Modelling Global Demand for Fertilizer

Moshe Buchinsky

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Commodity Studies and Projections Division
Economic Analysis and Projections Department
Economics and Research Staff
The World Bank

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Prepared by:

Moshe Buchinsky
Commodity Studies and Projections Division
Economic Analysis and Projections Department
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I. SUMMARY AND INTRODUCTION

1. This paper describes the recently-completed fertilizer model which is used by the Commodity Studies and Projections Division. The fertilizers included in the model are nitrogen, phosphate and potash. The model is a partial equilibrium model of production and consumption. A separate module was built for each of the three fertilizers, but cross linkages between the different types of fertilizers within a country or a region were established. On the demand side 24 regions are distinguished; 16 of these are individual countries while the remaining countries are modeled as 8 regions based on the geographic location of the countries.

2. The fertilizer supply model was built in a more aggregated way. For nitrogen and phosphate there are four country groups—Europe and Japan, North America, Developing Countries and Centrally Planned Economies (CPEs). The production of potash is specified only on a world basis.

3. The fertilizer demand model is linked to the Division's grains and soybean model in the sense that the two models are solved iteratively, i.e., the solutions from the grains model are entered into the fertilizer model, the results of which are then entered into the grains model. Model simulations are continued until the results become stable. \(^1\) Therefore, the production and prices of the four major commodities (wheat, rice, coarse grain and soybeans) in the grains and soybeans model are endogenous to the fertilizer model.

4. Major changes have occurred in the last 20 years in agricultural production. These changes have also changed the nature of the demand for

\(^1\) See Mitchell (1985).
fertilizers. Growth in fertilizer consumption is especially evident in the developing countries where there is generally a rapidly-increasing demand for farm inputs. But major macroeconomic changes, fiscal and monetary, have also taken place and these have strongly influenced the fertilizer market. In this study we have tried to capture the most important of these historical changes and to give an idea of what to expect in the next decade or so.

5. The format of the paper is as follows. The specification of the demand side of the model is introduced in Section II followed by the specification of the supply side in Section III. Section IV is devoted to the price equation specification while Section V presents some results of the estimated equations. An ex-post simulation of the model carried out over the historical period is presented in Section VI with summary statistics as well as graphical representation of the behavior of some of the major variables in the model. Short- and long-term projections for both production and consumption, run over the 1985-2000 period, are presented in Section VII. Section VIII contains the conclusions and suggestions for further work.
II. DEMAND FOR FERTILIZER

6. The demand for fertilizers is derived from the demand for agricultural products. In turn, the demand for products such as food and fiber are partially determined by the growth in income and population. In this study these macro-variables are assumed to influence the demand for fertilizers only through the demand for crops and other agricultural products.

7. Several approaches to modeling fertilizer demand have been used in the past and each has its advantages and disadvantages. The most popular approach has been the pure maximization approach as applied to an agronomic fertilizer response function. Although the calculus is straightforward it involves two critical elements, as has been mentioned by Timmer (1974). First, there is the necessity to assume some form of maximizing behavior on the part of the farmers and second, knowledge of the relevant agronomic function is required. One concern with this approach is the difficulty of accepting the underlying assumption of profit maximization by farmers the world over. Very few farmers equate marginal costs with marginal revenues for an input without regard to risk, uncertainty, knowledge and other constraints. Timmer has estimated that during the period 1960-80 the marginal return for the last dollar spent on fertilizer varied throughout the United States over the range $1.6 to $7.3. For developing countries, even higher marginal returns could be expected because of the widespread constraints on supplies.

8. Timmer mentions the additional problem of the difference in the use of fertilizer per hectare in various places in the world at the same price level (implying a different agronomic response function with respect to fertilizer use). The optimal level of fertilizer use varies significantly even within a country, depending on the location, the crop for which it is used,
the degree of water control, the availability of fertilizer, and other factors.

9. A second approach to analyzing fertilizer demand is the prescriptive approach; but although it is useful in understanding the nature of fertilizer use, it is somewhat irrelevant to our study. As noted by Barker (1972) "The analysis of fertilizer response can be useful. But the major problem is not necessarily one of determining the optimum level of fertilizer input, but rather of identifying the factors that constrain yield response on farmers' fields..." In short, neither the indirect demand functions derived from agronomic response functions nor the prescriptive approach to fertilizer demand give any idea of the impact of the different factors which affect fertilizer demand.

10. This paper adopts the direct approach following the work done by Griliches (1958, 1959), Timmer (1974) and others. The approach is a simple version of Nerlove's distributed lag technique, where the demand for fertilizer is specified and estimated directly.

11. The specification consists of two parts: a long-run demand function and an adjustment equation. The demand function assumes that the use of fertilizer is a function of the relevant product and input prices. Prices of agricultural products and fertilizers are affected by the aggregate response of both fertilizer consumption and product production, as well as other factors. The functional form of the demand equation is assumed to be linear in the variables, or in some cases, especially in the developing countries, linear in the logarithms of the variables.

12. The adjustment equation is based on the idea that changes in prices (both input and output) and other independent variables take time to be fully
reflected in demand. It is very clear, especially in the case where lower prices make fertilizer available to new users, that it takes time to introduce a new factor into the production process.

13. The partial adjustment method which was introduced by Griliches and others, consists basically of distinguishing between actual and "desired" levels of use. The demand function determines the long-run "desired" level of use. However, in the short run, the desired level may not be fulfilled and the actual level changes only by some fraction of the difference between the desired use and the current use. The adjustment equation takes into account the direction of the "desired" level but does not permit an instantaneous change. The structural form of the adjustment equation is a function of the difference between the "desired" and actual use of the fertilizer.

14. If we let lower case letters denote the logarithms of the variables, then:

(1) \[ tci^*_{it} = a_0 + \beta_1 P_{it} + \beta_2 \hat{a}_t + \beta_3 P_{jt} + \epsilon_t \]

represents the demand for fertilizer, where \( tci^*_{it} \) is the desired fertilizer consumption of fertilizer \( i \) at time \( t \). \( P_{it} \) is the real price of fertilizer (deflated by the CPI). A vector, \( \hat{a}_t \) is harvested areas of various crops planted. A vector, \( P_{jt} \) consists of all other relevant prices in the production process such as other fertilizers and agricultural products.

The adjustment equation is:

(2) \[ tci_{it} - tci_{it-1} = \gamma(tci^*_{it} - tci^*_{i \ t-1}) \]

where \( \gamma \) is the adjustment coefficient.

In original units we would then have

(2') \[ \frac{tci_{it}}{tci_{it-1}} = \frac{tci^*_{it}}{tci^*_{i \ t-1}} \gamma \]
The percentage change in actual consumption is a power function of the percentage difference between the "desired" and actual consumption. Substituting (1) into (2) and solving for $tc_{it}$ gives:

$$
(3) \quad tc_{it} = \gamma_0 + \gamma_1 p_{it} + \gamma_2 h_{it} + \gamma_3 p_{jt} + (1-\gamma)tc_{it-1} + \gamma e_t
$$

This is the basic equation estimated in the model and the results are given in the following section.

15. Since the variables are in logarithms, the short-run elasticity of fertilizer demand with respect to its own price is given as $\gamma_1$ and the long run elasticity is given as $\frac{\gamma_1}{1-(1-\gamma)}$. Some estimates of these long- and short-run elasticities are given in the discussion of the model results. Although such a model usually performs quite well in the sense of tracking historical observations, this good performance is partially due to the fact that a lagged dependent variable is included (although with good reason). The interpretation of the size of $\gamma$ may be disputed because the lagged variable captures some of the effects of excluded variables which therefore biases the estimation of $(1-\gamma)$ upward.

16. The demand side as a whole was constructed in a way that allows every region to change its demand, while the demand for the world is the sum of its 24 regions. The list of the regions and countries in each is shown in Table 2.1.
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III. FERTILIZER SUPPLY SPECIFICATION

17. The fertilizer supply model is based on work done by Choe (1986). It is presented here for completeness, though it was not part of this study.

18. The fertilizer industry is assumed to be competitive and is represented by a risk-neutral profit-maximizing firm. Further, fertilizer production is assumed to require two factors of production, a variable factor called material (M) and a quasi-fixed factor capital (K) or production capacity. \[1/\]

It is assumed that fertilizer production technology is represented by the following quadratic production function:

\[
Q_t = F(M_t, K_t ; t)
= a_0 + a_{0t} M_t + a_K K_t + a_M M_t + 1/2 a_{KK} K_t^2
+ 1/2 a_{MM} M_t^2 + a_{KM} K_t M_t.
\]

(1)

The first- and second-order conditions for profit maximization require:

\[
a_K > 0, a_M > 0, a_{KK} < 0, \text{ and } a_{KK} a_{MM} - a_{KM}^2 > 0.
\]

1/ The labor input is ignored because it is a relatively small part of the cost of fertilizer production. The most important material input for ammonia production is natural gas. Phosphate rock is the main raw material for phosphate fertilizers. Relatively simple processing is required to transform run-of-mine potash into potash fertilizers, involving little material input.
19. Under uncertainties of future output and input prices, the firm's problem is to choose a contingency plan for inputs that maximizes the present value of expected future profits:

$$\text{Max } E_T \left( \sum_{t=T}^{\infty} \rho^{t-T} [F(K_t, M_t; t) - w_t M_t - v_t K_t - 1/2 \beta I_t^2] \right), \quad (2)$$

subject to given initial capacity, $K_T$, and

$$I_t = K_t - (1 - \delta)K_{t-1}, \quad (3)$$

where $E_T$ is the mathematical expectation operator conditional on information available at time $T$; the term $\rho = (1+r)^{-1}$ is the discount factor where $\rho$ is the interest rate; $w_t$ is the price of material input and $v_t$ is the service price of capital, each normalized by the output price; $I_t$ is the gross investment, and $\delta$ is the constant depreciation rate.

20. The last term in the objective function $(1/2 \beta I_t^2)$ reflects the costs of adjusting the quasi-fixed factor. There are two ways of interpreting the adjustment cost term. One is to consider it as an expenditure, i.e., as a factor cost. The other is to consider it in the form of foregone output. In the latter case, the adjustment cost term can be included as an argument of the production function. The implications of this different treatment for the derivation of the model will be seen later.

21. It has been shown by Sargent (1979) that the first-order necessary conditions for the stochastic optimization problem can be derived by substituting (1) and (3) into (2) with respect to $M_t$ and $K_t$ for $t=T, T+1, \ldots, \infty$. 
\[ a_M + a_{MM} K_t^t + a_{KM} K_t - w_t = 0, \]  

\[ a_K + a_{KK} K_t + a_{KM} M_t + v_t - \beta [K_t - (1-\delta)K_{t-1}] \]

\[ + E_t (\rho \beta (1-\delta)[K_{t+1} - (1-\delta)K_t]) = 0, \]

where the certainty equivalence property of the quadratic specification is used. The condition (4) states that the marginal value product of material input should equal its price. The condition (5) is the "Euler equation" which states that the marginal value product of capital plus the expected future savings in adjustment cost by investing now rather than later should equal the service price of capital plus the current adjustment cost. Equation (4) yields the familiar demand equation for the variable factor; demand for the variable factor depends only on the current period values of the relevant variables.

