Determinants of Productivity Change Using a Profit Function: Smallholder Agriculture in Zimbabwe

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The concept of total factor productivity (TFP)—the ratio of quality-adjusted output to input—is straightforward. Yet explaining productivity change, and attributing residual output growth to its appropriate sources, raises numerous problems. It has long been argued that technical change, policy reform, and institutional innovation are complements and are all required to achieve sustained productivity growth (Johnson; Lipton; Evenson and Kramer; Binswanger and Pingali). However, in explaining productivity growth, the emphasis usually is put on weather and on investments that generate new technology, which farmers must be educated to use (usually public sector research and development expenditures, extension, farmer education). While these factors are undoubtedly important, the conventional approach (see Echeverria for a survey) has often neglected the role of policies and investments at other stages of the agricultural system affecting farm technology adoption.[1]

The danger of the conventional approach is that it may not adequately measure policy effects on productivity through their influence on input and output prices. The conventional approach may therefore provide misleading implications for promoting productivity growth. Weak infrastructure and institutions can prevent the potential gains from R&D from being realized. If these factors are necessary complements to R&D, their costs should be included in evaluating the returns to R&D (Howard, Chitalu, and Kalonge).

Our objective is to consider how the endogenization of prices in productivity models may substantially widen the range of variables perceived to affect farm-level productivity change. We apply this model to account for productivity change in Zimbabwe's smallholder sector, based on a dual normalized, restricted profit function for the period 1975–90. Zimbabwe has been one of the few African countries receiving widespread acclaim for an alleged "agricultural success story." Identifying the sources of Zimbabwean smallholder productivity growth has important implications for agricultural growth strategies elsewhere in Africa.

Profit Function and Determinants of Productivity Growth

Evenson, Landau, and Ballou explain the equivalence of including "shift variables" such as R&D and extension in single-stage estimation of the production or dual profit function, and the two-stage approach where a TFP index is constructed and changes in TFP are then explained by the shift variables. Whereas the production function (and the TFP) models only the physical relationship between inputs an outputs, the profit function imposes an economic model and allows the analysis to incorporate price effects on input demand and output supply. By endogenizing prices, the profit function approach facilitates measurement of policy effects on prices and, in turn, on productivity.

To incorporate these policy effects, farm-level prices of maize, the dominant smallholder

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[1]The common practice of using economic prices is normally designed to subtract the effects of policy rather than measure its impact on productivity.

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crop, are drawn from a price formation equation described in Jayne et al. Annual prices, set by government typically after planting, were modeled as a function of past prices and the previous year's ending stock (ST), which is itself identically equal to lagged stocks, supply (Q), demand (D), and net exports (NX)

$$(1) \quad P_t = f(\sum P_{t-i}, ST_{t-1}) + e_t$$

$$(2) \quad ST_{t-1} = ST_{t-2} + Q_{t-1} - D_{t-1} - NX_{t-1}.$$

Structural equations for supply, demand, and net exports, incorporating exogenous policy effects such as consumer subsidies and marketing board investments (not shown because of space limitations, see Jayne et al.) are substituted into (2). Then, by substituting (2) into (1), it is possible to estimate the effects of these policy variables and other exogenous effects on the output supply and input demand equations derived from the profit function.

Model

The commercial (large-scale) and communal (smallholder) sectors are treated as separate production units to which the restricted or variable profit functions (Lau) are applied, but only the smallholder results are discussed here.[1] Consider a multiple-output technology producing $Y(y_1, \ldots, y_m)$, with expected output prices $P(p_1, \ldots, p_m)$, using n variable inputs $X(x_1, \ldots, x_n)$ with prices $W(w_1, \ldots, w_n)$. Define variable expected profits as

$$(3) \quad \pi = \sum_{i=1}^{m} p_i y_i - \sum_{j=1}^{n} w_j x_j = P'Y - W'X.$$

Normalizing the profit function with respect to an output or input price has the practical advantages of ensuring that the homogeneity requirement is met and of reducing the number of parameters to be estimated. The functional form is the generalized quadratic, defined as

$$(4) \quad \Pi = \alpha_0 + \alpha'\hat{P} + \delta'\Theta + \frac{1}{2}\hat{P}'\beta\hat{P} + \frac{1}{2}\Theta'\phi\Theta + \hat{P}'\gamma\Theta$$

