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CREDIT MARKET CONSTRAINTS, CONSUMPTION SMOOTHING AND THE ACCUMULATION OF DURABLE PRODUCTION ASSETS IN LOW-INCOME COUNTRIES: INVESTMENTS IN BULLOCKS IN INDIA

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Credit Market Constraints, Consumption Smoothing and the Accumulation of Durable Production Assets in Low-Income Countries: Investments in Bullocks in India

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An essential feature of agricultural populations characterized by incomplete markets is the interlinkage between production and consumption decisions. In particular, almost all of the assets held by farmers contribute directly to production and, to the extent that there are asset markets, these can also serve as buffer stocks to smooth consumption when income is stochastically variable and credit markets are incomplete. Indeed, even financial assets, because of the lack of synchronization between payments and receipts within the crop-year, serve a production role ("working" capital) quite apart from their potential use as an interyear consumption-smoothing instrument. In settings in which agricultural incomes are uncertain and there are credit market constraints, therefore, a more complete understanding of the investment or savings decisions of farmers cannot be achieved without explicit recognition of the dual roles of capital stocks as productive inputs and as buffer stocks.

The vast literature focusing on risk-coping behavior in rural, low-income environments has tended to ignore either the consumption-smoothing role of assets or the determinants of their levels. Studies of risk-mitigating contractual arrangements such as sharecropping, for example, generally employ static models of risk-behavior which assume the absence of capital markets and the exogeneity of asset holdings. Empirical studies of savings behavior in low-income countries also do not explicitly characterize credit markets and ignore the direct effects of asset accumulations on income levels. Indeed, the "permanent income" model, which has been applied many times to agricultural populations in low-income countries (e.g., Bhalla, 1980; Wolpin, 1983; Paxson, 1988), assumes the absence of borrowing constraints, and studies incorporating this framework have treated income as exogenous to the process of asset accumulation and decumulation. A recent model of savings behavior incorporating constraints on borrowing (Deaton, 1989) and purporting to be relevant to low-income agricultural settings emphasizes the importance of assets as buffer stocks but also assumes that income is exogenous to savings decisions. All of these studies, however, suggest a considerable degree of consumption-smoothing behavior and the importance of this motivation for both asset accumulation and formal contractual arrangements.

In this paper we formulate and estimate a finite-horizon, structural dynamic model of agricultural investment behavior that incorporates income uncertainty, constraints on borrowing and rental markets, returns to farmer experience, and the use of investment assets to both generate income and to smooth consumption. The model yields implications for the purchase and sale of productive assets and for income levels that exhibit both "life-cycle" and "high-frequency" consumption-smoothing patterns and is fit to longitudinal household data on farm profits, bullock stocks and pumpsets from the semi-arid tropics of India.

The difficulties of formulating estimable dynamic models of behavior incorporating both uncertainty and borrowing constraints are well-known.[1] In recent years, however, advances in methodology and computation have made it feasible to estimate such models when the basic choice variables are discrete.[2] Our model discretizes assets by focusing on two of the most important assets of farmers--bullocks and pumpsets--in the environment we study, South India. The "lumpiness" of these assets makes more realistic the use of the discrete dynamic framework for studying investment and savings behavior. By estimating the structural parameters underlying farmer investment decisions, we can thus better assess the consequences of policy changes for farmer welfare. As we show below, in contrast to all other productive assets in India (chiefly land and pumpsets), bullock stocks, which are the principal source of motive power in that area of the world, appear to turn over at relatively high rates and to move inversely with income realizations. "Trimming the herd" through sales thus appears to be an important means of consumption-smoothing in the presence of borrowing constraints, with consequent implications for the efficiency and volatility of agricultural production.

In Section 1 of the paper, we set out a simple consumption-smoothing stock adjustment model and test its implications based on aggregate and individual farmer time-series data on output, agricultural profits, and bullock purchases and sales. We show that both the aggregate and individual farmer output data are characterized by positive serial correlation, net of fixed effects and time or age trends, despite the absence of any serial correlation in rainfall, consistent with the use of productive assets for consumption-smoothing. We also show that bullock sales respond inversely to profit realizations, net of initial-period stocks, suggesting the importance of the consumption-smoothing motivation for these investments.