22. Equation (5) is a second-order stochastic difference equation, the solution of which requires two boundary conditions. One of them is provided by the initial capacity, \( K_t \), and the other is the transversality (terminal) condition:

\[ \lim_{t \to T-1} \rho^{t-T-1} \{a_K + a_{KK} K_t + a_{KM} M_t - v_t - \beta [K_t - (1-\delta)K_{t-1}] \} = 0, \]

which states that the adjustment cost should not affect the optimal capacity level in the very long run. To solve the difference equation, substitute (4) into (5) and rearrange terms to get:

\[ \rho E_t K_{t+1} + \phi K_t + K_{t-1} = B + C w_t + D v_t \]

where
\[ \phi = D \{ A - \beta [1 + \rho (1-\delta)^2] \}, \]  
\[ A = \frac{a_{KK}a_{MM} - a_{KM}^2}{a_{MM}}, \]  
\[ D = \beta^{-1}(1-\delta)^{-1}, \]  
\[ C = D(a_{KM}/a_{MM}), \]  
\[ B = (a_{MM}a_{KM} - a_{KM}^2)/a_{MM}, \]

Sargent (1979) showed that the stochastic difference equation (7) has two characteristic roots, \( \lambda \) and \((1/\rho\lambda)\), such that \( \lambda < 1 < 1/\rho\lambda \). To satisfy the transversality condition (6), the difference equation should be solved backward with the stable root \((\lambda)\) and forward with the unstable root \((1/\rho\lambda)\), to get:

\[ \dot{K}_t \lambda K_{t-1} - \lambda \sum_{i=0}^{\delta} (\rho \lambda)^i E_t (B + C w_{t+1} + D v_{t+1}), \quad (9) \]

where

\[ \lambda = [-\phi + \phi^2 - 4\rho]/(2\rho). \quad (10) \]

23. It is postulated that the firm's expectations about future prices are formed according to the following two univariate autoregressive processes: \(^{1/}\)

\[ E_{t-1} w_t = \sum_{i=1}^{m} \theta_{1i} w_{t-i} + u_{1t}, \quad (11a) \]

\[ E_{t-1} v_t = \sum_{i=1}^{m} \theta_{2i} v_{t-i} + u_{2t}, \quad (11b) \]

where \( u_{1t} \) and \( u_{2t} \) are independently distributed white noise. The exponential order of the above processes are assumed to be less than \( \rho^{-1/2} \) in order to

---

\(^{1/}\) This formulation is chosen instead of the more general vector autoregressive representation to avoid unnecessary complication. The markets for the capital and raw material inputs for fertilizers are quite separate and one is not expected to have significant influence on the other.
ensure their stability. It has been shown by Hansen and Sargent (1980) that if (11) is the expectations formation process, then the dynamics of investment is as follows.

\[ \sum_{i=0}^{\infty} (\rho \lambda)^i E_t w_{t+1} = \sum_{i=0}^{m-1} \mu_{1i} w_{t-1}, \]  

(12a)

\[ \sum_{i=0}^{\infty} (\rho \lambda)^i E_t v_{t+i} = \sum_{i=0}^{m-1} \mu_{2i} v_{t-1}, \]  

(12b)

where

\[ \Pi = \rho \lambda \text{ and} \]

\[ \mu_{10} = (1 - \theta_{11} \Pi - \theta_{12} \Pi^2 - \ldots - \theta_{1m} \Pi^m)^{-1}, \]

\[ \mu_{11} = \mu_{10} (\theta_{12} \Pi + \theta_{13} \Pi^2 + \ldots + \theta_{1m} \Pi^{m-1}), \]

\[ \mu_{12} = \mu_{10} (\theta_{13} \Pi + \theta_{14} \Pi^2 + \ldots + \theta_{1m} \Pi^{m-2}), \]

\[ \ldots \]

\[ \mu_{1m-1} = \mu_{10} (\theta_{1m} \Pi), \]  

(13)

and likewise for \( \mu_{2i} \). Substituting (12) into (9), leads to

\[ K_t \lambda K_{t-1} - \frac{\rho B \lambda^2}{1 - \rho \lambda} + \lambda C \sum_{i=0}^{m-1} \mu_{1i} w_{t-i} - \lambda D \sum_{i=0}^{m-1} \mu_{2i} v_{t-i}, \]

Following the suggestion of Epstein and Yatchew (1985), the following set of equations are estimated:
where the parameters satisfy the restrictions in (8), (10) and (13), and 
\( \varepsilon_{it} \)'s are random variables assumed to be jointly normally distributed with 
zero mean and constant non-singular covariance matrix, and are serially inde-
pendent. The inclusion of the production function in the specification has the 
advantage of permitting identification of both technology and expectations, as 
suggested by Epstein and Yatchew. The system of equations yields closed-form 
solutions for all the parameters of the model \( (a_{0t}, a_{Kt}, a_{Mt}, a_{KK}, a_{MM}, a_{KM}, \beta, 
\rho, \delta, \theta_{1i}, \theta_{2i}, \theta_{1i}, \theta_{2i}, i=1, 2, \ldots, m) \). If \( \rho \) is treated as a variable, 
then equation (15) becomes the flexible accelerator investment equation.

25. The autoregressive structure in (11) postulated for the firm's expec-
tations formation and embedded in equation (15) is more general than the 
rational expectations hypothesis. The equations (16) and (17) describe the 
evolution of actual prices. If expectations are rational, the actual prices 
will evolve as expected and the equations (11) and (16)-(17) will be identical
If the rational expectations hypothesis holds, the parameter restrictions in (13) will apply with \( \theta_{1i} \) and \( \theta_{2i} \) replaced by \( \hat{\theta}_{1i} \) and \( \hat{\theta}_{2i} \). One can also experiment with the static expectations hypothesis adopted in earlier dynamic factor demand studies such as Berndt, Fuss and Waverman (1979). In the case of static expectations, \( \theta_{1i} = \theta_{2i} = 1 \) and \( \theta_{1i} = \theta_{2i} = 0 \), for \( i = 2, \ldots, m \), which greatly simplifies the restrictions in (13).

The hypotheses associated with the restrictions can be tested by progressively imposing restrictions on the parameters. Three different versions of the model have been estimated—the unrestricted model and the rational and static expectations models; they differ only in the way the investment equation (15) is parameterized. It is useful at this point to set out the investment equations for the three cases.

Unrestricted Model

\[
K_t = \theta_0 + \lambda K_{t-1} + \gamma_1 y_t + \gamma_2 y_t + \epsilon_{2t}
\] (18)

Rational Expectations Model

\[
K_t = -\rho B y^2 / (1 - \rho \lambda) + \lambda K_{t-1} + \lambda C w_t / (1 - \hat{\theta}_{11} \rho \lambda) - \lambda D v_t / (1 - \hat{\theta}_{21} \rho \lambda) + \epsilon_{2t}
\] (19)

Static Expectations Model

\[
K_t = -\rho B y^2 / (1 - \rho \lambda) + \lambda K_{t-1} + \lambda C w_t / (1 - \rho \lambda) - \lambda D v_t / (1 - \rho \lambda) + \epsilon_{2t}
\] (20)

Note that the "unrestricted" model is equivalent to the general autoregressive model in equation (15), except that the intercept term is free rather than constrained to take on a certain value implied by the adjustment cost and the autoregressive expectations. Rational and static expectations models are self explanatory.
27. The three models are estimated with and without the adjustment cost term \((1/2\beta I^2)\) in the production function (14). This corresponds to the alternative interpretations of the adjustment cost mentioned earlier.
IV. SPECIFICATION OF PRICE FORMATION

World Price Specification

28. The model is solved for the "world price" which equates world demand with the world supply. How the price is determined is a complex problem that involves questions about the structure of the market in which the commodity is traded. In the fertilizer market it would not be too extreme to assume that the market is competitive and therefore the "world price" equation is such that it corresponds to the law of supply and demand.

29. Following this idea it is straightforward to assume that three variables are to be determined by the model: supply, demand and the market-clearing price. The equilibrium condition of demand being equal to supply is achieved by a price that will determine such a condition and will take the short-term differences between demand and supply into account. However, in such a case it must be assumed that any excess of production over supply would be willingly held. Therefore, the price equation was constructed to give weight to the level of production (or capacity), the level of consumption and the desire to hold inventories. It still remains to be determined what path prices will take from one equilibrium situation to another and this relates to what one is willing to assume about the expected behavior of the participants in the market.

30. In order to simplify the price determination as well as the formula of the reduced form for the estimated price equation, rational expectations in price behavior is assumed. Under this assumption, a simple linear model of world demand and supply consists of the following equations:
(1) \[ q_t^s = \alpha_0 + \alpha_1 p_t + \alpha_2 p_t^e + \phi_s X_{st} + u_{st} \] (supply)

(2) \[ q_t^d = \beta_0 - \beta_1 p_t + \phi_d X_{dt} + u_{dt} \] (demand)

(3) \[ p_t^e = E(p_t / \Omega_{t-1}) \] (expectations)

(4) \[ q_t^s = q_t^d \] (market clearing conditions)

where

- \( q_t^d \) quantity desired for consumption and inventories
- \( q_t^s \) quantity supplied
- \( p_t \) price vector
- \( X_{st}, X_{dt} \) exogenous variables of supply and demand respectively
- \( \Omega_{t-1} \) the set of information available at time \( t-1 \)

and \( u_{st}, u_{dt} \) coming from a joint normal distribution.

31. Substituting (1) - (3) into (4) and solving for \( p_t \) will give

\[
p_t (\alpha_1 + \beta_1) = (\beta_0 - \alpha_1) + (\phi_d X_{dt} - \phi_s X_{st}) - \alpha_2 p_t^e + (u_{dt} - u_{st})
\]

(5) \[
p_t = \left( \frac{\beta_0 - \alpha_0}{\alpha_1 + \beta_1} \right) + \left( \frac{1}{\alpha_1 + \beta_1} \right) (\phi_d X_{dt} - \phi_s X_{st})
\]

\[
- \frac{\alpha_2}{(\alpha_1 - \beta_1)} p_t^e \frac{1}{(\alpha_1 + \beta_1)} + (u_{dt} - u_{st})
\]
32. The set of equations (1)-(4) is consistent with the world production and consumption equations which have been previously discussed. Nevertheless, to ensure the homogeneity property of demand and supply, the relevant deflators such as the world price level and the exchange rate should be used to deflate the price wherever the price is used in both the supply and demand equations. That is to say, the price used should be the "real" price. Rewriting (5) gives:

\[(5') \quad p_t = \mu_1 + \mu_2 X_{dt} - \mu_3 X_{st} - \mu_4 p_t^e + \xi_t\]

where \(\mu_1, \mu_2, \mu_3, \mu_4\) are defined as:

\[
\mu_1 = \frac{\beta_0 - \alpha_0}{A}
\]

\[
\mu_2 = \frac{\phi_d}{A}
\]

\[
\mu_3 = \frac{\phi_s}{A}
\]

\[
\mu_4 = \frac{\alpha_2}{A}
\]

\[A = \alpha_1 + \beta_1\]

\[\xi_t = \xi_{dt} - \xi_{st}\]

However, (5') is not an estimable equation since the expected price formation, \(p_t^e\), should be estimated first. If the expected price formation has the following simple rule
\[ \hat{p}_t = \rho \frac{p_{t-1}}{p_{t-2}} + u_t \]

where \( u_t \) is white noise,

then \( p_t^e = E(p_t / \Omega_{t-1}) = \rho \frac{p_{t-1}}{p_{t-2}} + E(u_t / \Omega_{t-1}) = \rho \frac{p_{t-1}}{p_{t-2}} \) without dependency on the future values of the exogenous variables. It can now be introduced into equation (5') without further complication, obtaining:

\[ p_t = \delta_0 + \delta_1 K_t + \delta_2 TC + \delta_3 \frac{p_{t-1}}{p_{t-2}} + \delta_4 EXR_t + \delta_5 INTR_t \]

where \( K_t \) is the capacity and represents all the exogenous variables determining the potential production at a given year \( t \). \( TC \) represents the exogenous and endogenous variables determining the consumption and is estimated as a behavioral equation at a first-stage estimation. \( EXR_t \) is the effective exchange rate index, reflecting strength of the dollar relative to other currencies since the price is in US$ per metric ton. \( INTR \) is the real short-term interest rate representing the cost of inventory holding since implicitly it was assumed that the demand \( q^d_t \) is both for inventories as well as for actual consumption at time \( t \).

**Domestic Price Linkages**

33. It is necessary to use domestic prices, or prices at the farmgate, in order to measure the correct price effect on fertilizer consumption. However, it is not always easy, and sometimes impossible, to obtain the relevant data. In cases where fertilizer prices paid by farmers were available, this price was linked to the world price through a simple equation as follows. If the
world price at time \( t \) be \( p_t \) expressed in US$ per metric ton, \( p_{it} \) is domestic prices in local currency per metric ton in region \( i \) at time \( t \), and \( XRT_{it} \) is the exchange rate of region \( i \) at time \( t \) expressed in local currency per one dollar. Then

\[
p_{it}^\$ = p_{it}/XRT_{it}
\]

and

\[
p_{it} = f(p_{it}^\$, t-1, p_t)
\]

The error term of this equation is assumed to be autoregressive of order 1, i.e. \( \epsilon_t = \lambda \epsilon_{t-1} + \tau_t \) where \( \tau_t \) is white noise.

34. In cases where we did not have domestic prices the international price (the so-called world price) was used as a border price, i.e., the deflated price in region \( i \) at time \( t \), defined as:

\[
p_{it} = p_t \times XRT_{it}/CPI_{it}
\]

This is a good approximation in a situation where the extent of subsidies is low. It is not a very good approximation where taxes and/or subsidies are high and therefore it does not reflect the prices farmers are facing. Nevertheless, it is often the only measure for fertilizer prices obtainable.
V. ESTIMATED EQUATIONS

Consumption Equations

35. Demand equations were estimated for each of the fertilizers and for each of the regions included in the model. A sample of equations are presented below.

