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Estimation of dynamic maize supply response in Zambia

Kenneth A. Foster [a,*], Anthony Mwanaumo [b]

[a] Department of Agricultural Economics at Purdue University, West Lafayette, IN 47907-1145, USA
[b] Zambian Ministry of Agriculture, Food, and Fisheries, Lusaka, Zambia

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Abstract

Increased attention on government pricing policies among African nations leads directly to a need for information about producer responses to price adjustments. This is especially true in the case of Zambian maize production. Maize is the most important crop grown in Zambia. It accounts for more than 80% of the value of marketed food crops, is heavily relied on for subsistence consumption, and is a staple food in the diet of all Zambian citizens. This paper analyzes the aggregate price response of maize supply in Zambia using a dynamic regression analysis. As a result, short, intermediate and long-run multipliers/elasticities are measured which can be used to analyze the effect of future price policy changes.

It was found that a second-order rational distributed lag model best fits the available data. Estimates of short-run elasticities of supply for maize and fertilizer prices are 0.54 and −0.48, respectively. The corresponding estimated long-run elasticities are 1.57 and −1.44.

1. A dynamic model of maize supply response in Zambia

Maize is the single most important crop in Zambia. It accounts for 70% of the total crop area, more than 80% of the total value of marketed food crops, and is the staple food for the majority of the 8.5 million Zambians. Consequently, changes to maize pricing policies have important impacts on the entire agricultural sector and other related industries. However, there has been little research conducted to estimate the response of Zambian maize producers when changes in the economic environment occur. Static estimates of price elasticities of supply for the Zambian maize sector derived from previous studies are: 0.21 (Katepa, 1984), 0.51 (Nakaponda, 1992), and 0.80 (Harber, 1992). In his survey of developing country agricultural supply response models, Rao (1989) notes that short-run acreage response elasticities range from zero to 0.8 while long-run estimates range from 0.3 to 1.2. In a recent paper, Holden (1993) uses peasant household models for northern Zambian farming systems to show that "removal of fertilizer subsidies would result in a dramatic reduction in maize production."

Maize pricing policies are continuously reviewed as part of the government's economic adjustment program. The recently proposed Food Security Act of 1993 (GRZ, 1993) would, among

* Corresponding author.

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other things, remove the government authority to control the internal price of maize. As government control on maize prices is relaxed and new policies are developed, the knowledge of farmer responsiveness to price adjustments is essential in determining the economic impacts of the new Food Security Act. Such information can improve the effectiveness of price policy reform and form a basis for developing transitional policies that are sensitive to the overall Zambian agricultural sector.

When estimating the aggregate supply response to maize price it is important to consider dynamics. For a number of reasons, the aggregate response of Zambian farmers may not be revealed in a single season. There exist constraints in capital markets which prevent the full desired adjustment in production to take place in the short run. Rao (1989) echoes this point when he writes, "When credit markets are imperfect, the long-run response of supply depends on the propensity of farmers to save and invest out of their incomes." Suppose an increase in production of 20% would restore equilibrium, after an exogenous price increase, but investment capital is available only to increase production by 10%. If the higher prices persist then additional production increases will occur in succeeding years until the equilibrium level of production is reached. In addition, there is likely to be an asset fixity problem once capital is devoted to maize production. This is especially true because maize comprises such a large percentage of agricultural production in Zambia. Once an increase in production takes place, it is likely to persist into the future. In fact, it is possible that producers optimizing under such constraints will overshoot the optimal production level and subsequent downward adjustments will be necessary. This suggests a possible cyclical dynamic response. These factors suggest that the process of supply response is dynamic. We propose to estimate these dynamic supply effects in order to track the possible effects of maize and fertilizer price reforms.

