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Abstract

Developing countries often tax agriculture heavily, a practice that might affect the productivity as well as the quantity of resources allocated to agriculture. A variable-coefficient cross-country agricultural production function is estimated, with past price expectations among the determinants of the production coefficients. Productivity's responsiveness to the expectations implies that, had these developing economies eliminated price interventions, agricultural productivity would have increased by and average of 25 percent.

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Prices and Productivity in Agriculture

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ABSTRACT

Developing countries often tax agriculture heavily, a practice that might affect the productivity as well as the quantity of resources allocated to agriculture. A variable-coefficient cross-country agricultural production function is estimated, with past price expectations among the determinants of the production coefficients. Productivity's responsiveness to those expectations implies that, had these developing economies eliminated price interventions, agricultural productivity would have increased by an average of 25 percent.

PRICES AND PRODUCTIVITY IN AGRICULTURE

During the 1950s and 1960s, most Western economies grew rapidly while international trade grew even more rapidly, stimulated perhaps by the large, multilateral trade barrier reductions during that period. On the other hand, during the 1970s and 1980s, most countries experienced much smaller output and total factor productivity growth rates. Economic policies directed toward goals unrelated to technical change may have affected the rate and direction of that change. Could the decline in productivity growth rates be a result of rapid growth in government programs, taxes, hidden barriers to trade, and other regulatory activities increasing distortions within the world economy? How do these and other economic variables affect the nature of technical change? A better understanding of endogenous technical change should enable economists and policymakers to answer these questions.

In this paper, we examine the direct effects of price policies on the productivity of the agricultural sectors of a sample of 18 developing countries between 1960 and 1984. We describe the theoretical basis for including a technology conditional on price expectations and we empirically estimate such a function to establish the productivity effect, as opposed to the allocative effect, of price distortions in those countries. The price distortions we examine are those created both by sector-specific policies and by general trade and exchange rate policies.

The first section identifies different hypotheses relating prices to productivity. The second section presents a model of endogenous technical change that leads to a variable-coefficients technology with expected prices among the factors affecting the value of the coefficients. The subsequent section presents an application to a set of developing countries, and the last section offers the conclusions.

Innovation, Efficiency, and Prices

In examining factors related to productivity, we must distinguish the concept of technical change through innovation from the concept of efficiency because both affect productivity but are fundamentally different phenomena (Fare and Dogramaci 1988). Technical change generally refers to the use of improved, innovative techniques, whereas efficiency refers to an increase in output occurring while both the level of inputs and the techniques of production are held constant.

Price has been identified as one of the determinants of both innovation and efficiency, though it has not been prominent in the explanation of either. The economics literature on innovation is extensive [see Dosi (1988) for a recent review], but devotes little attention to the role of price as a determinant. Innovation is generally considered an activity to which firms allocate resources according to the profitability of the innovation. This profitability can be affected by supply-side factors such as the existence of new knowledge or the costs of research, or by demand-side factors such as price changes or appropriability changes (Schmookler 1966). The clear implication of this conceptual approach is that increases in expected product price (or demand) should increase the incentives for innovation. Schmookler's examination of patent data clearly revealed a positive relationship between product demand and innovation.

Contemporaneously with Schmookler, Lucas (1967) provided more straightforward support for this hypothesis by identifying a negative regression relationship between the rate of factor productivity in the U.S. manufacturing sector and the price of both labor and capital (each divided by output price). Binswanger (1978) developed a very explicit firm behavior model to show that the benefits of innovation will increase with expected prices if the optimal quantity is expected to increase because of the innovation. These findings all imply a positive relationship between output price and innovation and, depending on the nature and the size of anticipated input biases, an ambiguous relationship between input price and innovation. Huffman and Evenson (1989) provide empirical evidence supporting the positive price-innovation relationship for the U.S. agricultural sector. Mundlak (1988) argues similarly that prices are one of the state variables that determine the choice of technique and therefore productivity. Mundlak's approach, however, does not offer a hypothesis regarding the sign of the relationship.

The literature on efficiency also suggests a role for price. Hicks (1932, 1935) suggested that monopolists with the luxury of the "quiet life" might be technically inefficient, and Leibenstein (1973) added that, within firms with market power, managerial motivation may be so lacking that technical inefficiency may be a significant source of reduced productivity. The role of price within this context is that, as competitive pressure forces prices lower, incentives for managers to improve technical efficiency (or to innovate, for that matter) are greater because the firm's survival is threatened. The hypothesis related to price is thus exactly the opposite of that suggested by the innovation literature, namely, a negative relationship between output price and productivity or a positive relationship between input price and productivity (Leibenstein 1966, 1973; Nelson and Winter 1974).

Various studies have offered empirical support for this hypothesis. Bergsman (1974), for example, examined the effects of import protection in six countries and calculated that the cost of protection included productivity reductions equal to between 2 percent and 6 percent of gross national product (GNP). Martin and Page (1983) estimated a frontier production function for logging and milling industries in Ghana and found that public price subsidies reduced productivity. In agriculture, Kalaintzandonakes and Taylor (1990) found that the average rate of productivity growth for a set of Florida vegetable crops with no import competition was 1.6 percent per year, whereas the average rate for a set of similar crops competing with Mexican imports was 5.1 percent per year.

Given the competitive structure of agriculture, there seems little a priori likelihood that the "quiet life" hypothesis would prevail, except perhaps in relatively small, highly concentrated, specialty commodities such as those examined by Kalaintzandonakes and Taylor (1990). Our expectation is that, in the aggregate, prices would be positively related to productivity, as suggested by the innovation literature. Indeed, without offering explicit models or extensive data to support their assertions, a number of observers of the agricultural economy have asserted the existence of a positive relationship between prices and productivity.

