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# SOME ESTIMATES OF THE PRICE ELASTICITY OF DEMAND FOR PHOSPHATIC AND NITROGENOUS FERTILISERS

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Manufactured phosphatic and nitrogenous fertilisers are used extensively in Australian agriculture to improve crop and pasture yields. Phosphatic fertilisers are applied mainly to pastures and those crops such as cereal grains which are extensive in their use of land. A little less than half of phosphatic fertiliser consumption is on pastures and the remainder on crops, mainly wheat. Nitrogenous fertilisers are applied mainly to the traditionally high return per area crops such as sugar cane and vegetables. About one-third of the nitrogenous fertiliser used is applied to sugar cane, about one-third to fruit and vegetables and about one-third to pasture and cereals. In recent years the use of nitrogenous fertilisers on cereal crops has been increasingly combined with phosphorus in the form of ammonium phosphates.

Various schemes have operated intermittently since the early 1930s to encourage the consumption of these fertilisers. Current arrangements involve subsidies paid on the quantity of available phosphorus and nitrogen per tonne. The effectiveness of the subsidies in stimulating consumption depends on the nature of the fertiliser demand function. In particular, the effectiveness depends on the responsiveness of consumption to changes in price as opposed to changes in other factors such as the profitability of agricultural industries. These factors determine the extent to which a fertiliser subsidy will affect the demand for fertiliser directly, via substitution with other inputs, or indirectly, via changes in agricultural output.

In this paper estimates are presented of some phosphatic and nitrogenous fertiliser demand relationships in Australian agriculture. For phosphatic fertilisers the aim is to obtain a demand function for agriculture as a whole. Demand functions are derived for nitrogenous fertilisers applied to five crop categories. Finally, an assessment is made of the relative importance of variations in fertiliser price, as opposed to variations in other factors, in explaining the observed year-to-year variation in the fertiliser application rate.

## *Previous Studies*

In its report on assistance for the consumption of phosphatic fertilisers, the Industries Assistance Commission (1976, p. 10) found that 'farmers can and do make quite significant adjustments in the case of phosphatic fertilisers if price changes'. The evidence to support this

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view, some of which has emerged since the above report was issued, is rather mixed.

Price elasticities of demand for superphosphate in selected regions of Australia were estimated by Duncan (1972) from a model designed to measure the effects of research on expansion in improved pastures. He obtained short-run estimates ranging from −0.7 (Northern Tablelands, New South Wales) to −3.2 (Maryborough, Queensland). Waring and Morris (1974) applied an *ad hoc* single-equation specification to estimate the demand for superphosphate on pastures in each state using data for the period 1947–48 to 1970–71. Their equation explained area top dressed as a function of lagged fertiliser price, lagged farm income, lagged area top dressed, time, and a dummy variable representing the operation of the bounty. The price elasticity of demand estimates ranged from −0.2 to −1.0. More recently, Gargett (1983) used an *ad hoc* single-equation specification relating superphosphate application rate to real prices of wool, wheat, beef and superphosphate, weather and a time trend. This equation, and a similar equation in which real product prices were replaced by real cash operating surplus per hectare, when fitted to time-series data from Australian Sheep Industry Survey farms for the period 1965–66 to 1978–79, yielded small and statistically insignificant coefficients on the superphosphate price variable. Coefficients on the real price of wool and real cash operating surplus per hectare were statistically insignificant.

Price elasticity estimates have also been derived from normative programming models of Australian agriculture which incorporated production activities using superphosphate. Easter and Kingma (1976) used the Bureau of Agricultural Economics' regional farm model for this purpose. Long-run demand elasticities were obtained by fitting functions to the simulated results for fertiliser consumption over a range of input and output prices. The price elasticity estimates so derived ranged from −0.2 to −0.4.

The only study of the demand for nitrogenous fertilisers reported in the literature is that undertaken by the Industries Assistance Commission (1974) in which estimated demand functions for nitrogenous fertilisers on six categories of crops are reported. In this study, the application rate in period $t$ was regressed on the application rate in the previous period, the real price of nitrogen and the real price of crop output for the period 1953–54 to 1972–73. For most of this period, statistics on application rate on individual crops were not available. A procedure was therefore devised to generate these data series. Short-run price elasticity estimates ranged from −0.2 (fruit and vines), −0.3 (vegetables), −0.7 (sugar) to −1.0 (pasture).