This paper analyzes the aggregate dynamic response of Zambian maize farmers as a way of assessing the effectiveness of the ongoing price reforms. A profile of dynamic multipliers for both maize and fertilizer price changes are estimated. The dynamic regression model used in this paper generates short, intermediate and long-run multipliers which are useful in evaluating the potential impacts of the Food Security Act over time. Typically, agricultural policies in most countries are motivated by short-run political needs and are rarely held unchanged long enough to realize the true long-run impact. However, the short and intermediate effects which are often realized will be based on the adjustment process which takes place toward the implied long-run equilibrium. A sound dynamic model is essential for accurately estimating the short and intermediate impacts of the Zambian Food Security Act of 1993. The supply response model developed in this paper yields estimates of how the Zambian maize sector has evolved over time and can be reflective of future evolution if the Food Security Act is not altered. The duration of the dynamic supply response is also of importance to policy makers when choosing an acceptable reform package. Dynamic multiplier estimates are subjected to statistical tests to determine whether they are significantly different from zero. The objective of this paper is to estimate a flexible dynamic supply equation for Zambian maize production which is consistent with a long run theoretical concept. The associated dynamic multipliers are also estimated and their statistical significance identified.

2. A rational distributed lag model of maize supply

The primary purposes of analyzing supply response in this study are threefold. They are identifying the dynamic structure which best describes the observed aggregate data, identifying the response to changes in price levels, and forecasting future supplies [1]. Three basic methodologies with respect to quantifying agricultural supply re-

[1] The potential structural change in maize prices due to deregulation within the Zambian government's economic adjustment program could invalidate the model for forecasting purposes.

sponse appear in the literature. They can be first classified as programming and econometric methods. However, at least two different econometric approaches have been used which leads to the three categories for discussion. The article by Colman (1983) provides an excellent review of these methods as well as an extensive review of literature employing them.

In this paper, the dynamic aggregate supply response equation will be directly estimated. Direct estimation does not attempt to build up the parameters of the supply function from the underlying technical parameters of the production, cost, or profit functions either directly (primal) or indirectly (primal-dual). The supply equation parameters are directly estimated via econometric methods from historical time series of aggregate output. Typically, this involves specifying output as a function of important current and past economic variables.

The decisions of Zambian maize farmers are made without perfect knowledge of the output prices they will receive. Although, in the past, prices were sometimes announced in advance of planting, they only became effective at the time of harvest. During the intervening period prices could sometimes be adjusted. Thus, planting decisions are based on expectations of future price adjustments. Allowing M^* and P^* to represent the equilibrium aggregate maize supply and price respectively, the sectoral equilibrium may be represented by the following relationship:

$$M^* = \gamma + \alpha P^* \tag{1}$$

where α is the long-run multiplier for maize supply with respect to maize price, and $\gamma \neq 0$ suggests that the equilibrium maize supply grows at a constant rate. Eq. (1) may be interpreted to fit equilibrium associated with the capital constrained environment alluded to in the introduction of this paper. If one is confident that the long-run equilibrium is representable by (1), then the associated dynamic regression model should nest this long-run equilibrium solution. Consequently, the dynamic regression model for maize supply may be given the following representation:

$$M_t = \gamma + \sum_{i=0}^{\infty} \alpha_i P_{t-i} + u_t \tag{2}$$

where u_t is a random disturbance term which is assumed to follow an unknown ARMA process with zero expectation, and the α_i's are unknown parameters. Note that α, the long-run cumulative impact in Eq. (1), is analogous with $\Sigma_{i=0}^{\infty} \alpha_i$ in (2). Eq. (2) represents a general distributed lag in prices and as such is not estimatable. Also note that the exact specification of u_t is of interest, but must be determined empirically.