where $\hat{\mathbf{P}}$ is the stacked vector of normalized output and input prices and $(P, R)'$ and Θ are the stacked vector of quasi-fixed, fixed, and conditioning factors $(Z, \theta)'$. Vector $\alpha(\alpha_1, \ldots, \alpha_{m+n-1})$ and matrices $\beta(\beta_{ij}, i, j = 1, \ldots, m + n - 1)$, $\phi(\phi_{gh}, g, h = 1, \ldots, K + L)$ and $\gamma(\gamma_{ig}, i = 1, \ldots, m + n - 1, g = 1, \ldots, k + l)$ contain the parameter coefficients to be estimated. Applying Hotelling's lemma, the output supply and input demand functions are

$$(5) \quad y_i^* = \alpha_i + \sum_{j=1}^{m} \beta_{ij} p_j + \sum_{j=m+1}^{m+n-1} \beta_{ij} w_j + \sum_{g=1}^{k+1} \gamma_{ig} \Theta_g \qquad i = 1, \ldots, m$$

$$(6) \quad -x_i^* = \alpha_i + \sum_{j=1}^{m} \beta_{ij} p_j + \sum_{j=m+1}^{m+n-1} \beta_{ij} w_j + \sum_{g=1}^{k+1} \gamma_{ig} \Theta_g \qquad i = m + 1, \ldots, m + n - 1$$

Denoting nonnormalized or actual expected prices with a superscript A, the elasticities of outputs and inputs to prices for the *nonnumeraire* cases are

$$(7) \quad \eta_{ij} = \frac{1}{wO} \beta_{ij} \frac{p_j^A}{y_i} \qquad i, j = 1, \ldots, m$$

$$\eta_{ij} = -\frac{1}{wO} \beta_{ij} \frac{w_j^A}{x_i} \qquad i, j = m + 1, \ldots, m + n - 1.$$

Price elasticities relating to the *numeraire* price or demand are derived from (4).

If the elements of Θ are treated as short-run production constraints, we can derive the effects of relaxing the Θ variable constraints on output and variable input levels. We derive these effects in elasticity form by logarithmic differentiation of (5) and (6) [and of (4) for the *numeraire* input] with respect to the elements of Θ

$$(8) \quad \epsilon_{ih} = \frac{\Theta_h}{y_i} \gamma_{ih}$$

[1] See Khatri et al. for commercial sector (i.e., large-scale) analysis.

$$i = 1, \ldots, m;\ h = 1, \ldots, k+1$$

$$\epsilon_{jh} = -\frac{\Theta_h}{x_j}\gamma_{jh}$$

$$j = m+1, \ldots, m+n-1;\ h = 1, \ldots, k+1$$

$$\epsilon_{0g} = -\left(\delta_g + \sum_{j=1}^{k+l}\phi_{gj}\Theta_j\right)\frac{\Theta_g}{x0}$$

$$g = 1, \ldots, k+1.$$

Shadow prices of the Θ variables can be derived as partial derivatives of the profit function (Diewert). The derived shadow values can be interpreted equivalently as (*i*) the marginal change in profit of an increment in a particular Θ element, (*ii*) the imputed rental value of an additional unit of that factor, or (*iii*) the effect on expected profit of relaxing the particular constraint represented by each Θ variable. The shadow value equations are

$$(9)\quad \lambda_g = \frac{\partial\pi}{\partial\Theta_g} = wO\frac{\partial\Pi}{\partial\Theta_g}$$

$$= wO\left(\delta_g + \sum_{h=1}^{k+l}\phi_{gh}\Theta g + \sum_{i=1}^{m}\gamma_{ig}p_i + \sum_{j=m+1}^{m+n-1}\gamma_{jg}w_j\right)$$

where the shadow values of land and policy variables are of particular interest.

Results and Interpretation

The annual data, covering 1975–90, are from Thirtle et. al. and a further description can be found there. The output groups are maize, livestock, and all other crops (mainly oilseeds, sorghum, and millets). Variable inputs are aggregated into a livestock input and a crop input (the latter used as the *numéraire* in the normalization procedure). A price is defined for each output and input group. Land and labor were treated as quasi-fixed,[2] because lack of price information precluded any other approach. Both the land and labor series are somewhat crude and it was not possible to adjust for land quality or for full-time adult labor equivalents.