Schultz (1979), for example, argues passionately that it is clear from his observations that the higher the prices are in agriculture, the faster the productivity rate grows. Schuh (1974) argues that in the 1960s the overvalued U.S. dollar tended to depress agricultural prices in the United States and that this in turn reduced the rate at which new production technology was adopted. But despite the considerable attention to the question of price and productivity in agriculture, as Capalbo and Antle (1988) state, "We know of virtually no research that has attempted to account for the effects of government intervention or regulation in agriculture on the measurement and explanation of agricultural productivity . . .", and they add that ". . . we would expect that government policies may have substantial effects on agricultural productivity."

An Endogenous Technology Approach to Productivity

According to Dixit (1976), a technique is a particular combination of inputs producing a particular output; that is, a production process. We define the collection of all available techniques, as described by an isoquant map or a production function or indirectly by a cost function, as the technology available at a point in time. When new techniques become available through new knowledge, technology changes. Our objective here is to develop a model of production within which the technology embodied is to some degree endogenous and responsive to previous choices. Our general approach is to posit a production function for which the coefficients are variable and determined at any one place and time by those previous choices and the current technological, natural, and institutional environment. We refer to these as *technology-changing variables*.[1] The focus of this paper is on the effects of prices as technology-changing variables. Other technology-changing variables of interest are those related to the quality of natural and human resource endowments.

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 innovations as the literature reviewed here suggests, then the price regime of one period must in some way affect the technology relevant to a subsequent period. In terms of a meta-production function, we argue that any new technique (technical change) can be described in terms of a unique combination of inputs if inputs are narrowly enough defined and distinguished. Then we can specify the meta-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," in Mundlak's (1988) terms] that are individually either unknown at a specific time or unobservable by the researcher. Over time, new inputs in the vector x_2 are discovered and adopted; 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; that is, one might reasonably express their current values as a function of previous prices: $x_{2t} = g(p_{t-1})$, and thus $y_t = f(x_{1t}, p_{t-1})$.

The General Model

In this paper, we assume the production function

$$y = f(x;\beta) \tag{1}$$

to be a real-valued function characterizing the maximum amount of y that can be produced from any given set of conventionally measured inputs $x = (x_1, \ldots, x_n)$, where β designates the vector of all parameters. Let τ_k, $k = 1, 2, \ldots, m$ represent technology-changing variables that determine the production function parameters according to

$$\beta_i = G_i(\tau_1, \ldots, \tau_m). \tag{2}$$

As mentioned, the technology-changing variables can be related to the quality of natural and human resources as well as to technical change that is proxied by past price regimes or other policy variables. We introduce the concept of elasticity of productivity with respect to the τ_i's, defined as

$$\psi_k \equiv \partial y/\partial\tau_k\, \tau_k/y, \tag{3}$$

which indicates the percentage by which a productivity index (percentage output change with inputs fixed) would change in response to a 1.0 percent change in τ_k.

It is not just the productivity effect that is of interest, but also the input bias effects of the technology-changing variables. We define pair-wise bias to be the log of the change in the ratio of marginal products of the two inputs in question. Thus, we define the bias induced by the technology-changing variable τ_i as the change in the log of the ratio of marginal products:

$$B_{n,i,\tau k} \equiv \partial\{\log \partial y/\partial x_n - \log \partial y/\partial x_i\} / \partial\tau_k,$$

or

$$= \partial \log MRS_{i,n} / \partial \tau_k , \tag{4}$$

where MRS is the marginal rate of substitution between input i and input n. If $B_{n,i,\tau k}$ is positive, an increase in τ_i will increase the marginal product of input n more than that of input i, and the use of input n will increase relative to i, ceteris paribus. We define a measure of the net bias effect of τ_k with respect to input n as

$$B_{n,\tau k} \equiv \Sigma_i\, \beta_i\, B_{n,i,\tau k}\, , \tag{5}$$

where β_i is the production elasticity with respect to input i, namely, $\beta_i = \partial y/\partial x_i(y/x_i)$. See the Appendix for a complete explanation.

In the general case, the elasticities (3), (4), and (5) with respect to the technology-changing parameters may be variable and depend upon all the quantities of inputs $x_1, \ldots, x_n$ and all the technology-changing variables.

A Cobb-Douglass Specification

In this paper, the following algebraic class of production functions is considered:

$$y(x;\beta) = A\, \Pi_i\, x_i^{\beta i}\ , \tag{6}$$

where

$$\log A = \alpha_0 + \Sigma_k\, \alpha_k\, \tau_k + \mu_0\ , \qquad k = 1, \ldots, m, \tag{6a}$$

$$\beta_i = \gamma_{i0} + \Sigma_k\, \gamma_{ik}\, \tau_k + \mu_i\ , \qquad i = 1, \ldots, n, \tag{6b}$$

where y is the maximum output producible from a given vector of n inputs, x; τ_k's are the technology-changing variables; α's and γ's are fixed coefficients; μ_0 is a random variable distributed independently of the x_i's and τ_k's; and the μ_i's are random variables independent of the τ_k with mean zero and a finite positive semidefinite covariance matrix. Thus, the β_i's here represent a variable elasticity of output with respect to each of the input variables x.[2] The technology-changing variables τ determine the production elasticities and are taken by the decision makers as parameters for the current production period. Expressing (6) in logs, we obtain the convenient econometric model

$$\log y = \alpha_0 + \Sigma_k\, \alpha_k\, \tau_k + \Sigma_i\, \gamma_{io} \log x_i + \Sigma_i\, \Sigma_k\, \gamma_{ik}\, \tau_k \log x_i + \Sigma_i\, \mu_i \log x_i + \mu_0\ . \tag{7}$$