In order to devise a model with a finite number of parameters, an alternative specification must be devised. Several popular schemes have been developed to obtain such a representation of the lag structure. The rational distributed lag model has the advantage of providing a parsimonious specification while maintaining the generality of the dynamic response. The rational lag model which approximates (2) is:

$$M_t = \gamma + \frac{\Theta(L)}{\Phi(L)} P_t + u_t \tag{3}$$

where $\Phi(L)$ and $\Theta(L)$ are polynomials in the lag operator, the ϕ's and θ's are parameters, and L is the lag operator such that $L^j P_t = P_{t-j}$. The rational lag model may be further transformed into the following p^{th}-order difference equation by inverting the denominator polynomial $\Phi(L)$:

$$M_t = \gamma^* + \theta_0 P_t + \ldots + \theta_q P_{t-q} + \phi_1 M_{t-1} + \ldots + \phi_p M_{t-p} + \Phi(L) u_t \tag{4}$$

Error structures with moving average components, such as $\Phi(L) u_t$ in Eq. (4), have typically been avoided by econometricians. Nicholls et al. (1975) hint that the lack of moving average error structures in applied work is due to the computational difficulties faced by early econometricians. The resulting familiarity with the easier to estimate autoregressive structure probably accounts for its wider usage.

The use of difference equations in estimating supply and inventory relationships has a rich background. Both the partial adjustment and adaptive expectations models are estimatable in a difference equation form. More recently error correction schemes, of which the partial adjustment is a sub-case, have been shown to give rise to difference equation models (see Akiyama and Trivedi (1987) for an application). The agricultural supply response models estimated by Bond (1983) for sub-Saharan African countries are based on the partial adjustment framework.

Estimation of (4) with modern computers is not difficult and can be performed by the usual mean-variance iteration procedures. However, iteration to convergence is necessary in order to obtain consistency since there are lagged endogenous variables included in the set of regressors.

The order of the lag on the dependent and independent variables of these models remains a matter of choice. This leads to occasional criticism that distributed lag models are not appropriately specified by the underlying economic theories. However, Burt (1986) suggests that a second-order rational lag approximation is sufficiently general to capture most of the dynamic adjustments observable in annual time series data. That is, the second-order specification can approximate any of three time paths that one is likely to observe. For example, if the roots of the denominator polynomial in the lag operator are complex then the distributed lag pattern will be cyclical, if the two roots are both non-zero and real then the pattern will be hump-shaped, and finally if one of the roots is zero then the pattern of lag effects will decay geometrically. The geometric case corresponds to the partial adjustment model like those used by Bond (1983). It is assumed throughout this paper that the difference equations discussed are stable. That is, the roots of the denominator polynomial of the rational distributed lag model must lie outside the unit circle.

A second-order rational distributed lag model was specified for Zambian maize supply. In addition to the price of maize, the price of fertilizer (urea) was also included as an important and costly input increasingly used by Zambian maize growers. This price is also included in the distributed lag effects of, $\Phi(L)$. This results in a model which allows for dynamic supply responses from both maize and fertilizer prices. Thus, the full second-order rational distributed lag specification in (4) becomes:

$$M_t = \gamma^* + \Theta(L)P_t + B(L)\,\mathrm{FP}_t + \phi_1 M_{t-1} + \phi_2 M_{t-2} + \Phi(L)\,u_t \qquad (5)$$

where FP_t is the price of fertilizer in year t, and $B(L)$ is potentially another polynomial in the lag operator. Four alternative schemes for estimating rational distributed lag models such as (5) where the disturbance follows a dynamic process can be found in Burt (1980), Dhrymes (1971), Maddala and Rao (1971), and Dhrymes et al. (1970). The approach developed by Burt (1980) is especially appealing since it decouples the correlation between lagged supply and lagged disturbances in an economically interpretable manner. That is, taking the expectation of (5) yields:

$$E(M_t) = \gamma^* + \Theta(L)\,P_t + B(L)\,\mathrm{FP}_t + \phi_1 E(M_{t-1}) + \phi_2 E(M_{t-2}) \qquad (6)$$

