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Price-Conditional Technology

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Economics theorists for years have considered the possibility that the direction of technical change is altered by changes in relative prices. Prices also have been identified as one of the determinants of technical change through innovation. This article extends the theory of the firm to cover situations in which the firm's technology set is conditional on expected prices. The basic idea is to distinguish between "market prices," or the prices that guide the firm's choices subject to the technology that is in place, and "normal prices," the prices conditioning the choice of technology. A "generalized" price effect is obtained that includes the traditional price effect as well as the technical change effect of price changes, and an example is presented.

Key words: conditional technology, market prices, normal prices, technical change.

Introduction

Economics theorists for years have considered the possibility that the direction of technical change is altered by changes in relative input prices. The theory of induced innovation argues that technological change responds to price movements so as to save on factors of production that have become relatively more expensive. Early applications of the theory by Hayami and Ruttan, and by Binswanger to the study of agriculture have been useful in explaining long-run historical trends. Output prices also have been identified as a determinant of technical change through innovation, although they have not been as prominent a determinant as input prices.

Innovation generally is considered an activity to which a firm allocates resources according to its profitability. Profitability can be affected by supply-side factors, such as the existence of new knowledge or the cost of research, and by demand-side factors, such as price changes or changes in appropriability. The clear implication of this conceptual approach is that increases in expected product prices (or demand) increase innovation benefits. Both Schmookler and Lucas provided empirical support for this hypothesis. Binswanger developed an explicit firm behavior model showing that the benefits of innovation increase with expected prices if the optimal quantity is expected to increase because of innovation. In order to capture the effect of prices on technical change, Fulginiti and Perrin propose a production function for which the coefficients are variable and determined at any one place and time by previous choices and the current technological, natural, and institutional environment. They refer to these as technology-changing variables and focus on the role of prices as a technology-changing variable. The work by Fulginiti and Perrin provides empirical support to the Schmookler-Lucas hypothesis, that is, the existence of a positive price-technical change relationship.

This study extends the theory of the firm to cover situations in which the firm's technology set is conditional on expected prices. In particular, it focuses on the implications of price-conditional technology on the producer's behavior, i.e., netput functions properties. We consider the "technology set" to refer to all possible combinations of inputs

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and outputs that are achievable with any techniques that are currently available. We consider "technical change" to be an augmentation of the technology set with new techniques that were previously unknown or unavailable to the firm.

The idea of prices as an argument of a production function requires some justification. Our rationalization is straightforward. If it is true that prices serve as an incentive for innovation and for the adoption of new innovations, as the literature reviewed above suggests, then the price regime of one period must in some way affect the technology relevant to a subsequent period. In terms of a production function, we argue that any new technique (technical change) can be described in terms of a unique combination of inputs if inputs are sufficiently narrowly defined and distinguished. Then one can specify the production function as $y_t = f(x_{1t}, x_{2t})$, with x_{2t} being a very long vector of specific inputs (such as one-row cultivators, IR-8 rice, DDT, and other "techniques") that are individually either unknown at a point in time or unobservable by the researcher. Over time, new inputs in the vector x_2 are discovered and adopted, and old ones are discarded. If prices are one of the factors determining this innovation process, then prices can serve as a proxy for these unobservables, i.e., current values might reasonably be expressed as a function of previous prices: $x_{2t} = g(p_{t-1})$, and thus $y_t = f(x_{1t}, p_{t-1})$.

The literature on price-conditional technology is not extensive. The induced innovation hypothesis usually is associated with Hicks. Hayami and Ruttan seem to have been among the first to use this idea to suggest biased technical change in agriculture due to relative input price changes. Basmann et al. (1987) present a method for testing technological change, with input prices and total cost entering the production function, but their discussions do not focus on the implications of the hypothesis for output supply and input demand behaviors. Fawson, Shumway, and Basmann use a model selection procedure to assess the likelihood support for a production model, which does not restrict technical change to be invariant to changes in exogenous economic variables or to stochastic shocks to the production system. In contrast, we find that in consumer demand analysis, the effect on demand behavior of price-dependent preferences has been analyzed by Basmann et al. (1983); Pollak; Allingham and Morishima; and Kalman; and, to a lesser extent, by Arrow and Hahn; Samuelson; Scitovsky; and Veblen.