Section 2 of the paper contains a description of the structural model and the estimation procedure employed and Section 3 reports parameter estimates and both intra- and extra-sample tests of the predictive power of the model. In the final section we use the structural estimates to assess the potential effects on the life-cycle accumulation and turnover rate of bullock stocks, purchases of pumpsets, agricultural profits, consumption and welfare associated with policies that (i) alter the prices of bullocks and pumpsets, through taxation and subsidization, (ii) provide assured sources of income to farmers and (iii) provide weather insurance. We are able to use our estimates as well to compute the price farmers are willing to pay for weather insurance and compare this to our estimates of the actuarially-fair cost of weather insurance.

Our estimates indicate that farmers are considerably averse to risk. They also suggest that there is substantial underinvestment in bullocks as a direct result of the evident constraints on farmers' abilities to smooth consumption via the credit market. As a consequence, our estimates indicate that increasing opportunities for earning non-risky incomes for members of farm households will increase farm productivity, as would improvements in the consumption loan market, if feasible. Our results also indicate, however, that reductions in the price of bullocks may lower welfare for farmers and that the gains to farmer welfare resulting from the implementation of an actuarially-fair (fully-funded) insurance scheme are quite small. Farmers are evidently able in part to cope with the vagaries of weather through informal means, which have almost completely substituted for a formal weather insurance scheme.

1. The Data and Some Nonstylized Facts

a. Stock adjustment and output auto-correlations

The environment we study, the semi-arid tropics of India from 1960 through 1985, is one in which there has been little or no technical change. If the principle source of uncertainty in output, weather, is characterized by a stationary i.i.d. stochastic process, as is commonly assumed, then net of trends in population levels we would expect that output would also be i.i.d. over time in this environment. This is the pervasive assumption in the literature on savings in low-income countries. Consider, however, a simple linear stock adjustment model incorporating a consumption-smoothing motive. Output or income Y_t in period t is a function of stocks B_t held at the beginning of the period and an i.i.d. shock ϵ_t:

(1) $Y_t = \alpha B_t + \epsilon_t , \quad \alpha > 0$.

Because of a desire to smooth consumption, farmers divest stocks when previous-period output is low and accumulate stocks when it is high, such that

(2) $B_t = \gamma_1 Y_{t-1} + \gamma_2 B_{t-1}, \ \gamma_1 > 0,$

where we also assume that stocks may exhibit serial correlation net of income.

Substituting (2) in (1) recursively, we obtain

$$(3) \quad Y_t = \alpha\gamma_1 \left[Y_{t-1} + \sum_{1}^{t-1} \gamma_2^i Y_{t-i-1} \right] + \epsilon_t .$$

Thus, if productive stocks respond positively to income realizations ($\gamma_1 > 0$) output exhibits first-order positive serial correlation even if ϵ_t is i.i.d.; second and higher-order autocorrelations will occur as a result of net stock purchases adjusting to current stocks, although these effects are smaller the higher the order of the lag. Of course, relations (1) and (2) are unlikely to be linear, but the implication of at least a first-order correlation in output is robust to functional form. Note that the prediction of a first-order positive serial correlation in output is in contrast to the negative autocorrelation implied by dynamic soil depletion models (e.g., Eckstein, 1979), although it is delivered by dynamic cost-of-adjustment models (Sargent, 1976).

We have two data sets describing the semi-arid tropics. The first provides an annual time-series of rainfall and a Laspeyres-weighted index of aggregate farm output from 1960 to 1982 from five districts in the Indian semi-arid tropics (Binswanger and Khandker, 1988). The second data set is from a longitudinal survey of ten "ICRISAT" villages located in the five districts (Singh et al., 1985). We use data from three of the villages, the three that provide complete information on assets, farm profits, and demographic characteristics for farm households over the greatest number of years, 1975-1984. Table 1 reports fixed-effects autoregressions of real output value, for lags of orders one and two, estimated from each data set. Both sets of results indicate that, net of fixed effects and of time or age trends, farm output exhibits a strong degree of positive serial correlation, although higher-order partial correlations appear to be absent--the Box-Pierce statistic applied to the residuals from the aggregate time-series data, based on 20-year lags, indicates no autocorrelation once the one-period lag in output is accounted for ($\chi^2(20)=37.7$), although net of the one-period lag the hypothesis of no autocorrelation is rejected ($\chi^2(20)=23.0$). The autocorrelation in output is not evidently the result of any correlation in rainfall. The estimated fixed-effects autocorrelations for average daily rainfall obtained from the district-level data over the 23-year period are

$$\text{(4)} \quad rain_t = \underset{(0.43)}{-.0455} \cdot rain_{t-1} \underset{(0.01)}{-.00109} \, rain_{t-2}$$

where t-ratios are in parentheses. The coefficients on lagged rainfall are neither individually nor jointly significant ($F(2,93) = 0.09$). The autocorrelation in agricultural output thus appears to reject models employing the simple permanent income framework for understanding the asset and savings behavior of farmers in credit-constrained environments.