where E is the expectations operator. The nonstochastic difference equation in (6) has the following possible economic interpretation. Producers, in aggregate, make decisions to generate an expected supply based on the past and current economic environment. These expected supply responses are also impacted by the expected supply decisions made in the past through capital investments which were made and production processes which were or were not adopted. The flexible distributed lag on maize price allows for a variety of dynamic supply responses consistent with asset fixity in a country such as Zambia where there are few alternative uses for the physical and human capital invested in maize production. Because asset fixity and subsistence consumption are important factors guiding supply decisions, a major role of the distributed lag on maize price is to indirectly reflect the evolution of capital and the structure of agricultural production. In this regard, we should not be surprised to find a protracted supply response from a price change and possibly responses which follow cyclical patterns as farmers in the aggregate with varying expectations and access to capital overshoot the equilibrium supply.

In this formulation, the unobservable $E(\cdot)$ are implicitly functions of the unknown parameters in the equation, lagged right-hand side variables back to the beginning of the sample, and the two initial condition parameters. Estimates of the parameters can be obtained by adding the disturbance, u_t, to both sides of Eq. (6) to get:

$$M_t = \gamma^* + \Theta(L) P_t + B(L)\,\mathrm{FP}_t + \phi_1 E(M_{t-1}) + \phi_2 E(M_{t-2}) + u_t \quad (7)$$

A non-linear least squares algorithm that uses procedures comparable to those of Box and Jenkins (1976) can be used to estimate the econometric model in Eq. (7). Note that the appended disturbance term may follow a general ARMA(p, q) process. The parameters of the ARMA error process must also be estimated, but the appended error structure is uncorrelated with the $E(M_{t-j})$, $j \neq 0$.

As pointed out in Foster and Burt (1992), this approach has several advantages over the usual ARMAX or stochastic difference equation. One advantage is that the non-stochastic difference equation separates the exogenous and endogenous components of the model to ensure that the parameter estimates of the ARMA disturbance and those of the systematic portion of the equation are asymptotically uncorrelated. From this result, it can be shown that the structural parameter estimates are consistent even if the disturbance structure is misspecified (see Pierce (1972)). Finally, the rational distributed lag model requires fewer parameters relative to other methods for approximating general distributed lag structures.

3. Empirical results

Good time series data on production and prices is difficult to obtain in most developing economies. However, in the case of Zambia it was possible to compile a sample of maize production and price from 1971 to 1990. These data were compiled from the Government Republic of Zambia official documents GRZ (1988), GRZ (1989/90) and GRZ (1991). In addition to output quantity and price, it was also possible to construct a time series for the prices of seed and fertilizer from these same sources. Models which included seed price were estimated, but, as one might expect, seed price is highly correlated with maize price so that unsatisfactory results were obtained. Subsequent models omitted seed price as an explanatory variable. Furthermore, average annual rainfall was another variable considered in estimation, but no significant role was found for that variable. An anonymous referee correctly pointed out that using the rainfall during the maize growing season may better explain variation in maize supply. We were, unfortunately, unable to secure such data.

In general, the second-order rational distributed lag model specifies $\Theta(L)$ as a second-order polynomial in the lag operator. However, when a second-order term was introduced, both coefficients on maize prices were not significant and had opposite signs. This suggests a multicollinearity problem between current and lagged maize price. The fact that maize price was historically government controlled supports using the current price over the lag to model supply response. An additional result of announced prices is that the distributed lag on maize price measures the effect of accumulating capital for maize production and the sticky nature of that capital as well as price expectations. As previously argued, Zambian farmers have few alternatives to maize production due to climate, culture, and the structure of markets. Consequently, a price shock which results in capital accumulation will have a long term effect. This adjustment process and the potential for price changes during the growing season leaves an element of price expectations intact even though a price is announced prior to planting. Furthermore, it is not certain that price increases signal a long term commitment on the part of the government to support producer prices.