Most econometric studies do not directly specify prices as determinants of technical change and factor biases. Changes in technology usually are modeled by introduction of a time trend variable into the production function. The use of conventional methods perpetuates the perception that changes in technology remain invariant to changes in exogenous economic variables. Changes in exogenous economic variables may provide incentives for producers to change the efficiency with which they extract production from factor bundles. That is, they may alter their choice of techniques from among the complete set of available microproduction processes comprising the aggregate technology (Mundlak). Rather than model technical change as an explicit function of time, exogenous to the economic system, the approach presented in this study allows for technical change to occur as prices and other factors change from period to period.

We suggest a mechanism for incorporating price-conditional technology into production analysis. The basic idea is to distinguish between "market prices," or the prices guiding the firm's choices subject to a technology that is in place, and "normal prices," or the prices conditioning the level of technology chosen.[1] The objective is to disentangle the allocative from the technical change effect of prices.

When market prices and normal prices are treated as distinct and independent variables, the resulting model is tractable. Viewed as a function of market prices, the supply and derived demand functions exhibit all the properties of traditional production theory.

To develop the normal price model of price-conditional technology, it is necessary to specify both the way technology is affected by normal prices and the process by which normal prices are determined. Our casual understanding of induced innovation suggests that the price variables influencing technical change are some complex construct related to past prices. It is this construct that we refer to as "normal prices." The "normal price function" specifies normal prices as a function of past prices.

The remainder of the article is organized as follows. First, the general model is presented. The next section shows the effect of price-conditional technology on netput functions characteristics. Next, using estimates from a variable coefficient Cobb–Douglas meta-production function fitted to the agricultural sectors of a set of 18 developing countries, an example is presented. Conclusions are offered in the final section.

The General Model

We formulate in this section the problem of the firm, the objective of which is taken to be that of maximizing profits, when the transformation function is conditional on prices of inputs and outputs used in production. The firm selects the technology and the levels of inputs and outputs subject to that technology. With the objective of identifying qualitative properties of the supply and derived demand functions in the context of a price-conditional technology, we derive from the necessary conditions for equilibrium of the firm a generalized price effect different from the traditional price effect. The producer's problem is

$$\max_{y} \sum_{i=1}^{n} p_i y_i \quad \text{subject to } F(y; p) = 0, \tag{1}$$

where y is an $n \times 1$ netput vector (inputs are negative, and outputs positive), p is an $n \times 1$ vector of input and output prices, and F is a transformation function satisfying the standard regularity conditions in y such as differentiability and convexity. The necessary conditions for a maximum are

$$\begin{aligned} p_i + \lambda F_i &= 0, \\ F(y; p) &= 0, \qquad i = 1, 2, \ldots, n, \end{aligned} \tag{2}$$

where λ is the Lagrange multiplier. The sufficient conditions for a maximum are (2) and

$$(-1)^s \begin{vmatrix} \lambda F_{11} & \cdots & \lambda F_{1s} & F_1 \\ \vdots & & \vdots & \vdots \\ \lambda F_{s1} & & \lambda F_{ss} & F_s \\ F_1 & \cdots & F_s & 0 \end{vmatrix} > 0, \qquad s = 2, \ldots, n. \tag{3}$$

An important objective of this section is to place restrictions on the supply and derived demand functions derived from system (2). We will show how these functions can be derived from system (2) and will establish some of their properties. System (2) can be written as $n + 1$ implicit functions in $2n + 2$ arguments $(y_1, \ldots, y_n; p_1, \ldots, p_n; \lambda; F)$. Furthermore, at the point $(y_1^*, \ldots, y_n^*; p_1, \ldots, p_n; \lambda; F)$ in Euclidean $2n + 2$ space, the functions vanish and their Jacobian [in view of (3)] is

$$J = \begin{vmatrix} \lambda F_{ij}(y^*, p) & F_i(y^*, p) \\ F_j(y^*, p) & 0 \end{vmatrix} \neq 0. \tag{4}$$

Moreover, the $n + 1$ implicit functions have continuous first partials; consequently, there exist netput functions

$$y_i = f^i(p) \tag{5}$$

in a neighborhood of p, functions that are unique and possess continuous first partials in the same neighborhood.

Thus far, the introduction of prices in the transformation function has distinguished our theory of the firm from the traditional theory only to a limited extent. During the comparative static analysis, however, it will become evident that a clear distinction exists. We will try to deduce qualitative properties of the netput functions (5).

We will call system (2) a system of *equilibrium equations* if we replace y with y^*, the equilibrium netput level. To simplify notation, the asterisk superscript (*) will be omitted, and $F(y, p)$ will be written F, and similarly for the first and second partials of F. We will adhere to this modification of notation through the remainder of this section, remembering that the analysis is true only for the neighborhood of the maximum.