Table 1

Fixed Effects Estimates: Tests of First- and Second-Order

Serial Correlation in Real Value of Farm Output

	Sample			
	Districts: 1960-1982[a]		Households: 1975-1984[b]	
Variable	(1)	(2)	(1)	(2)
Output (t-1)	.220 (2.22)[c]	.245 (2.30)	.297 (4.46)	.163 (1.80)
Output (t-2)	-	-.0505 (0.48)	-	.0226 (0.25)
Year	-.102 (1.85)	-.111 (1.68)	-	-
Year squared ($x10^{-3}$)	.795 (2.04)	.858 (1.85)	-	-
Age of farmer	-	-	380 (1.28)	849 (1.75)
Age squared	-	-	-1.49 (0.50)	-3.48 (0.73)
F	51.3	40.7	11.2	7.61
Number of districts	5	5	-	-
Number of farmers	-	-	94	93
Number of observations	105	100	794	604

a. Districts in which ICRISAT villages are located: Mahbubnagar, Sholapur, Akola, Sabarkantha, Raisen.

b. Farm households in ICRISAT villages with ten years of information for farmers: Aurepalle, Shirapur, Kanzara.

c. Absolute values of t-ratios in parentheses.

b. Bullock stocks

In a stationary environment with perfect capital and contingent claims markets and i.i.d. shocks, we would expect to observe income to be i.i.d. with no purchase or sale of productive assets (except for replacement) after the initial period of life. The most important production asset, land, indeed exhibits little turnover in India (Rosenzweig and Wolpin, 1985). In contrast, bullock stocks, the most critical factor of production in Indian agriculture next to land, appear to exhibit high turnover rates. Information from a national probability sample of farmers in rural India in the crop year 1970-71 indicates that only 1.5 percent of farm households sold any land while 9.5 percent sold livestock, the bulk of which were bullocks, and less than one tenth of one percent sold irrigation equipment (National Council of Applied Economic Research Additional Rural Income Survey, Third Round). Moreover, in areas in which crops were adversely affected by weather conditions, the probability that a farmer sold livestock was higher by 34 percent ($\chi^2 = 5.13$); the incidence of land sales, however, was not statistically significantly related to transitory weather conditions.

Bullock stocks in the ICRISAT villages also exhibit high turnover rates: Table 2 provides descriptive statistics for the farmers in the three villages, classified by the three farm size strata used in the ICRISAT sampling frame. As indicated in the table, for the top two land classes, over 86 percent of farmers bought or sold bullocks over the ten-year survey period, with up to almost a third of all the household-year observations for the largest land class characterized by at least one bullock purchase or sale. In contrast, less than 2.5 percent of observations were characterized by a pump purchase for any land class.

Table 2

Characteristics of Farmers, by Land Class

	Small	Medium	Large
Mean land size (hectares)	1.78	3.45	10.3
Standard deviation of land size	0.94	1.43	6.77
Mean farm profits (1983 rupees)	1431	2508	9706
Mean household food consumption (1983 rupees)	2541	2609	3772
Mean age	46.9	48.7	47.6
Mean number of bullocks owned	0.49	0.94	2.72
Percent of all sample years in which bullocks are bought or sold	14.6	22.5	32.7
Percent of farmers ever buying or selling bullocks during survey period	50.0	88.8	86.7
Percent of farmers ever owning a pump	13.8	31.0	57.1
Percent of all sample years in which a pump is purchased	1.1	2.3	2.3
Percent of farmers purchasing a pump during survey period	9.4	18.2	16.7
Number of observations (farmer-years)	264	263	261
Number of farmers	32	33	30

Source: ICRISAT Village Studies, 1975-1984: Aurepalle, Shirapur, and Kanzara villages.

The villages also do not appear to be closed economies with respect to bullock stocks, as indicated in Figure 1, which displays the movements in average bullock stocks over time for the same farmers. While bullock stocks can increase due to breeding in a closed economy, they cannot decrease except due to death, and too few deaths of bullocks occurred during the survey period to account for the downward swings in bullock stocks (all deaths are "natural" in this economy). However, some of the movements depicted in Figure 1 could reflect sampling error and bullock deaths appear to be underreported.

