or firm-level output change. The equation representing the Hotelling-Shephard condition (9e) specifies that in the absence of changes in input prices or output per firm, the use of input i will fall by the same percentage as the rate of technological change, offset or exacerbated by the bias for that input, β_i. If there are output increases, the level of the input will also increase by the size factor θ, and an additional adjustment if the technology is not locally homothetic (i.e., if φ_i is not zero).

This system of equations can be expressed in detached coefficient form as

$$
(10)\qquad
\begin{bmatrix}
-1/\eta & 0 & 1 & 0 & 0 & 0 & 0 \\
1 & -1 & 0 & -1 & 0 & 0 & 0 \\
0 & -\theta & 1 & 0 & -k' & 0 & 0 \\
0 & -\mu & 1 & 0 & -(\varphi' + \theta\iota)K & 0 & 0 \\
0 & -(\varphi + \theta\iota) & 0 & 0 & -H & I & 0 \\
0 & 0 & 0 & -\iota & 0 & -I & I \\
0 & 0 & 0 & 0 & I & 0 & -S^{-1}
\end{bmatrix}
\begin{bmatrix}
d \ln Y \\ d \ln y \\ d \ln p \\ d \ln N \\ d \ln w \\ d \ln x \\ d \ln X
\end{bmatrix}
$$

$$
= \begin{bmatrix}
0 \\ 0 \\ -\delta \\ -(\delta + \sigma) \\ B - \delta\iota \\ 0 \\ 0
\end{bmatrix} dt +
\begin{bmatrix}
-d\rho \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ d\omega
\end{bmatrix}.
$$

Given estimates of the relevant parameters, this system is easily solved numerically in the context of a spreadsheet. However, an analytical solution that is a generalization of the Muth result can be obtained by using row and column operations to invert the matrix. The resulting solution (under the assumption of locally constant returns to size, $\theta = 0$, as would be the case for competitive long-run equilibrium) allows us to express changes in the endogenous variables in terms of the parameters characterizing the nature of the technological change:

$$
(11)\qquad
\begin{bmatrix}
d \ln Y \\ d \ln y \\ d \ln p \\ d \ln N \\ d \ln w \\ d \ln x \\ d \ln X
\end{bmatrix}
=
\begin{bmatrix}
-\eta & 0 & 0 & \eta k' \\
0 & \frac{1}{\mu} & 0 & -\frac{1}{\mu}\varphi' K \\
-1 & 0 & 0 & k' \\
-\eta & -\frac{1}{\mu} & 0 & \left(\frac{1}{\mu}\varphi' K + \eta k'\right) \\
0 & 0 & 0 & I \\
-\iota & \frac{1}{\mu}(\varphi + \iota) & I & H - \frac{1}{\mu}(\varphi + \iota)\varphi' K \\
-(1 + \eta)\iota & \frac{1}{\mu}\varphi & I & H - \left(\frac{1}{\mu}\varphi\varphi' + \eta\iota\iota'\right)\varphi' K
\end{bmatrix}
\begin{bmatrix}
\delta \\ \sigma \\ B \\ \Gamma
\end{bmatrix} dt
$$

$$
+ \begin{bmatrix} 1 & \eta k' \\ 0 & -\frac{1}{\mu}\varphi' K \\ 0 & k' \\ 1 & \left(\frac{1}{\mu}\varphi' + \eta \iota'\right) K \\ 0 & I \\ 0 & H - \frac{1}{\mu}(\varphi + \iota)\varphi' K \\ 0 & S \end{bmatrix} \begin{bmatrix} -\eta \\ -\eta \Omega^{-1}\iota \end{bmatrix} d\rho + \begin{bmatrix} 0 & \eta k' \\ 0 & -\frac{1}{\mu}\varphi' K \\ 0 & k' \\ 0 & \left(\frac{1}{\mu}\varphi' + \eta \iota'\right) K \\ 0 & I \\ 0 & H - \frac{1}{\mu}(\varphi + \iota)\varphi' K \\ -I & S \end{bmatrix} \begin{bmatrix} S \\ -\Omega^{-1} S \end{bmatrix} d\omega,
$$

where

$$
\Gamma = \Omega^{-1}\left[B - (1 + \eta)\iota\delta + \frac{1}{\mu}\varphi\sigma\right], \quad \text{and}
$$

$$
\Omega = \left[S - H + \eta\iota k' + \frac{1}{\mu}\varphi\varphi' K\right].
$$

These results are expressed with detached technical change coefficients to facilitate interpretation. The expression at first appears complicated, but the structure offers a number of insights.