The final estimated model for maize supply retains the second-order difference equation form. Even though the coefficient on $E(M_{t-2})$ proved to be statistically not different from zero, the geometric distributed lag model (first-order difference equation form), when estimated, proved to be unstable. If $\hat{\phi}_2$ were zero and $|\hat{\phi}_1| < 1$, then the second-order model would reduce to a stable geometric distributed lag by definition. Furthermore, a first-order moving average error structure proved to be consistent with the data. Recall, that a moving average structure was foreshadowed by the model development in Eq. (4).

Table 1
Estimated coefficients of the dynamic Zambian maize supply equation

Variable	Coefficient estimate	Standard error	t-Statistic
Intercept	154 [a]	54	2.85
Maize Price	0.77 [a]	0.19	4.05
Fertilizer Price	−0.38 [a]	0.08	−4.75
$E(M_{t-1})$	1.20 [a]	0.37	3.24
$E(M_{t-2})$	−0.54	0.31	1.74
Moving average	0.90 [a]	0.27	3.33
$R^2 = 0.90$	Standard error of the estimate = 117		

[a] Denotes significance at $\alpha = 0.05$
Note: Maize supply is measured in metric tonnes, maize price and fertilizer price are measured in Zambian Kuacha (ZK) per metric tonne.

Table 1 presents the estimated coefficients of the dynamic supply equation and their standard errors. Note that the rational lag structure results in weights for successive years which can be calculated from recursive substitution of the model t times for the t^{th} year ahead. For the first 5 years the pattern is: 1.2, 0.91, 0.45, 0.06, and −0.16. It is interesting to speculate why this might be the case. Consider, the price increase which results in a stimulus to invest in capital for maize production. Maize production in Zambia is not extremely capital intensive, and output price is known, with some certainty, in advance. Thus, producers are able to adjust more rapidly to changes in the economic environment than in a more uncertain and capital intensive environment. The cyclical aspect of the dynamic response is likely to be related to overshooting of the equilibrium supply by the aggregate of individual producers acting independently.

Production specific capital, once devoted to maize production, creates a sunk cost if that capital is transferred to alternative uses. Dixit (1989a) and Dixit (1989b) has shown that the sunk costs may be such that capital will remain in production and continue to affect future supply even if price ultimately declines. As capital deteriorates or slowly moves to alternative uses, the

