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INVESTMENT BEHAVIOR IN DEVELOPING COUNTRIES: THE CASE OF AGRICULTURE IN INDIA†

Investment behavior is an important economic relationship that has been difficult to determine in the context of developing economies (see Sundarajan and Thakur, 1980, and Blejer and Khan, 1984, for review). This is principally because of the long-term and complex nature of the behavior, imperfections, and interventions in developing country markets, as well as the lack of necessary data. The behavior of consumption, money demand, imports, and exports has been explored within a number of theoretical models, and empirical findings indicate some convergence of views on them. Theoretical models for investment behavior, however, are few and their applications in developing countries are almost nonexistent. As a result, not only is investment behavior in developing countries poorly understood, but the investment functions used in modeling for developing countries tend to be overly simplistic. Since the government often plays an important role in capital formation, investment is frequently treated as a policy rather than a behavioral variable. Such approaches, while indicating the importance of public investment, disregard the fact that the major component of investment in developing countries may still be private investment.

The theoretical literature on investment behavior is substantial and has yielded a well defined class of models of the flexible accelerator type first proposed by Chenery (1952) and Koyck (1954). The most popular of these are the neoclassical models of investment behavior associated with Jorgen-

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son (1963, 1967, 1971; Jorgenson and Stephenson, 1967), and variants of these have been applied with a good degree of success to manufacturing in several industrial countries (Abel, 1980). A few applications have also appeared for agriculture of developed countries (Fisher, 1974, and Waugh, 1977a, b, for Australian agriculture; and Girao, Tomek, and Mount, 1974, Hrubovcak and Le Blanc, 1985, and Vasavada and Chambers, 1986, for U.S. agriculture). There is, however, a very large gap between the theory and the study of investment behavior in developing countries. Three exceptions are recent efforts by Sundarajan and Thakur (1980), Tun Wai and Wong (1982), and Blejer and Khan (1984), which apply some features of the investment behavior theory, such as the flexible accelerator principal and the neoclassical determination of capital stock, to behavior of *total* investment in developing countries (see Gandhi, 1986, for a review). The empirical results have been varied, often constrained by data limitations, but encouraging by confirming some features of the theory. However, thus far no theoretically based studies are available that examine the behavior of agricultural investment in developing countries. Important insights have come from Binswanger, Khandkar, and Rosenweig (1989), that use cross district panel data from India to examine associations between different district charecteristics/variables and private investment in a few types of assets. However, this study is not based on the theory of investment behavior.

The present paper pursues a study of aggregate private agricultural investment in India drawing on and modifying the economic theory of investment behavior. It uses the large information base on India, including some recently published, carefully compiled time series data on estimates of agricultural investment in India from its Central Statistical Organization (CSO) for empirical estimations.

BACKGROUND

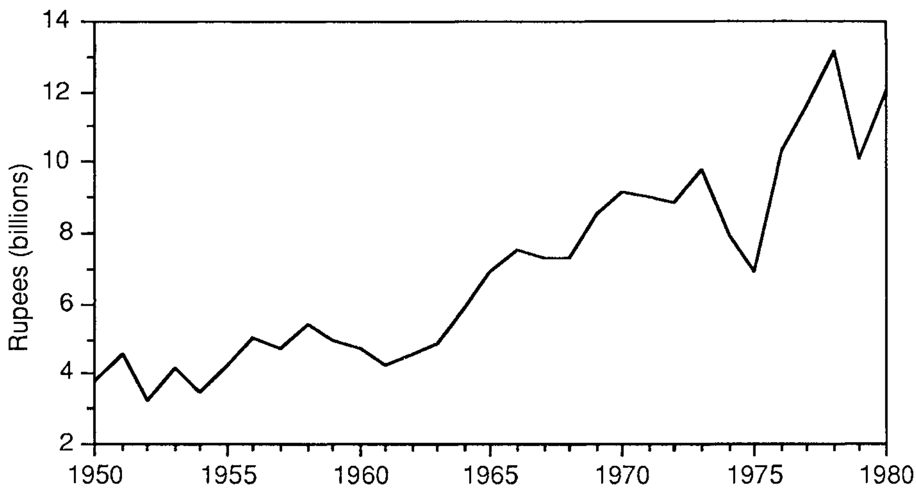
Given the compulsions of a rising food demand from a large and growing population, India has placed substantial emphasis on agricultural development. Agriculture in India, unlike some other sectors of the economy, is largely a decentralized and private economic activity, operated mainly by small- and medium-sized private farmers all over the country. An examination of the investment estimates (India, CSO, various years; Chaturvedi and Bagchi, 1984) shows that, despite massive developmental investment by the government, about 70 percent of the agricultural investment in the country is private investment. The assets created take many different forms such as land improvement, construction (nonresidential), including irrigation, agricultural implements, machinery and equipment, transport equipment, and farm animals. The early development literature placed substantial emphasis on the role of capital in development (Hirschman, 1958; Rostow, 1961). Later studies (Hayami and Ruttan, 1971; Mellor, 1976) tended to emphasize technological change as the critical determinant of growth and development. What is often overlooked in these observations is that technology itself is frequently embodied or dependent on new investment. This is the case in irrigation investments including pumps and tubewells, new farm machinery and equipment, and even new breeds of farm animals.

Private investment in Indian agriculture has been estimated to be some rupees (Rs) 12 billion in 1980[1] (in 1970 constant prices), against a private capital stock of about Rs 155 billion in the same year (based on India, CSO, various years; Chaturvedi and Bagchi, 1984; RBI, 1972). Chart 1, which shows the dynamics of investment behavior, indicates that private investment has fluctuated substantially but has grown considerably in real terms. Starting at about Rs 4 billion in the early 1950s, investment grew at an annual rate of about 3.2 percent in the 1950s, 7.8 percent in the 1960s, and 3.3 percent in the 1970s. The overall rate over the 30 years (1950–80) was about 4.1 percent. Over the same period, private capital stock grew at 3.4 percent, government capital stock at 9.7 percent, and agricultural output at 2.2 percent (all annually at constant prices). These growth rates indicate an increasing capital-output ratio and an increasing share of the government in the capital stock. They also show that the transformation in Indian agriculture has been associated with increasing capital need and use per unit, with sizable direct capital input from the government. Private investment grew at a rate of 2.9 percent during the pre-Green Revolution period (1950–65) and at rate of 3.4 percent during the Green Revolution period (1967–80). Chart 1 indicates periods of steady growth with frequent interruptions. There are peaks in 1958, 1966, 1973, and 1978, and troughs in 1961, 1968, 1975, and 1978. Relating these features individually to output, government investment, institutional credit, and several other associated variables indicate that these movements in private investment are not consistently and directly linked with any individual explanatory variable. Rather, fluctuations in private investment seem to be related to several of these factors at a time, possibly in a complex way, meriting investigation through a theoretical model.

Theory suggests that private investment may be expected to be linked to profitability, and the literature suggests that profitability is associated with factors such as output demand/prices, input use/prices, the cost of capital including interest rates and government investment. Private investment also may be related to the availability of own savings and of credit. The theoretical relationship between these variables and private investment is examined in the next section. In the Indian setting, there have been a

[1] All year references stand for the fiscal year, which extends from April of the given year to March of the following year.

Chart 1.—India: Private Investment in Agriculture, 1950–80
(*Constant 1970 prices*)



large number of policies that have influenced these determinants, and these could in turn influence private investment in agriculture.

Output price support was occasionally exercised from the late 1950s, but systematic output price support policy was initiated only in 1965 with the formation of the Agricultural Prices Commission in the central government. The Commission annually recommends price policies to the government through its cost studies, analyses, and negotiations. Attempts have been made to stabilize prices with the prior announcement of floor prices for major crops and through government agency market operations. Krishna and Raychaudhuri (1980a) found that wheat and rice market prices were usually above or close to the floor prices, indicating policy effectiveness. Such a policy could stimulate private investment directly as well as indirectly by helping the diffusion of technological change based on high yielding varieties with consequent impact on private investment, such as tubewells and tractors.