Of interest are the effects of technological change on both the output market and the input markets. Note from row five of the solution that the input price effects of the technological change are represented by the vector Γ. It is then evident from row three that the effect of the technological change on output price is to reduce it by the rate of technological change plus the share-weighted average of these changes in input prices. The technology-induced changes in input prices may be negative if product demand is sufficiently inelastic and input supplies are sufficiently elastic. In this case product price will fall by more than the rate of technological change. If product demand is sufficiently elastic, then the input price index will be driven up because the increase in output more than offsets the reduced input required per unit of output, and product price will fall by less than the rate of technological change.

The vector Γ is also crucial in determining the distribution of any new producers' surplus created by the technological change, because it represents changes in the level of quasi-rents to owners of inputs (profits are zero in a competitive industry and all producer surplus is distributed to input owners.) Consideration of the structure of this vector indicates that even with a locally homothetic production function and independently supplied inputs, the effect of technological change on input prices is not a simple story. This is because induced adjustments in input prices depend upon the interaction of underlying demand, supply, and technology elasticities as well as the three technological change parameters. Although the induced input price change vector can be estimated or evaluated for particular cases of technological change, further generalities are not evident.

If all inputs are in perfectly elastic supply, however, Ω^{-1} converges to the null matrix, and of course there are no input price effects of the technology. In this case Γ is the null vector and the effects of the technological change are simpler. All benefits of the technology are passed to consumers of the product. Product price falls by exactly the rate of technological change (evident from row three). Total output increases to match the demand response to the lower price (evident from row one), and the number of firms increases by the same proportion unless the technological change is size biased (row four). Inputs used per firm will fall by the rate of technological change, with additional adjustments for input bias and for a size bias effect (row six). Aggregate input use will change by the same percentages plus the percentage increase in number of firms.

The effect of a technological change in shifting the output supply curve has been the subject of a great deal of the agricultural economics literature previously cited. In much of this and related literature, the percentage by which the supply curve is shifted downward has been referred to as the "k-shift." As noted by Alston, Norton, and Pardey (in section 5.3), the size of this shift is a crucial element in the literature examining the total benefits from research. Following Muth, the size of this shift can be determined by evaluating (11) for the special case of a vertical demand curve, $\eta = 0$. It is evident from this exercise that the k-shift is the percentage $-\delta$, plus a share-weighted average of input price effects that are affected by, but not eliminated by, the assumption that $\eta = 0$. Hence *only in the simple case of no input price effects does the supply curve shift downward by the rate of technological change*; otherwise one must be able to ascertain the induced input price effects to determine the size of the k-shift.

The impact of the new technology on the amount of inputs used is determined by rows six and seven of the solution. In the simplest case of unbiased and size-neutral technical change to a locally homothetic technology with no input price changes, the last three terms of these rows vanish and the effect of technological change is simply to reduce firms' use of each input by the percentage δ, and the industry's use by $(1+\eta)\delta$. If we add to this case a demand elasticity of zero, the aggregate use of each input will decrease by exactly the rate of technological change. As demand elasticity increases to a value of 1.0, this decline in aggregate input use will disappear, and for demand elasticities larger than one, industry input use will increase. These results are mitigated by the input bias of technological change (B), by any size bias inherent in the technological change, and finally by input price adjustments if input elasticities are less than infinite.

Many of the results above are anticipated by Muth's earlier analysis for the case of two inputs, with independent input supplies. His appendix equations, analogous to equation (11), describe equilibrium impacts as linear functions of the (primal) rate of technological change and a bias parameter. His method of characterizing the input bias in terms of the ratio of marginal products (a notion roughly corresponding to β_{ij} in fig. 2) was an impediment to generalization to more than two inputs, which can be easily achieved by a dual representation of the technology. Alston, Norton, and Pardey (pp. 264–67) describe an ad hoc generalization of the Muth model to the case of n inputs and cite a number of users of such a model. In that approach, each differentiated factor demand equation analogous to (9e) is arbitrarily augmented by a technology-induced shift parameter. Such an approach has three limitations: (*a*) it does not explicitly relate the derived demand shifts to biases in the cost or production function shifts; (*b*) it does not distinguish between the demand shifts due to the rate of technological change versus those due to the bias of technological change; and (*c*) it does not recognize the $n - 1$ degrees of freedom available to specify biases in technological change.