The conditioning factors, assumed to shift the production function, are lagged R&D and extension (following Ito), the number of Grain Marketing Board (GMB) depots and collections points servicing smallholder areas, and the annual number of government loans disbursed to smallholders. Household-level analysis of survey data indicate that government credit facilitated input purchases such as hybrid seed and fertilizer (Rohrbach); credit repayment was tied to crop sales to the GMB. Besides providing closer market outlets, the expansion of GMB infrastructure into smallholder areas was designed to stimulate farm technology adoption by providing the means for government to implement its agricultural credit program. However, both GMB market infrastructure and state credit disbursement contracted after the mid 1980s, when the costs of the system rose dramatically.

Table 1 summarizes price and fixed factor elasticities evaluated at the variable means. Own-price elasticities of maize (0.76), livestock (0.60), and livestock inputs (–0.42) have the expected sign and significantly differ from zero at the 0.05 level. Smallholders' apparent responsiveness to maize price incentives indicates that factors drawing down stocks, and hence exerting upward pressure on producer prices, stimulate agricultural production.[3] For example, a subsidy reducing the consumer price of maize meal by 10% reduces stocks and hence increases next year's expected maize price, output, and crop input use by 7.5%, 5.6%, and 1.6%, respectively. However, the system-wide effects of such policies on agricultural productivity are not clear because they have had consequences at other stages of the agricultural system that are not fully captured through their effects on productivity at the farm level. For example, historic subsidies on maize meal distributed through the official marketing system have hampered the development of less costly decentralized milling and trading networks, to the detriment of household food security (Jayne et al.).

All outputs appear to be substitutes and the relatively large negative cross elasticities explain why aggregate supply response is far lower than that of individual crops.

Maize output appears highly responsive to the number of GMB crop buying stations, and inversely (but nonsignificantly) related to the number of loans. Livestock output is negatively

[2] The term "fixed" refers to the manner in which the variables are included in the function, and does not imply that they are treated as constants; in fact, the land and labor variables varied considerably over the sample period.

[3] Similar elasticity estimates and a discussion of the relationship between maize prices and stock levels in Zimbabwe are presented in Buccola and Sukume.

Table 1. Elasticities and Shadow Values, Smallholder Agricultural Sector

Explanatory variable	Dependant variable					Shadow value at variable means
	Maize	Livestock	Other crops	Livestock inputs	Crop inputs	
P Maize	0.76 (3.32)	–0.28 (–3.05)	–0.03 (–0.59)	0.07 (0.26)	0.21 (7.10)	
P Livestock	–0.56 (–3.05)	0.60 (4.74)	–0.10 (–3.12)	0.42 (1.76)	–0.65 (–2.85)	
P other crops	–0.43 (–0.59)	–0.22 (–3.12)	–0.17 (–0.82)	–0.21 (–1.70)	0.28 (1.30)	
P livestock inputs	0.01 (0.26)	0.05 (1.76)	–0.01 (–1.70)	–0.42 (–2.46)	–0.20 (–1.40)	
P crop inputs	0.78 (7.10)	–0.12 (2.85)	0.02 (1.30)	–0.39 (–1.40)	–0.06 (0.44)	
LAND (per ha)	3.12 (0.87)	0.34 (0.33)	–0.59 (–0.19)	4.54 (1.91)	2.41 (0.81)	–Z$20,212 (–0.34)
LABOR (per person)	–1.44 (–0.53)	1.73 (2.42)	1.86 (0.77)	–1.58 (–1.02)	–0.02 (–0.16)	Z$207 (0.30)
RESEARCH (Z$)	–0.86 (–1.36)	0.04 (0.23)	–1.24 (–2.60)	–0.47 (–0.96)	–6.12 (–1.01)	Z$1.48 (6.13)
DEPOT (per station)	0.29 (2.45)	–0.09 (–2.78)	0.10 (1.03)	–0.07 (–1.01)	0.16 (0.19)	Z$5.47 mil. (2.29)
CREDIT (per loan)	–0.23 (–1.55)	–0.01 (–0.28)	–0.18 (–1.44)	–0.36 (–3.71)	0.34 (2.39)	Z$9,185 (2.12)

* t-values given in parentheses.

related to the number of GMB buying stations (with a small but significant elasticity), indicating that the dramatic increase in maize output after independence may have come at the expense of livestock production. Credit disbursement appears to be positively and significantly related to the purchase of crop inputs.