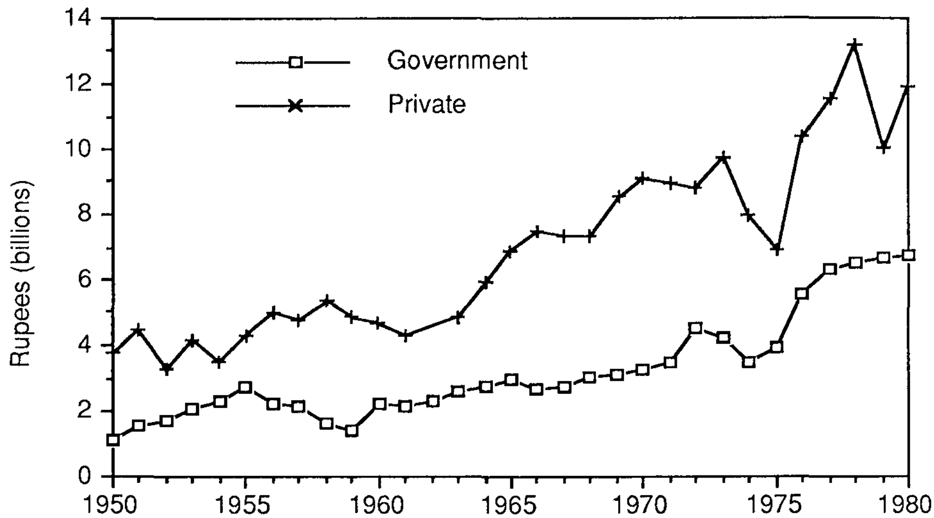
The prices with respect to some of the important purchased inputs were also regulated by the government. Fertilizer prices are fixed on a uniform national level and, especially in recent years, they incorporate sizable subsidies. Fertilizer is the major purchased input with a special role in the economics of production and can therefore influence investment decisions. Further, there is a close interrelationship between fertilizers, high yielding varieties, and investment, and fertilizer pricing policy, by insulating the farmers from external shocks, may have fostered adoption of new technology and investment.

With respect to user cost of capital, the institutional lending policy for the agriculture sector has been to lend to the sector at a somewhat subsidized interest rate as compared to general lending. These lending rates are usually much lower than the relatively exploitative interest rates charged by private money lenders. However, subsidizing lending could have a negative effect on the viability of agricultural lending. The gains from this subsidy in fostering greater agricultural investment have never been empirically analyzed but can be assessed by studying investment behavior.

Direct government investment in agriculture has been a major policy since the beginning of planned development in early 1950s. While being substantial, government investment has fluctuated with changes in plan strategies, policies, and resources (Chart 2). A significant part of the government's investment is in large irrigation projects such as the Bhakhra-Nangal in the north and the Periyar-Vaigai in the south. Substantial government investment has also been made in improving other infrastructure in the rural areas. Such government investments can influence private investment by increasing opportunity, reducing private costs, and often directly contributing to productivity, thereby directly and indirectly raising the desired level of private capital stock. The direct effect is revealed in the adoption of new activities and technologies, and the indirect effect may be seen, for example, in development of conjunctive water use, resulting in greater private investment.

Given the scarcity of credit in developing countries, investment to create the desired capital stock is frequently constrained by the lack of credit to finance it. Farmers' acute need for credit has long been recognized in India's agricultural development policy even before the introduction of high yielding varieties. Expansion of institutional credit for farmers was incorporated into the objectives of India's central bank, the Reserve Bank of India (RBI) from its inception in 1935 in British India, addressing the scarcity of credit, exploitative money-lending practices in the rural areas, as well as the severe indebtedness of large numbers of farmers. A major step was the *All India Rural Credit Survey Report* in 1954, which led to the redefinition of creditworthiness making cultivators eligible for credit on the basis of the value of the crop rather than the value of assets held. The short- and medium-term credit system was organized and streamlined into a three-tier cooperative system with primary agricultural credit societies at the village level, central cooperative banks at the district level, and state cooperative banks at state level. For long-term credit, a two-tier system was promoted with state cooperative land development banks at the state level and their branches or primary cooperative land development banks at the district or block level. These measures have provided significant momentum to lending

Chart 2.—India: Government and Private Investment
in Agriculture, 1950–80
(*Constant 1970 prices*)



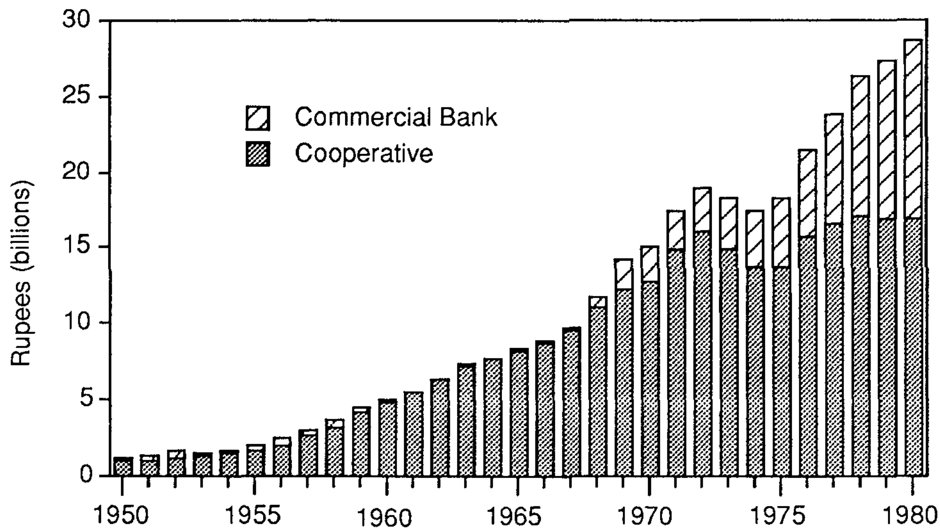
for agricultural investment as shown in Chart 3.

Commercial banks joined the cooperatives in substantial agricultural lending following their nationalization in 1969 (Chart 3). In 1975 yet another institution, the Regional Rural Bank, was introduced into agricultural lending. The shares of the different institutions in loans outstanding to agriculture by 1980 were: cooperatives, 59.4 percent; commercial banks, 38.8 percent; and rural banks, 1.8 percent; the total amount was about Rs 28 billion (in 1970 prices). Despite such a large outlay, little is known about the effectiveness of this lending with respect to generating real agricultural investment. A study of investment behavior can help in addressing this issue.

DEVELOPMENT OF THE THEORETICAL MODEL

The term investment is often somewhat broadly used in the literature, but in economic theory, investment is generally defined as the periodic addition to the physical capital stock. Most theories of investment behavior consider investment to take place in response to a gap between the actual level of capital stock and the desired level of capital stock (see Gandhi, 1986, for a survey). The adjustment from the actual to the desired may, however, be partial in any given period; it depends on the patterns or relationships of adjustment behavior. Given this structure based on the theory

Chart 3.—India: Cooperative and Commercial Bank Credit to Agriculture, 1950–80
(*Outstanding, constant 1970 prices*)



of investment behavior, investment would depend on the actual (past) capital stock, the new desired capital stock (related to its determinants), and factors affecting adjustment from the actual to the desired.

Following the theoretical work of Jorgenson and Stephenson (1967), the desired level of capital stock may be considered to be a behavioral outcome of the objective of maximizing the net return over time, or the net present value (net of major costs). This can be expressed as follows:

Maximize:

$$\text{Net present value} = \int_0^\infty e^{-rt}[P(t)F[KP(t), KG(t), L(t), FR(t)] - W(t)L(t) - PF(t)FR(t) - PK(t)[\dot{K}P(t) + \delta KP(t)]]dt, \tag{1}$$

where

P = price of output,
$F(.)$ = production function,
KP = private capital stock,
KG = government capital stock,
L = labor use,
FR = fertilizer use,
W = wage,
PF = price of fertilizer,
PK = price of capital,
$\dot{K}P = dKP/dt$,
δ = rate of depreciation,
r = interest rate, and
t = time.

With respect to the overall formulation, profit-maximizing behavior in Indian agriculture has been tested by Yotopoulos and Nugent (1976) using data from farm management studies covering five states in India from 1957 to 1962. Their tests indicated that 83 percent of the farm economic behavior could be explained by profit maximization. It is, therefore, considered appropriate to assume profit-maximizing behavior. Since capital is a multiperiod input, this maximization needs to be assumed over time, and therefore over the time-discounted value of profits or the net present value.

Private capital stock and labor are conventional inputs in the production function. Government capital stock has been separately introduced since public infrastructure development could have a significant impact on production behavior and in this context can be considered an important policy variable. Government capital stock, however, may have little effect and may even crowd out private investment if it draws too heavily on the total investible resource. Elias (1985) found a sizable positive relationship between government expenditure on agriculture and agricultural growth in Latin American countries and compared its contribution to that of modern inputs. Ahmed and Hossain (1988) found that development of rural infrastructure plays a critical role in promotion of development and commercialization in rural Bangladesh.

Technological change in Indian agriculture has been largely associated with the increase in use of modern inputs, including fertilizer use. Fertilizer is a major input in Indian agriculture and constitutes almost 60 percent in value of the total purchased inputs used (India, CSO, 1985). Fertilizer is also closely associated with the development and spread of modern technology. Empirical studies that introduce modern inputs such as fertilizer, high yielding varieties, and irrigation together in the production function framework frequently reveal them to be highly correlated, and factor analysis shows that they load on the same factor (Sarma and Gandhi, 1990). This indicates that fertilizer could be used to represent them.

Mathematical details of the derivation are shown in Appendix 1. (The following equation numbers are based on the Appendix.)