## *Methodology*

In the present study, two approaches to estimation of phosphatic fertiliser demand were pursued. The first involved estimating the demand for fertiliser as part of a system of farm input demand equations with explicit allowance for substitution between fertiliser and other inputs. Variants of this approach, one using a system of input share equations derived from a translog cost function, the other involving direct specification of the input demand system on which homogeneity and symmetry conditions were imposed, yielded unsatisfactory results. The failure of the systems approach was attributed to insufficient variation in relative input prices and input mix leading to an extremely flat likelihood surface with respect to the input substitution parameters.

The second approach, used in both phosphatic and nitrogenous fertiliser demand relationships, involved a single-equation specification designed to minimise the problem of high correlation between agricultural input prices. It was postulated that the desired demand for fertiliser on crop $i$, $Q_i^*$, is a function of the price of fertiliser, $P_k$, the price of other farm inputs, $P_o$, and the desired level of output of crop $i$, $Y_i^*$. That is,

$$(1)\quad Q_i^* = f(P_k, P_o, Y_i^*)$$

In turn, the desired output level was specified as a function of the price of a unit of output of crop $i$, $P_i$, the desired area fertilised, $A_i^*$, and the price of all inputs including fertiliser. That is,

$$(2)\quad Y_i^* = g(P_i, A_i^*, P_k, P_o)$$

Assuming linear homogeneity of the production function and homogeneity of degree zero in prices of the input demand function, (1) and (2) can be written as:

$$(3)\quad X_i^* = z\left(\frac{P_i}{P_o}, \frac{P_k}{P_o}\right)$$

where $X_i^* = Q_i^*/A_i^*$, the desired application rate of fertiliser on crop $i$.

The application rate observed in a particular year may not reflect the long-run or desired level given prevailing prices and conditions. It is assumed that changes in the desired (long-run) application rate are only partially achieved due to habit persistence and the time taken to obtain information on fertiliser response and prices. A partial adjustment mechanism of the form:

$$(4)\quad \ln X_{i(t)} - \ln X_{i(t-1)} = a_i(\ln X^*_{i(t)} - \ln X_{i(t-1)})$$

was proposed, where $a_i$ is an adjustment coefficient $(0 < a_i < 1)$ measuring the extent to which current usage of fertiliser on crop $i$ represents the desired use rather than the past level of use.

Combining (4) with, for convenience, a double logarithmic version of (3) yields an estimating equation of the form:

$$(5)\quad \ln X_{i(t)} = a_i b_{0i} + (1 - a_i)\ln X_{i(t-1)} + a_i b_{1i} \ln\left(\frac{P_k}{P_o}\right)_{(t)} + a_i b_{2i} \ln\left(\frac{P_i}{P_o}\right)_{(t)} + u_{i(t)}$$

where $a_i$, $b_{0i}$, $b_{1i}$, $b_{2i}$ are parameters to be estimated and $u_{i(t)}$ is a disturbance term. In (5) the short-run elasticities of fertiliser application rate with respect to changes in the real price of fertiliser and changes in the real price of output of type $i$ are $a_ib_{1i}$ and $a_ib_{2i}$, respectively. The corresponding long-run elasticities are $b_{1i}$ and $b_{2i}$.

## *Estimation and Results*

For phosphatic fertilisers, equation (5) was fitted using annual data on application rate and input prices covering the period 1952–53 to 1979–80. The series on application rate (kg/ha) refers only to superphosphate. Although the use of high analysis phosphatic fertilisers has grown rapidly in recent years, phosphorus in the form of superphosphate still accounts for over 70 per cent of total phosphorus applied on Australian farms.

The application rate series was constructed from information in Gargett (1983) and the Bureau of Agricultural Economics' Australian Sheep Industry Survey (which is drawn from a farm population accounting for about 80 per cent of total phosphatic fertiliser usage in Australia). This series was constructed by dividing total superphosphate used by the area of crop fertilised plus the area of improved pasture, that is, pasture with a history of fertilisation though not necessarily fertilised in that year.

By using this formulation it was possible to represent approximately the 'super bank' aspect of phosphatic fertiliser application. In the development phase, heavy application rates are required as a large proportion of the applied phosphorus reacts in the soil to form products not readily available to plants. Once a sufficient soil level of phosphorus is achieved, it becomes available through accumulation in what is commonly referred to as the super bank. In the maintenance phase, less of the applied phosphorus is fixed in the soil and some existing fixed phosphorus reverts to an available form. Unfortunately, it is not possible to apportion with any confidence the total fertiliser usage in a particular year between usage on unimproved land and usage on land previously fertilised. The land base receiving phosphatic fertiliser expanded by about 240 per cent between 1952–53 and 1979–80.