The total differential of the equilibrium equations is

$$\begin{aligned} &\sum_{j=1}^{n} \lambda F_{ij}\, dy_j + F_i\, d\lambda = -dp_i - \lambda \sum_{k=1}^{n} F_{i,n+k}\, dp_k, \qquad i = 1, \ldots, n, \\ &\sum_{j=1}^{n} F_j\, dy_j = -\sum_{k=1}^{n} F_{n+k}\, dp_k, \end{aligned} \tag{6}$$

where

$$F_i = \frac{\partial F}{\partial y_i}, \quad F_{n+k} = \frac{\partial F}{\partial p_k},$$

and

$$F_{i,n+k} = \frac{\partial^2 F}{\partial y_i\, dp_k}.$$

This system can be rewritten as

$$\begin{bmatrix} \lambda F_{11} & \cdots & \lambda F_{1n} & F_1 \\ \vdots & & \vdots & \vdots \\ \lambda F_{n1} & \cdots & \lambda F_{nn} & F_n \\ F_1 & \cdots & F_n & 0 \end{bmatrix} \begin{bmatrix} dy_1 \\ \vdots \\ dy_n \\ d\lambda \end{bmatrix} = \begin{bmatrix} -dp_1 - \lambda \sum_{k=1}^{n} F_{1,n+k}\, dp_k \\ \vdots \qquad \vdots \\ -dp_n - \lambda \sum_{k=1}^{n} F_{n,n+k}\, dp_k \\ -\sum_{k=1}^{n} F_{n+k}\, dp_k \end{bmatrix} \tag{7}$$

$$\text{Let } D = \left| \begin{array}{c:c} \lambda F_{ij} & F_i \\ \hdashline F_j & 0 \end{array} \right|.$$

Hence, in view of (3), we can solve this system uniquely for $(dy_1, \ldots, dy_n; d\lambda)$. The solution, via Cramer's rule, may be written

$$\begin{aligned} dy_i &= -\sum_{j=1}^{n} \frac{D_{ji}}{D}\, dp_j - \lambda \sum_{j=1}^{n} \sum_{k=1}^{n} \frac{D_{ji}}{D} F_{j,n+k}\, dp_k - \frac{D_{n+1,i}}{D} \sum_{j=1}^{n} F_{n+j}\, dp_j, \\ d\lambda &= -\sum_{j=1}^{n} \frac{D_{j,n+1}}{D}\, dp_j - \lambda \sum_{j=1}^{n} \sum_{k=1}^{n} \frac{D_{j,n+1}}{D} F_{j,n+k}\, dp_k - \frac{D_{n+1,n+1}}{D} \sum_{j=1}^{n} F_{n+j}\, dp_j, \end{aligned} \tag{8}$$

where D_{ji} denotes the cofactor of the element of the jth row and the ith column of D. The system of equations (8) yields the changes in our unknowns $(dy_1, \ldots, dy_2; d\lambda)$ for any sufficiently small changes in the parameters $(p_1, \ldots, p_n)$. As special cases, the following partial derivative may be evaluated:

$$\frac{\partial y_i}{\partial p_h} = -\frac{D_{hi}}{D} - \left(\lambda \sum_{j=1}^{n} \frac{D_{ji}}{D} F_{j,n+h} + \frac{D_{n+1,i}}{D} F_{n+h} \right), \qquad i, h = 1, \ldots, n, \tag{9}$$

where

$$\frac{\partial y_i}{\partial p_h} = f^i_h(p).$$

We may consider the basic equation (9), taking the terms in order, as "generalized" price effect = "traditional" price effect[2] + technical change effect (in parentheses).

The technical change term is the change in supply and derived demand arising from the change in technology brought about by the change in prices. With respect to the "traditional" price effect, if we assume that the transformation function is strictly convex in y, then cross-partial derivatives could be positive, negative, or zero, but own-price effects would be well defined because for $h = i$, we can establish a sign for the cofactor D_{hi}. Compared with the "traditional" case, equation (9) shows two extra terms on the right-hand side. Representing the effect arising when the change in p_h shifts the production locus, these terms can be positive or negative. Because there are no restrictions on the signs of the terms, the slopes of the supply and derived demand functions are undetermined.

Symmetry of the price effects in the "traditional" case is derived from the fact that cofactors are symmetric. The technical change effect in equation (9) indicates that when the transformation function is conditional on prices, symmetry is not satisfied.