R&D had insignificant effects in all the models tested, in sharp contrast to findings for the commercial sector by Thirtle et al.[4] This is not entirely surprising. Most of the new hybrids adopted by commercial farmers were introduced into a system of relatively well functioning input, output, and credit markets. By contrast, the maize hybrids now universally adopted by smallholders were on the shelf for a decade before the post-independence government substantially expanded credit and market infrastructure for smallholders in the early and mid 1980s. The use of on-shelf maize hybrids increased from 29% of smallholder maize area in 1979 to virtually 100% by 1985 (Rohrbach). Zimbabwe's smallholder experience suggests that the payoffs from R&D investments may not be fully realized without attention to complementary investments in input and output markets, and that the costs of these investments should be taken into account when evaluating the benefits of R&D research.

[4] The rate of return to R&D for the commercial sector was estimated from the TFP and from a translog production function, and was between 40% and 60% (see Thirtle et al).

Shadow Prices

The last column of table 1 presents estimated mean shadow values of fixed and policy variables. Estimated shadow prices of land were not significantly different from zero, and actually declined somewhat over the sample period. In spite of increased population pressure in smallholder lands, total cropped area has decreased slightly since the mid 1980s, as real producer prices have gradually declined, government buying stations have been closed, and government credit supply has been contracted. A shift of resources out of agriculture, consistent with other evidence of declining returns to land and labor in marginal smallholder areas (MLARR), may account for the low shadow prices of land and labor, although as mentioned earlier, data constraints suggest that the results should be interpreted cautiously.

Shadow values of the policy variables are large and significant, indicating the importance of state marketing infrastructure and increased credit availability in stimulating crop production and the uptake of "green revolution" technologies by smallholders in the 1980s. On the presumption that increased use of these modern technologies accounts for the rapid growth of TFP identified by Thirtle et al., the results suggest that TFP growth over the period examined can be attributed partially to the policy variables and their complementarity with earlier R&D expenditures. By contrast, the government has, since the mid 1980s, reduced the

number of loans to smallholders and the number of state buying stations in smallholder areas due to mounting budget pressures. The decline in these investments has progressively shifted the costs of capital and marketing from the state to smallholders, and has been associated with a decline in total factor productivity growth in the late 1980s, as indicated by Thirtle et al.[5]

However, these results indicate the effect of such investments only on farm-level productivity. A comprehensive assessment of the post 1980 Zimbabwean smallholder strategy requires examination of the state marketing expansion and associated regulations at other stages of the system. For example, Jayne et al. have estimated that policy restrictions on private trade designed to ensure the state's monopoly on grain trading have reduced real incomes and food security in the grain-deficit regions of the country. That is, investments that increase farm productivity growth do not necessarily improve welfare.

Conclusions

While R&D and extension clearly promote the availability of new productivity-enhancing technology, conventional productivity studies have often held constant the effects of complementary policies facilitating the use of new technology. The danger of such an approach is that it may overestimate payoffs to R&D, when R&D may not actually generate anticipated impacts without supportive investments in input and product markets (Howard, Chitalu, and Kalonge). This underscores the importance of viewing productivity from a systems perspective, in which the rate of return to investments at one stage are liable to depend on the kinds of investments made at other stages of the agricultural system (Boughton, Shaffer). A challenge for future research is to more accurately assess the importance of "prime movers" (e.g., human capital, technical innovation, policies, and institutions) that may be individually essential but largely insufficient to generate appreciable productivity growth without improvements in other prime movers.

The Zimbabwe case has major implications for other governments seeking to meet the needs of an expanded client base. The rise and subsequent decline in TFP growth during the 1980s has mirrored an expansion and subsequent contraction of key public investments shown to stimulate smallholder production incentives but involving large treasury outlays. A major issue is how to redesign (rather than abandon under budget pressure) key public sector programs to raise agricultural productivity and serve a larger clientele in a sustainable way.

[5] Similar findings from Zambia indicate that substantial public investment in and control of input and output markets, while stimulating smallholder adoption of green revolution technologies, was uneconomic and financially unsustainable over the long run (Howard, Chitalu, and Kalonge).

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