The series on other input prices and the price of output were constructed using Bureau of Agricultural Economics' series on farm input prices and prices received for crops and livestock.

Nitrogenous fertilisers are used on a variety of crops whose production functions and underlying input demand relationships exhibit marked differences. Equation (5) was therefore estimated separately for five categories of crops — sugar, wheat, vegetables, fruit and pasture — using annual data for the period 1970–71 to 1982–83.

Data on the application of nitrogen by crop are available only on a bulk fertiliser basis and not in terms of elemental nitrogen. Series on the application of elemental nitrogen to each crop were constructed by apportioning the total crop application of elemental nitrogen in year $t$ according to the ratio of the bulk application of nitrogenous fertiliser on crop $i$, to the total bulk application to crops for that year. These series were obtained from Australian Bureau of Statistics (1984). This procedure is not entirely satisfactory in that it is necessary to assume that the concentration of nitrogen on an elemental basis in bulk fertiliser applied to crop $i$ is the same as that applied to crop $j$. Nevertheless it is the best that can be done with the available data.

By dividing each series by the area fertilised (obtained from

Australian Bureau of Statistics 1984), series on the application rate of elemental nitrogen for each crop were obtained. Unlike the case with phosphatic fertilisers, nitrogenous fertilisers have little if any residual effect. They are much more subject to loss by leaching and volatilisation and cannot be stored in inorganic form in the soil. Hence, the application rate series obtained by dividing application quantity by the area actually fertilised is likely to reflect accurately the desired demand for nitrogen on a per unit area basis.

The nitrogenous fertiliser price series, $P_N$, is a weighted sum of the elemental prices of nitrogen in each of three types of nitrogenous fertilisers used on the crops under consideration. It was constructed according to the formula:

$$(6) \quad P_N = 0.33 \sum_{j=1}^{3} (P_j/a_j)$$

where $P_j$ denotes the per unit bulk price of the $j$-th type of nitrogenous fertiliser ($j$ = urea, ammonium sulphate, ammonium nitrate), $a_j$ denotes the amount of elemental nitrogen in nitrogenous fertiliser of type $j$($a_j = 46$ per cent where $j$ = urea, $a_j = 21$ per cent where $j$ = ammonium sulphate, $a_j = 34$ per cent where $j$ = ammonium nitrate). Information on $a_j$ and $P_j$ was obtained from Department of Primary Industry (1984).

The other input and crop output price series were constructed from Bureau of Agricultural Economics' indexes of input and output prices. In the case of nitrogen use on pastures, the output price series for market milk was used to reflect the considerable use of nitrogen by dairy farmers engaged in supplying the fresh milk market.

Equation estimates are presented in Table 1. The results for phosphatic fertiliser application rate and the application rate of nitrogenous fertiliser on sugar cane are satisfactory from economic and statistical viewpoints. In the case of the equation for nitrogenous fertiliser applied on wheat, the coefficient on the real price of wheat is statistically insignificant. To improve the specification, equation (5) was modified by replacing the other input price variable with the price of superphosphate, with both this price and the price of nitrogen deflated by the price of wheat. In most wheat areas, soil nitrogen is built up by growing wheat in rotation with legumes which require the application of phosphatic fertiliser for satisfactory growth. A change in the real price of superphosphate might cause farmers to change their reliance on the superphosphate–legume nexus for soil nitrogen. All coefficients in the modified equation are significant at the 5 per cent level.

Because of the unsatisfactory results with the habit persistence model in the case of nitrogenous fertiliser applied to pastures, the lagged adjustment rate variable was replaced by a time trend. The estimated coefficients on the real price of nitrogen and output are therefore interpreted as long-run elasticities. In the revised equation, the coefficient on the real price of nitrogen is not significant at the 5 per cent level.