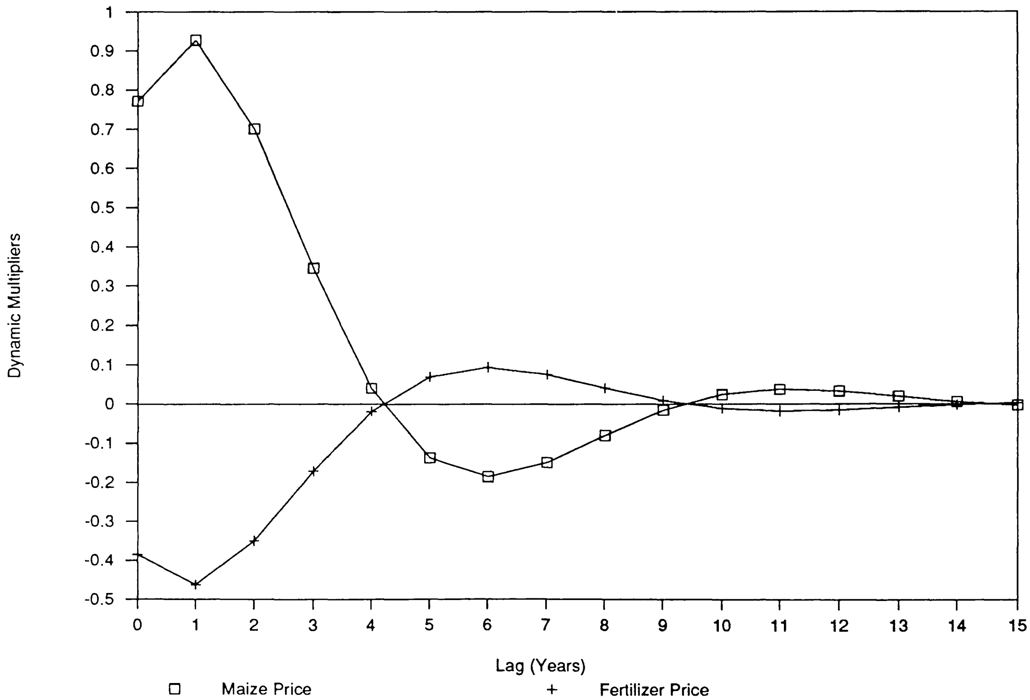

Fig. 1. Estimated dynamic multipliers for Zambian maize supply.

lagged supply responses converge toward zero. Summing over the infinite stream of dynamic multipliers yields the long-run or steady state multiplier which can be calculated from the estimated parameters by the following formula: $\hat{\lambda} = \hat{\theta}/(1 - \hat{\phi}_1 - \hat{\phi}_2)$. The estimated long-run multiplier for maize price is 2.31 and for fertilizer price it is -1.15. These are the total cumulative marginal impacts of increases in maize and fertilizer prices, respectively. The immediate impact multipliers are simply the coefficients on the price variables listed in Table 1.

In order to determine if the estimated long-run multiplier for maize price is significantly different from zero it was necessary to construct an estimate of the variance of $\hat{\lambda}$. Because the long-run multiplier is a non-linear combination of estimated parameters, it is necessary to use a numerical approximation. A first-order Taylor series approximation was chosen to accomplish this task. The following formula was used to calculate the variance of the long-run multiplier:

$$\begin{aligned}\mathrm{VAR}(\hat{\lambda}) = {} & \frac{1}{\left(1-\hat{\phi}_1-\hat{\phi}_2\right)^2}\mathrm{VAR}(\hat{\theta}) \\ & + \frac{\hat{\theta}^2}{\left(1-\hat{\phi}_1-\hat{\phi}_2\right)^4}\mathrm{VAR}(\hat{\phi}_1) \\ & + \frac{\hat{\theta}^2}{\left(1-\hat{\phi}_1-\hat{\phi}_2\right)^4}\mathrm{VAR}(\hat{\phi}_2) \\ & + \frac{2\hat{\theta}}{\left(1-\hat{\phi}_1-\hat{\phi}_2\right)^3}\mathrm{COV}(\hat{\theta},\hat{\phi}_1) \\ & + \frac{2\hat{\theta}}{\left(1-\hat{\phi}_1-\hat{\phi}_2\right)^3}\mathrm{COV}(\hat{\theta},\hat{\phi}_2) \\ & + \frac{2\hat{\theta}^2}{\left(1-\hat{\phi}_1-\hat{\phi}_2\right)^4}\mathrm{COV}(\hat{\phi}_1,\hat{\phi}_2) \qquad (8)\end{aligned}$$

From (8), a standard error of 0.68 for the maize price long-run multiplier was calculated. Assuming normality of the long-run multiplier, a t-statistic can be constructed by dividing the estimated long-run multiplier by its standard error. The resulting t-statistic was 3.39 suggesting that the long-run multiplier is significantly greater than zero (see Table 2).

Table 2
Estimated dynamic multipliers for maize and fertilizer prices and their standard errors

Lag (years)	Maize price multiplier	Fertilizer price multiplier
0	0.77 *	−0.38 *
	(0.19) [a]	(0.08)
1	0.93 *	−0.46 *
	(0.10)	(0.25)
2	0.70 *	−0.35 *
	(0.10)	(0.04)
3	0.35	−0.17
	(0.45)	(0.32)
4	0.04	−0.02
	(0.87)	(0.79)
Long run	2.31 *	−1.15 [b]

* Denotes significance at $\alpha = 0.05$

[a] Numbers in parentheses are estimated standard errors of the dynamic multipliers.