This model allows us to directly evaluate the impact of past prices policies (included in the vector of technology-changing variables) on the technology. The elasticity of productivity of the technology-changing variables for this function is evaluated from (3) as

$$\psi_k = (\tau_k \Sigma_i \gamma_{ik} \log x_i + \alpha_k) \,. \tag{8}$$

If technology-changing variable τ_k is expressed as the log of some variable, say z_k, then the elasticity of productivity with respect to z_k is simply

$$\psi_k = \Sigma_i \gamma_{ik} \log x_i + \alpha_k \,. \tag{8a}$$

Thus, if changes in past price policies were matched by changes in past price expectations, we can conclude that ψ_k provides a measure of the effect of that price policy on current productivity.

The production elasticities as specified in (6b) depend on the level of the variables that condition the individual's choice, so they differ by observation.[3] The quality of available resources, the set of techniques available for production, and past price expectations will combine to determine the productivity of each input.

The bias parameters introduced in (4) and (5) determine whether increases in the technology-changing variables have neutral or biased effects on input use. The pair-wise bias parameters for the production function (6) may be evaluated as

$$B_{n,i,\tau k} = \gamma_{nk}/\beta_n - \gamma_{ik}/\beta_i. \tag{9}$$

A zero pair-wise bias parameter value implies Hicks neutrality, whereas a positive (negative) value implies an n-using (n-saving) technical change from an increase in τ_i. The net bias parameter for the production function in (6) is evaluated as

$$\begin{aligned} B_{n,\tau k} &= \Sigma_i \beta_i B_{n,i,\tau k} \\ &= \Sigma_i \beta_i (\gamma_{nk}/\beta_n - \gamma_{ik}/\beta_i) \\ &= (\gamma_{nk}/\beta_n) \Sigma_i \beta_i - \Sigma_i \gamma_{ik}. \end{aligned} \tag{10}$$

A positive (negative) $B_{n,\tau k}$ value implies that increases in the technology-changing variable τ_k will increase (decrease) the cost share of input n.

We now use this approach to measure the effect of past price policies on agricultural productivity in a set of 18 developing countries.

An Application to Agricultural Protection and Productivity in 18 Developing Countries

We have selected for this study a set of 18 countries for which recent World Bank studies have made considerable data available [for more detail, see Elisiana, Fulginiti, and Perrin (1991)]. Table 1 lists these countries, the years for which we examined each, and the average level of agricultural protection during the period. The protection rates include the price effects of both direct commodity price interventions and the indirect agricultural price effects of real exchange rate distortions and protection afforded to nonagricultural commodities. The simple average total discrimination against the sector amounts to 36 percent.

Agricultural output will be reduced by interventions of this size (except in South Korea, where net protection was provided to the sector) because of reallocation of resources away from agriculture. But our concern is whether the productivity of resources allocated to the sector is also affected. To estimate the productivity effect of price distortions, we first fit the production function in (7) using pooled data for these countries, and then use the parameter estimates along with estimated price distortions to calculate estimated agricultural productivity effects of past price policies. The elasticity of productivity [Equation (8)] multiplied by the percentage of price distortion will indicate the shift that would have occurred in the production function if past prices had been at border prices, as opposed to the protected levels determined by past policies.

The basic assumption is that all countries have access to the same technology and that they thus share a common meta production function. It is recognized that different countries use different

Table 1. Agricultural protection and growth in 18 developing countries

Country	Years	NPR[a]	Production Growth
		--------Percent--------	
Argentina	1961-84	–40	2.1
Brazil	1969-83	–13	3.8
Chile	1961-83	–25	1.8
Colombia	1961-83	–33	2.8
Dominican Republic	1966-85	–40	2.8
Egypt	1964-84	–53	2.7
Ghana	1958-76	–24	1.1
Ivory Coast	1961-82	–53	5.2
Malaysia	1961-83	–18	3.3
Morocco	1963-84	–34	4.0
Pakistan	1961-84	–47	3.8
Philippines	1961-82	–32	3.8
Portugal	1961-83	–18	–0.1
South Korea	1961-84	16	4.2
Sri Lanka	1961-85	–49	2.1
Thailand	1961-84	–41	4.7
Turkey	1961-83	–36	2.8
Zambia	1966-84	–53	2.2

[a] NPR is the nominal protection rate, or (domestic price/border price) minus 1, adjusted for exchange rate misalignment and protection to industry.

[b] Calculated from Food and Agricultural Organization production indexes (United Nations [a]).

production techniques and that the coexistence of some countries using advanced techniques with others using traditional techniques could be explained by economic variables. Cross-country production functions have been the subject of a number of papers in the past, starting with a study by Bhattacharjee (1955), and followed by a series of studies by Hayami and Ruttan and their associates (Hayami 1969; Hayami and Ruttan 1970, 1971; Nguyen 1979; Yamada and Ruttan 1980; and Kawagoe, Hayami, and Ruttan 1985). Evenson and Kislev (1975), Antle (1983), Peterson (1988), and Lau and Yotopolous (1989) examined countries and/or variables that differed from the Hayami and Ruttan series of studies. A study by Mundlak and Hellinghausen (1982) is of special relevance to our study because it was the only previous effort to specify a variable-coefficients Cobb-Douglass production function. In the latter study, the coefficients are determined by variables representing the country's resource endowments.