Neither Muth nor recent adaptations of Muth have isolated the technology-induced input price impact of technological change (the Γ of the present study), which has helped to clarify the analysis of the impact of the change as shown in equation (11). Likewise, neither Muth's study nor any other has examined the possibility of size bias in technological change and its impact on the equilibrium number of firms, an issue of some interest in agriculture.

Conclusions

This analysis examines the impact of technological change on a competitive industry. It follows earlier contributions by Hicks and Muth by using a comparative statics model based on a parametric local approximation of both the technological change itself and the initial firm-level technology. Curvatures of the technology are approximated by parameters representing elasticity of marginal cost, derived demand elasticities, and elasticities of input shares with respect to output. Technological change is approximated in terms of parameters representing the rate of change, the size bias of change, and a vector of input biases.

The model permits a coherent and comprehensive method of characterizing technological change and evaluating its impact on competitive input and output markets, including the distribution of benefits and costs. The analysis here extends in a number of ways previous literature in this genre. The possibility of firm-size bias in technological change is explicitly introduced, along with the resulting impact on the equilibrium number of firms. The technology-induced shifts in derived demands are analytically derived in terms of both the rate of technological change and its input biases. The comparative statics analysis isolates the impact of technological change on input prices and, thus, clarifies analytically the contributions of the separate components of technological change (rate of change, size bias, and input bias) with and without input price effects. The industry supply shift (the *k*-shift) due to a change in firm-level technology is shown to be equal to the rate of technological change plus the share-weighted induced change in input prices.

The model may be empirically useful in examining the effects of technological change either in an ex ante sense when parameters can be surmised and/or estimated, or as a basis for formulating econometric models to examine ex post impacts of technological change. For the analysis of technological change, this approach provides a concise but more general conceptual framework than has heretofore been available, and it clarifies how market elasticities interact with the parameters of technological change to determine the distribution of gains from new technology.

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References

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

Alston, J. M., G. W. Norton, and P. G. Pardey. *Science under Scarcity: Principles and Practice for Agricultural Research Evaluation and Priority Setting.* Ithaca NY: Cornell University Press, 1995.

Antle, J. M., and S. M. Capalbo. "An Introduction to Recent Developments in Production Theory and Productivity Measurement." In *Agricultural Productivity: Measurement and Explanation,* eds., S. M. Capalbo and J. M. Antle, pp. 17–95. Washington DC: Resources for the Future, 1988.

Baumol W. J., J. C. Panzar, and R. D. Willig. *Contestable Markets and the Theory of Industry Structure.* New York: Harcourt Brace Jovanovich, 1982.

Berndt, E. R. "Comment." In *New Developments in Productivity Measurement and Analysis* (NBER Studies in Income and Wealth) Vol. 44, eds., J. W. Kendrick and B. N. Vaccara, pp. 259–68. Chicago: University of Chicago Press, 1980.

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

Chambers, R. G. *Applied Production Analysis: A Dual Approach.* Cambridge: Cambridge University Press, 1988.

Floyd, J. E. "The Effects of Farm Price Supports on the Return to Land and Labor in Agriculture." *J. Polit. Econ.* 73(1965):148–58.

Hicks, J. R. *The Theory of Wages.* London: MacMillan, 1932.

Holloway, G. J. "Distribution of Research Gains in Multistage Production Systems: Further Results." *Amer. J. Agr. Econ.* 71(May 1989):338–43.

Lemieux, C. M., and M. K. Wohlgenant. "Ex Ante Evaluation of the Economic Impact of Agricultural Biotechnology: The Case of Porcine Somatotropin." *Amer. J. Agr. Econ.* 71(November 1989):903–14.

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(May 1988):245–54.

Muth, R. F. "The Derived Demand Curve for a Productive Factor and the Industry Supply Curve." *Oxford Econ. Pap.* 16(1964):685–99.

Nadiri, M. I. "Some Approaches to the Theory and Measurement of Total Factor Productivity: A Survey." *J. Econ. Lit.* 8(1970):1137–178.

Ohta, M. "A Note on the Duality between Production and Cost Functions: Rate of Returns to Scale and Rate of Technical Progress." *Econ. Stud. Quart.* 25(1974):63–65.

Wohlgenant, M. K. "Distribution of Gains from Research and Promotion in Multi-Stage Production Systems: The Case of the U.S. Beef and Pork Industries." *Amer. J. Agr. Econ.* 75(August 1993):642–51.