By using partial integration, first-order conditions for this maximization over time can be derived as:

$$PF_{KP} = PK(r + \delta + \pi), \tag{6}$$

$$PF_L = W, \quad \text{and} \tag{7}$$

$$PF_{FR} = PF, \tag{8}$$

where $F_.$ is the derivative of the production function with respect to the subscripted input. The prices and the government capital stock are assumed to be exogenous. Equation (6) can be interpreted as stating that the farmers would desire to build capital stock until the expected discounted return from the last additional unit of capital is (working through the production process) equal to the implicit user cost of capital.

The production function is assumed to be of the Cobb-Douglas form:

$$Q = A(KP)^{\alpha_1}(KG)^{\alpha_2}(L)^{\beta_1}(FR)^{\beta_2}, \tag{9}$$

where Q is the real output.

The Cobb-Douglas functional form while superior to the linear is still somewhat restrictive. However, Jorgenson and Stephenson (1967) and Jorgenson (1971) have used the Cobb-Douglas form extensively in their sector-level investment models. Further, in a study by Yotopoulos, Lau, and Somel (1970) using Indian Farm Management Studies data, the estimated value of the elasticity of substitution was not found to be significantly different from 1. Under this assumption, other forms such as the constant elasticity of substitution (CES) production function reduce to the Cobb-Douglas form. Other studies, such as Bardhan (1971), Srivastava and Heady (1973), and Binswanger (1974), have reached varying conclusions, but the Cobb-Douglas function has the advantage in simplicity of form and parsimony of parameters.

Further mathematical derivation (see Appendix 1) gives the following expression for the desired level of capital stock:

$$\begin{aligned} KP = (constant) P^{\left(\frac{\beta_1+\beta_2+1}{1-\alpha_1}\right)} Q^{\left(\frac{\beta_1+\beta_2}{1-\alpha_1}\right)} KG^{\left(\frac{\alpha_2}{1-\alpha_1}\right)} \\ UC^{-\left(\frac{1}{1-\alpha_1}\right)} W^{-\left(\frac{\beta_1}{1-\alpha_1}\right)} PF^{-\left(\frac{\beta_2}{1-\alpha_1}\right)}. \end{aligned} \tag{14}$$

This equation represents the desirable or profit-maximizing level of capital stock, given (or as influenced by) the product price, input prices, level of government capital stock, input-output relationships, and desired level of output. The output and user cost of capital may be considered conventional determinants from standard neoclassical and flexible accelerator models. In addition, price of output, government capital stock, wage rate, and fertilizer price are explicitly incorporated in the model. The price of output would help to show the effect of price support on the desired level of capital stock. Wages would help to show the impact wages on investment through capital-labor substitution. Furthermore, it would also indicate the impact of wages (through the opportunity cost of labor) on direct labor investment, which is an important component of investment in agriculture of developing countries (Levi, 1979; Alamgir, 1976). The effect of government capital stock on investment behavior has been discussed earlier, and the fertilizer price would show the influence of fertilizer prices on investment.

After the work of Chenery (1952) and Koyck (1954), it is well recognized that actual capital stock will not usually adjust fully to the desired capital stock in a single period, but that lags are involved and adjustment is generally partial. However, the specification of this adjustment process has remained somewhat ad hoc in a majority of studies, including those of Chenery and Koyck and of Jorgenson (1967). In most of these cases a lag distribution structure is imposed, and the parameters of this distrubution are empirically estimated to provide the best fit to the data. Koyck uses the well known Koyck-lag distribution in which the weights decline geometrically over time. Jorgenson uses a rational lag distribution in which the weights can increase first and then decline over time, depending on the parameters. Jorgenson (1971) reviewing different lag distributions used in investment models finds that whereas the finite lag distributions generally tend to underestimate the lag, the Koyck lag distribution tends to greatly overestimate the lag, and the rational lag distribution comes close to industry estimates. All these distributions, however, remain largely empirical and without an explicit base with respect to behavior or theory.

Blejer and Khan (1984) have indicated that in developing countries financial constraints may be more crucial in explaining adjustment behavior than arbitary implementation lags. This appears plausible given the scarcity of credit in most developing countries and, in the case of agriculture, the relatively smaller units and projects that usually make up private agricultural investment. In developing countries, credit is frequently in short supply and financial markets are not very deep. Rural financial markets are often highly dualistic and the price of credit from the unorganized market is often prohibitively high. Thus, the the available sources of finance for productive investment are mainly own resources and finance from the organized credit markets/agencies. It is therefore assumed that these would play the major role in the adjustment from actual capital stock to the desired level of capital stock for agricultural investment in developing countries. In the case of India, development-oriented financial interventions have been very large since Independence (1947), first through the cooperatives and after the late 1960s also through the commercial banks. The finance variable for India, therefore, can be broken down to rural savings (representing own finance), cooperative credit, and commercial bank credit (representing the two modes of institutional finance). It is desirable to separate these sources of finance because they are usually controlled in different ways and degrees and therefore may not be considered perfect substitutes. Note that they do not represent the only sources of liquidity and therefore do not constitute a binding constraint. The partial adjustment model can then be developed as follows:

Let

$$KP_t - KP_{t-1} = b_t(KP_t^* - KP_{t-1}),$$

where b_t is the adjustment cofficient and $*$ indicates "desired." Following methodology developed by Coen (1968) and the above discussion, b_t can be expressed as:

$$b_t = b_0 + b_1 \frac{RS_t}{KP_t^* - KP_{t-1}} + b_2 \frac{CRCP}{KP_t^* - KP_{t-1}} + b_3 \frac{CRCB}{KP_t^* - KP_{t-1}}, \quad (16)$$

where

$$RS = \text{rural savings,}$$
$$CRCP = \text{cooperative credit to agriculture, and}$$
$$CRCB = \text{commercial bank credit to agriculture.}$$

All three variables are deflated by the investment-goods deflator to reflect their buying power with respect to investment goods. Further, all of them are considered relative to the gap between the actual capital stock and the desired capital stock.

Gross investment can be expressed as

$$IP_t = (KP_t - KP_{t-1}) + \delta KP_{t-1}, \quad (17)$$

where IP is gross private investment in agriculture, and δ is rate of depreciation.

Further derivation results in the following expression for gross private investment in agriculture:

$$IP = (\text{constant}) P_t^{\left(\frac{\beta_1+\beta_2+1}{1-\alpha_1}\right)} Q_t^{\left(\frac{\beta_1+\beta_2}{1-\alpha_1}\right)} KG_t^{\left(\frac{\alpha_2}{1-\alpha_1}\right)} UC_t^{-\left(\frac{1}{1-\alpha_1}\right)} W_t^{-\left(\frac{\beta_1}{1-\alpha_1}\right)}$$
$$PF_t^{-\left(\frac{\beta_2}{1-\alpha_1}\right)} + b_1\ RS_1 + b_2\ CRCP_t + b_3\ CRCB_t + (\delta - b_0) KP_{t-1}, \tag{20}$$

This gives the following expression for empirical estimation:

$$\begin{aligned} IP = (constant) P_t^{\gamma_1}\ Q_1^{\gamma_2}\ KG_t^{\gamma_3}\ UC_t^{\gamma_4}\ W_t^{\gamma_5}\ PF_t^{\gamma_6} \\ + b_1\ RS_t + b_2\ CRCP_t + b_3\ CRCB_t + b_4\ KP_{t-1} + u_t, \end{aligned} \tag{21}$$

where u_t is a disturbance term.

It may be noted that the model is nonlinear. Many studies including the three recent studies on total investment cited above (Sundarajan and Thakur, 1980; Tun Wai and Wong, 1982; Blejer and Khan, 1984) have chosen to ignore nonlinearities and adopt linear formulations for estimation, often resulting in unrealistic behavioral assumptions. To provide a comparison and test between linear and nonlinear formulations, a form linear in parameters is also estimated:

$$\begin{aligned} IP_t = d_0 + d_1 P_t + d_2 Q_t + d_3 KG_t + d_4 UC_t + d_5 W_t d_6 PF_t \\ + d_7 RS_t + d_8 CRCP_t + d_9 CRCB_t + d_{10} KP_{t-1} + v_t, \end{aligned} \tag{22}$$

where v_t is a disturbance term.

EMPIRICAL ESTIMATION OF THE MODEL

Data for empirical testing are obtained from numerous official sources in India. Specific details on sources, background, and assumptions are given in Appendix 2.