Empirical Estimates

Data. The main empirical concern of this paper is growth in aggregate productivity, as opposed to growth in production. We measure productivity as the rate of change in total factor productivity, which is essentially the residual difference between observed output growth and the output growth predicted by observed input growth. This measure of productivity is, of course, not without ambiguity; one may arbitrarily reduce productivity differences that are measured by adjusting observed input quantities to account for "quality" changes. One logical response to this ambiguity is the position that all technological change must be embodied in some input, with the implication that, if inputs and input quality are correctly measured, then the measured change in total factor productivity will be zero (for example, Schultz 1969). In this paper, we want to measure differences in output for a given amount of conventionally measured inputs, so our approach is to account for changes in the productive quality of these inputs by introducing separate variables such as schooling of workers and an index of land quality.

A distinction is made in the previous section between inputs and technology-changing variables. The former consist of traditionally measured physical inputs, whereas the latter consist of measures of qualities of these inputs, prices, and research effort. To achieve comparability with other studies, we use the same input variables as those in the Hayami and Ruttan series of studies. The variables in the data set consist of the following:

Output (y): Value of agricultural production in millions of 1980 "international" dollars;[4]

Land (x_1): Thousands of hectares of arable and permanent cropland and permanent pastures (U.S. Department of Agriculture n.d.);

Livestock (x_2): Number of cow equivalent livestock units (United Nations [a]) as reported by Hayami and Ruttan;

Machinery (x_3): Agricultural tractors and garden tractors (United Nations [a]) in thousands of horsepower units, aggregated according to Hayami and Ruttan's procedures.

Fertilizer (x_4): The sum of nitrogen, potash, and phosphate content of various fertilizers consumed, measured in thousands of metric tons in nutrient units (U.S. Department of Agriculture n.d.); and

Labor (x_5): Thousands of participants in the economically active population in agriculture.[5]

We distinguish three types of technology-changing variables: those related to past price expectations, those related to the introduction of new techniques, and those related to the quality of the country's endowments. The proxies we used for them are explained here.

Output Price (τ_1): Five-year moving averages of Tornquist indexes of prices received for major agricultural products. Price indexes were constructed in the following manner. Tornquist indexes were constructed for each country by using deflated domestic currency price series for the relevant commodities. Then, for 1980, a cross-country price index was constructed as a Tornquist index value for each country relative to a base consisting of the 18-country average price and quantity for each commodity (prices converted to U.S. dollars at the 1980 official exchange rates). The domestic price index series for each country was then divided by the 1980 cross-country index value for that country.

Wages (τ_2): Five-year moving averages of monthly wages in U.S. dollars paid to agricultural workers. The deflated wages for each country were divided by a 1980 cross-country index consisting of the 18-country wages weighted by employment.

Fertilizer Prices (τ_3): Five-year moving averages of an index of prices paid for fertilizer (nitrogen, potash, and phosphate). The index was constructed in the same manner as the output price index described above.

Agricultural Research (τ_4): Stock of agricultural research, measured with a five-year inverted-V lag structure to accumulate annual research expenditures in thousands of 1980 U.S. dollars. Alternatives considered include research expenditures accumulated with no lag and with a nine-year lag and a five-year inverted-V lag structure to accumulate the number of research personnel in scientific man years (Judd, Boyce, and Evenson 1986; Pardey and Roseboom 1989).

Land Quality Index (τ_5): Peterson's (1987) international land quality index. An alternative measure considered is the soil-type weighted potential production of dry matter (WPDM) in tons per hectare for each country.

Human Capital (τ_6): The gross enrollment ratio for primary schools. An alternative measure of the quality of human capital considered is life expectancy (United Nations [b]).

To keep the data set as large as possible, we used regression interpolations to generate estimates of missing observations. A list of the specific sources, a detailed explanation of the data manipulation, and a listing of the variables used in this analysis can be found in Elisiana, Fulginiti, and Perrin (1991).

Base Model Estimates. All countries and years are pooled together in a single equation of the form specified in (7). This pool gives a total of 410 observations, and the parameters are estimated with ordinary least squares (OLS). Although the error structure in (7) is uncorrelated with the variables representing inputs, its variance is not. The Breusch-Pagan (Breusch and Pagan 1979) test for heteroskedastic errors indicated that the null hypothesis of homoskedasticity cannot be rejected at the 5 percent significance level. Table 2 presents the parameter estimates of the model in (7). The table contains a total of 22 parameters, 12 of which are significant at the 1 percent level, 2 at the 5 percent level, and 2 at the 10 percent level. R^2 for the equation is 0.94 and collinearity diagnostics developed by Belsley, Kuh, and Welsch (1980) indicate an absence of multicollinearity.