NITROGEN CONSUMPTION

---------------------

BRAZIL

\[
\begin{align*}
\text{NTTCBRA} &= -13841.2695 \text{ DFNTPFBRA2} + 0.2817 \text{ NTTCBRA(-1)} \\
& \quad + 0.0537 \text{ SBHABRA(-1)} + 0.0074 \text{ CRHABRA(-1)} \\
& \quad (1.3258) (1.3904) (1.9308) (3.0789)
\end{align*}
\]

R-SQUARED(CORR.): 0.914SEE: 77.707 DW: 2.50

PERIOD OF FIT: 1966 1982

\[F(4, 13): 43.012\]

MEXICO

\[
\begin{align*}
\text{NTTCMEX} &= -186.3516 - 1573.0941 \text{ DFNTPFMEX} + 0.9041 \text{ NTTCMEX(-1)} \\
& \quad + 0.4632 \text{ WHHAMEX} \\
& \quad (-2.3193) (14.5988) (1.4579)
\end{align*}
\]

R-SQUARED(CORR.): 0.981 SEE: 33.877 DW: 2.75

PERIOD OF FIT: 1963 1981

\[F(3, 15): 304.630\]

LATIN AMERICA

\[
\begin{align*}
\text{NTTCLAC} &= -875.3987 - 0.3399 \text{ DFNTPFLAC} + 0.4876 \text{ NTTCLAC(-1)} \\
& \quad + 0.1141 \text{ CGHALAC} + 0.4619 \text{ RPHALAC} \\
& \quad (-2.2754) (1.4579) (1.4579)
\end{align*}
\]

R-SQUARED(CORR.): 0.961 SEE: 46.552 DW: 1.86

PERIOD OF FIT: 1963 1981

\[F(4, 14): 110.788\]
NORTH AFRICA

$$\text{NTTCNAF} = -0.5514 \text{DFNTPFNAF} + 1.0202 \text{NTTCNAF}(-1) + 0.0090 \text{WHHANAF}(-1)$$

$$(3.6210) \quad (28.5250) \quad (3.9674)$$

R-SQUARED(CORR.): 0.981  SEE: 69.933  DW: 2.27
PERIOD OF FIT: 1963 1982
F(3, 17): 335.732

EAST ASIA

$$\text{NTTCEAS} = -699.0209 - 0.4754 \text{DFNTPFEAS} + 0.8492 \text{NTTCEAS}(-1)$$

$$(-1.7633) \ (-2.0930) \ (9.5204)$$

+ 0.2162 CGHAEAS

$$(2.0118)$$

R-SQUARED(CORR.): 0.979  SEE: 64.051  DW: 2.26
PERIOD OF FIT: 1963 1981
F(3, 15): 278.050

INDIA

$$\text{NTTCIND} = -4494.4146 - 54.2922 \text{DFNTPFIND} + 0.7916 \text{NTTCIND}(-1)$$

$$(-2.5018) \ (-2.0202) \ (7.7784)$$

+ 0.1469 RPHAIND

$$(2.7202)$$

R-SQUARED(CORR.): 0.975  SEE: 158.88  DW: 1.85
PERIOD OF FIT: 1963 1981
F(3, 15): 230.459

CHINA

$$\text{NTTCPRC} = -9484.2725 - 238.7235 \text{DFNTPFPRC2} + 1.0598 \text{NTTCPRC}(-1)$$

$$(-2.7834) \ (-2.5707) \ (13.5603)$$

+ 0.3927 WHHAPRC

$$(2.8177)$$

R-SQUARED(CORR.): 0.965  SEE: 625.36  DW: 2.26
RHO(1): -0.388
PERIOD OF FIT: 1968 1981
F(3, 9): 111.938
NTTCEEC = -1335.2217 + 1.0898 NTTCEEC(-1) - 0.7083 DFNTPFEEC2
(-0.6214) (8.0771) (-1.7949)
+ 654.3002 DFWHPFEEC
(0.8960)
R-SQUARED(CORR.): 0.986 SEE: 189.80 DW: 1.95
RHO(1): -0.078
PERIOD OF FIT: 1963 1983
F(3, 16): 446.935

NTTCJPN = 306.5961 - 346.5631 DFNTPFJPN + 0.2306 NTTCJPN(-1)
(3.2033) (-4.1251) (1.5600)
+ 0.2224 TCHAJPN(-1) - 118.5227 D76
(5.1712) (-2.2892)
R-SQUARED(CORR.): 0.761 SEE: 47.977 DW: 1.93
RHO(1): -0.263
PERIOD OF FIT: 1965 1982
F(4, 12): 13.767

NTTCUSA = -2718.2876 - 71336.3594 DFNTPFUSA + 0.7461 NTTCUSA(-1)
(-2.1586) (-4.2600) (11.4621)
+ 1374.0574 DFWHPFUSA(-1) + 0.0972 WHCGHAUSA
(3.0336) (3.5109)
R-SQUARED(CORR.): 0.976 SEE: 325.18 DW: 2.15
PERIOD OF FIT: 1964 1981
F(4, 13): 171.974

NTTCODC = -0.2455 DFNTPFODC + 0.8334 NTTCODC(-1) + 0.0432 CGHAODC
(-2.4411) (14.8798) (3.7322)
R-SQUARED(CORR.): 0.982 SEE: 50.037 DW: 2.58
PERIOD OF FIT: 1963 1981
F(3, 16): 331.550
SOVIET UNION

\[ \text{NTTCUSR} = -1266.5438 + 1.0020 \text{NTTCUSR}(-1) + 0.0258 \text{WHHAUSR}(-1) \]
\[ (-0.6161) \quad (21.6761) \quad (0.8819) \]

R-SQUARED(CORR.): 0.988 SEE: 260.35 DW: 1.95
PERIOD OF FIT: 1964 1982
F(2,16): 726.317

PHOSPHATE CONSUMPTION

BRAZIL

\[ \text{POTCBRA} = -16538.3965 \text{DFPOPFBRA2} + 0.8707 \text{POTCBRA}(-1) \]
\[ (-1.4680) \quad (6.9253) \]
\[ + 0.0059 \text{CGHABRA} + 0.0420 \text{SBHABRA} \]
\[ (1.2927) \quad (1.8473) \]

R-SQUARED(CORR.): 0.981 SEE: 86.454 DW: 2.10
PERIOD OF FIT: 1964 1981
F(4,14): 220.226

MEXICO

\[ \text{POTCMEX} = -680.0370 + 0.7097 \text{POTCMEX}(-1) + 0.0678 \text{CGHAMEX}(-1) \]
\[ (-4.4882) \quad (4.9484) \quad (4.0144) \]
\[ + 0.1613 \text{CRHAMEX}(-1) \]
\[ (2.7782) \]

R-SQUARED(CORR.): 0.912 SEE: 25.872 DW: 2.51
PERIOD OF FIT: 1965 1982
F(3,14): 59.961

LATIN AMERICA

\[ \text{POTCLAC} = -537.5496 - 0.0956 \text{DFPOPFLAC} + 0.5800 \text{POTCLAC}(-1) \]
\[ (-2.1729) \quad (-1.1809) \quad (3.4754) \]
\[ + 0.1130 \text{CGHALAC} + 0.0572 \text{RPHALAC}(-1) \]
\[ (2.4313) \quad (1.1726) \]

R-SQUARED(CORR.): 0.862 SEE: 28.562 DW: 2.23
PERIOD OF FIT: 1963 1981
F(4,14): 29.160
EAST ASIA

\[
POTCEAS = 1363.8975 + 0.4404 \text{ POTCEAS}(-1) + 0.2141 \text{ CGHAEAS}(-1) \\
(2.4859) \quad (2.6501) \quad (2.9932) \\
- 0.1046 \text{ CRHAEAS}(-1) \\
(-3.2853)
\]

\[
R-\text{SQUARED(Corr.)}: 0.840 \quad \text{SEE}: 50.477 \quad \text{DW}: 1.70 \\
\text{PERIOD OF FIT}: 1966 \quad 1982 \\
F(3, 13): 28.931
\]

INDIA

\[
POTCIND = - 2040.3231 - 12.8347 \text{ DPPOPFIN} + 0.6659 \text{ POTCIND}(-1) \\
(-2.2091) \quad (-2.0693) \quad (4.0522) \\
+ 0.0631 \text{ RPHAIND} \\
(2.3660)
\]

\[
R-\text{SQUARED(Corr.)}: 0.906 \quad \text{SEE}: 94.627 \quad \text{DW}: 1.77 \\
\text{PERIOD OF FIT}: 1963 \quad 1981 \\
F(3, 15): 58.769
\]

CHINA

\[
POTCPRC = - 2283.5125 + 0.4789 \text{ POTCPRC}(-1) + 0.1990 \text{ WHHAPRC}(-1) \\
(-0.4841) \quad (1.2484) \quad (1.6929) \\
- 0.0206 \text{ TCHAPRC}(-1) - 932.9116 \text{ D79} \\
(-0.7458) \quad (-2.5857)
\]

\[
R-\text{SQUARED(Corr.)}: 0.734 \quad \text{SEE}: 311.51 \quad \text{DW}: 1.74 \\
\text{PERIOD OF FIT}: 1967 \quad 1981 \\
F(4, 10): 10.669
\]

NORTH AFRICA

\[
POTCNAF = - 1006.3026 + 0.8673 \text{ POTCNAF}(-1) + 0.0536 \text{ WHHANAF}(-1) \\
(-2.5444) \quad (12.9925) \quad (2.6840)
\]

\[
R-\text{SQUARED(Corr.)}: 0.964 \quad \text{SEE}: 75.153 \quad \text{DW}: 2.61 \\
\text{PERIOD OF FIT}: 1963 \quad 1982 \\
F(2, 17): 256.973
\]
SOUTH AFRICA

\[
POTCSAF = + 0.9867 \text{ POTCSAF}(-1) + 0.0039 \text{ CGHASAF}
\]
\[
(29.6900) \quad (2.1106)
\]

R-SQUARED(CORR.): 0.978 SEE: 13.278 DW: 2.26
PERIOD OF FIT: 1963 1981
F( 2, 17): 397.888

AUSTRALIA

\[
POTCAUS = 361.7017 - 346.5064 \text{ DFPOPFAUS} + 0.0833 \text{ WHHAAUS}
\]
\[
(2.4417) \quad (-11.9181) \quad (9.7422)
\]
\[
- 0.0107 \text{ CRHAAUS} + 365.1413 \text{ DFWHPFAUS}(-1)
\]
\[
(-0.4126) \quad (5.1420)
\]

R-SQUARED(CORR.): 0.903 SEE: 50.468 DW: 2.48
RHO(1): -0.494
PERIOD OF FIT: 1968 1981
F( 4, 8): 28.841

EEC - 10

\[
POTCEEC = - 2824.4636 - 1.9086 \text{ DFPOPFEEC2} + 0.5923 \text{ POTCEEC}(-1)
\]
\[
(-2.2849) \quad (-7.7600) \quad (6.8121)
\]
\[
+ 10.2253 \text{ RPHAEEC}(-1) + 0.1773 \text{ CRHAEEC2}(-1)
\]
\[
(3.1205) \quad (1.9750)
\]

R-SQUARED(CORR.): 0.932 SEE: 108.51 DW: 1.94
PERIOD OF FIT: 1966 1982
F( 4, 12): 56.031

JAPAN

\[
POTCJPN = 379.3159 - 146.7041 \text{ DFPOPFJPN} + 0.4396 \text{ POTCJPN}(-1)
\]
\[
(2.7608) \quad (-2.7613) \quad (3.4093)
\]
\[
+ 143.0723 \text{ DFRIPFJPN}(-1)
\]
\[
(2.7370)
\]

R-SQUARED(CORR.): 0.813 SEE: 42.387 DW: 2.03
PERIOD OF FIT: 1963 1983
F( 3, 17): 29.935
UNITED STATES

\[
\begin{align*}
POTCUSA &= -20750.6699 + 0.8018 POTCUSA(-1) \\
&\quad -2.1707 + 0.0185 CGHAUSA + 0.0478 WHHAUSA \\
&\quad (8.4024) (2.0648) \\
R-SQUARED(CORR.) &= 0.874 \quad \text{SEE: 244.85} \quad \text{DW: 2.55} \\
\text{PERIOD OF FIT:} &\quad 1963 \quad 1981 \\
F(4, 15) &= 31.825 
\end{align*}
\]

SOVIET UNION

\[
\begin{align*}
POTCUSR &= +0.9895 POTCUSR(-1) + 0.0024 \text{WHCGHAUSR}(-1) \\
&\quad (31.7278) (2.5487) \\
R-SQUARED(CORR.) &= 0.982 \quad \text{SEE: 217.18} \quad \text{DW: 1.98} \\
\text{PERIOD OF FIT:} &\quad 1963 \quad 1982 \\
F(2, 18) &= 519.137 
\end{align*}
\]