The netput functions (5), derived from the equilibrium equations (2), generally are not homogeneous of degree zero in prices. This result, which can be easily verified, is not surprising in view of the absence of restrictions on F with respect to p, a subset of its arguments. If we multiply every price in (1) by $t > 0$, then, from (2), the marginal rate of technical substitution involving any pair of commodities is not necessarily independent of t. There exists a class of transformation functions, however, admitting netput functions homogeneous of degree zero in prices. Specifically, $f^i(p) = f^i(tp)$, $t > 0$ if and only if[3]

$$(10) \qquad -\lambda \sum_{j,k=1}^{n} \frac{D_{ki}}{D} F_{k,n+j} p_j = \sum_{j=1}^{n} \frac{D_{n+1,i}}{D} F_{n+j} p_j.$$

We derive for the class of transformation functions characterized by this property the traditional result that the supply (demand) for the ith commodity is homogeneous of degree zero. That is, using (9) and (10),

$$(11) \qquad \sum_{j=1}^{n} \frac{\partial y_i}{\partial p_j} p_j = -\frac{1}{D} \sum_{j=1}^{n} D_{ji} p_j = 0.$$

We have shown in this section that the generalized price effect, equation (9), includes a traditional price response and a technical change price effect. Without placing qualitative restrictions on the latter term, we would be unable to deduce qualitative properties of the "observable relation" on the left side of equation (9). The matrix of price effects need not be symmetric, positive semidefinite, or homogeneous of degree zero in prices unless we impose additional restrictions on the term that reflects the effect of prices on innovation and technical change.

Additional Restrictions on Producer Behavior

The basic idea is to distinguish notationally and conceptually between the two roles played by prices in a model in which they condition the technology. We call the prices conditioning the technology "normal prices" and they are denoted by p^N; those prices guiding the firms' allocative decisions are called "market prices" and are denoted by p^M.

If market prices and normal prices were distinct and independent, we could distinguish between the two roles they played in a price-conditional technology model. The theory of induced innovation implies specific hypotheses concerning the causal linkages between prices, future price expectations, and the eventual development of new technologies. As prices change, farmers change the input-output mix, given the existing technology. If these price changes are permanent, they alter producers' future price expectations and the demand for new technologies. Firms allocate resources to innovation according to profitability, which will be affected both by supply-side factors (such as new knowledge) and also by demand-side factors (such as price expectations). There is often a long gestation period between initial research expenditures and the development of new technologies. There is also a lag between the development of a potentially useful technique and its eventual adoption and diffusion. Given the time lag, research allocation decisions and the consequent expansion of the technology set likely will depend upon past price expectations. On the other hand, producers will decide on the optimal input-output mix according to today's information set, which includes today's price expectations and technology set. Given a *sequential* interpretation of the firm's decision process, in any period, a configuration of past prices is historically given; these past prices determine a normal price vector. Corresponding to these normal prices is a technology set, $T(p^N)$, satisfying all the assumptions of the traditional theory of the firm, and hence represented by a transformation function, $F(y; p^N)$. The supply and derived demand functions, $y_i = f^i(p^M; p^N)$, are found by

$$\max_{y} \sum_{i=1}^{n} p_i^M y_i \quad \text{subject to } F(y; p^N) = 0, \tag{12}$$

where p^M refers to market prices. Changes in market prices induce movements along and between fixed isoquants, whereas changes in normal prices induce the development of new technologies, which causes movement of the isoquant map over time.

The supply and derived demand functions, viewed as functions of market prices, exhibit all the properties that traditional theory ascribes to netput functions. They are homogeneous of degree zero in market prices, and the implied matrix of price effects is symmetric and positive semidefinite. These results depend crucially upon holding normal prices fixed and viewing the producer's choice as a function of market prices; they follow immediately from the observation that these functions are derived by maximizing profits subject to a well-behaved transformation function. Because profits are independent of the prices conditioning the transformation function, the situation is precisely the same as in the traditional theory of the firm: normal prices are simply parameters shifting the transformation function and causing no more difficulty than does the use of fixed inputs.