Elasticities of productivity with respect to technology-changing variables can be evaluated at the mean value of input variables, using the coefficients in Table 2 and Equation (8). The results show

Table 2. Least squares estimates of Equation (7) for 18 countries

	Inputs					Intercept
	Land	Livestock	Machinery	Fertilizer	Labor	(α_0, α_k)
Linear Terms (γ_{i0})	0.040 (0.083)	0.146 (0.114)	0.173 (0.061)	0.093 (0.051)	0.838 (0.093)	−1.964 (0.652)
Output Price Exp. (γ_{i1})	0.527 (0.044)	−0.554 (0.054)	0.064 (0.030)	−0.019 (0.024)	0.231 (0.048)	−2.266 (0.336)
Expected Wages (γ_{i2})					−0.011 (0.003)	
Expected Fertilizer Price (γ_{i3})				0.006 (0.006)		
Research (γ_{i4})	0.011 (0.016)	0.041 (0.022)	0.005 (0.013)	0.022 (0.009)	−0.140 (0.017)	0.523 (0.119)
Land Quality (γ_{i5})	0.054 (0.007)					
Schooling (γ_{i6})					0.040 (0.009)	

Note: Based on 410 observations during 1961 to 1985. Standard errors are in parentheses, and overall $R^2 = 0.94$.

relatively small effects of the technology-changing variables (see Table 3). The productivity elasticities of greatest interest here are the ones representing the effects of past price expectations. They indicate that a 10 percent change in past output price expectations (attributable to different policy choices, for example) would produce a 1.3 percent shift of the production function, whereas increases in expected wages and fertilizer prices of the same magnitude would shift it down by 1.0 percent and up by 0.3 percent, respectively. The effects of output price expectations are consistent with the innovation literature that suggests a positive effect of output prices on productivity and inconsistent with the efficiency literature that suggests a negative correlation between prices and productivity.

Quality of the soil and schooling have positive and significant effects on productivity, whereas the coefficient of agricultural research, proxied as a five-year inverted-V lag structure of agricultural research expenditures, is negative but not significantly different from zero. While the insignificance

Table 3. Productivity elasticities

Productivity with Respect To	Mean/Standard Errors
Output Price Expectations	0.13 (0.028)
Expected Wages	–0.09 (0.023)
Expected Fertilizer Prices	0.03 (0.028)
Research	–0.02 (0.020)
Land Quality	0.51 (0.065)
Schooling	0.30 (0.071)

of this research variable is in marked contrast to significant positive effects estimated by Evenson and Kislev (1975) and by Antle (1983) (who used the number of scientific publications as the research variable), it is important to note that lagged price expectations in this model also serve as a proxy for research, and we obtain significant positive effects for that variable. In other words, these results indicate a significant impact of price-induced research, but not so for research measured by government expenditures. We shall return to this issue later.

Production elasticities evaluated at the average values of the variables are presented in row one of Table 4. All are significantly different from zero. The sum of the coefficients is 1.06, very close to constant returns to scale. Previous estimates of labor elasticity are concentrated in the range of 0.35 to 0.42, although the estimates by Bhattacharjee (1955) and Lau and Yotopolous (1989) were approximately 0.3. Thus, our estimate of 0.25 is low relative to others, suggesting that the cost share of labor should be only about one-fourth, but our data set is not adequate to observe this share empirically.

Previous estimates of land elasticity have been anything but consistent. The Lau and Yotopolous estimate was approximately 0.9 when country effects were included, Bhattacharjee's estimate was

Table 4. Production elasticities

Regression Model	Land	Livestock	Machinery	Fertilizer	Labor	Sum
Variable Coefficient	0.25 (0.036)	0.17 (0.044)	0.21 (0.022)	0.18 (0.026)	0.25 (0.035)	1.06
Fixed Coefficient	–0.10 (0.027)	0.40 (0.036)	0.17 (0.022)	0.03 (0.021)	0.33 (0.028)	0.83

Note: Standard errors are in parentheses.

0.36, the first Hayami estimates and those of Mundlak and Hellinghausen (1988) were approximately 0.2, and the remaining estimates were smaller, many near zero. Our estimate of 0.25 is large relative to the majority of these previous studies. Our estimate of livestock elasticity is slightly below the average of others, our estimate of machinery elasticity is higher than most others, and our estimate of fertilizer elasticity is very close to the mean of previous estimates.

The second row of Table 4 shows the estimates of a fixed coefficients model, that is, Equation (7) restricted by $\alpha_k = \gamma_{ik} = 0$ for all i and k, in contrast to those derived from the variable coefficients model. The fixed coefficient results are similar to those of Evenson and Kislev (1975) in a similarly restricted aggregate output model, and to those of Kawagoe, Hayami, and Ruttan (1985) for their subset of less developed countries (LDCs). Lau and Yotopolous (1989) hypothesized that a lack of country-specific effects is the explanation for low land elasticity estimates from such a model, and, upon introducing them into the Kawagoe, Hayami, and Ruttan model and data, their estimates of land elasticity rose to approximately 0.9. Because our variable-coefficients model also includes country-specific effects via the land quality and other technology-changing variables and it too yields higher estimates of land elasticity, our results support the Lau-Yotopolous hypothesis that the omission of country-specific effects biases the estimates of land elasticity downward.

The effect of price-induced technical change on the relative levels of input use is revealed by the pair-wise measures of bias $B_{n,i,\tau k}$ in (10). The estimates of these parameters evaluated at the average values of the variables (Table 5) indicate that past price policies (which affected output prices negatively) biased the input mix against land and in favor of livestock relative to each of the remaining inputs. Past price expectations were labor-saving relative to each of the other inputs except land, fertilizer-using relative to each of the other inputs except livestock, and machinery-saving relative to livestock and fertilizer and machinery-using relative to land and labor. The net bias

Table 5. Biasing effects of an increase in output price expectations

Factor	Bias Relative to Land	Livestock	Machinery	Fertilizer	Labor	Net Bias
Land	–	5.31	1.79	2.91	1.21	1.99
Livestock	–5.31	–	–3.51	–3.12	–4.11	–3.70
Machinery	–1.79	3.51	–	0.40	–0.59	0.07
Fertilizer	–2.91	3.12	–0.40	–	–0.99	–0.36
Labor	–1.21	4.11	0.59	0.99	–	0.70

parameters $B_{n,\tau k}$ indicate that, overall, past price-depressing policies induced technical change that increased the cost shares of livestock and fertilizer and reduced those of land, machinery, and labor.