POTASH CONSUMPTION

BRAZIL

\[
\begin{align*}
KOTCBRA &= -59.6716 - 50557.2891 DFKOPFBRA2 + 1.1130 KOTCBRA(-1) \\
&\quad (-0.2668) (-1.5536) (10.8048) \\
&\quad + 0.0157 CGHABRA \\
&\quad (0.6999) \\
R-SQUARED(CORR.) &= 0.978 \quad \text{SEE: 57.339} \quad \text{DW: 2.39} \\
\text{PERIOD OF FIT:} &\quad 1963 \quad 1981 \\
F(3, 15) &= 272.733 
\end{align*}
\]

LATIN AMERICA

\[
\begin{align*}
KOTCLAC &= -591.4120 + 0.4049 KOTCLAC(-1) + 0.0884 CCHALAC \\
&\quad (-2.7673) (2.9938) (2.2461) \\
&\quad + 0.2328 RPHALAC - 0.7364 DFKOPFLAC(-1) \\
&\quad (4.0846) (-1.7081) \\
R-SQUARED(CORR.) &= 0.925 \quad \text{SEE: 27.094} \quad \text{DW: 1.99} \\
\text{PERIOD OF FIT:} &\quad 1963 \quad 1981 \\
F(4, 14) &= 56.238 
\end{align*}
\]
EAST ASIA

\[ \text{KOTCEAS} = -0.7448 \text{DFKOPFEAS} + 0.8292 \text{KOTCEAS(-1)} \]
\[ (-1.2163) \quad (7.6451) \]
\[ + 0.1033 \text{CGHAES} - 0.0172 \text{CRHAES} \]
\[ (1.9167) \quad (-1.4081) \]
\[ \text{R-SQUARED(CORR.)}: 0.945 \quad \text{SEE}: 37.753 \quad \text{DW}: 2.68 \]
\[ \text{PERIOD OF FIT}: 1965 \quad 1981 \]
\[ \text{F( 4, 13)}: 69.186 \]

INDIA

\[ \text{KOTCIND} = -699.1591 + 0.6560 \text{KOTCIND(-1)} - 60.7125 \text{DFKOPFIND} \]
\[ (-3.0497) \quad (11.8951) \]
\[ + 0.0211 \text{RPHAIND} + 0.0164 \text{WHHAIND} + 142.1651 \text{D68} \]
\[ (2.8522) \quad (4.7196) \quad (6.0442) \]
\[ \text{R-SQUARED(CORR.)}: 0.984 \quad \text{SEE}: 23.695 \quad \text{DW}: 2.28 \]
\[ \text{RHO(1)}: -0.595 \]
\[ \text{PERIOD OF FIT}: 1963 \quad 1981 \]
\[ \text{F( 5, 12)}: 207.012 \]

CHINA

\[ \text{KOTCPRC} = -96.1513 - 87.7067 \text{DFKOPFPRC2} + 1.3255 \text{KOTCPRC(-1)} \]
\[ (-0.1618) \quad (-1.0436) \quad (4.0079) \]
\[ + 180.9829 \text{RWHHAPRC} + 161.2131 \text{D74} \]
\[ (0.3002) \quad (3.2311) \]
\[ \text{R-SQUARED(CORR.)}: 0.853 \quad \text{SEE}: 50.338 \quad \text{DW}: 1.63 \]
\[ \text{RHO(1)}: 0.387 \]
\[ \text{PERIOD OF FIT}: 1967 \quad 1981 \]
\[ \text{F( 4, 9)}: 19.870 \]

SOUTH AFRICA

\[ \text{OTCSAF} = 1.1384 - 40.2878 \text{DFKOPFSAF2} + 0.6829 \text{KOTCSAF(-1)} \]
\[ (0.1036) \quad (-1.1015) \quad (5.9301) \]
\[ + 0.0116 \text{WHHASAF} + 47.0672 \text{DFWHPPSAF(-1)} \]
\[ (1.7826) \quad (3.0767) \]
\[ \text{R-SQUARED(CORR.)}: 0.941 \quad \text{SEE}: 5.1252 \quad \text{DW}: 2.22 \]
\[ \text{PERIOD OF FIT}: 1966 \quad 1981 \]
\[ \text{F( 4, 11)}: 61.294 \]
EEC - 10

KOTCEEC = -1731.2428 - 6.1897 DFKOPFESEC + 0.6652 KOTCEEC(-1)
          (-0.8629) (-2.1381) (5.8578)
          + 8.2492 RPHEEC + 0.1659 WHHAESEC
          (1.8124) (1.5372)
R-SQUARED(CORR.): 0.819 SEE: 181.33 DW: 1.96
PERIOD OF FIT: 1964 1981
F( 4, 13): 20.290

JAPAN

KOTCJPN = 1060.8259 - 669.9056 DFKOPFJPN - 0.2224 KOTCJPN(-1)
          (8.1666) (-8.3149) (-1.7281)
          + 0.0676 RPHAJPN
          (3.9068)
R-SQUARED(CORR.): 0.798 SEE: 27.968 DW: 2.14
RHO(1): -0.591
PERIOD OF FIT: 1963 1981
F( 3, 14): 23.326

UNITED STATES

KOTCUSA = -90627.1797 DFKOPFUSA + 0.7780 KOTCUSA(-1)
          (-1.9009) (7.4630)
          + 0.0636 WHHAUSA + 0.0261 CGHAUSA
          (2.0077) (1.6687)
R-SQUARED(CORR.): 0.936 SEE: 278.92 DW: 2.56
PERIOD OF FIT: 1963 1981
F( 4, 15): 66.380

OTHER DEVELOPED

KOTCODC = -0.5512 DFKOPFODC(-1) + 0.6538 KOTCODC(-1) + 0.0461 CGHAODC
          (-1.1200) (4.0962) (2.1613)
R-SQUARED(CORR.): 0.899 SEE: 54.490 DW: 1.82
PERIOD OF FIT: 1963 1981
F( 3, 16): 53.995
SOVIET UNION

\[ \text{KOTCUSR} = -11674.7217 + 0.2489 \text{KOTCUSR}(-1) + 0.1004 \text{WHCGHAUSR}(-1) \]
\[ (-3.0529) \quad (1.2016) \quad (3.0984) \]
\[ -19.8792 \text{KOPRWRD} + 253.3810 \text{TIME} \]
\[ (-3.1345) \quad (3.5287) \]

R-SQUARED(CORR.): 0.948  SEE: 326.43  DW: 1.46
PERIOD OF FIT: 1965 1982
F(4, 13): 79.176
Variables and Country Codes for Demand Equations

Every region, whether it is an individual country or a set of countries, was given a name consisting of three letters. The regions and their abbreviations are listed below.

- Australia: AUS
- Canada: CAN
- EEC 10: EEC
- Japan: JPN
- United States: USA
- Other Industrial Countries: ODC
- Eastern Europe: EEU
- Union of Soviet Socialist Republics: USR
- People's Republic of China: PRC
- Argentina: ARG
- Brazil: BRA
- Central Africa: CAF
- East Asia: EAS
- Egypt: EGY
- India: IND
- Indonesia: INO
- Latin America: LAC
- Mexico: MEX
- Nigeria: NIG
- North Africa: NAF
- Pakistan: PAK
- South Africa: SAF
- South Asia: SAS
- Thailand: THA

Two letters were used to identify each of the commodities used in the model: wheat-WH; coarse grains-CG; rice paddy-RP; rice-RI; total crop-TC; soybean-SB; nitrogen-NT; phosphate-PO; potash-KO. The type of variable is also indicated by two letters: total consumption-TC; production-PD; price paid by farmers-PF; harvested area-HA. If a variable is a price variable deflated by the consumer price index it is preceded by DF. For example, WHHATHA = harvested area of wheat in Thailand and DFNTPFNAF = deflated price of nitrogen paid by farmers in North Africa. The macro variables i.e. population, exchange rate and consumer price index are indicated by the letters XRT-exchange rate; CPI-consumer price index; and POP-population.
Capacity and Production Equations

37. Capacity equations were estimated for nitrogen and phosphate in Europe & Japan, North America, Developing Countries and Centrally Planned Economies. For those same fertilizers a production function was estimated which takes into account the potential capacity available and other factors (as explained in Section III). The capacity and production of potash were estimated only on a world basis. The capacity equation and the production equation are presented below for each of the fertilizers.

**NITROGEN**

EUROPE AND JAPAN

**CAPACITY**:

\[
NKEJ = 1092.7333 + 0.9444 \cdot NKEJ(-1) - 851.9091 \cdot PMNEJ(-2) + 98.5891 \cdot PMNEJ(-3) \\
+ 605.5921 \cdot PMNEJ(-4) + 5132.2632 \cdot PKN(-2) - 4455.6479 \cdot PKN(-3) \\
(0.9701) \quad (16.8222) \quad (-1.8262) \quad (0.1520) \\
+ (1.3453) \quad (2.6953) \quad (-1.9352)
\]

R-SQUARED(CORR.): 0.971  SEE: 665.12  DW: 1.67
PERIOD OF FIT: 1964 1984
F( 6, 14): 113.276

**PRODUCTION**:

\[
NQEJ = 1651.7440 + 305.1215 \cdot TIME + 1.0929 \cdot NKEJ - 0.0001 \cdot NKEJ^2 \\
+ 159.5117 \cdot PMNEJ^2 \\
(1.2979) \quad (4.1638) \quad (4.0492) \quad (-3.9179) \\
- (3.3772)
\]

R-SQUARED(CORR.): 0.900  SEE: 510.76  DW: 1.84
PERIOD OF FIT: 1964 1984
F( 4, 16): 45.986
NORTH AMERICA

CAPACITY:
NKNA = -9107.6074 + 0.1905 NKNA(-1) - 1472.6921 PMNNA(-2)
       (-2.8662) (0.9268) (-1.1750)
       - 1334.7931 PMNNA(-3) + 2991.6907 PKN(-2)
       (-0.7784) (1.1870)
       - 2703.5776 PKN(-3) + 8412.0430 LOGTIME
       (-0.9423) (3.7616)
R-SQUARED(CORR.): 0.974 SEE: 657.14 DW: 2.26
PERIOD OF FIT: 1964 1984
F( 6, 14): 127.323

PRODUCTION:
NQNA = 806.4847 + 477.1568 TIME + 0.2891 NKNA - 0.0000 NKNA2
       (0.7828) (5.5900) (1.6130) (-1.0864)
       - 372.6502 PMNNA2
       (-4.1807)
R-SQUARED(CORR.): 0.958 SEE: 541.93 DW: 1.12
PERIOD OF FIT: 1964 1984
F( 4, 16): 115.808

CENTRALLY PLANNED COUNTRIES (EUROPE)

CAPACITY:
NKCP = 3873.6460 + 1.0764 NKCP(-1) - 535.5579 PMNAVG(-2)
       (4.3202) (53.1602) (-0.5565)
       + 2303.0950 PMNAVG(-3) - 4099.2563 PMNAVG(-4)
       (1.8900) (-5.3783)
       - 3333.0867 PKN(-2) + 2480.0168 PKN(-3)
       (-1.2685) (0.8624)
R-SQUARED(CORR.): 0.997 SEE: 772.73 DW: 2.87
PERIOD OF FIT: 1964 1984
F( 6, 14): 956.701
PRODUCTION:
NQCP = -2010.2239 + 800.0512 TIME + 0.2156 NKCP + 0.0000 NKCP2
(-4.9521) (5.9929) (1.6269) (1.4277)
- 129.5176 PMNAV2
(-2.3784)

R-SQUARED(CORR.): 0.998 SEE: 392.18 DW: 2.27
PERIOD OF FIT: 1964 1984
F(4, 16): 2579.396

DEVELOPING COUNTRIES

CAPACITY:
NKDC = 1871.8712 + 1.0828 NKDC(-1) + 523.7126 PMNAV(-2)
(2.5632) (33.2701) (0.7547)
- 1658.8002 PMNAV(-3) + 372.4431 PMNAV(-4)
(-1.3297) (0.3870)
- 3266.5479 PKN(-2) + 6106.0317 PKN(-3) - 4161.8843 PKN(-4)
(-1.3297) (0.3870)

R-SQUARED(CORR.): 0.994 SEE: 554.21 DW: 2.40
PERIOD OF FIT: 1964 1984
F(7, 13): 440.768

PRODUCTION:
NQDC = -1158.9550 + 476.2791 TIME - 0.2157 NKDC + 0.0000 NKDC2
(-2.2905) (3.6606) (-1.1917) (4.8512)
- 385176.9063 PUREA-1-2
(-0.8410)

R-SQUARED(CORR.): 0.996 SEE: 234.21 DW: 1.63
PERIOD OF FIT: 1964 1984
F(4, 16): 1315.560
PHOSPHATE
------------
EUROPE AND JAPAN
--------------