To examine the way in which the supply and derived demand functions depend upon normal prices, it is necessary to specify precisely the determination of normal prices as well as the relation between normal prices and the transformation function. The normal price function specifies the relation between normal prices and actual prices. The model is tractable if normal prices depend upon past price expectations:

$$p_t^N = N(p_{t-1}, p_{t-2}, \ldots). \tag{13}$$

The normal price function will be assumed to be continuous and to satisfy nonnegativity, homogeneity, and convergence. Nonnegativity implies that if, ceteris paribus, the price of good i in some previous period were higher, its normal price in the current period would not be lower. Homogeneity of degree one of the normal price function establishes that if all prices were twice as high, then all normal prices would be twice as high. Finally, if prices converge to a particular configuration, then normal prices also will converge to that configuration.

Although supply and derived demand functions are homogeneous of degree zero in market prices, we have no indication of how they relate to normal prices. It is important, then, to specify precisely the way in which normal prices influence the transformation function. We postulate that the technology depends upon relative rather than absolute normal prices.[4] Technically, we assume that the technology set $T(p^N)$ is unaffected by a proportional change in all normal prices. That is, if $y^* > y'$ at normal prices p'^N, then $y^* > y'$ at normal prices tp'^N, $t > 0$. Thus the marginal rate of substitution involving any pair of commodities is homogeneous of degree zero in normal prices:

$$\frac{F_j(y;\, tp^N)}{F_i(y;\, tp^N)} = \frac{F_j(y;\, p^N)}{F_i(y;\, p^N)} \qquad \forall\, t > 0, \qquad i, j = 1, \ldots, n. \tag{14}$$

Hence, the supply and derived demand functions are unaffected by a proportional increase in all normal prices:

$$y_i^*(p^M;\, p^N) = y_i^*(p^M;\, tp^N) \quad \forall\, t > 0, \qquad i = 1, \ldots, n. \tag{15}$$

Placing additional qualitative restrictions on the transformation function, we were able to deduce meaningful properties on observable behavior. The supply and derived demand functions are homogeneous of degree zero in market prices and, under the relative price hypothesis, homogeneous of degree zero in normal prices. Thus, we are dealing with well-behaved supply and derived demand functions.

An Illustration

In this section, we use a generalized Cobb–Douglas production function to illustrate the effect of price-conditional technology on the choice functions and on the price effects corresponding to this particular functional form. It is assumed that the producer maximizes current profits subject to a production technology of the form

$$y = B \prod_{i=1}^{n} x_i^{\beta_i}, \tag{16}$$

where

$$\begin{aligned} \log(B) &= \delta_0 + \sum_{j=1}^{k} \delta_k \tau_j, \\ \beta_i &= \gamma_{oi} + \sum_{j=1}^{k} \gamma_{ji} \tau_j, \end{aligned} \tag{17}$$

where y is output, x_i are inputs, and τ_j are technology changing variables among which we include output and input price expectations and other variables affecting the technology set, such as research and schooling. The output supply and input demand equations take the form

$$y = B\left[\prod_{i=1}^{n} B^{\beta_i(1-\mu)^{-1}} \left(\frac{\beta_i}{w_i}\right)^{\beta_i} p^{\beta_i\mu(1-\mu)^{-1}+\beta_i} \prod_{j=1}^{n} \left(\frac{\beta_j}{w_j}\right)^{\beta_i\beta_j(1-\mu)^{-1}}\right] \tag{18}$$

and

$$x_i = B^{(1-\mu)^{-1}} \frac{\beta_i}{w_i} p^{\mu(1-\mu)^{-1}+1} \prod_{j=1}^{n} \left(\frac{\beta_j}{w_j}\right)^{\beta_j(1-\mu)^{-1}}, \tag{19}$$

where

$$\mu = \sum_{i=1}^{n} \beta_i,$$

and p and w are output and input prices, respectively.

The generalized own-price effects in this instance would be

$$\frac{\partial y}{\partial p} = \frac{y}{1-\mu}\frac{\mu}{p} + \left(\frac{y}{(1-\mu)^3}\left\{\sum_{i=1}^{n}\gamma_{ip}\left[\frac{\mu}{p} + B^{-1} + 1 + \sum_{\substack{j=1\\ j\neq i}}^{n}\beta_j(w_j - 1)\right]\right\} + \frac{y}{1-\mu}B^{-1}\delta_p\right) \tag{20}$$

and

$$\begin{aligned}\frac{\partial x_i}{\partial w_i} &= \frac{x_i}{(1-\mu)}\frac{1-\mu+\beta_i}{w_i} \\ &+ \left(\frac{x_i}{(1-\mu)^3}\left\{\gamma_{iw_i}\left[B^{-1} - p^{-1} + \beta_i^{-1}(\beta_i + 1 - \mu)^2 + \sum_{\substack{j=1\\ j\neq i}}^{n}\beta_j w_j\right]\right.\right. \\ &\left.\left. + \sum_{\substack{k=1\\ k\neq i}}^{n}\gamma_{kw_i}\left[B^{-1} - p^{-1} + \sum_{j=1}^{n} w_j(\beta_j + 1 - \mu)\right]\right\} + \frac{x_i}{1-\mu}B^{-1}\delta_{w_i}\right),\end{aligned} \tag{21}$$

where the first term on the right reflects the "traditional" price effect and where the remaining terms reflect the technical change effect. The latter terms show the change in output supplied and inputs demanded arising through innovation brought about by change in prices.