For vegetables, the coefficient on the real price of output is not statistically significant. For fruit and vines, equation (5) gave unsatisfactory results. The model was modified by deflating the price of

## TABLE 1

*Parameter Estimates of Fertiliser Demand Relationships*[a]

| Dependent variable | Constant | $\ln X_{i(t-1)}$ | $\ln(\frac{P_k}{P_o})_{(t)}$ | $\ln(\frac{P_i}{P_o})_{(t)}$ | Time | $\ln(\frac{P_s}{P_i})_{(t)}$ | $\ln(\frac{P_k}{P_i})_{(t)}$ | $R^2$ | $H$ statistic |
|---|---|---|---|---|---|---|---|---|---|
| Phosphatic fertiliser application rate | 3.40 | 0.27 | −0.26 | 0.62 | | | | 0.81 | 0.49 |
| | (6.54) | (2.43) | (2.68) | (7.11) | | | | | |
| Nitrogenous fertiliser application rate on: | | | | | | | | | |
| sugar cane | 2.76 | 0.54 | −0.16 | 0.15 | | | | 0.93 | 0.78 |
| | (7.27) | (9.05) | (1.54) | (6.07) | | | | | |
| wheat[b] | 0.03 | 0.57 | −1.81 | 0.08 | | | | 0.88 | −1.09 |
| | (0.13) | (3.91) | (2.50) | (0.12) | | | | | |
| wheat[c] | 0.66 | 0.58 | | | | 1.01 | −1.40 | 0.89 | −1.73 |
| | (2.92) | (4.80) | | | | (2.39) | (2.54) | | |
| pasture | 0.68 | [d] | −0.32 | 1.29 | 0.08 | | | 0.65 | 2.28[e] |
| | (1.78) | | (0.50) | (2.59) | (3.66) | | | | |
| vegetables | 1.56 | 0.50 | −2.02 | 0.63 | | | | 0.66 | −1.46 |
| | (1.48) | (2.23) | (2.46) | (1.66) | | | | | |
| fruit and vines | 1.01 | 0.79 | | | | | −0.35 | 0.71 | −1.04 |
| | (1.14) | (4.82) | | | | | (0.41) | | |

[a] The values shown in parentheses are $t$-values.
[b] Model as specified in equation (5).
[c] Revised model with price of superphosphate and price of nitrogen deflated by output price.
[d] No habit persistence assumed.
[e] Durbin-Watson statistic.

TABLE 2

*Short-Run and Long-Run Own-Price and Output-Price Elasticity Estimates*

| | Own-price | | Output-price | |
|---|---|---|---|---|
| Dependent variable | Short-run | Long-run | Short-run | Long-run |
| Phosphatic fertiliser application rate | −0.26 | −0.36 | 0.62 | 0.85 |
| Nitrogenous fertiliser application rate on: | | | | |
| sugar cane | −0.16 | −0.36 | 0.15 | 0.34 |
| wheat[a] | −1.18 | −4.22 | 0.08 | 0.20 |
| wheat[b] | −1.40 | −3.33 | | |
| pasture | | −0.32 | | 1.29 |
| vegetables | −2.02 | −4.05 | 0.63 | 1.27 |
| fruit and vines | −0.35 | −1.67 | | |

[a] Model as specified in equation (5).

[b] Revised model with price of superphosphate and price of nitrogen deflated by output price. In the revised model the short-run and long-run elasticities with respect to superphosphate price are 1.01 and 2.40, respectively.

nitrogen by the output price and therefore deleting the real output price as an explanatory variable. In the revised equation the coefficient on the real price of nitrogen is not significant.

Table 2 contains estimates of the short-run and long-run elasticities of application rate with respect to real fertiliser price and real output price. For Australia as a whole, the own-price elasticity of demand for superphosphate is low. The elasticity with respect to product price is somewhat higher than the own-price elasticity of demand. For nitrogenous fertilisers, the own-price elasticity is lowest for sugar cane and pasture and highest for wheat and vegetables. The elasticity with respect to product price is highest for pasture and vegetables and lowest for wheat.

### *Decomposing the Variation in Application Rate*

An issue separate from the estimation of the responsiveness of fertiliser demand to changes in price is the source of year-to-year variations in this demand. In particular, the following question is addressed. How important in explaining variation in fertiliser use is the price of fertiliser as opposed to a measure of farm profitability such as the price of farm output?