CAPACITY:
PKEJ = 1864.7880 + 0.8114 PKEJ(-1) - 2626.2107 PMP(-2)
     (2.7224)  (6.5994)  (-1.5258)
     - 752.3315 PMP(-3) + 444.9250 PKP(-2) - 82.6618 PKP(-3)
     (-0.3918)  (0.8768)  (-0.1200)
     - 409.5767 PMP(-4) - 320.0896 PKP(-4) + 282.6097 RPKPQEJ
     (-0.3596)  (-0.6041)  (0.3592)

R-SQUARED(CORR.): 0.981  SEE: 146.22  DW: 2.13
PERIOD OF FIT: 1965 1984
F( 8, 11): 121.050

PRODUCTION:
PQEJ = 2890.5840 - 131.9156 TIME + 2.4341 PKEJ
     (3.8594) (-4.2505) (6.7581)
     - 0.0004 PKEJ2 - 11792.9004 PMP2
     (-3.6958) (-4.5292)

R-SQUARED(CORR.): 0.903  SEE: 318.38  DW: 1.94
PERIOD OF FIT: 1960 1984
F( 4, 20): 56.882

NORTH AMERICA
-------------

CAPACITY:
PKNA = 1723.0560 + 0.9122 PKNA(-1) - 5093.8765 PMP(-2)
      (0.9182)  (16.2011)  (-1.1255)
      - 533.9583 PMP(-3) + 1791.9712 PKP(-2) - 2181.9109 PKP(-3)
      (-0.1385)  (1.1500)  (-1.3106)
      + 1303.3057 RPKPQNA
      (0.8942)

R-SQUARED(CORR.): 0.976  SEE: 511.74  DW: 2.73
PERIOD OF FIT: 1963 1984
F( 6, 15): 142.926
PRODUCTION:
\[ PQNA = 3900.0164 - 204.3221 \text{ TIME} + 0.6859 \text{ PKNA} + 0.0000 \text{ PKNA}^2 \]
\[ - 9637.8809 \text{ PMP}^2 \]
\[ (-4.1158) (-1.4101) (2.5568) (1.2218) \]
\[ R^2 \text{(CORR.): 0.926 SEE: 537.57 DW: 1.66} \]
\[ \text{PERIOD OF FIT: 1963 1984} \]
\[ F(4, 17): 66.914 \]

CENTRALLY PLANNED COUNTRIES

CAPACITY:
\[ PKCP = -705.5914 + 0.7881 \text{ PKCP}(-1) - 978.4176 \text{ PMP}(-2) \]
\[ (-0.7353) (8.8050) (-0.3588) \]
\[ - 451.1628 \text{ PMP}(-3) + 2417.7961 \text{ PMP}(-4) + 130.2768 \text{ PKP}(-2) \]
\[ (-0.2383) (1.5051) (0.1628) \]
\[ - 304.9286 \text{ PKP}(-3) + 3769.4492 \text{ RPKPQCP} \]
\[ (-0.3178) (2.7382) \]
\[ R^2 \text{(CORR.): 0.992 SEE: 248.89 DW: 2.11} \]
\[ \text{PERIOD OF FIT: 1964 1984} \]
\[ F(7, 13): 365.032 \]

PRODUCTION:
\[ PQCP = 953.1170 + 339.4733 \text{ TIME} + 0.7812 \text{ PKCP} - 0.0001 \text{ PKCP}^2 \]
\[ (1.7337) (3.8371) (2.4829) (-3.0594) \]
\[ - 2484.3335 \text{ PMP}^2 \]
\[ (-0.7578) \]
\[ R^2 \text{(CORR.): 0.990 SEE: 376.94 DW: 2.03} \]
\[ \text{PERIOD OF FIT: 1960 1984} \]
\[ F(4, 20): 577.122 \]
DEVELOPING COUNTRIES

CAPACITY:

\[
PKDC = 524.4303 + 1.0669 \text{PKDC(-1)} + 874.6616 \text{PMP(-2)} + 2506.5728 \text{PMP(-3)} + 1929.1949 \text{PMP(-4)} - 505.3241 \text{PKP(-2)} + 148.0381 \text{PKP(-3)} - 119.5401 \text{RPKPQDC}
\]

\[
(0.5674) (46.1274) (0.3483) (-0.9386) (0.8486) (-0.4841) (0.1346) (-0.2125)
\]

R-SQUARED(CORR.): 0.988  SEE: 367.74  DW: 2.16
RHO(1): -0.590
PERIOD OF FIT: 1964 1984
\[
F( 7, 12): 233.153
\]

PRODUCTION:

\[
PQDC = 221.1357 + 114.6447 \text{TIME} + 0.3252 \text{PKDC} + 0.0000 \text{PKDC2} - 830.7317 \text{PMP2}
\]

\[
(0.4170) (1.1738) (1.0382) (0.1952)
\]

R-SQUARED(CORR.): 0.985  SEE: 238.70  DW: 2.15
PERIOD OF FIT: 1963 1984
\[
F( 4, 17): 341.358
\]

POTASH WORLD CAPACITY AND PRODUCTION

CAPACITY:

\[
KKWD = 1208.8502 + 0.8716 \text{KKWD(-1)} + 100.5937 \text{PPOT(-2)} - 73.3431 \text{PPOT(-3)} + 3164.8545 \text{PKK(-2)} - 1784.6998 \text{PKK(-3)}
\]

\[
(0.4275) (9.1955) (2.0775) (-1.4199) (0.8557) (-0.4504)
\]

R-SQUARED(CORR.): 0.952  SEE: 1552.9  DW: 1.90
PERIOD OF FIT: 1963 1984
\[
F( 5, 16): 85.216
\]

PRODUCTION:

\[
KQWD = 504.9231 + 818.6190 \text{TIME} + 0.6357 \text{KKWD} - 0.0000 \text{KKWD2} + 14.7639 \text{PPOT}
\]

\[
(0.1158) (3.1746) (1.6762) (-2.1525) (0.6578)
\]

R-SQUARED(CORR.): 0.980  SEE: 953.33  DW: 1.75
RHO(1): 0.570
PERIOD OF FIT: 1960 1984
\[
F( 4, 19): 278.578
\]
Codes for the Capacity and Production Equations

38. Four regions are differentiated for the supply side of the model. These regions are denoted by two letters.

- Europe and Japan and other industrial countries: EJ
- North America: NA
- Developing Countries: DC
- Centrally Planned Economies: CP

Capacity is denoted by the letter K and production by the letter Q. Other variables appear in the capacity and production equations and are defined as follows:

- \( PKN = \frac{MUV}{\text{Nitrogen price}} \) where MUV is the manufacturing unit value index
- \( PMNNA = \frac{\text{natural gas price in North America}}{\text{nitrogen price}} \) × 100.0
- \( PMNAV = \frac{(PMNNA + PMNEJ)}{2.0} \)
- \( PUREA-1-2 = \left[ \text{nitrogen price} \right]^2 \)
- \( PMP = \frac{\text{phosphate rock price}}{\text{phosphate price}} \)
- \( PKK = \frac{MUV}{\text{potash price}} \)
- \( PPOT = \text{potash price} \)

Price Equations

39. Nitrogen and phosphate prices are estimated as a ratio of the price of the fertilizer and its most important input. Therefore the estimated equations for prices these two fertilizers are:
Natural gas price $\frac{\text{Nitrogen price}}{\text{Phosphate rock price}} = f(x_1, y_1)$

and

where $x_1$, $x_2$ are vectors of variables exogenous to the model, and $y_1$, $y_2$ are vectors of variables endogenous to the model. The potash price is estimated directly i.e., potash price $= f(x_3, y_3)$ where $x_3$ and $x_4$ are defined similarly to the equations above.

40. Regression estimates of the fertilizer price equations are shown below.

**NITROGEN WORLD PRICE**

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>t-stat</th>
<th>Constant:</th>
<th>1962-1984</th>
</tr>
</thead>
<tbody>
<tr>
<td>(PMNAVGC)</td>
<td>$-2.1948$</td>
<td>$0.0000525$</td>
<td>$0.1084$</td>
</tr>
<tr>
<td>NKWD</td>
<td>$(-3.6691)$</td>
<td>$(2.7977)$</td>
<td>$(-2.0598)$</td>
</tr>
<tr>
<td>FNTTCWRD</td>
<td>$0.00000636$</td>
<td>$0.0000636$</td>
<td></td>
</tr>
<tr>
<td>INTR</td>
<td>$0.1084$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EXR</td>
<td>$0.0227$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PMNAVGRISK</td>
<td>$0.0227$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D7483</td>
<td>$-1.0418$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-SQUARED(CORR.):</td>
<td>$0.939$</td>
<td>SEE:</td>
<td>$0.19741$</td>
</tr>
<tr>
<td>Period of fit:</td>
<td>$1962$</td>
<td>$1984$</td>
<td></td>
</tr>
<tr>
<td>F(6, 16):</td>
<td>$57.501$</td>
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<td></td>
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**PHOSPHATE WORLD PRICE**

<table>
<thead>
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<th>Coefficient</th>
<th>t-stat</th>
<th>Constant:</th>
<th>1963-1984</th>
</tr>
</thead>
<tbody>
<tr>
<td>(PMP)</td>
<td>$0.3780$</td>
<td>$0.0000123$</td>
<td>$0.0027$</td>
</tr>
<tr>
<td>PKWD</td>
<td>$(4.7683)$</td>
<td>$(2.8185)$</td>
<td>$(-2.9676)$</td>
</tr>
<tr>
<td>FPOTCWRD</td>
<td>$0.0000203$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DINTR</td>
<td>$0.0096$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PMPRISK</td>
<td>$0.1200$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D72</td>
<td>$-0.0995$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-SQUARED(CORR.):</td>
<td>$0.796$</td>
<td>SEE:</td>
<td>$0.26303E-01$</td>
</tr>
<tr>
<td>Period of fit:</td>
<td>$1963$</td>
<td>$1984$</td>
<td></td>
</tr>
<tr>
<td>F(6, 15):</td>
<td>$14.671$</td>
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</tr>
</tbody>
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**POTASH WORLD PRICE**

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>t-stat</th>
<th>Constant:</th>
<th>1962-1984</th>
</tr>
</thead>
<tbody>
<tr>
<td>(PPOT)</td>
<td>$1.3275$</td>
<td>$0.0057$</td>
<td>$0.0096$</td>
</tr>
<tr>
<td>KKWD</td>
<td>$(0.1796)$</td>
<td>$(-5.0617)$</td>
<td>$(5.9448)$</td>
</tr>
<tr>
<td>FKOTCWRD</td>
<td>$0.6153$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DINTR</td>
<td>$3.6374$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D77</td>
<td>$-20.6276$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-SQUARED(CORR.):</td>
<td>$0.903$</td>
<td>SEE:</td>
<td>$8.8564$</td>
</tr>
<tr>
<td>Period of fit:</td>
<td>$1962$</td>
<td>$1984$</td>
<td></td>
</tr>
<tr>
<td>F(5, 17):</td>
<td>$41.854$</td>
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</tr>
</tbody>
</table>
VI. AN EX-POST MODEL SIMULATION

41. In order to validate the specification of the equations as well as the overall performance of the model an ex-post simulation was run dynamically, i.e., where the lagged variables in any equation are the simulated values, except for the first year for which the model is solved.

42. The ex-post simulation was carried out for the period 1970-1984 and the simulated series were compared with the actual series to derive statistics to evaluate the performance of each variable. The summary statistics for simulations of nitrogen, phosphate and potash consumption are shown in Tables 6.1, through 6.3, respectively. 1/

43. As Tables 6.1 and 6.2 show, the overall performance of the model is quite good; the RMSPE 2/ are low for almost all of the variables. For the major economic regions it can be seen that the RMSPE for nitrogen consumption does not exceed 7.403 (for the developing countries), and it is even lower for phosphate consumption.

44. The fluctuations in potash consumption through the period of this simulation were much greater than for nitrogen and phosphate. Even so, the diagnostics of the potash consumption variables are satisfactory (Table 6.3). The RMSPE for the world is slightly higher than 4.2, which is not as low as for nitrogen and phosphate but is still creditable. Special attention should be given to the inequality proportions. For nitrogen the covariance proportion is very close to 1.0 for all of the major economic regions. The covariance proportion factor for the centrally planned economies is slightly lower,

1/ The definitions of each of the statistics used in the following tables are provided in Appendix A.

2/ Root mean square percentage error.
0.569, but in the other regions the proportions are very high (developing 0.986, industrial 0.992 and for the world 0.999). The results for phosphate and potash are generally not as good as those for nitrogen. Graphic displays of the tracking performance for the consumption variables can be found in Figures 6.1 through 6.16 for nitrogen, 6.17 through 6.33 for phosphates and 6.34 through 6.48 for potash.