Data for Empirical Testing

A major gap in the data was that of a relatively accurate and long time-series on investment in Indian agriculture. A time-series is essential to the application of the theory due to the long-term nature of investment behavior including adjustment and expectations. The gap has been recently filled by India's Central Statistical Organization, Ministry of Planning, in the form of a 30-year time series on gross domestic capital formation in India by industry of use, agriculture being one of the "industries." The series starts in 1950. The agriculture series is put together by working on disaggregates of capital formation (i.e., investment) consisting of major forms such as *pucca* (brick and cement) construction, *kutcha* (earth and mud work including land improvement) construction, machinery and equipment, and livestock. Estimates are developed for each of these categories with all available information. Apart from various annual surveys on both the production/supply of investment goods as well as acquisition and stocks, the major check points for the series are the large decennial *All India Debt and Investment Surveys* conducted by the Reserve Bank of India (RBI) having large randomized samples of up to 100,000 households. Details on sources and derivation of all variables are given in Appendix 2. Details on measurement of capital formation are given in Appendix 3.

Estimation and Results: Linear Model

The linear model was estimated using ordinary least squares. Econometric issues and details are discussed in Appendix 4. Note, for instance, that since this is time-series estimation (and not cross-section), some issues of simultaneity do not affect estimation. Government investment and institutional credit are separate institutional policies in India and are not necessarily and greatly related over time. Output is, as in Jorgenson (1967, 1971), Jorgenson and Stephenson (1967), and other investment behavior work, determined by existing capital stock and other determinants. Therefore, the contemporaneous relation between output and investment may be considered as being one-way. The relationship between savings and investment fits into a recursive framework and is thus amenable to single equation estimation. (Note that lagged variables were generally not found useful in the estimation except for lagged private capital stock.)

The linear model results are given in Table 1. The model does well in overall measures such as F-statistic and R^2. All the coefficients have the theoretically expected signs with 6 out of the 10 significant. The lagged private capital stock has a significant negative coefficient that is critical in confirming the basic theory of the model. Since the Durbin-Watson statistic diverges from 2, indicating auto-correlation, generalized least squares was carried out using the Cochrane-Orcutt method. These results are presented in Table 2. The significance improves in a number of variables including Q, P, RS, CRCP, CRCB, and LAGKP. The linear model results indicate that output and output price are significant determinants of investment. The finance variables of rural savings, cooperative credit, and bank credit are also significant showing that the adjustment process is an important part of the model. To provide a unit-free measure for comparison of responsiveness, elasticities at the mean are calculated. The results are given in Table 3. These results, based on the linear model, show that the important variables are lagged capital stock (structurally important for the model), output, cooperative credit, and price of output.

Table 1.—Linear Model: Ordinary Least Squares*

Time period: 1951–80

$$IP = \underset{(1.51)}{866.682} + \underset{(2.10)}{0.03328}\,Q + \underset{(2.04)}{4.3384}\,P + \underset{(0.33)}{0.02956}\,KG - \underset{(-0.16)}{0.6729}\,UC - \underset{(-1.32)}{3.9704}\,W - \underset{(-0.83)}{0.9564}\,PF + \underset{(4.35)}{0.6245}\,RS + \underset{(2.23)}{0.4816}\,CRCP + \underset{(2.28)}{0.4674}\,CRCB - \underset{(-1.67)}{0.1976}\,LAGKP$$

Adj. $R^2 = 0.957$ $DW = 1.60$ $F = 65.5$

Table values (2 tail):

$t_{0.95} = 2.02$, $t_{0.90} = 1.73$

$t_{0.80} = 1.33$, $F_{0.95} = 2.38$

*t-values in parentheses below the coefficients.

Table 2.—Linear Model: Generalized Least Squares*

Time period: 1951–80

$$IP = \underset{(1.80)}{1100.11} + \underset{(2.50)}{0.03416}\,Q + \underset{(2.36)}{4.7227}\,P + \underset{(0.68)}{0.06908}\,KG - \underset{(-0.13)}{0.5391}\,UC - \underset{(-0.95)}{2.9869}\,W - \underset{(-0.89)}{0.9332}\,PF + \underset{(4.10)}{0.5624}\,RS + \underset{(2.31)}{0.5155}\,CRCP + \underset{(2.12)}{0.4585}\,CRCB - \underset{(-1.98)}{0.2514}\,LAGKP$$

Adj. $R^2 = 0.93$ $DW = 2.01$ $Rho = 0.28$ $F = 20.89$

Table values (2 tail):

$t_{0.95} = 2.02$, $t_{0.90} = 1.73$,

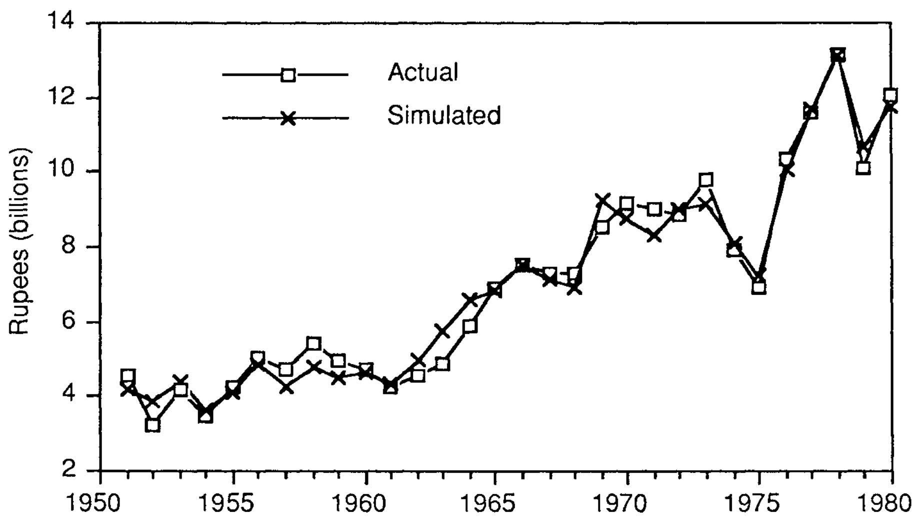
$t_{0.80} = 1.33$, $F_{0.95} = 2.38$

*t-values in parentheses below the parameters.

Estimation and Results: Nonlinear Model

The nonlinear model was estimated using an iterative Gauss-Newton method (see Appendix 4 for econometric details and issues), and convergence was achieved after 24 iterations. The results are presented in Table 4, and Chart 4 shows the overall tracking of the model to actual data.

Chart 4.—Plot of Actual and Simulated Values: Nonlinear Model



The results appear fairly robust but show important differences from the linear model. The output variable drops in significance becoming barely significant only at an 80 percent level, and the output price variable drops out of significance. The government capital stock variable becomes significant with a positive sign indicating a fostering or incentive role of government investment toward private investment, rather than a crowding-out or competitive role. The user cost of capital also becomes significant with a negative sign indicating that private investment may be sensitive to the price of capital including the interest rates on loans. The wage variable has a positive coefficient, indicating that the capital-labor substitution effect may be dominating the labor-investment effect, but this is not significant.

Table 3.—Elasticities at the Mean from the Linear Model*

Q	P	KG	UC
0.894	0.637	0.342	−0.005
(2.50)	(2.36)	(0.68)	(−0.13)
W	PF	RS	CRCP
−0.388	−0.140	0.614	0.638
(−0.95)	(−0.89)	(4.10)	(2.31)
CRCB	LAGKP		
0.145	−3.302		
(2.12)	(−1.98)		

*t-statistics for coefficients in parentheses.

Table 4.—Nonlinear Model*

Time period: 1951–80

$$
\begin{aligned}
IP = 258.726 \; &* \; Q\ (exp)\ 0.1247 \; * \; P\ (exp)\ 0.0661 \\
&\quad (1.18) \qquad\qquad (1.34) \qquad\qquad (1.05) \\
&* \; KG(exp)\ 0.0900 \; * \; UC\ (exp)\ -0.0193 \\
&\qquad\qquad (3.92) \qquad\qquad (-2.27) \\
&* \; W(exp)\ 0.0637 \; * \; PF(exp)\ 0.0049 \; + \; 0.5096 RS \\
&\qquad\qquad (0.80) \qquad\qquad (0.13) \qquad (3.61) \\
&+ 0.7201\ CRCP + 0.9824\ CRCB - 0.3972\ LAGKP \\
&\quad (3.50) \qquad\qquad (3.43) \qquad\qquad (-3.44)
\end{aligned}
$$

$(\sigma\ of\ IP - \sigma\ of\ residual)/\sigma\ of\ IP = 80.8\ percent,\ DW = 1.69$
Table values (2-tail):
$t_{0.95} = 2.02, \quad t_{0.90} = 1.73, \quad t_{0.80} = 1.33$

*(exp) = exponent; t-statistics in parenthesis below the parameters.

The finance variables continue to be strong and significant, and in addition the lagged capital stock is negative and significant confirming the basic theory of the model. The positive sign of the fertilizer price variable indicates substitution, but this is not significant.