In a sequential interpretation of the producer's decision process, the configuration of past prices is historically given; these past prices determine the normal price vector through the normal price function. Corresponding to these normal prices is a technology set (and corresponding isoquant map) satisfying all assumptions of the traditional theory of the firm. This set can be represented by (16) and (17). In this configuration, normal prices will be the technology-changing variables determining the production function coefficients, whereas market prices will be the set of prices, different and independent from normal prices, used by the producer in making input-output decisions. The supply and derived demand functions are formulated as in equations (18) and (19), with $p = p^M$ and $\tau_j = p^N$. Now we can separate the allocative ("traditional") effect of market prices from the technical change effect of normal prices on the supply of output and derived demand of inputs. For this particular functional form, the allocative effects conditional on the level of normal prices are

$$\left.\frac{\partial y}{\partial p^M}\right|_{\substack{p^N\\ w^N}} = \frac{\mu}{1-\mu}\frac{y}{p^M} \tag{22}$$

and

$$\left.\frac{\partial x_i}{\partial w_i^M}\right|_{\substack{w^N\\ p^N}} = -\frac{1-\mu+\beta_i}{1-\mu}\frac{x_i}{w_i^M}. \tag{23}$$

These relations exhibit all the properties of the traditional price effect, a result depending crucially on our holding normal prices fixed and viewing these choices as functions of market prices exclusively.

The effect on output supplied and inputs demanded of price changes influencing technical change through innovation is obtained as

$$\left.\frac{\partial y}{\partial p^N}\right|_{\substack{p^M\\ w^M}} = -\frac{y}{1-\mu^3}\sum_{i=1}^{n}\gamma_{ip^N}\left[\frac{\mu}{p^M} + B^{-1} + \sum_{\substack{j=1\\ j\neq i}}^{n}\beta_j(w_j^M - 1) + 1\right] + \frac{y}{1-\mu}B^{-1}\delta p^N; \tag{24}$$

$$(25)\quad \left.\frac{\partial x_i}{\partial w_i^N}\right|_{\substack{w^M\\ p^M}} = \frac{x_i}{(1-\mu)^3}\left\{\gamma_{iw_i^N}\left[B^{-1} - p^{-1} + \beta_i^{-1}(\beta_i + 1 - \mu)^2 + \sum_{\substack{j=1\\ j\neq i}}^{n} \beta_j w_j^M\right] + \sum_{\substack{k=1\\ k\neq i}}^{n} \gamma_{kw_i^N}\left[B^{-1} - p^{-1} + \sum_{j=1}^{n} w_j^M(\beta_j + 1 - \mu)\right]\right\} + \frac{x_i}{1-\mu}B^{-1}\delta_{w_i^N}.$$

These relations are defined conditionally on the levels of market prices. We can identify qualitative properties of the supply and the derived demand functions in the context of price-dependent technology when normal prices are independent of market prices: they are simply parameters shifting the production function in the same way as a change in the level of a fixed input would. Changes in p^N correspond to shifts of the supply/derived demand functions, while p^M changes represent movements along these functions.

To illustrate the relative magnitudes of the traditional and the technical change effects, consider the results from a price-conditional technology study of a group of developing countries. Equations (16) and (17) are estimated using pooled data for a set of 18 countries from 1960–84. The basic assumption is that all countries have access to the same technology; thus, they share a common meta-production function. This assumption recognizes that different countries use different production techniques and that the coexistence of some countries using advanced techniques and others using traditional techniques can be explained in terms of economic variables. A distinction is made between inputs and technology-changing variables. The former consist of traditionally measured physical inputs. The latter consist of measures of input and output price expectations, input qualities, and research effort. The technology-changing variables determine the production function parameters according to equation (17). Output is measured as gross output net of agricultural intermediate products, such as feed and seeds, and expressed in terms of international dollars. The variables consist of five conventional inputs: labor, land, livestock, fertilizer, and machinery; and six technology-changing variables: output price expectations, expected wages, expected fertilizer prices, research stock, land quality, and schooling.