45. Tables 6.4 through 6.6 summarize the tracking statistics for the ex-post simulation of capacity and production. As can be seen, the performance of the supply side of the model is at least as good as the demand side. For nitrogen the highest RMSPE is about 6.6%, which was for capacity in developing countries, but even so the RMSPE for production of the developing countries is less than 2%. The fact that the covariance inequality proportion for capacity in the developing countries is 0.998 and the inequality proportion for production in that region is 0.673—which is the lowest among all the nitrogen capacity and production equations—is indicative of the good performance. There are mixed results concerning phosphate. Generally, the results are not nearly as good as for nitrogen. However, in absolute terms the results are reasonably good. The bias inequality proportions are very small for all of the regions for both fertilizers and the covariance inequality proportions are relatively high in most cases.

46. Equations for potash world capacity and production have been estimated, as previously mentioned, on a world basis. Given the difficulties of estimating a "world equation" the results are encouraging. The RMSPE of the capacity equation is 6.5 and the bias inequality proportion is almost zero. The production equation produced a RMSPE which is only 4.7 with a bias inequality proportions which is effectively zero. For both of these variables, the covariance inequality proportion is reasonably high—0.531 for capacities
and 0.548 for production. Graphical displays of the tracking performance of production by the model are presented in Figures 6.49-6.70.

47. Finally, we illustrate the performance of the most important variables in the model—prices. It should be remembered that this is a dynamic ex-post simulation; only the first year simulated uses actual lagged variables. The lagged values for periods thereafter are the simulated values. A forecast error of up to 15% can therefore be considered a reasonably good result.

48. As can be seen from Table 6.7 the RMSPE for nitrogen prices is 15.29. A large part of the reason for this result is because the model overshot in predicting the price level in 1974—the highest price peak during the simulation period. The contribution of this single year to the RMSPE statistic is very high (25%). Otherwise, the RMSPE would be no more than (9%). The same problem occurs with the phosphate price. The RMSPE for this equation is 13.18, but if the unusual case of 1974 is taken into consideration it would be less than 8% on the average.

49. It appears from our experience in estimating the potash price that the variables we were using did not fully explain the events of 1980-84 at all well. Even so, the RMSPE is only 15.86.

50. Clearly the simulated series of all three world prices do closely follow the actual series, especially in the cases of nitrogen and phosphate. The covariance inequality proportions prove this point. They are 0.69 for both nitrogen and phosphate while the bias inequality proportions are very close to zero. The coefficients for these two statistics can make the argument that there is no systematic deviation from the actual series for any of these prices and that the equations used do have the capability of duplicating the degree of variability of any of the world fertilizer prices.

51. Figures 6.71-6.73 provide the visual backup to the above discussion.
<table>
<thead>
<tr>
<th>REGION</th>
<th>MEAN OF ACTUAL</th>
<th>MEAN ERROR</th>
<th>ROOT MEAN SQUARED ERROR</th>
<th>MEAN $%$</th>
<th>ROOT MEAN SQUARED $%$ ERROR</th>
<th>THEIL BIAS</th>
<th>VARIANCE</th>
<th>COVARIANCE</th>
<th>--INEQUALITY PROPORTIONS--</th>
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# TABLE 6.2: SUMMARY STATISTICS FOR EX-POST SIMULATION OF PHOSPHATE CONSUMPTION

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<th>MEAN ERROR</th>
<th>ROOT MEAN SQUARED ERROR</th>
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<th>ROOT MEAN SQUARED % ERROR</th>
<th>THEIL BIAS VARIANCE</th>
<th>COVARIANCE %</th>
<th>THEIL INEQUALITY PROPORTIONS</th>
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### TABLE 6.3: SUMMARY STATISTICS FOR EX-POST SIMULATION OF POTASH CONSUMPTION

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<th>MEAN OF ACTUAL</th>
<th>MEAN ERROR</th>
<th>ROOT MEAN ERROR</th>
<th>MEAN $%$ ERROR</th>
<th>ROOT MEAN ERROR $%$</th>
<th>THEIL BIAS</th>
<th>VARIANCE</th>
<th>COVARIANCE</th>
<th>--INEQUALITY PROPORTIONS--</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARGENTINA</td>
<td>7,446</td>
<td>3,438</td>
<td>4,085</td>
<td>59,301</td>
<td>79,611</td>
<td>0.841</td>
<td>0.004</td>
<td>0.323</td>
<td>0.673</td>
</tr>
<tr>
<td>BRAZIL</td>
<td>691,582</td>
<td>102,806</td>
<td>122,357</td>
<td>17,367</td>
<td>23,538</td>
<td>0.693</td>
<td>0.019</td>
<td>0.106</td>
<td>0.875</td>
</tr>
<tr>
<td>CENTRAL AFRICA</td>
<td>127,568</td>
<td>10,353</td>
<td>12,842</td>
<td>8,225</td>
<td>10,433</td>
<td>1.028</td>
<td>0.000</td>
<td>0.140</td>
<td>0.860</td>
</tr>
<tr>
<td>EAST ASIA</td>
<td>420,698</td>
<td>44,542</td>
<td>55,631</td>
<td>9,898</td>
<td>11,634</td>
<td>0.916</td>
<td>0.001</td>
<td>0.271</td>
<td>0.728</td>
</tr>
<tr>
<td>EGYPT</td>
<td>4,720</td>
<td>1,037</td>
<td>1,637</td>
<td>19,354</td>
<td>25,725</td>
<td>0.977</td>
<td>0.000</td>
<td>0.002</td>
<td>0.998</td>
</tr>
<tr>
<td>INDIA</td>
<td>421,747</td>
<td>48,801</td>
<td>55,868</td>
<td>12,810</td>
<td>14,572</td>
<td>0.679</td>
<td>0.009</td>
<td>0.211</td>
<td>0.780</td>
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<td>INDONESIA</td>
<td>52,828</td>
<td>8,706</td>
<td>10,483</td>
<td>50,295</td>
<td>86,910</td>
<td>0.733</td>
<td>0.007</td>
<td>0.573</td>
<td>0.419</td>
</tr>
<tr>
<td>LATIN AMERICA</td>
<td>366,453</td>
<td>18,695</td>
<td>21,793</td>
<td>5,122</td>
<td>5,995</td>
<td>0.771</td>
<td>0.019</td>
<td>0.007</td>
<td>0.973</td>
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<td>MEXICO</td>
<td>50,114</td>
<td>7,401</td>
<td>8,613</td>
<td>17,503</td>
<td>22,280</td>
<td>0.977</td>
<td>0.008</td>
<td>0.161</td>
<td>0.831</td>
</tr>
<tr>
<td>NORTH AFRICA</td>
<td>117,192</td>
<td>16,001</td>
<td>18,501</td>
<td>14,555</td>
<td>17,122</td>
<td>0.889</td>
<td>0.015</td>
<td>0.124</td>
<td>0.860</td>
</tr>
<tr>
<td>NIGERIA</td>
<td>15,624</td>
<td>2,660</td>
<td>3,736</td>
<td>40,956</td>
<td>67,206</td>
<td>0.631</td>
<td>0.093</td>
<td>0.452</td>
<td>0.455</td>
</tr>
<tr>
<td>PAKISTAN</td>
<td>8,156</td>
<td>2,355</td>
<td>2,978</td>
<td>86,692</td>
<td>112,490</td>
<td>0.737</td>
<td>0.040</td>
<td>0.266</td>
<td>0.694</td>
</tr>
<tr>
<td>PEOPLE'S REP. OF CHINA</td>
<td>305,533</td>
<td>73,255</td>
<td>90,265</td>
<td>46,767</td>
<td>65,438</td>
<td>0.873</td>
<td>0.010</td>
<td>0.635</td>
<td>0.355</td>
</tr>
<tr>
<td>SOUTH AFRICA</td>
<td>125,806</td>
<td>9,961</td>
<td>11,314</td>
<td>7,882</td>
<td>8,867</td>
<td>0.992</td>
<td>0.001</td>
<td>0.082</td>
<td>0.917</td>
</tr>
<tr>
<td>SOUTH ASIA</td>
<td>54,444</td>
<td>5,562</td>
<td>7,155</td>
<td>11,512</td>
<td>16,430</td>
<td>0.922</td>
<td>0.002</td>
<td>0.399</td>
<td>0.599</td>
</tr>
<tr>
<td>THAILAND</td>
<td>36,048</td>
<td>12,679</td>
<td>14,843</td>
<td>42,247</td>
<td>51,373</td>
<td>N.A.</td>
<td>N.A.</td>
<td>N.A.</td>
<td>N.A.</td>
</tr>
<tr>
<td>TOTAL DEVELOPING</td>
<td>2805,959</td>
<td>156,899</td>
<td>181,810</td>
<td>6,044</td>
<td>7,266</td>
<td>0.621</td>
<td>0.008</td>
<td>0.178</td>
<td>0.813</td>
</tr>
<tr>
<td>AUSTRALIA</td>
<td>107,223</td>
<td>8,577</td>
<td>11,181</td>
<td>8,402</td>
<td>11,281</td>
<td>0.699</td>
<td>0.010</td>
<td>0.599</td>
<td>0.392</td>
</tr>
<tr>
<td>CANADA</td>
<td>267,203</td>
<td>11,617</td>
<td>13,602</td>
<td>4,172</td>
<td>4,791</td>
<td>0.721</td>
<td>0.004</td>
<td>0.055</td>
<td>0.942</td>
</tr>
<tr>
<td>EEC-10</td>
<td>4148,763</td>
<td>157,626</td>
<td>202,107</td>
<td>3,734</td>
<td>4,746</td>
<td>0.759</td>
<td>0.004</td>
<td>0.235</td>
<td>0.761</td>
</tr>
<tr>
<td>JAPAN</td>
<td>620,420</td>
<td>47,979</td>
<td>65,465</td>
<td>8,149</td>
<td>11,556</td>
<td>0.905</td>
<td>0.000</td>
<td>0.105</td>
<td>0.894</td>
</tr>
<tr>
<td>OTHER INDUSTRIAL</td>
<td>1156,871</td>
<td>57,086</td>
<td>78,935</td>
<td>4,968</td>
<td>6,759</td>
<td>0.849</td>
<td>0.004</td>
<td>0.646</td>
<td>0.351</td>
</tr>
<tr>
<td>UNITED STATES</td>
<td>4740,339</td>
<td>240,141</td>
<td>288,765</td>
<td>5,105</td>
<td>6,305</td>
<td>0.810</td>
<td>0.000</td>
<td>0.213</td>
<td>0.787</td>
</tr>
<tr>
<td>TOTAL INDUSTRIAL</td>
<td>11040,819</td>
<td>435,839</td>
<td>510,520</td>
<td>3,904</td>
<td>4,521</td>
<td>0.839</td>
<td>0.001</td>
<td>0.296</td>
<td>0.703</td>
</tr>
<tr>
<td>EASTERN EUROPE</td>
<td>3065,786</td>
<td>162,299</td>
<td>206,787</td>
<td>5,054</td>
<td>6,232</td>
<td>0.888</td>
<td>0.009</td>
<td>0.459</td>
<td>0.532</td>
</tr>
<tr>
<td>USSR</td>
<td>4357,733</td>
<td>460,552</td>
<td>553,433</td>
<td>9,830</td>
<td>11,436</td>
<td>0.925</td>
<td>0.003</td>
<td>0.112</td>
<td>0.885</td>
</tr>
<tr>
<td>TOTAL CENTRALLY PLANNED</td>
<td>7423,520</td>
<td>499,293</td>
<td>639,466</td>
<td>6,320</td>
<td>7,768</td>
<td>0.860</td>
<td>0.001</td>
<td>0.198</td>
<td>0.801</td>
</tr>
<tr>
<td>TOTAL WORLD</td>
<td>21270,301</td>
<td>724,013</td>
<td>937,516</td>
<td>3,342</td>
<td>4,232</td>
<td>0,726</td>
<td>0.002</td>
<td>0.269</td>
<td>0.729</td>
</tr>
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</table>

N.A.: NOT APPLICABLE.