One approach to answering this question relies on the identity:

$$(7)\quad \mathrm{Var}(X) = \sum_{i=1}^{n} \hat{\alpha}_i^2 \mathrm{Var}(V_i) + 2 \sum_{i=1}^{n} \sum_{j>i} \hat{\alpha}_i \hat{\alpha}_j \, \mathrm{Cov}(V_i, V_j) + \mathrm{Var}(\mu)$$

where Var $(X)$, Var $(V_i)$ and Cov$(V_i, V_j)$ are the sample variances of the dependent variable $X$, the independent variables $V_i$, and the covariance of $V_i$ and $V_j$, respectively; var$(\mu)$ is the variance of the estimated residuals and $\hat{\alpha}_i$ are the estimated regression coefficients in the regression of $X$ on $V_i$. If Cov$(V_i V_j)$ is close to zero for all $i \neq j$ then,

$$(8)\quad \mathrm{Var}(X) \simeq \sum_i \hat{\alpha}_i^2 \, Var(V_i) + \mathrm{Var}(\mu)$$

## TABLE 3

*Decomposition of the Variation in Fertiliser Demand*

| | | Nitrogen applied to | | | | | |
|---|---|---|---|---|---|---|---|
| | Superphosphate | Sugar cane | Wheat[a] | Wheat[b] | Pasture | Vegetables | Fruit and vines |
| $V_1$ $\ln X_{(t-1)}$ (lagged application rate) | 0.07 | 0.77 | 0.40 | 0.40 | [d] | 0.28 | 0.69 |
| $V_2$ $\ln(\frac{P_i}{P_o})_{(t)}$ (real own price of fertiliser) | 0.07 | 0.03 | 0.13 | 0.06 | 0.01 | 0.35 | 0.01 |
| $V_3$ $\ln(\frac{P_i}{P_o})_{(t)}$ (real price of product) | 0.60 | 0.44 | 0.00 | | 1.26 | 0.15 | [f] |
| $V_4$ (other variables) | | | | 0.10 | 2.43 | | |
| Covariance term between | | | | | | | |
| $V_1$ and $V_2$ | −0.05 | −0.01 | 0.37 | 0.06 | 0.06 | 0.32 | 0.01 |
| $V_1$ and $V_3$ or $V_4$ | −0.12 | −0.20 | −0.01 | 0.26[c] | −0.02[e] | −0.20 | |
| $V_2$ and $V_3$ or $V_4$ | 0.24 | −0.10 | −0.01 | 0.01[c] | −3.09[e] | −0.24 | |
| $R^2$ | 0.81 | 0.93 | 0.88 | 0.89 | 0.65 | 0.66 | 0.71 |
| Error term | 0.19 | 0.07 | 0.12 | 0.11 | 0.35 | 0.34 | 0.29 |

[a] Model as specified in equation (5).
[b] Revised model with price of superphosphate and price of nitrogen deflated by price of output.
[c] Covariance with the price of superphosphate.
[d] No habit persistence assumed.
[e] Covariance with time.
[f] Modified model with price of nitrogen deflated by output price and deleting real output price as an explanory variable.

Hence the ratio defined by contribution $i[i = \hat{\alpha}_i^2 \mathrm{Var}(V_i)/\mathrm{Var}(X)]$ can be interpreted as the proportion of the sample variance in $X$ associated with the variance in $V_i$. On the other hand, if $\mathrm{Cov}(V_i, V_j)$ are large then no unambiguous method is available for attributing the variance in $X$ to variations in individual regressors. The results of applying (7) to the phosphatic and nitrogenous fertiliser demand equation estimates are shown in Table 3.

Although there is some covariance between regressors, changes in the real price of superphosphate are relatively unimportant in explaining changes in superphosphate application rate. Of far greater importance are changes in the profitability of farming as indicated by changes in the real price of farm output. For nitrogen applied to pasture, the covariance terms are large, making it impossible to attribute the variation in application rate to specific variables. Only for nitrogen applied to vegetables do variations in real nitrogen price account for greater application rate variability than other regressors.

It should be emphasised that there is no necessary connection between the relative magnitudes of the own-price and product-price elasticities of demand and the relative contributions made by variations in fertiliser price and in output price to variations in application rate. For the time period under study, fertiliser prices have exhibited considerably less variability than output prices, hence their lesser contribution to variations in application rate irrespective of the own-price elasticity relative to the output-price elasticity.

## *Conclusion*

The price elasticity of demand for phosphatic fertiliser for Australia as a whole is low in both the short run and long run, a conclusion consistent with those obtained in previous studies. The price elasticity of demand for nitrogenous fertilisers appears higher, especially in the case of application to wheat, where significant opportunities exist for substitution between phosphatic and nitrogenous fertilisers. Variations in fertiliser prices appear to be relatively unimportant in explaining variations in application rate for both phosphatic and nitrogenous fertilisers.

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