Labor, land, and livestock are measured, respectively, by the economically active population in agriculture, by the hectares of agricultural land, and by the equivalent livestock units. Similarly, fertilizer and machinery are measured in equivalent nutrient (nitrogen, phosphorous, and potash) units and tractor horsepower. Prices are indexes of prices received for major agricultural products and paid for fertilizers and to agricultural workers. A five-year moving average of divisia price indexes is used to estimate the technical change effect of past price expectations on short-run supply and derived demand functions. Research stock is measured imposing a five-year inverted V lag structure on annual research expenditures, and schooling is the percentage of students enrolled in primary schools. The land quality index is a country-specific variable obtained from Peterson.[5]

The estimated effect of market prices in the allocation of resources (traditional effect), equations (22) and (23), when land and labor are considered fixed resources, is presented in elasticity terms in the first column of table 1. The estimates indicate an elastic output supply and labor and fertilizer demand. Because land, livestock, and machinery prices are unavailable, equations (24) and (25), which indicate the effect of price changes through the innovation process, cannot be used. But at the optimum,

$$(26)\qquad y^* = B\prod_{i=1}^{n} x_i^*(p^M,\ w^M)^{\beta_i(p^N, w^N)}.$$

Therefore, we can evaluate the technical change effect of prices under the assumption that the observed input and output levels are optimal:

Table 1. Traditional and Technical Change Own-Price Elasticities

	$p^M \neq p^N$	
Commodity	Traditional[a]	Technical Change
Output	1.27	.13
	(.45)	(.028)
Labor	−1.57	.72
	(.497)	(.142)
Fertilizer	−1.41	−.55
	(.351)	(.184)

Note: Normal prices are five-year moving averages of past prices.
[a] The traditional (short-run) own-price derived demand elasticity for livestock is −1.38, for machinery is −1.48, and for land is −1.57.

(27)
$$\left.\frac{\partial y^*}{\partial p^N}\right|_{x^*} = \left.\frac{\partial y^*}{\partial p^N}\right|_{\substack{p^M\\ w^M}} = \sum_{j=1}^{n} \frac{\partial y^*}{\partial \beta_j}\frac{\partial \beta_j}{\partial p^N} + \frac{\partial y^*}{\partial B}\frac{\partial B}{\partial p^N} = \frac{y^*}{p^N}\left[\sum_{j=1}^{n} \gamma_{jp}\log(x_j^*) + \delta_p\right]$$

and

(28)
$$\left.\frac{\partial x_i^*}{\partial w_i^N}\right|_{\substack{y^*\\ x_j^*\\ j\neq i}} = \left.\frac{\partial x_i^*}{\partial w_i^N}\right|_{\substack{w^M\\ p^M}} = \sum_{j=1}^{n} \frac{\partial x_i^*}{\partial \beta_j}\frac{\partial \beta_j}{\partial w_i^N} + \frac{\partial x_i^*}{\partial B}\frac{\partial B}{\partial w_i^N}$$
$$= -\beta_i^{-1}\frac{x_i^*}{w_i^N}\left\{\gamma_{iw_i^N}\beta_i^{-1}\left[\log(y^*) - \log(B) - \sum_{\substack{j=1\\ j\neq i}}^{n} \beta_j\log(x_j^*)\right] + \sum_{\substack{j=1\\ j\neq i}}^{n} \gamma_{jw_j^N}\log(x_j^*) + \delta_{w_i}\right\}.$$

We can evaluate this price effect only for output, fertilizer, and labor, given that their respective prices are the only ones included in the estimation as technology-changing variables. The second column in table 1 shows the technical change effect of past price expectations. These elasticities indicate that a 10% increase in normal prices would induce an upward shift of the production function reseulting in a 1.3% increase in output. A 10% increase in wages will result in a 7.2% increase in labor use as a result of changes in production techniques. An increase of the same magnitude in fertilizer prices will induce a 5.5% decline in its use. These results provide additional evidence supporting the lack of invariance of technical change to changes in economic variables reported by Fawson, Shumway, and Basmann for agriculture and by Basmann et al. (1988) for manufacturing.