SOURCE: WORLD BANK, ECONOMIC ANALYSIS AND PROJECTIONS DEPARTMENT.
### TABLE 6.4: SUMMARY STATISTICS FOR EX-POST SIMULATION OF NITROGEN CAPACITY AND PRODUCTION

<table>
<thead>
<tr>
<th>REGION</th>
<th>MEAN OF ACTUAL</th>
<th>MEAN ERROR</th>
<th>ROOT MEAN SQUARED ERROR</th>
<th>MEAN % ERROR</th>
<th>ROOT MEAN SQUARED % ERROR</th>
<th>THEIL BIAS</th>
<th>VARIANCE</th>
<th>COVARIANCE</th>
<th>--INEQUALITY PROPORTIONS--</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEVELOPING COUNTRIES</td>
<td>13698.667</td>
<td>651.101</td>
<td>723.844</td>
<td>5.591</td>
<td>6.656</td>
<td>0.010</td>
<td>0.002</td>
<td>0.988</td>
<td></td>
</tr>
<tr>
<td>EUROPE &amp; JAPAN</td>
<td>14494.333</td>
<td>700.830</td>
<td>806.388</td>
<td>4.780</td>
<td>5.492</td>
<td>0.014</td>
<td>0.000</td>
<td>0.986</td>
<td></td>
</tr>
<tr>
<td>NORTH AMERICA</td>
<td>15556.733</td>
<td>537.054</td>
<td>704.891</td>
<td>3.298</td>
<td>4.226</td>
<td>0.008</td>
<td>0.032</td>
<td>0.967</td>
<td></td>
</tr>
<tr>
<td>CENTRALLY PLANNED</td>
<td>26922.400</td>
<td>858.964</td>
<td>974.346</td>
<td>3.930</td>
<td>4.868</td>
<td>0.043</td>
<td>0.011</td>
<td>0.997</td>
<td></td>
</tr>
<tr>
<td>WORLD</td>
<td>70672.133</td>
<td>N.A.</td>
<td>N.A.</td>
<td>3.112</td>
<td>3.683</td>
<td>0.014</td>
<td>0.140</td>
<td>0.855</td>
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**CAPACITY:**

**PRODUCTION:**

<table>
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<th>REGION</th>
<th>MEAN OF ACTUAL</th>
<th>MEAN ERROR</th>
<th>ROOT MEAN SQUARED ERROR</th>
<th>MEAN % ERROR</th>
<th>ROOT MEAN SQUARED % ERROR</th>
<th>THEIL BIAS</th>
<th>VARIANCE</th>
<th>COVARIANCE</th>
<th>--INEQUALITY PROPORTIONS--</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEVELOPING COUNTRIES</td>
<td>7452.000</td>
<td>145.955</td>
<td>210.052</td>
<td>1.886</td>
<td>2.643</td>
<td>0.010</td>
<td>0.000</td>
<td>0.327</td>
<td>0.673</td>
</tr>
<tr>
<td>EUROPE &amp; JAPAN</td>
<td>11035.733</td>
<td>509.074</td>
<td>580.708</td>
<td>4.662</td>
<td>5.368</td>
<td>0.007</td>
<td>0.000</td>
<td>0.999</td>
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</tr>
<tr>
<td>NORTH AMERICA</td>
<td>10654.000</td>
<td>421.473</td>
<td>578.665</td>
<td>3.894</td>
<td>5.223</td>
<td>0.003</td>
<td>0.023</td>
<td>0.957</td>
<td></td>
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<tr>
<td>CENTRALLY PLANNED</td>
<td>19703.066</td>
<td>371.926</td>
<td>499.543</td>
<td>2.155</td>
<td>2.787</td>
<td>0.008</td>
<td>0.141</td>
<td>0.852</td>
<td></td>
</tr>
<tr>
<td>WORLD</td>
<td>48934.801</td>
<td>792.745</td>
<td>N.A.</td>
<td>1.417</td>
<td>2.037</td>
<td>0.003</td>
<td>0.007</td>
<td>0.990</td>
<td></td>
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</tbody>
</table>

N.A. - NOT APPLICABLE.

**SOURCE:** WORLD BANK, ECONOMIC ANALYSIS AND PROJECTIONS DEPARTMENT.
# TABLE 6.5: SUMMARY STATISTICS FOR EX-POST SIMULATION OF PHOSPHATE CAPACITY AND PRODUCTION

<table>
<thead>
<tr>
<th>REGION</th>
<th>MEAN OF MEAN %</th>
<th>ROOT MEAN ERROR</th>
<th>SQUARE MEAN ERROR</th>
<th>MEAN % ERROR</th>
<th>SQUARE MEAN % ERROR</th>
<th>THEIL BIAS VARIANCE</th>
<th>COVARIANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAPACITY:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DEVELOPING COUNTRIES</td>
<td>6034.200</td>
<td>198.236</td>
<td>224.057</td>
<td>4.543</td>
<td>6.562</td>
<td>0.565</td>
<td>0.031</td>
</tr>
<tr>
<td>EUROPE &amp; JAPAN</td>
<td>5271.000</td>
<td>107.859</td>
<td>136.518</td>
<td>2.076</td>
<td>2.621</td>
<td>0.659</td>
<td>0.018</td>
</tr>
<tr>
<td>NORTH AMERICA</td>
<td>9381.200</td>
<td>351.527</td>
<td>434.322</td>
<td>4.187</td>
<td>5.464</td>
<td>0.646</td>
<td>0.000</td>
</tr>
<tr>
<td>CENTRALLY PLANNED</td>
<td>5492.533</td>
<td>193.958</td>
<td>243.179</td>
<td>5.419</td>
<td>8.269</td>
<td>0.395</td>
<td>0.031</td>
</tr>
<tr>
<td>WORLD</td>
<td>26178.934</td>
<td>512.034</td>
<td>598.251</td>
<td>2.413</td>
<td>3.131</td>
<td>0.245</td>
<td>0.025</td>
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<tr>
<td>PRODUCTION:</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DEVELOPING COUNTRIES</td>
<td>4274.267</td>
<td>170.463</td>
<td>227.677</td>
<td>4.473</td>
<td>5.786</td>
<td>0.576</td>
<td>0.013</td>
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<tr>
<td>EUROPE &amp; JAPAN</td>
<td>7191.000</td>
<td>347.752</td>
<td>447.150</td>
<td>4.832</td>
<td>6.245</td>
<td>0.935</td>
<td>0.001</td>
</tr>
<tr>
<td>NORTH AMERICA</td>
<td>7720.667</td>
<td>583.506</td>
<td>630.664</td>
<td>7.631</td>
<td>8.193</td>
<td>0.812</td>
<td>0.006</td>
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<tr>
<td>CENTRALLY PLANNED</td>
<td>9526.400</td>
<td>252.610</td>
<td>330.226</td>
<td>3.038</td>
<td>4.261</td>
<td>0.735</td>
<td>0.015</td>
</tr>
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<td>28712.334</td>
<td>866.467</td>
<td>N.A.</td>
<td>3.132</td>
<td>3.736</td>
<td>0.639</td>
<td>0.017</td>
</tr>
</tbody>
</table>

**N.A.** - NOT APPLICABLE.

**SOURCE:** WORLD BANK, ECONOMIC ANALYSIS AND PROJECTIONS DEPARTMENT.
### TABLE 6.6: SUMMARY STATISTICS FOR EX-POST SIMULATION OF POTASH CAPACITY AND PRODUCTION

<table>
<thead>
<tr>
<th>REGION</th>
<th>MEAN OF MEAN</th>
<th>MEAN ROOT MEAN</th>
<th>MEAN % ROOT MEAN</th>
<th>THEIL BIAS VARIANCE COVARIANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ACTUAL</td>
<td>ERROR</td>
<td>SQUARED ERROR</td>
<td>ERROR</td>
</tr>
<tr>
<td>CAPACITY:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WORLD</td>
<td>30838.045 N.A.</td>
<td>N.A.</td>
<td>5,320   6.487</td>
<td>0.858</td>
</tr>
<tr>
<td>PRODUCTION:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WORLD</td>
<td>23317.400</td>
<td>855.499 N.A.</td>
<td>3,536   4,679</td>
<td>0.792</td>
</tr>
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</table>

N.A. - NOT APPLICABLE.

SOURCE: WORLD BANK, ECONOMIC ANALYSIS AND PROJECTIONS DEPARTMENT.

### TABLE 6.7: SUMMARY STATISTICS FOR EX-POST SIMULATION OF WORLD FERTILIZER PRICES

<table>
<thead>
<tr>
<th>REGION</th>
<th>MEAN OF MEAN</th>
<th>MEAN ROOT MEAN</th>
<th>MEAN % ROOT MEAN</th>
<th>THEIL BIAS VARIANCE COVARIANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ACTUAL</td>
<td>ERROR</td>
<td>SQUARED ERROR</td>
<td>ERROR</td>
</tr>
<tr>
<td>NITROGEN</td>
<td>148,127</td>
<td>18,234</td>
<td>32,926</td>
<td>11,564</td>
</tr>
<tr>
<td>PHOSPHATE</td>
<td>128,920</td>
<td>16,687</td>
<td>26,192</td>
<td>11,212</td>
</tr>
<tr>
<td>POTASH</td>
<td>65,987</td>
<td>9,344</td>
<td>12,508</td>
<td>13,765</td>
</tr>
</tbody>
</table>

SOURCE: WORLD BANK, ECONOMIC ANALYSIS AND PROJECTIONS DEPARTMENT.
NITROGEN CONSUMPTION: DYNAMIC SOLUTION TRACKING

FIGURE 6.1: BRAZIL

FIGURE 6.2: MEXICO

FIGURE 6.3: LATIN AMERICA & CARIBBEAN

FIGURE 6.4: NORTH AFRICA & MIDDLE EAST
NITROGEN CONSUMPTION: DYNAMIC SOLUTION TRACKING (CONTINUED)

FIGURE 6.5: EAST ASIA

FIGURE 6.6: INDIA

FIGURE 6.7: CHINA

FIGURE 6.8: EEC-10
NITROGEN CONSUMPTION: DYNAMIC SOLUTION TRACKING (CONTINUED)

FIGURE 6.9: JAPAN

FIGURE 6.10: UNITED STATES

FIGURE 6.11: OTHER INDUSTRIAL COUNTRIES

FIGURE 6.12: U.S.S.R.
NITROGEN CONSUMPTION: DYNAMIC SOLUTION TRACKING (CONTINUED)

FIGURE 6.13: DEVELOPING COUNTRIES

FIGURE 6.14: INDUSTRIAL COUNTRIES

FIGURE 6.15: CENTRALLY PLANNED ECONOMIES

FIGURE 6.16: WORLD
PHOSPHATE CONSUMPTION: DYNAMIC SOLUTION TRACKING

FIGURE 6.17: BRAZIL

FIGURE 6.18: MEXICO

FIGURE 6.19: LATIN AMERICA & CARIBBEAN

FIGURE 6.20: EAST ASIA
PHOSPHATE CONSUMPTION: DYNAMIC SOLUTION TRACKING (CONTINUED)

FIGURE 6.21: INDIA

FIGURE 6.22: CHINA

FIGURE 6.23: NORTH AFRICA & MIDDLE EAST

FIGURE 6.24: SOUTH AFRICA
PHOSPHATE CONSUMPTION: DYNAMIC SOLUTION TRACKING (CONTINUED)

**FIGURE 6.25: AUSTRALIA**

- **THOUSAND METRIC TONS**
- **1970** - 1984

**FIGURE 6.26: EEC-10**

- **THOUSAND METRIC TONS**
- **1970** - 1984

**FIGURE 6.27: JAPAN**

- **THOUSAND METRIC TONS**
- **1970** - 1984

**FIGURE 6.28: UNITED STATES**

- **THOUSAND METRIC TONS**
- **1970** - 1984
PHOSPHATE CONSUMPTION: DYNAMIC SOLUTION TRACKING (CONTINUED)

FIGURE 6.29: U.S.S.R.
PHOSPHATE CONSUMPTION: DYNAMIC SOLUTION TRACKING (CONTINUED)

**FIGURE 6.30: DEVELOPING COUNTRIES**

**FIGURE 6.31: INDUSTRIAL COUNTRIES**

**FIGURE 6.32: CENTRALLY PLANNED ECONOMIES**

**FIGURE 6.33: WORLD**
POTASH CONSUMPTION: DYNAMIC SOLUTION TRACKING

FIGURE 6.34: BRAZIL

FIGURE 6.35: LATIN AMERICA & CARIBBEAN

FIGURE 6.36: EAST ASIA

FIGURE 6.37: INDIA
POTASH CONSUMPTION: DYNAMIC SOLUTION TRACKING (CONTINUED)

FIGURE 6.38: CHINA

FIGURE 6.39: SOUTH AFRICA

FIGURE 6.40: EEC-10

FIGURE 6.41: JAPAN
POTASH CONSUMPTION: DYNAMIC SOLUTION TRACKING (CONTINUED)