Alternative Measures of Research and Resource Quality. Given that our estimates indicate a negative impact of government research expenditures on productivity, different specifications for this variable were constructed. Equations (1) through (4) in Table 6 show the results of these alternative specifications. Column (1) shows the productivity and production elasticities previously described. This is the model of Tables 2, 3, and 4, repeated here for reference. In model (2), we impose no lags on research expenditures to obtain a stock variable, which results in a positive productivity elasticity, whereas a nine-year lag [column (3)] results in a negative elasticity. These results suggest that there may be a productivity effect of research expenditures in addition to the price-induced productivity effect, but the short lag evidence supports the hypothesis that agricultural research in developing countries is mostly adaptive, requiring a much shorter gestation and implementation period than is considered to be the case in developed countries. Although these alternative measures of research change the estimate of its own productivity, it is notable that the other elasticity estimates were unaffected.

Table 6. Productivity and production elasticities under alternative proxies for research stock and input quality

	(1)	(2)	(3)	(4)	(5)	(6)
Productivity Elasticities						
Output Price	0.13	0.12	0.13	0.11	0.16	0.13
	(0.028)	(0.028)	(0.027)	(0.029)	(0.028)	(0.025)
Wages	–0.09	–0.10	–0.08	–0.11	–0.12	–0.08
	(0.023)	(0.023)	(0.023)	(0.023)	(0.024)	(0.021)
Fertilizer Prices	0.03	0.02	0.05	–0.04	0.02	0.02
	(0.028)	(0.028)	(0.028)	(0.026)	(0.031)	(0.025)
Research Lag						
Five Years Lag	–0.02				0.07	–0.07
	(0.020)				(0.022)	(0.019)
No Lag		0.02				
		(0.021)				
Nine Years Lag			–0.04			
			(0.018)			
Personnel				0.07		
				(0.019)		
Land Quality						
Peterson's Index	0.51	0.49	0.52	0.57		0.25
	(0.065)	(0.066)	(0.064)	(0.065)		(0.068)
WPDM					–0.37	
					(0.078)	
Human Capital						
Schooling	0.30	0.29	0.29	0.31	0.21	
	(0.071)	(0.072)	(0.070)	(0.073)	(0.082)	
Life Expectancy						2.42
						(0.259)
Production Elasticities						
Land	0.25	0.25	0.25	0.30	0.06	0.32
	(0.036)	(0.036)	(0.036)	(0.035)	(0.031)	(0.034)
Livestock	0.17	0.18	0.17	0.23	0.19	0.10
	(0.044)	(0.045)	(0.043)	(0.043)	(0.046)	(0.041)
Machinery	0.21	0.19	0.24	0.13	0.18	0.15
	(0.022)	(0.022)	(0.022)	(0.019)	(0.023)	(0.022)
Fertilizer	0.18	0.19	0.18	0.21	0.09	0.19
	(0.026)	(0.026)	(0.025)	(0.026)	(0.028)	(0.023)
Labor	0.26	0.25	0.27	0.14	0.40	0.45
	(0.035)	(0.036)	(0.035)	(0.034)	(0.032)	(0.040)

Note: Standard errors are in parentheses.

An alternative measure of government research is scientific man-years. This might be a more appropriate measure if it is true that in many of these countries agricultural scientists are paid low salaries, in which case research measured by expenditures may underestimate the true level of research activity. Hence, we consider [regression (4)] research man-years as an alternative measure, accumulated with a five-year inverted-V lag structure. With this measure of research, the productivity coefficient is positive, but still smaller than elasticities measured by Evenson and Kislev and by Antle (1983), which would be expected given that our model also includes a price-induced technology variable. While the introduction of this measure of research does not affect elasticities of technology changing variables, it does affect the estimated production elasticities, yielding larger estimates for land, livestock, and fertilizer and smaller estimates for machinery and labor.

Equations (5) and (6) of Table 6 introduce different quality measures for land and labor. In (5), the Peterson (1987) land quality index is replaced by the Buringh measure of weighted potential production of dry matter (WPDM), a variable that was also used by Mundlak and Hellinghausen (1982). This variable yields a negative coefficient, suggesting that it is a very poor measure of aggregate land quality. It also substantially affects the estimates of a number of the other elasticities. Equation (6) shows that replacing schooling with life expectancy as a measure of human capital increases considerably (and implausibly) the estimated impact of this variable on productivity, the estimated labor production elasticity, and total returns to scale. For this study, much of the significance of Table 6 is in the stability of the estimates of productivity elasticities for lagged output and input prices. While fertilizer prices do not have a significant effect, the effect of lagged output price on productivity is consistently and significantly estimated at approximately 0.13, and the effect of lagged wages on productivity is also consistent and significant at approximately -0.09.

Estimated Productivity Effects of Agricultural Policies

In this section, we examine the implications of the base model [Tables 2 through 5 and column (1) of Table 6] for evaluating the impact of various government policies on agricultural productivity. The previous theory suggests that the agricultural productivity of LDCs will be affected by policies causing implicit or explicit taxation of the sector. Evidence for a set of developing countries was presented in Table 1. The nominal protection rate reported there is the multiple by which an index of domestic agricultural prices has been raised by government policies above a comparable index of international prices. These are Divisia indexes constructed across commodities representing between 60 percent and 80 percent of the total value of agricultural output for each of the 18 countries in the series. The period analyzed covers the years 1961-84. The protection rates include both the price effects of direct commodity price interventions and the indirect agricultural price effects of real exchange rate distortions and protection afforded to nonagricultural commodities.