To provide a unit-free comparison, elasticities at the mean are computed using a separate procedure given the nonlinearities in the model, and the results are given in Table 5. For quantity variables the derivatives might be more meaningful, in most cases, than the elasticities. The lagged capital stock shows a high elasticity, partly attributable to the large magnitude of the private capital stock relative to private investment; its derivative, which represents rupee for rupee change, is smaller in absolute magnitude compared to finance variables. Other than this, the largest elasticity obtained is that for cooperative credit. Rural savings and government capital stock also have large positive elasticities. Among the derivatives of the quantity variables, the largest is for commercial bank credit.

Table 5.—Derivatives and Elasticities at the Mean Form the Nonlinear Model*

Variable	Derivative	Elasticity	t-statistic
Q	0.02	0.58	(1.34)
P	2.27	0.31	(1.05)
KG	0.08	0.42	(3.92)
UC	−9.38	−0.09	(−2.27)
W	2.28	0.30	(0.80)
PF	0.15	0.03	(0.13)
RS	0.51	0.56	(3.61)
CRCP	0.72	0.89	(3.50)
CRCB	0.98	0.31	(3.43)
LAGKP	−0.40	−5.29	(−3.44)

*The derivatives and elasticities are evaluated at the means.

Comparison of Results

Two sets of results have been obtained: one from a linear version of the model frequently used in the literature, and another from the nonlinear model derived directly from the theory. A non-nested specification test is carried out below to compare the two models.

The test is set up according to the framework developed by Davidson and MacKinnon (1981). See Appendix 4 for details.

In the first test,

Null hypothesis: $H_0 : Y = f(X, \beta)$ Linear model
Alternate hypothesis: $H_1 : Y = g(X, \gamma)$ Nonlinear model

The nonlinear model is first estimated and the fitted values of $Y(= IP) = \hat{g}(X, \hat{\beta})$ are retrieved from it. Then the following equation is estimated:

$$Y = (1 - \alpha)f(X, \beta) + \alpha\hat{g}.$$

Since this equation is linear it can be estimated by OLS. The following estimates are obtained:

$$\alpha = 1.2716$$

t-statistic for $\alpha = 0 = 2.27$ | Table value of
t-statistic for $\alpha = 1 = 0.49$ | $t_0.95 = 2.10$
Likelihood ratio test:
$LR = 4.51 \sim \chi^2$ Table value of $\chi^2 = 3.84$

The t-test and the likelihood ratio test reject $\alpha = 0$ and, therefore the tests reject the linear model. On the other hand, $\alpha = 1$ cannot be rejected by the t-test, indicating that the nonlinear model is the better model.

An alternative confirmatory test was set up as follows:

$H_0 : Y = g(X, \beta)$ Nonlinear model
$H_1 : Y = f(X, \beta)$ Linear model

The linear model was estimated and the fitted values $\hat{Y} = f(X, \hat{\beta})$ were retrieved from the procedure. Then the following equation was estimated:

$$Y = (1 - \alpha)g(X, \beta) + \alpha\hat{f}.$$

The equation is nonlinear and was estimated by an iterative Gauss-Newton procedure. The following results were obtained:

$\alpha = 0.8680$
t-statistic for $\alpha = 0 = 0.49$ | Table value of
t-statistic for $\alpha = 1 = -0.0063$ | $t_{0.95} = 2.10$
Likelihood ratio test
$LR = 1.20 \sim \chi^2$ Table value of $\chi^2 = 3.84$.

Both the t-test and the likelihood ratio test cannot reject the hypothesis that $\alpha = 0$. Thus the nonlinear model cannot be rejected over the linear model. The Davidson-MacKinnon non-nested specification test, therefore, concludes that the nonlinear model is the superior specification, and its results should therefore be preferred over the results of the linear model. The differences between the results, since they are based on the same data, would be indicative of the specification biases that may be related to the use of the linear model.

DISCUSSION OF RESULTS

The empirical results show that with appropriate modifications, the theory of investment behavior provides a useful framework for explaining private investment behavior in developing country agriculture. The modifications are important because, for instance, the theory excludes the influence of government investment on private investment. It also grossly underplays the critical role of credit, particularly institutional credit, in developing countries. With these modifications it becomes apparent that many government policies can have an important influence on private investment in developing countries.

The dominance of the nonlinear model over the linear in the non-nested specification test is indicative of the usefulness of the theoretical basis and derivation. The substantial differences in their results show that linearized functions of determinants, such as used in Tun Wai and Wong (1982), Blejer and Khan (1984), and Sundarajan and Thakur (1980), might be inappropriate and might give misleading results. Furthermore, linear models seem to have unrealistic production function assumptions.

An important difference between the developing country results obtained here and the common developed country results (see reviews in Jorgenson, 1971, and Eisner, 1974), is that output does not play as strong a role here as in developed country models. This could reflect some fundamental differences, but from the structure of the model described earlier, it appears that output would play an important role given that it is central in the profit-maximizing behavior. It may be noted, however, that output in the theory implies planned or desired output, whereas the output data that are used in the empirical estimation are of the actual output. Since in agriculture, actual output is influenced by many other factors such as the weather, the exogenous random shocks may cause the actual output to differ considerably from the desired or planned output on a year-to-year basis. This could explain weak empirical relations between output and investment in models for developing country agriculture. The coefficient of output price is reasonable and positive but is also not significant. This may also reflect influence of factors such as weather as well as general conditions of underdevelopment. Under the given conditions, empirical results do not indicate a strong relationship between output prices and private investment in agriculture. Price support policy may be very important for creating a stable environment for technological change and private investment, but high and rising price support levels might not be as crucial for private investment in agriculture as some non-price policies.

Another difference between developed and developing country results concerns liquidity variables. In a survey of developed country investment models, Jorgenson (1971) found that both internal and external liquidity variables play a relatively weak role in developed country models, indicating that investment behavior is principally determined by the desired levels of capital stock. However, results on India indicate that cash and credit limitations can strongly affect investment in developing country agriculture. The savings and credit variables emerge as highly significant investment determinants. The significance of the savings varible confirms Campbell's (1958) residual funds hypothesis of investment behavior from Australian agriculture, but unlike his theory, the results here indicate many other determinants. The significance of the institutional credit variables indicate the importance of the credit policy in influencing investment behavior. The coefficient magnitudes (derivatives) for external finance variables in the form of cooperative credit (0.72) and commercial bank credit (0.98) indicate that, despite fungibility and possible leakages, institutional credit has a large impact on productive investment, with the coefficients indicating a fairly high percentage of conversion. (These results also suggest that commercial bank credit may have a higher percentage conversion.)

Another difference from developed country results is that the user cost of capital plays a statistically significant but smaller role (as shown by the elasticity) when compared to usual observations in developed country models. This indicates that, though the volume of institutional credit has an important role, the price of credit, principally, the interest rate may not have a large influence on borrower decisions. This appears consistent with an environment of credit scarcity.

Agricultural wages do not emerge as a statistically significant determinant of investment, possibly because their positive impact on investment through capital-labor substitution may be cancelled by their negative effect on direct labor-investment. This may support the importance of labor-investment in agriculture as indicated by Levi (1979) and Alamgir (1976). Fertilizer prices do not emerge as statistically significant either, possibly because fertilizer use itself is influenced by many factors other than prices (Desai and Stone, 1987). The non-significance indicates a lack of evidence for any strong substitution relationship with investment.

Another major finding of this study, especially with regard to development strategy, is that government investment represented by the government capital stock is a highly significant determinant of private investment in agriculture. The elasticity of this variable is 0.42 and its derivative is 0.08, which represents current impact. The cumulative impact on private investment is likely to be much greater. The important role of infrastructure development in enhancing the pace of agricultural and rural development has been stressed by Mellor (1986), Ahmed and Hossain (1988) and Binswanger et al. (1989). Infrastructure development can stimulate economic activity by increasing opportunities and reducing transaction costs. But in recent years, most developing country governments have tended to shy away from public sector investment in rural areas because of the high costs and what they see as limited direct benefits. However, it appears that substantial secondary benefits may be there and that governments may not be looking at the proper benefit estimates.

The findings of this study, based on long-term time-series data, indicate that government investment in agriculture significantly stimulates private investment, thereby having a multiplier effect on raising capital stock available for productive activities in the rural areas. This increase in capital stock, apart from directly contributing to growth, can also help in removing constraints to rapid technological change. Furthermore, since some capital stock itself embodies new technology, it may make a direct contribution to technological change and higher productivity in agriculture.

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APPENDIX 1.—MODEL DERIVATION

Maximize:

$$\begin{aligned}\text{Net present value} = \int_0^{\infty} & e^{-rt}[P(t)F[KP(t), KG(t), L(t), FR(t)] \\ & - W(t)L(t) - PF(t)FR(t) \\ & - PK(t)[\dot{K}P(t) + \delta KP(t)]]dt\end{aligned} \tag{1}$$

where

P = price of output,
$F(.)$ = production function,
KP = private capital stock,
KG = government capital stock,
L = labor use,
FR = fertilizer use,
W = wage,
PF = price of fertilizer,
PK = price of capital,
$\dot{K}P = dKP/dt$,
δ = rate of depreciation,
r = interest rate, and
t = time.