FIGURE 6.42: UNITED STATES

FIGURE 6.43: OTHER INDUSTRIAL COUNTRIES

FIGURE 6.44: U.S.S.R.
NITROGEN PRODUCTION CAPACITY: DYNAMIC SOLUTION TRACKING

FIGURE 6.49: EUROPE & JAPAN

FIGURE 6.50: NORTH AMERICA

FIGURE 6.51: DEVELOPING COUNTRIES

FIGURE 6.52: CENTRALLY PLANNED ECONOMIES
PHOSPHATE PRODUCTION CAPACITY: DYNAMIC SOLUTION TRACKING

FIGURE 6.53: EUROPE & JAPAN

FIGURE 6.54: NORTH AMERICA

FIGURE 6.55: DEVELOPING COUNTRIES

FIGURE 6.56: CENTRALLY PLANNED ECONOMIES
NITROGEN PRODUCTION: DYNAMIC SOLUTION TRACKING

FIGURE 6.60: EUROPE & JAPAN

FIGURE 6.61: NORTH AMERICA

FIGURE 6.62: DEVELOPING COUNTRIES

FIGURE 6.63: CENTRALLY PLANNED ECONOMIES
PHOSPHATE PRODUCTION: DYNAMIC SOLUTION TRACKING

FIGURE 6.64: EUROPE & JAPAN

FIGURE 6.65: NORTH AMERICA

FIGURE 6.66: DEVELOPING COUNTRIES

FIGURE 6.67: CENTRALLY PLANNED ECONOMIES
FIGURE 6.68: WORLD NITROGEN PRODUCTION

FIGURE 6.69: WORLD PHOSPHATE PRODUCTION

FIGURE 6.70: WORLD POTASH PRODUCTION
FIGURE 6.71: NITROGEN WORLD PRICE DYNAMIC SOLUTION TRACKING

FIGURE 6.72: PHOSPHATE WORLD PRICE DYNAMIC SOLUTION TRACKING
FIGURE 6.73: POTASH WORLD PRICE
DYNAMIC SOLUTION TRACKING

Actual

Simulated

US $ / METRIC TON

VII. MODEL PROJECTIONS FOR THE PERIOD 1985-2000

49. The ex-ante simulation was carried out for the period 1985-2000. Most variables were solved endogenously except for the macro-economic variables i.e., GDP, exchange rates and consumer price index. Assumptions for these macro-economic variables were taken from forecasts provided by the World Bank and Wharton Econometric Forecasting Associates. The projections for grains prices, planted area and yields were generated by the Division's grains model to which the fertilizer model is linked.

50. The projections of fertilizer production, consumption and price are in line with those reported recently in the Division's Report No. 814/86, Price Prospects for Major Primary Commodities. Graphs showing forecast changes in the market shares held by the industrial, developing and centrally planned country groups are presented in Figures 7.1 through 7.8.

51. The share of nitrogen consumption held by the industrial countries constantly declined throughout the 1960s and 1970s—from about 68% in 1962 to 51% in 1970 and 39% in 1980. This decline was mainly due to the "green revolution" which significantly increased fertilizer use in the developing countries. The developing countries went from a nitrogen consumption share of 16% in 1962 to 40% in 1980. It appears that the trend will continue in the next decade with projected shares of 48% in 1990 and 52% in 2000 for the developing countries. Much the same applies to phosphate and potash consumption, with the share of the developing countries in the phosphate market projected to increase gradually to about 39% by the year 2000, and to grow to 18% of total potash consumption.

52. The centrally planned economies of Europe increased sharply their consumption of fertilizers during the 1960s and 1970s. As a result their world
shares also increased sharply. However, due to the expected slowdown in their agricultural production, their share of world consumption is forecast to decline somewhat over the 1985-2000 period.

53. Nitrogen was produced almost exclusively in the industrial countries only 20 years ago. In 1962, they accounted for a market share of 74%. Their current share of the market has decreased to only 34% and is projected to decrease to less than 25% by the year 2000. The same appears to be happening in the phosphate market. The industrial countries' share of the market fell from 77% in 1962 to 43% in 1985 and is projected to decline to about 26% by the year 2000. The share of the developing countries in the production of these fertilizers increased sharply from about 8% in 1962 to about 20% in 1985. According to the projections, by the year 2000 they will produce about 35% of world nitrogen output and about 40% of world phosphate output.
FIGURE 7.1: NITROGEN CONSUMPTION SHARE OF WORLD TOTAL BY MAIN ECONOMIC REGIONS, 1962-2000

FIGURE 7.2: PHOSPHATE CONSUMPTION SHARE OF WORLD TOTAL BY MAIN ECONOMIC REGIONS, 1962-2000
FIGURE 7.3: POTASH CONSUMPTION SHARE OF WORLD TOTAL
BY MAIN ECONOMIC REGIONS, 1962-2000

INDUSTRIAL COUNTRIES

CENTRALLY PLANNED ECON.

DEVELOPING COUNTRIES
**FIGURE 7.4:** Nitrogen production share of world total by main economic regions, 1962-2000

- Industrial Countries
- Centrally Planned Economies
- Developing Countries

**FIGURE 7.5:** Phosphate production share of world total by main economic regions, 1962-2000

- Industrial Countries
- Centrally Planned Economies
- Developing Countries
FIGURE 7.6: NITROGEN PRICE FORECAST  

FIGURE 7.7: PHOSPHATE PRICE FORECAST  
FIGURE 7.8: POTASH PRICE FORECAST
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VIII. CONCLUSIONS AND SUGGESTIONS FOR FURTHER WORK

57. This paper summarizes the work that has been done to date on the global fertilizer model. It describes the structure of the model and the estimated equations, as well as providing statistical measures which allows evaluation of the performance of each equation individually and the model as a whole.

58. The model performs well. However, additional work would provide improved analysis of the nature and characteristics of the fertilizer markets. For example, one improvement would be to estimate the consumption equations on a per acre basis and allow the yield and price of both fertilizers and commodities produced determine the level of fertilizer use per acre.

59. Another refinement would be to disaggregate the supply side further and with greater detail for individual countries, especially for the large producers. The model could also be expanded to include trade, and perhaps also stocks in addition to consumption and production. The degree of expansion will be largely determined by data availability.

60. Much additional work would be needed to reach a stage where the fertilizer model could be solved simultaneously with the grains model. Such a model would enable us to examine the interaction between products and fertilizers in a more comprehensive way. This exercise would be very difficult to carry out due to its size, however.
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FORECAST ERROR STATISTICS

1. **Root mean squared error (RMSE)**

Let $Y_t$ be the actual value of variable $Y$ at time $t$, and let $\hat{Y}_t$ be the simulated value of that same variable at time $t$, then

$$RMSE = \left( \frac{1}{T} \sum_{t=1}^{T} (Y_t - \hat{Y}_t)^2 \right)^{\frac{1}{2}}$$

2. **Average absolute percentage error (AAPE):**

Under the same definition of $Y_t$ and $\hat{Y}_t$

$$AAPE = \left( \frac{1}{T} \sum_{t=1}^{T} \left| \frac{Y_t - \hat{Y}_t}{Y_t} \right| \right) \cdot 100$$

and

3. **Root mean squared percentage error (RMSPE):**

will be defined as:

$$RMSPE = \left( \frac{1}{T} \sum_{t=1}^{T} \left( \frac{Y_t - \hat{Y}_t}{Y_t} \right)^2 \right)^{\frac{1}{2}} \cdot 100$$

A very useful statistic related to the root mean square (RMS) simulation error and applied to the evaluation of historical simulations (ex-post forecasts) is Theil's inequality coefficient defined as:
the numerator is exactly RMSE but it is scaled by such a denominator that
allows $U$ to always fall between zero and one. As $U$ approaches one the forecast
may be considered better.

This Theil inequality coefficient can be decomposed into three
different elements.

It can be shown that the following identity holds

$$U = \frac{\left[ \frac{1}{T} \sum_{t=1}^{T} (\hat{Y}_t - Y_t)^2 \right]^{1/2}}{\left[ \frac{1}{T} \sum_{t=1}^{T} (\hat{Y}_t^2) \right]^{1/2} + \left[ \frac{1}{T} \sum_{t=1}^{T} (Y_t^2) \right]^{1/2}}$$

where $\sigma_s$ and $\sigma_a$ are the standard deviation of the simulated variable and the
actual variable respectively, and $\rho$ is their correlation coefficient. The
proportions of inequality can then be defined as:

The bias proportion

$$u^b = \frac{(Y - \bar{Y})^2}{\frac{1}{T} \sum_{t=1}^{T} (\hat{Y}_t - Y_t)^2}$$

The variance proportion

$$u^v = \frac{(\sigma_s - \sigma_a)^2}{\frac{1}{T} \sum_{t=1}^{T} (\hat{Y}_t - Y_t)^2}$$

and the covariance proportion $$u^c = \frac{2(1-\rho) \sigma_s \sigma_a}{\frac{1}{T} \sum_{t=1}^{T} (\hat{Y}_t - Y_t)^2}$$
These three statistics are essential in determining the source of a problem if there is one.

\( U^m \) gives an indication of a systematic error since it measures the extent to which the average values of the simulated and actual series deviate from each other.

\( U^s \) indicates the ability of the model to replicate the degree of variability in the variable simulated. Therefore, a large \( U^s \) indicates that the variability of the actual series is different from the variability of the simulated series.

\( U^c \) measures the degree of correlation between the actual and simulated series. It represents the remaining error after deviations from average value and average variabilities have been accounted for.

In the case of this model the inequality Theil statistic is calculated based on log-relative changes, which can be explained as follows. Let \( \hat{y}_t \) be defined as \( \hat{y}_t = \ln \left( \frac{Y_t}{Y_{t-1}} \right) \) and similarly let \( y_t = \ln \left( \frac{Y_t}{Y_{t-1}} \right) \).

Let \( S_a \) and \( S_p \) be the standard deviation of the series \( y_t \) and \( y_t \) respectively, and let \( \rho_{ap} \) be the correlation coefficient of these two series; then the inequality coefficient \( U^* \) will be determined by:

\[
U^* = \frac{\left[ \frac{1}{T-1} \sum_{t=2}^{T} (\hat{y}_t - y_t)^2 \right]^{1/2}}{\left[ \frac{1}{T-1} \sum_{t=2}^{T} (y_2)^2 \right]^{1/2} + \left[ \frac{1}{T-1} \sum_{t=2}^{T} (y_t)^2 \right]^{1/2}}
\]

Hence the proportions of inequality \( U^*_m, U^*_s \) and \( U^*_c \) will be defined as:
\[ U^*_m = \frac{\overline{\sigma}}{\left[ \frac{1}{T-1} \sum_{t=2}^{T} (y_t - \overline{y})^2 \right]} \]

where \( \overline{y} = \frac{1}{T-1} \sum_{t=2}^{T} y_t \)

and \( \overline{\sigma} = \frac{1}{T-1} \sum_{t=2}^{T} \overline{\hat{y}_t} \)

\[ U^*_s = \frac{(S_p - S_a)^2}{\frac{1}{T-1} \sum_{t=2}^{T} (\hat{y}_t - y_t)^2} \]

\[ U^*_c = \frac{2(1-\rho_{ap}) S_p S_a}{\frac{1}{T-1} \sum_{t=2}^{T} (\hat{y}_t - y_t)^2} \]

When a variable changes sign from positive to negative (or vice versa) the ratio \( y_t/y_{t-1} \) is negative and therefore \( y_t \) (and/or \( \hat{y}_t \)) is not defined. That is what has happened when we see the number 999.999 in the table. In this case the Theil statistic and hence the inequality proportion are completely irrelevant.
APPENDIX B

DATA SOURCES AND DEFINITIONS

The primary historical data sources are the World Bank, FAO and the International Monetary Fund.

The world prices that are used are as follows:

- **Nitrogen** - Urea, fob Europe bagged.
- **Phosphate** - Triple superphosphate, fob US Gulf ports.
- **Potash** - Muriate of potash (potassium chloride) fob Vancouver.
- **Phosphate Rock** - 72%, fas Casablanca.
- **Rice** - US No. 2 long-grained, milled, fob Houston, Aug-July year.
- **Corn** - (proxy for all coarse grains) US No. 2 yellow, fob Gulf ports, Oct-Sept year.

The macro economic data is taken from the World Bank and International Financial Statistics (International Monetary Fund). Income is defined in terms of gross domestic product measured in billions of local currency. The exchange rate is measured in units of local currency per US dollar and the consumer price index (CPI) is expressed as an index with the base year in 1980.

The data for the regions was created in a special way. It was aggregated from the country data for those variables with common units (hectares, tons, etc.). GDP for a region was obtained by first converting the GDP of all of the countries in a region into dollars using the average exchange rate of 1971-80, and then aggregating it across countries in a region. The regional exchange rate and CPI were obtained also in a two-stage process. First, every exchange rate was converted to an index and then the regional exchange rate was created as a weighted average where the weight was the GDP share of a country of the regional total.
REFERENCES

Barker, R., "The Place of Agriculture in the Developing Countries of Southeast Asia with Special Reference to Fertilizer Use," prepared for the Conference on Economics of Fertilizer Use, Asian and Pacific Council, Food and Technology Center, Taipei, Taiwan, June 1972.