In general, the effect of a policy can be described as a percentage price wedge; that is, the difference between the expected demand price and the expected supply price in the period when decisions about the techniques to use are made, expressed as a percentage of the equilibrium price. We assume in this study that prices are exogenous to the agricultural sector so that the price wedges created by various policies can be characterized as exogenous price changes.

To evaluate the effects of policy wedges on the agricultural productivity of each country, we multiply the productivity elasticities (column 1 of Table 7) by the estimated policy-induced price wedges (columns 2 and 3 of Table 7). The productivity elasticities are calculated using Equation (8) evaluated at the mean of inputs for each country. Two price wedges are considered. Column 3 presents the average effect of direct government interventions, that is, those aimed directly at agricultural outputs. The total intervention wedge in column 4 adds to this the price effect of exchange rate policies and other interventions.

Table 7. Estimated productivity changes from eliminating output price policies

Country	Elasticity of Productivity with Respect to Output Price[a]	Price Changes from Eliminating Direct Intervention	Price Changes from Eliminating Total Intervention	Productivity Changes from Eliminating Direct Intervention	Productivity Changes from Eliminating Total Intervention
		(Percent)			
Argentina	0.257	31.3	66.1	8.1	17.0
Brazil	0.515	−6.6	15.2	−3.4	7.8
Chile	0.105	3.2	32.7	0.3	3.5
Colombia	0.028	11.9	48.5	0.3	1.4
Dominican Republic	0.435	32.2	67.5	14.0	29.4
Egypt	0.577	75.7	114.3	43.7	66.0
Ghana	0.505	−7.8	32.1	−3.9	16.2
Ivory Coast	0.787	56.1	111.8	44.2	88.0
Malaysia	0.300	11.8	21.6	3.5	6.5
Morocco	0.345	26.1	52.2	9.0	18.0
Pakistan	0.133	32.9	88.8	4.4	11.8
Philippines	0.088	14.4	46.9	1.3	4.1
Portugal	0.250	28.0	22.8	7.0	5.7
South Korea	0.078	−34.8	−13.9	−2.7	−1.1
Sri Lanka	0.379	33.2	97.4	12.6	36.9
Thailand	0.223	45.9	71.1	10.2	15.9
Turkey	0.338	−1.7	56.4	−0.6	19.0
Zambia	1.122	29.0	115.1	32.5	129.1

[a] Evaluated from Equation (8) using estimated coefficients and the mean value of inputs for each country.

Eliminating direct (commodity-specific) interventions would have increased productivity in every country except those that have been subsidizing their agricultural sector. Brazil, Ghana, South Korea, and Turkey have had direct subsidies, and eliminating those subsidies would have reduced price expectations, which in turn would have led to a lower rate of productivity increase in those countries. Indirect interventions have taxed agriculture in every country except Portugal, with the result that, even in Brazil, Ghana, and Turkey, the net effect of all interventions is to tax agriculture. Thus, all countries except South Korea would have experienced increased productivity had all interventions been eliminated. The estimated productivity increases range from 1.4 percent in Chile to 129 percent in Zambia.

Summary and Conclusions

In this study, we have shown that price policies have had a significant negative impact on agricultural productivity in a sample of 18 developing countries. The policies in question include both direct agricultural price interventions and policies that have affected agricultural prices indirectly, such as trade and macroeconomic policies, which distort agricultural prices. Recent studies indicate that, if all such policies had been eliminated over the study period, agricultural prices would have fallen by 14 percent in South Korea, but would have risen in all other countries, even by as much as 115 percent in Zambia. The simple average price rise across countries would have been 56 percent. This price increase would have increased output through a reallocation of inputs to agriculture. But the concern of this study is the productivity effect of these price changes, measured as the percentage change in output for given levels of traditionally measured inputs (land, livestock, machinery, fertilizer, and labor). The results of the analysis indicate that the price changes would have increased this measure of productivity by a simple average of approximately 25 percent.

The theoretical basis for prices having an effect on productivity arises from the effect that price expectations can have on the incentives for discovering and adopting new technology. Although there is considerable theoretical and empirical support in the literature for the idea that prices can affect innovation and/or efficiency (both of which contribute to productivity), there is no consensus as to whether this effect is positive or negative. Our empirical results indicate a significant positive productivity effect of output prices, and a significant negative effect of agricultural wages, supporting results previously obtained by Schmookler (1986), Lucas (1967), Binswanger (1978), and others as opposed to the results of studies by Leibenstein (1973), Nelson and Winter (1974), Martin and Page (1983), and some others.

To establish the relationship between price expectations and productivity, we have estimated a cross-country production function for the 18 countries for 1960 through 1985. We used a variable-coefficient specification in which the production elasticities of such traditionally measured inputs as land, labor, and tractors are themselves functions of expected prices (measured as five-year moving averages of realized prices) and other technology-shifting variables. Although a number of similar cross-country agricultural production functions have been previously estimated, this study is unique in using a variable-coefficient specification with technology-shifting variables that include input and output price expectations as determinants of the variable coefficients. Our estimates of production elasticities at the mean of the data are 0.25 for land, 0.17 for livestock, 0.21 for machinery, 0.18 for fertilizer, and 0.26 for labor. Estimates in this study indicate higher land and machinery elasticities and lower labor and livestock elasticities than the average of previous studies, but all elasticity estimates are within the range of previous estimates. This indicates that the introduction of technology-changing variables including lagged prices into the production function does not take explanatory power away from the traditional inputs but instead adds to the explanation of the residual.