[b] The Taylor Series approximation for the standard error was negative.

Note: The dynamic multipliers measure the marginal impact of a price change in time t on the supply in time $t+j$ (i.e. $\partial M_{t+j}/\partial P_t$), where j is the lag in years.

The dynamic multipliers at longer lags are rather small compared to their shorter-run counterparts. Fig. 1 demonstrates that they are essentially zero after 8 years. Table 2 lists the first four dynamic multipliers and their standard errors. The standard errors for intermediate run multipliers were computed in similar manner to Eq. (8), because they are also non-linear combinations of parameter estimates.

Notice that, assuming normality for the multipliers, only the first two multipliers are significantly different from zero. This suggests that the supply adjustment process is quite rapid and that significant dynamic supply effects fade quickly. It is important to realize that the econometric model can only capture the supply response conditional on current infrastructure and marketing efficiency. Should these or the sophistication of farmer price expectations change along with structural adjustments, then potentially different impacts could ensue. Thus, it is of importance to also consider the likely responses of other agents besides farmers in formulating a policy strategy. For example, will private marketing agents increase or decrease their role in moving maize to urban markets such as Lusaka? Will producers more accurately internalize the value of marginal production from fertilizer use, or formulate expectations based on a longer time series of prices?

4. Conclusions

The profile of dynamic multipliers suggests that the impacts of changes in pricing policy will be statistically significant. However, the duration of the impacts will be short (less than 10 years). Unfortunately, this may still be too long to wait for stabilization in a developing country. Consider that structural adjustment policies in the Zambian maize sector will likely lower the price received by farmers in surplus maize regions, and consequently, the overall supply of maize. The cumulative response after ten years to a 1% decrease in maize price is estimated to be −1.57 (measured at the sample means of the data). The full estimated long-run elasticity of supply is 1.62% for a 1% price increase. The estimated short-run or immediate elasticity for maize price is 0.54. These are high compared to those listed in the survey article by Rao (1989). As Chibber (1982) has demonstrated, the omission of important structural variables may lead to an overstatement of the true response magnitude. However, Askari and Cummings (1977) demonstrated that overwhelmingly important crops, such as maize in Zambia, are more often characterized by large supply responses due to the huge costs associated with errors in resource allocations. Maize is a dietary staple in Zambia so that the responsiveness of farmers to a price change is enhanced due to their reliance on it as a source of income and future investment capital. Unless prices subsequently rise, gross receipts to Zambian farmers from the production of maize would decline by 2.55% over the ten year period, measured at mean values. In order to accurately quantify the overall effect it would be necessary to simulate the effects of a price decline through the dynamic supply equation and its counterpart demand equation.

Fertilizer use is also an important consideration in aggregate maize supply response in Zambia. Fertilizer use has drastically effected the level of production. Heavy government price subsidies have motivated much of the increased use of fertilizer (Holden, 1993). However, fertilizer subsidies alone would probably not be sufficient to generate greater adoption of fertilization in the future. On the other hand, to minimize the impact of removing fertilizer price subsidies, more emphasis is needed on support systems such as extension education, agricultural research, infrastructure, and marketing. The suggestion for an integrated approach to maize production policies comes on the heels of the recent devastating drought (1991–92 season). The urgency to return to and perhaps exceed pre-drought food production levels necessitates a more elastic supply response which may be infeasible to generate by pricing policies alone.

The results of this paper suggest that the newly adopted policy of the Zambian government to free the prices of maize and primary inputs like fertilizer would have relatively large supply impacts over the long run. The long run is defined as approximately 10 years because after that point the dynamic multipliers essentially drop to zero. In fact, all of the maize price dynamic multipliers after the second lag are statistically insignificant. This conclusion is consistent with the result obtained by Holden (1993) which suggested that removal of fertilizer subsidies would result in large reductions in maize production.

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