Assuming a general inflation rate of π, and for notational simplicity dropping the t's, but keeping in mind that all the input and price variables are functions of time, Equation (1) can be rewritten as:

Maximize:

$$\text{Net present value} = \int_0^\infty e^{-(r-\pi)t}[P\ F[KP, KG, L, FR] - W\ L \\ - PF\ FR - PK[\dot{K}P + \delta KP]]\ dt. \tag{2}$$

Now integration by parts can be applied on the following lines:

$$\int_a^b v\ du = uv\Big]_a^b - \int_a^b u\ dv \\ = u(b)\ v(b) - u(a)\ v(a) - \int_a^b u\ dv. \tag{3}$$

One part of Equation (2) is the following expression:

$$\int_o^\infty e^{-(r-\pi)t}\dot{K}P\ dt.$$

Now in Equation (3), let

$$v = e^{-(r-\pi)t},$$

and let

$$du = \dot{K}P\ dt.$$

Then

$$dv = -(r-\pi)e^{-(r-\pi)t},$$

and

$$u = KP.$$

Therefore,

$$\int_0^\infty e^{-(r-\pi)t}\dot{K}P\ dt = K\ P\ e^{-(r-\pi)t}\Big]_0^\infty + \int_0^\infty KP(r-\pi)e^{-(r-\pi)t}dt \\ = -KP(0) + \int_0^\infty KP(r-\pi)e^{-(r-\pi)t}dt. \tag{4}$$

Now, substituting Equation (4) into (2) and rearranging, gives

$$\text{NPV} = \int_0^\infty e^{-(r-\pi)t}[P\ F[KP, KG, L, FR] - W\ L - PF\ FR \\ - PK[KP(r-\pi) + \delta KP]]dt + PK\ KP(0),$$

which can be rewritten as

$$NPV = \int_0^\infty e^{-(r-\pi)t}[P\ F[KP, KG, L, FR] - W\ L - PF\ FR \\ - KP\ PK[r + \delta - \pi]]dt + PK\ KP(0). \tag{5}$$

Maximization for Equation (5) is equivalent to maximizing the expression within the square brackets, since the last term is unimportant for maximization. The first-order conditions for this maximization are

$$PF_{KP} = PK(r + \delta - \pi), \tag{6}$$

$$PF_L = W, \quad \text{and} \tag{7}$$

$$PF_{FR} = PF, \tag{8}$$

where $F.$ is the derivative of the production function with respect to the subscripted input. The government capital stock and prices are considered exogenous.

Deriving a specific expression for the desired level of capital stock requires selection of a specific form for the production function. Based on discussion in the text, the following Cobb-Douglas functional form is assumed:

$$Q = A(KP)^{\alpha_1}(KG)^{\alpha_2}(L)^{\beta_1}(FR)^{\beta_2}, \tag{9}$$

where Q is the real output. Differentiating the production function with respect to the private capital stock gives

$$\frac{\delta Q}{\delta KP} = F_{KP} = \alpha_1 A(KP)^{\alpha_1 - 1}(KG)^{\alpha_2}(L)^{\beta_1}(FR)^{\beta_2}. \tag{10}$$

Now differentiating Equation (9) with respect to L, gives

$$F_L = A\beta_1 KP^{\alpha_1} KG^{\alpha_2} L^{\beta_1 - 1} FR^{\beta_2}.$$

Substituting Equation (9) back into the above equation gives

$$F_L = \frac{\beta_1 Q}{L}.$$

Substituting the above into the first-order condition Equation (7) gives

$$\frac{PB_1 Q}{L} = W.$$

Therefore,

$$L = \frac{P\beta_1 Q}{W}. \tag{11}$$

Similarly differentiating Equation (9) with respect to FR gives

$$F_{FR} = A\beta_2 KP^{\alpha_1} KG^{\alpha_2} + L^{\beta_1} FR^{\beta_2 - 1}.$$

Substituting Equation (9) back into the above equation gives

$$F_{FR} = \frac{\beta_2 Q}{FR}.$$

Now substituting the above equation into the first-order condition Equation (8) gives

$$\frac{P\beta_2 Q}{FR} = PF.$$

Therefore,

$$FR = \frac{P\beta_2 Q}{PF}. \tag{12}$$

Now substituting Equations (11) and (12) into (10) gives

$$F_{KP} = \alpha_1 A(KP)^{\alpha_1 - 1}(KG)^{\alpha_2}[\frac{P\beta_1 Q}{W}]^{\beta_1}[\frac{P\beta_2 Q}{PF}]^{\beta_2}. \tag{13}$$

Substituting Equation (13) into the first-order condition (6) gives

$$P\alpha_1 A(KP)^{\alpha_1 - 1}(KG)^{\alpha_2}[\frac{P\beta_1 Q}{W}]^{\beta_1}[\frac{P\beta_2)Q}{PF}]^{\beta_2} = PK(r + \delta - \pi).$$

Letting $UC = PK(r + \delta - \pi)$, and transposing, gives

$$\begin{aligned} KP = (constant)P^{[\frac{\beta_1+\beta_2+1}{1-\alpha_1}]}Q^{[\frac{\beta_1+\beta_2}{1-\alpha_1}]}KG^{[\frac{\alpha_2}{1-\alpha_1}]} \\ UC^{-[\frac{1}{1-\alpha_1}]}W^{-[\frac{\beta_1}{1-\alpha_1}]}PF^{-[\frac{\beta_2}{1-\alpha_1}]}. \end{aligned} \tag{14}$$

The next section develops the second part of the model that determines whether and the extent to which the change in desired capital stock is translated into actual investment. The partial adjustment model can now be developed as follows. Let

$$KP_t - KP_{t-1} = b_t(KP_t^* - KP_{t-1}), \tag{15}$$

where b_t is the adjustment coefficient and $*$ indicates "desired." Following methodology developed by Coen (1968), b_t can be expressed as

$$b_t = b_0 + b_1 \frac{RS_t}{KP_t^* - KP_{t-1}} + b_2 \frac{CRCP}{KP_t^* - KP_{t-1}} + b_3 \frac{CRCB}{KP_t^* - KP_{t-1}}, \quad (16)$$

where RS is rural savings, CRCP is cooperative credit to agriculture, and CRCB is commercial bank credit to agriculture.

Gross investment can be expressed as

$$IP_t = (KP_t - KP_{t-1}) + \delta KP_{t-1}, \quad (17)$$

where IP is gross private investment in agriculture and δ is the rate of depreciation. Now substituting Equation (15) into (17) gives

$$IP_t = b_t(KP_t^* - KP_{t-1}) + \delta KP_{t-1}. \quad (18)$$

Substituting Equation (16) into (18) gives

$$IP_t = [b_0 + b_1[\frac{RS_t}{KP_t^* - KP_{t-1}}] + b_2[\frac{CRCP_t}{KP_t^* - KP_{t-1}}] + b_3[\frac{CRCB_t}{KP_t^*}]]$$

$$+(KP_t^* - KP_{t-1}) + \delta KP_{t-1}.$$

Therefore,

$$IP_t = b_0\ KP_t^* + b_1\ RS_t + b_2\ CRCP_t + b_3\ CRCB_t + (\delta - b_0)KP_{t-1}. \quad (19)$$

Substituting Equation (14) for KP^* into (19), gives the complete model:

$$\begin{aligned} IP = (\text{constant})P_t^{[\frac{\beta_1+\beta_2+1}{1-\alpha_1}]} Q_t^{[\frac{\beta_1+\beta_2}{1-\alpha_1}]} KG_t^{[\frac{\alpha_2}{1-\alpha_1}]} UC_t^{-[\frac{\beta_1}{1-\alpha_1}]} PF_t^{-[\frac{\beta_2}{1-\alpha_1}]} \\ + b_1\ RS_t + b_2\ CRCP_t + b_3\ CRCB_t + (\delta - b_0)KP_{t-1}. \end{aligned} \quad (20)$$

It may be noted that the model has a linear and a nonlinear component and therefore cannot be simplified by taking logarithms. The function for estimation can be stated as

$$\begin{aligned} IP = (\text{constant})P_t^{\gamma_1} Q_t^{\gamma_2} KG_t^{\gamma_3} UC_t^{\gamma_3} UC_t^{\gamma_4} W_t^{\gamma_5} PF_t^{\gamma_6} \\ + b_1 RS_t + b_2 CRCP_t + b_3 CRCB_t + b_4 KP_{t-1} + u_t, \end{aligned} \quad (21)$$

where u_t is a disturbance term. This form clearly requires a nonlinear estimation procedure. An alternative is to assume a simplified linear form (common in the literature; see Tun Wai and Wong, 1982, and Blejer and Khan, 1984), that gives

$$\begin{aligned} IP_t = d_0 + d_1P_t + d_2Q_t + d_3KG_t + d_4UC_t + d_5W_t + d_6PF_t \\ + d_7RS_t + d_8CRCP_t + d_9CRCB_t + d_{10}KP_{t-1} + v_t, \end{aligned} \quad (22)$$

where v_t is a disturbance term. Equations (21) and (22) are the two alternative functions for estimation.