The analytical approach permits the calculation of elasticities of productivity with respect to each of the technology-changing variables. Evaluated at the mean of data values for all countries, these elasticities are 0.13 for past output price expectations, -0.10 for past wage expectations, 0.03 for past fertilizer price expectations, -0.02 for the stock of agricultural research, 0.51 for land quality, and 0.30 for schooling. Such estimates are obviously of great interest for evaluating public policies related to these variables.

The results of this study are important because they demonstrate that taxing the agricultural sector in developing economies can significantly affect the productivity of resources employed in agriculture as well as the amount of resources allocated to agriculture. These results underscore Schultz's (1969) contentions of decades ago that growth in agricultural output cannot be satisfactorily explained by an analysis based solely on conventional inputs and that policies that depress agricultural prices have a negative effect on agricultural productivity.

APPENDIX

Net Bias Effect of τ_k

To show that $B_{n,\gamma k} = (\Sigma_i\beta_i)\partial\ln s_n/\partial\gamma_k$, first assume that factor markets are in equilibrium, so that $\partial y/\partial x_i = w_i/p$ and thus $(x_i/y)\partial y/\partial x_i = \beta_i = x_i w_i/yp$. The cost share may thus be written $s_n = x_n w_n/\Sigma_j x_j w_j$, and if inputs are fixed so that factor markets adjustments occur through price changes, then

$$\begin{aligned}
\frac{\partial\ln s_n}{\partial\gamma_k} &= \frac{\partial\ln w_n}{\partial\gamma_k} + \frac{\partial\ln x_n}{\partial\gamma_k} + \frac{\partial\ln(\Sigma_i w_i x_i)}{\partial\gamma_k} \\
&= \frac{\partial\ln w_n}{\partial\gamma_k} + \frac{\partial\ln x_n}{\partial\gamma_k} + \Sigma_i\left[\frac{\partial\ln w_i}{\partial\gamma_k} + \frac{\partial\ln x_i}{\partial\gamma_k}\right] \\
&= \frac{\partial\ln w_n}{\partial\gamma_k} - \Sigma_i s_i\frac{\partial\ln w_i}{\partial\gamma_k}.
\end{aligned}$$

From the definition of $B_{n,\gamma k}$, and input market equilibrium,

$$\begin{aligned}
B_{n,\gamma_k} &= \Sigma_i\beta_i\left[\frac{\partial\ln\left(\frac{\partial y}{\partial x_n}\right)}{\partial\gamma_k} - \frac{\partial\ln\left(\frac{\partial y}{\partial x_i}\right)}{\partial\gamma_k}\right] \\
&= \Sigma_i\beta_i\left[\frac{\partial\ln w_n}{\partial\gamma_k} - \frac{\partial\ln w_i}{\partial\gamma_k}\right] \\
&= (\Sigma_i\beta_i)\left[\frac{\partial\ln w_n}{\partial\gamma_k} - \Sigma_i\frac{\beta_i}{\Sigma_i\beta_i}\frac{\partial\ln w_i}{\partial\gamma_k}\right] \\
&= (\Sigma_i\beta_i)\left[\frac{\partial\ln w_n}{\partial\gamma_k} - \Sigma_i\frac{x_i w_i}{\Sigma_i x_i w_i}\frac{\partial\ln w_i}{\partial\gamma_k}\right] \\
&= (\Sigma_i\beta_i)\left[\frac{\partial\ln w_n}{\partial\gamma_k} - \Sigma_i s_i\frac{\partial\ln w_i}{\partial\gamma_k}\right] \\
&= (\Sigma_i\beta_i)\frac{\partial\ln s_n}{\partial\gamma_k}. \quad QED
\end{aligned}$$

ENDNOTES

1. Mundlak (1988) has proposed a similar specification using the term *state variables* rather than technology-changing variables. Mundlak's approach endogenizes the choice of techniques within one period but does not allow for changes in the technology set; for example, technical change. This paper departs from his approach by relaxing this assumption and by focusing on the determinants of change in the technology set.

2. This type of model has also been used by Zellner (1969), who showed that a macro coefficient estimator will not possess aggregation bias if the coefficient vectors of individual micro units satisfy the assumptions of this model.

3. If the technology-changing variables were to include contemporaneous prices, this model would imply nonuniqueness in the relationship between the marginal rate of substitution and the corresponding price ratios, in contrast to neoclassical theory. Although that is not the case for the present application, the possibility resurrects an issue addressed by Robinson, who argued for production models allowing reswitching, meaning that a technology may be more profitable than other technologies at more than one set of relative input prices (Harcourt 1969).

4. "International" dollars are obtained by the Food and Agricultural Organization (United Nations [b]) using the Geary-Khamis (see Elisiana, Fulginiti, and Perrin 1991) price index to aggregate agricultural products for international comparison. The international average prices of agricultural commodities are determined simultaneously with the exchange rates of the national currencies in such a manner that the calculated exchange rates equalize the purchasing power of national currencies with respect to the defined groups of commodities.

5. To the extent that the labor input is measured with error, if this error remains constant over time for each country, its effect can be captured through country-specific variables. Adjustments for labor "quality" differences are attempted through the introduction of a "schooling" variable.

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