Conclusions

This section summarizes the implications of price-conditional technology for producer behavior. The first two sections of this article presented a discussion of a model in which prices influence the technology set because the innovation process is hypothesized to be price responsive. The model distinguishes between normal prices (the prices influencing innovation and the technology set) and market prices (the prices influencing a firm's allocation of resources). In a sequential interpretation of the firm's decision process, the choice functions hold normal prices fixed and view output supply and input demand as functions of market price, exhibiting all the properties attributed to them by traditional production theory. The relative price hypothesis postulates that the technology depends upon relative rather than absolute normal prices.

An example was presented in which the effect of price changes on supply and derived demand functions was estimated. Estimates from a variable coefficients Cobb–Douglas meta-production function fitted to agricultural production in a set of 18 developing countries were used to determine the relative importance of the allocative (traditional) versus the technical change effect of price changes. Approximately 8% of the change in the quantity of output supplied was due to the introduction of new techniques through the technical change effect of output price changes. As a result of fertilizer-saving techniques, an increase in fertilizer prices would induce a 55% decrease in the use of this input in production. On the other hand, rising wages would induce changes in the structure of production that would diminish the responsiveness of labor demand.

Our results provide additional evidence supporting the findings of Fawson, Shumway, and Basmann about the "fundamental and powerful impact" on firms' choices of agricultural policies that result in distorted prices. These results also provide a means for modeling technical change without strict reliance on time trend variables.

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Notes

[1] The terminology is borrowed from Pollak, who analyzes the implications of price-dependent preferences for individual demand behavior.

[2] When the transformation function is independent of prices (the "traditional" case), changes in quantity supplied and demanded due to small changes in prices gives

$$dy_i = -\sum_{j=1}^{n} \frac{D_{ji}}{D}\, dp_j. \tag{29}$$

For the special case of a change in the price of the hth commodity,

$$\frac{\partial y_i}{\partial p_h} = -\frac{D_{hi}}{D} \qquad i, h = 1, \ldots, n. \tag{30}$$

[3] We know from Euler's theorem on homogeneous of degree zero functions that

$$f^i(tp) = f^i(p), \qquad i = 1, \ldots, n, \tag{31}$$

where $t > 0$ is equivalent to

$$\sum_{j=1}^{n} f_j^i(p) p_j = 0, \tag{32}$$

where

$$f_j^i(p) = \frac{\partial f^i(p)}{\partial p_j}.$$

Substituting from (9) into (32),

$$-\frac{1}{D}\sum_{j=1}^{n} D_{ji} p_j - \lambda \sum_{j,k=1}^{n} \frac{D_{ki}}{D} F_{k,n+j} p_j - \sum_{j=1}^{n} \frac{D_{n+1,i}}{D} F_{n+j} p_j = 0. \tag{33}$$

The first term vanishes because it is an expansion of D by alien cofactors.

[4] It is also assumed that the technology is continuous in y and p^N.

[5] See the appendix for production function estimates, and see Fulginiti and Perrin for a complete description of procedures used.

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Appendix

All countries and years are pooled together in a single equation of the form specified in equations (16) and (17). This pool gives a total of 410 observations, and the parameters are estimated with OLS. Although the error structure is uncorrelated with the variables representing inputs, its variance is not. The Breusch–Pagan test for heteroskedastic errors indicated that the null hypothesis of homoskedasticity cannot be rejected at the 5% significance level. The parameter estimates of the model in equations (16) and (17) are presented in appendix table A1. The table contains a total of 22 parameters, 12 of which are significant at the 1% level, two at the 5% level, and two at the 10% level. The R^2 for the equation is 0.94, and collinearity diagnostics developed by Belsley, Kuh, and Welsch indicate an absence of multicollinearity.

Table A1. Least Squares Estimates of Production Function Parameters for 18 Countries

	Inputs					
	Land	Livestock	Machinery	Fertilizer	Labor	Intercept
Linear Terms	.040 (.083)	.146 (.114)	.173 (.061)	.093 (.051)	.838 (.093)	−1.964 (.652)
Past Output Price	.527 (.044)	−.554 (.054)	.064 (.030)	−.019 (.024)	.231 (.048)	−2.266 (.336)
Past Wages	—	—	—	—	−.011 (.003)	—
Past Fertilizer Price	—	—	—	.006 (.006)	—	—
Research	.011 (.016)	.041 (.022)	.005 (.013)	.022 (.009)	−.140 (.017)	.523 (.119)
Land Quality	.054 (.007)	—	—	—	—	—
Schooling	—	—	—	—	.040 (.009)	—

Notes: Estimates are based on 410 observations during the years 1961–85. Standard errors are in parentheses; overall R^2 = 0.94.