APPENDIX 2.—DATA AND DATA SOURCES

1. Data for total gross fixed capital formation (investment) in agriculture both in nominal and real (1970–71 prices) terms are obtained from Chaturvedi and Bagchi (1984). They use the same basic data base as used by India's Central Statistical Organization (CSO). The reason for choosing their series over the CSO series is that the CSO series includes change in stocks (stocks of agricultural commodities) that are not a part of fixed capital formation. Data for gross fixed capital formation in agriculture by the government (government investment in agriculture) are obtained from *Transactions of the Public Sector* (India, CSO, 1983). Capital formation in buildings, roads and bridges, and in other construction and works (mainly irrigation works) is grouped under brick/cement construction. This is deflated to real terms using the implicit deflator for total brick/cement construction from Chaturvedi and Bagchi (1984). Capital formation in machinery and other equipment and transport equipment is grouped under machinery and equipment. This is deflated to real terms using the implicit deflator of total machinery and equipment from Chaturvedi and Bagchi (1984). Unfortunately, these series on public capital formation extend only from 1960 to 1979. Data for the earlier years are obtained from Narain, Sarkar, and Chandra (1978). For 1980, extrapolation is done using the figure on gross capital formation from *National Accounts Statistics* (India, CSO, 1985) by deducting an estimate of change in stocks from this figure.

To obtain the private sector figures for concrete cosntruction and machinery and equipment, the above public sector figures are deducted from the total gross fixed capital formation figures. The entire fixed capital formation in mud and indigenous construction and in livestock is considered to be of the private sector. These different components are aggregated to give the gross private capital formation (investment in agriculture).

2. The series of agricultural output is the gross value of output in real terms and is obtained from disaggregated tables in *National Accounts*

Statistics (India, CSO, 1975) and later issues. The agricultural output price index is derived as an implicit deflator from the real and nominal values of gross value of output from the same sources. However, nominal values for years earlier than 1960 were not available in this source. The price index from 1950 to 1959 is of wholesale prices and was obtained from Chandhok (1978). Both the price index and the real value of output are readjusted to make 1970–71 as the base year (1970–71 = April 1970 to March 1971).

3. Agricultural wage data are calculated from the daily wage rates of unskilled agricultural labor (field labor/ploughman), which are reported monthly from over a hundred different rural centers all over the country to the Ministry of Agriculture. A weighted average is calculated and is converted into an index. The basic source is *Agricultural Wages in India* (India, Ministry of Agriculture, 1950–).

4. Calculation of user cost of capital required data on the price of capital, the interest rate, the depreciation, and the rate of inflation, which were obtained as follows:

a. Data on price of capital is the implicit deflator of investment in agriculture obtained from Chaturvedi and Bagchi (1984).

b. Data on interest rate is the weighted average lending rate of Primary Agricultural Credit Cooperative Societies, and for this basic information was obtained from various issues of the Reserve Bank of India's (RBI) *Statistical Statements Relating to Cooperative Movement in India* (RBI, 1950–80). Where a range was given, a simple average was used. Where there was a choice available between short-term and medium-term rates, the medium-term rate was used. A weighted average was calculated over the states for each year, using the amount of loans issued in that year in each state as the weight.

c. Assuming expected life spans of approximately 50 years for concrete constructions, 20 years for mud and indigenous construction, 15 years for machinery and equipment, and 10 years for livestock, assuming a declining balance method of depreciation (with 10 percent of initial value as residual) and making adjustments based on the discussion of Yotopoulos (1967) and Grilliches (1960) given in the text, the following rounded depreciation rates were calculated: concrete construction, 2 percent; mud and indigenous construction, 6 percent; machinery and equipment, 8 percent; and livestock, 10 percent. A weighted average was calculated using the capital stocks in 1960–61 in these different forms as weights, and this gave an overall depreciation rate of 4 percent for capital in agriculture. The absolute accuracy of this depreciation rate is not very crucial for the estimation of the model, given the estimation procedure.

d. The rate of inflation was calculated using the formula:

$$\pi(t) = \frac{P(t) - P(t-1)}{P(t-1)},$$

using the implicit deflator for investment in agriculture from Chaturvedi and Bagchi (1984).

5. The price of fertilizer is the wholesale fertilizer price index (1970–71 = 100), and this is obtained from a compilation by Chandhok (1978) for the years 1952 to 1977. The data for 1978 to 1980 was obtained from different issues of the *Bulletin of Food Statistics* (India, Ministry of Agriculture). For the years 1950 and 1951, an extrapolation was accomplished using the wholesale price index for chemicals and chemical products as a guide by regression. These data were also available in Chandhok (1978).

6. The rural savings figures were obtained from Krishna and Raychaudhuri (1980b). This series covers the period from 1950 to 1973 and is extended on the same basis from 1974 to 1980. For the time period 1950 to 1959, Krishna's series is based on RBI's data published in its *Bulletin* (March 1965). For the later years (1960 to 1973), it is based on CSO data and is extended to 1980 on the same basis. These figures are deflated by the implicit investment goods deflator for agriculture from Chaturvedi and Bagchi (1984).

7. The cooperative credit data consists of credit outstanding to agriculture from the Primary Agricultural Credit Societies, the Land Development Banks, Grain Banks, and the Non-Credit Agricultural Cooperative societies. Compiled figures of total cooperative lending to agriculture are available only from 1971 onward from various issues of *Report on Currency and Finance* published by RBI. For earlier years, figures for different types of cooperative have to be put together year by year. These are available in issues of *Statistical Statements Relating to Cooperative Movement in India* published annually by RBI. Separation between long-term lending and short-term lending was not possible for the entire time-series. The figures are adjusted to the uniform April to March financial year. Then this figure is deflated by the implicit investment goods deflator from Chaturvedi and Bagchi (1984).

8. The bank credit data are loans outstanding of commercial banks to agriculture. From 1968 onward these data are available in various issues of the RBI's *Report on Currency and Finance.* Data from 1950 to 1964 were obtained from RBI's *Supplement to Banking and Monetary Statistics of India, Part l* (1964). Figures for 1965 to 1967 were obtained from Sharma (1974). All figures were deflated by the implicit investment goods deflator for agriculture from Chaturvedi and Bagchi (1984).

9. Several estimates of capital stock are available for India, but perhaps the most reliable is from "Estimates of Tangible Wealth in India," *RBI Bulletin* (1972). This estimate is based on RBI's *All India Rural Debt and Investment Survey*, carried out in 1961–62 with a sample size of 82,000 rural households spread over some 2,000 villages across the country. However, there are some differences in the classification provided by RBI for

the capital stock estimates and that used by CSO for the investment series, and the two need to be equated to construct a consistent capital stock series. Total capital stock in construction is considered to be a sum of rural nonresidential property, land improvement, and irrigation works (private) and land improvement and irrigation works (public). Next, the share of concrete construction in total construction is obtained by moving the capital stock estimates for 1950 provided by Chaturvedi and Bagchi (1984) to 1961. The proportion works out to 75 percent concrete construction and 25 percent mud construction. All land improvement and irrigation works (public) is assumed to be part of concrete construction, and the remaining concrete construction is private. The capital stock estimates of private construction are converted to 1970–71 prices using the concrete and mud construction deflators of Chaturvedi and Bagchi. Capital stock of agricultural implements is considered to be private capital stock in machinery and equipment. This is price-adjusted using the machinery and equipment deflator of Chaturvedi and Bagchi. Capital stock in the form of livestock poses particular problems since whereas RBI includes the entire livestock populations in the capital stock, the CSO definition includes only the productive part of the population (as defined in Appendix B). Chaturvedi and Bagchi provide an estimate of the stock by CSO definition for 1950, and an RBI basis stock estimate for 1950 is available from Roychaudhuri (1977). The stock by the CSO definition works out to only 8.6 percent of the stock by RBI, and this proportion is then applied to the RBI 1961 estimate to arrive at the capital stock in livestock. This is price-adjusted to 1970–71 prices using the relevant deflator from Chaturvedi and Bagchi.

All of the components calculated above are added to give the private capital stock in agriculture at the end of March 1961 in 1970–71 prices. The complete series for private capital stock is then calculated applying the following formula:

$$KP(t) = (1 - \delta)\ KP(t-1) + IP(t),$$

where KP is capital stock, δ is rate of depreciation, which is assumed to be 4 percent as discussed earlier, and IP is gross private investment in agriculture.

10. The government capital stock for March 1961, as described in 9., is obtained from the RBI estimate under the category of land improvement and irrigation works (public). Since this consists almost entirely of concrete construction works (evident from the government investment series data), it is moved to the other years applying a depreciation rate of 2 percent and the formula given in 9. The figures for gross government investment in agriculture are obtained from *Transactions of the Public Sector*, (India, CSO, 1983) and Narain, Sarkar, and Chandra (1978), a description of which is provided in 1.

APPENDIX 3.—MEASUREMENT OF CAPITAL FORMATION/INVESTMENT

Estimates of gross capital formation or investment in agriculture depend on the definition of its scope and coverage. In the case of India this definition is based on *A System of National Accounts: Studies in Methods* (United Nations, 1968). A description of the scope and coverage for agriculture is given briefly below:

1. Nonresidential buildings: Value of work put in place on buildings and structures that are entirely, or primarily, for industrial or commercial use; outlays on major alterations in and additions to these buildings and structures and transfer and similar costs with respect to purchases of existing nonresidential buildings.

2. Land improvement: Outlays on all land reclamation and land clearance, irrespective of whether or not it represents an addition to total land availability; irrigation and flood control projects, and dams and dikes that are part of these projects; clearance and afforestation of timber tracts and forests; and transfer costs of transactions in land, farms, and concessions.

3. Transport equipment: Purchasers' value of new tractors for road haulage and carts. Outlays on major alterations and improvements in existing transport equipment of this type owned. Dealer margins, transport, and other transfer costs for purchase (sale) of second-hand assets.

4. Agricultural machinery and equipment: Purchasers' value of new agricultural machinery and equipment like harvesters, threshers, ploughs, harrows, and other cultivators and tractors other than for road haulage; outlays on major alterations and improvements in such machinery and equipment; and dealers' margins, transport, and other transfer charges for purchase of second-hand agricultural machinery and equipment.

5. Breeding stock, draft animals, and dairy cattle: Value of additions to, less disposal of, breeding stock, draft animals, dairy cattle, and sheep.

Several methods can be used for the actual estimation of the different components of capital formation or investment described above (see Lal, 1977). Frequently used methods include income, expenditure, commodity flow, and inventory.

The income method involves estimation of the number of workers employed in construction or other capital-creation activity, the number of days employed, and average daily income. From this the value of capital formation in terms of factor income earned in the process of capital creation can be calculated. In the expenditure method of estimation, data are collected on the actual expenditure of different industries in the creation of capital. This method provides easy industrial classification of capital formation, but the estimates are likely to be influenced by accounting conventions used by different industries that may lead to some lack of uniformity. The commodity flow approach is based on estimation of the domestic production of capital goods, which is then adjusted for changes in stock, imports, and exports. Transport costs, dealer margins, and indirect taxes need to be added to arrive at purchaser's value. Finally, the inventory method requires estimation of the stock of capital goods annually or at different points in time, and the difference between two consecutive values estimates the net capital formation in that period. The choice between these different methods is dictated by the type of goods in question and also the availability of data. Major reliance is commonly placed on expenditure and commodity flow approaches.

National Accounts Statistics (India, CSO, 1976) provides a time series on capital formation by industry of use, beginning in 1950. Estimates of fixed capital formation for each of the industrial categories are prepared following primarily the expenditure approach and also the commodity flow approach for some components. See specific details in *National Accounts Statistics* (India, CSO, 1980).

APPENDIX 4.—ESTIMATION TECHNIQUES

1. The linear model for estimation given in Equation (22) is estimated by ordinary least squares regression (OLS) under the standard assumptions for the error term:

$$E(v_i) =, 0 \qquad \text{all } i,$$

$$E(v_i v_j) = cov(v_i, v_j) = 0, \quad \text{all } i \neq j,$$

$$E(var_i^2) = var(v_i) = \sigma_\nu^2, \quad \text{all } i,$$

and

$$v_i \sim N(O, \sigma_\nu^2), \quad \text{all } i.$$

It is also assumed that explanatory variables and the error term are independent. Under these conditions, OLS is the best linear unbiased estimator and also the maximum likelihood estimator.

2. The nonlinear model for estimation is given in Equation (21). It is estimated using a nonlinear model optimization procedure, an iterative least squares method. The criterion function Q is the sum of squared residuals. It is assumed here that the error in the model is additive and is

normally distributed, and under these conditions minimizing Q is equivalent to maximizing the likelihood function.

Q is a function of the vector of parameter estimates $B, Q = Q(B)$, and d is a direction vector such that Q decreases in the direction defined by d. The Gauss method (same as the Gauss-Newton method) is used for optimization, for easier approximation of the Hessian matrix when the objective function is of the form:

$$Y = f(X, B^*) + e = f(B^*) + e,$$

where

$$Y = (y_1, ..., y_T)', f(.) = [f_1(B), ..., f_T(B)]',$$

and

$$e = (e_1, ..., e_T)',$$

and the objective function is the sum of squared errors:

$$Q(B) = [Y - f(B)]'[Y - f(B)] = e(B)' \, e(B).$$

The Gauss algorithm works by a sequence of linear regressions in which at each stage least squares estimators are computed for a linear approximation of the nonlinear model. A generalization of this method has been developed by Berndt, Hall, Hall, and Hausman (1974). It is possible to show that the coefficients in the linearized regression will be zero if and only if the current parameters are at a local minimum of Q. The covariance matrix of the regression coefficients from the last OLS is asymptotically equivalent to the covariance matrix of the nonlinear least squares estimates of the parameters of the equation. This allows the testing of the statistical significance of the parameters of the equation. Judge et al. (1985) caution that only the asymptotic properties of the parameter estimators for nonlinear models are generally available and only under certain regular conditions that, however, are not too restrictive. Therefore, the usual estimators or confidence regions are asymptotically valid. Judge et al. report that Monte Carlo experiments have been carried out in order to evaluate the small sample properties, but they have limited generality. Despite some of these limitations of interactive optimization, nonlinear models are now widely employed.

3. Mention may be made here about simultaneous equations since a question about simultaneity exists between private investment and output. Whereas private investment may depend on current output, output can be validly assumed to depend on private capital stock already in place, and therefore relatively independent of current investment. Thus contemporaneously, the dependence can be assumed to be one way. Another such

question is about the simultaneity between private investment and rural savings, since both can be determined at the same time by output. Moreover, private investment also depends on rural savings. This interrelationship, however, can be cast in a recursive system framework as follows:

$$y = \beta_1 y_2 + \beta_2 z_1 + \beta_3 z_2 + u_1, \quad \text{and}$$

$$y_2 = \gamma_1 z_1 + \gamma_2 z_2 + u_2,$$

where y_i are endogenous variables, z_i are exogenous variables, and u_1 are disturbance terms. y_1 (private investment) depends on y_2 (rural savings), and other exogenous variables, but y_2 depends only on exogenous variables (such as output and interest rate). In such a recursive system, each equation can be validly separately estimated by OLS (Judge et al., 1985). Thus the investment function can be separately estimated.

4. Following estimation of the nonlinear model, a non-nested specification test is carried out to compare the linear and nonlinear models. Such a test has recently been developed by Davidson and MacKinnon (1981). Suppose a base model is to be tested against an alternative model. Then the base model is taken as the null hypothesis:

$$H_0 : Y = f(X, B) + e,$$

where Y is the vector of the dependent variable, X is a matrix of exogenous variables, B is the vector of parameters to be estimated, and e is the error term assumed to be $NID(0, \sigma_e^2)$. Suppose the theory suggests an alternative model; then this model is framed as the alternative hypothesis:

$$H_1 : Y = g(Z, \gamma) + u,$$

where Z is a matrix of exogenous variables, γ is the vector of parameters to be estimated, and u is the error term assumed to be $NIDO(0, \sigma_u^2)$. It is assumned that H_1 is not nested within H_0, and H_0 is not nested within H_1. Davidson and MacKinnon (1981) propose that the above non-nested specification test can be carried out by running the following linear or nonlinear regression:

$$Y = (1 - \alpha)f(X, B) = \alpha\hat{g} + v,$$

where $\hat{g} = g(Z, \hat{\alpha})$ and $\hat{\gamma}$ is the maximum likelihood estimate of γ. If H_0 is true, then the true value of α is zero. Now $\hat{\gamma}$ is independent of v, and asymptotically Z and $\hat{\gamma}$ are also independent of v. Thus asymptotically $\hat{g}$ is independent of v, and the validity of whether $\alpha = 0$ can be tested by using the conventional t statistic or a likelihood ratio test.

Two tests can be done to confirm the accuracy of the results. First the linear model can be framed as $f(.)$ and the nonlinear model as $g(.)$, and then vice versa. In other words, each model can be made the null hypothesis model in turn. Besides, both a t-test and a likelihood ratio test can be carried out to confirm the statistical significance of the test parameter.