Figure 2 plots the average stocks of bullocks by farmer's age. In contrast to Figure 1, high-frequency fluctuations are more likely to be sampling noise; the overall pattern, however, appears to suggest that there is a life-cycle component to bullock accumulation. A simple regression of bullock stocks on a linear-quadratic function of age indicates that bullock stocks peak at age 45. In contrast to the year-to-year variability in bullock stocks, ownership of pumpsets merely exhibits an upward drift over the sample period, as shown in Figure 3. And Figure 4 suggests that pumpset ownership increases more or less linearly with age.

The ownership of bullock stocks is critical for farmers' capabilities to produce income. The importance of animal traction in Indian agriculture compared to other areas of the world is well known, and reflects the unique agroclimatic conditions of the country.[3] In particular, the monsoon economy, in which a long, hot dry period is followed by intensive rainfall, requires a substantial input of motive power in a short period of time to produce even a single crop. Moreover, the soil, hardened and dried during the non-rainy season, must be tilled in the generally short period of time between the onset of monsoon showers (which are required to render the soil

Figure 1

Movements in Average Bullock Stocks Over Time in Three ICRISAT Villages

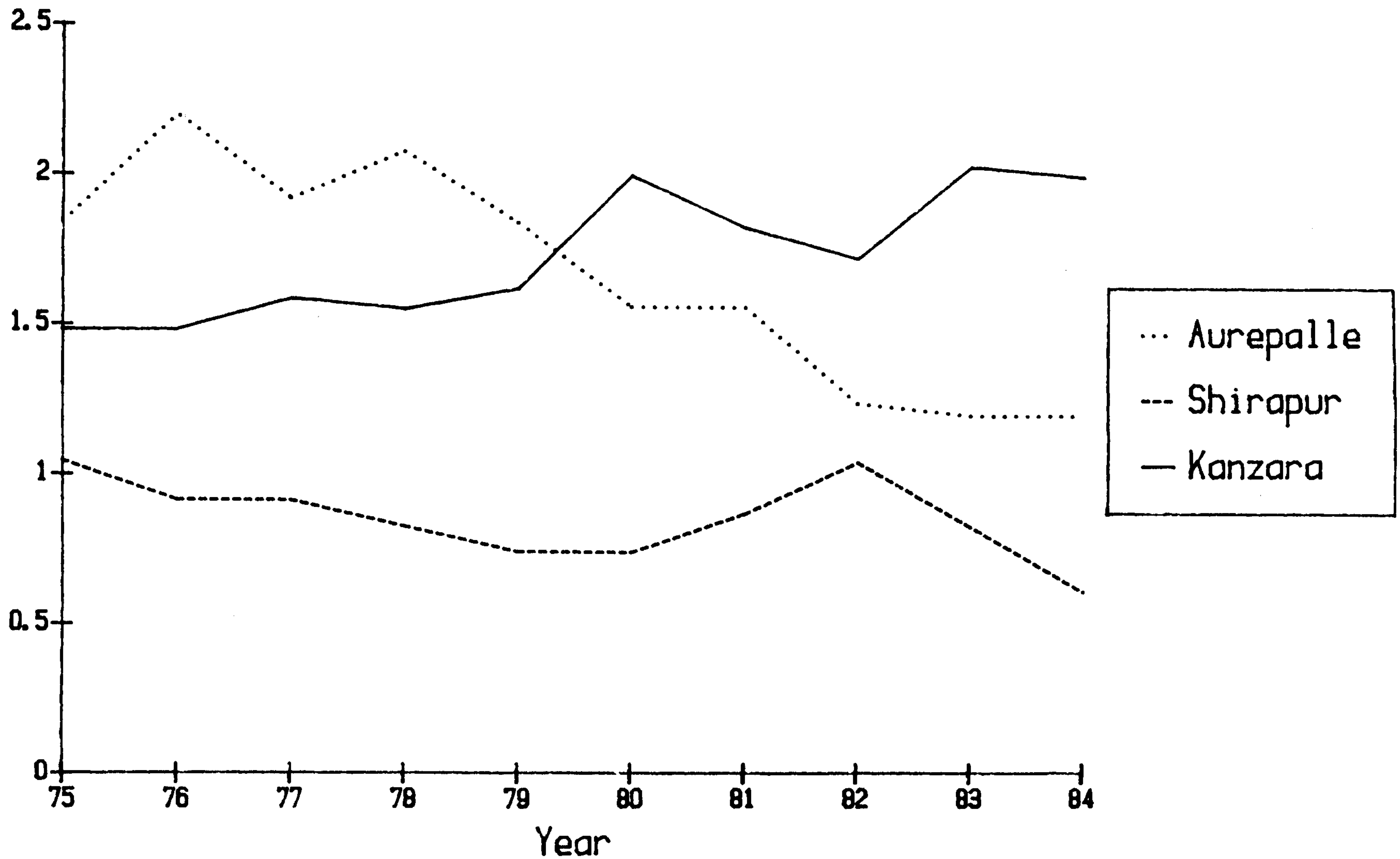


Figure 2

Average Bullock Stocks by Age of Farmer in Three ICRISAT Villages

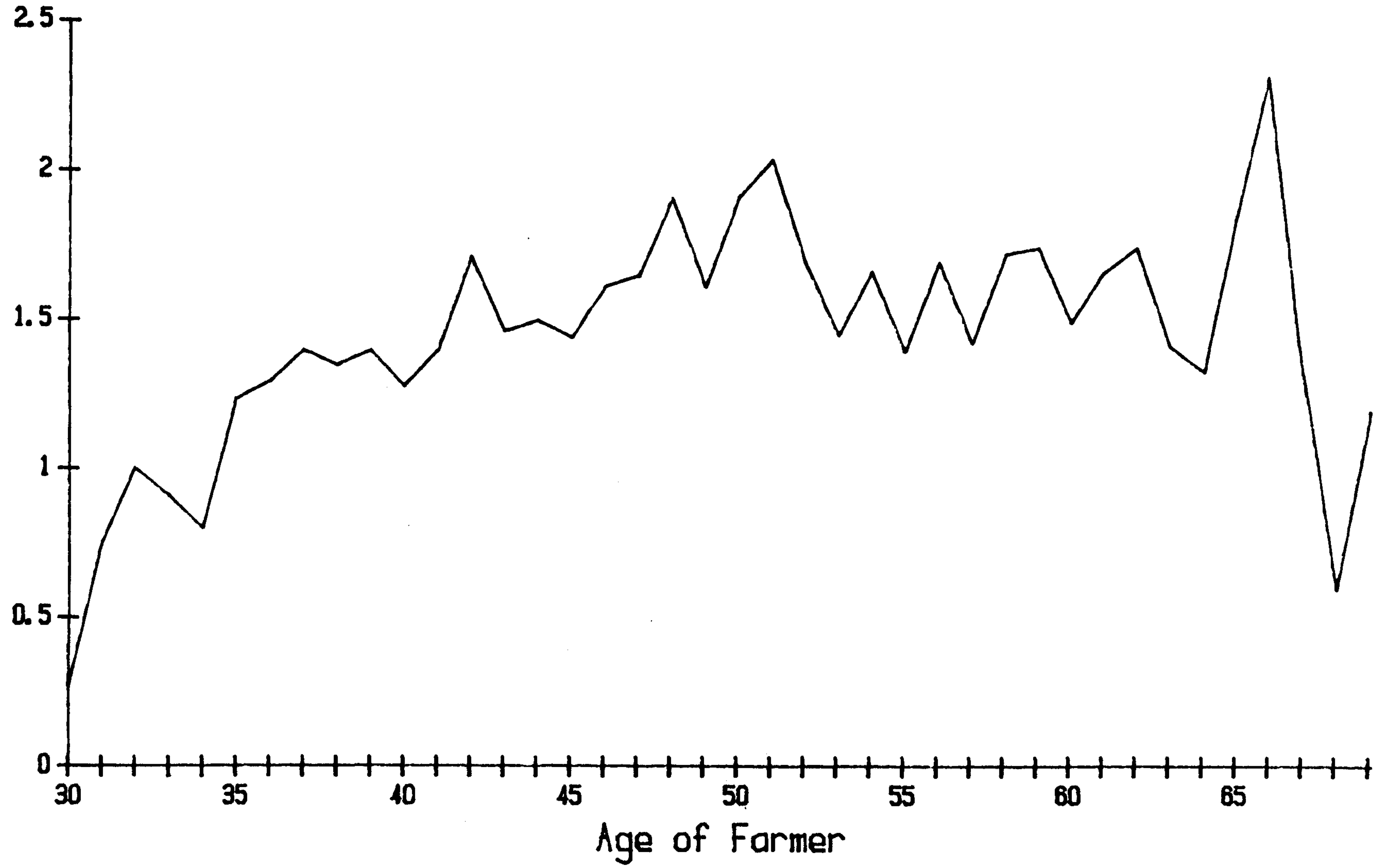


Figure 3

Proportion of Farmers with Pumpsets, by Year, in Three ICRISAT Villages

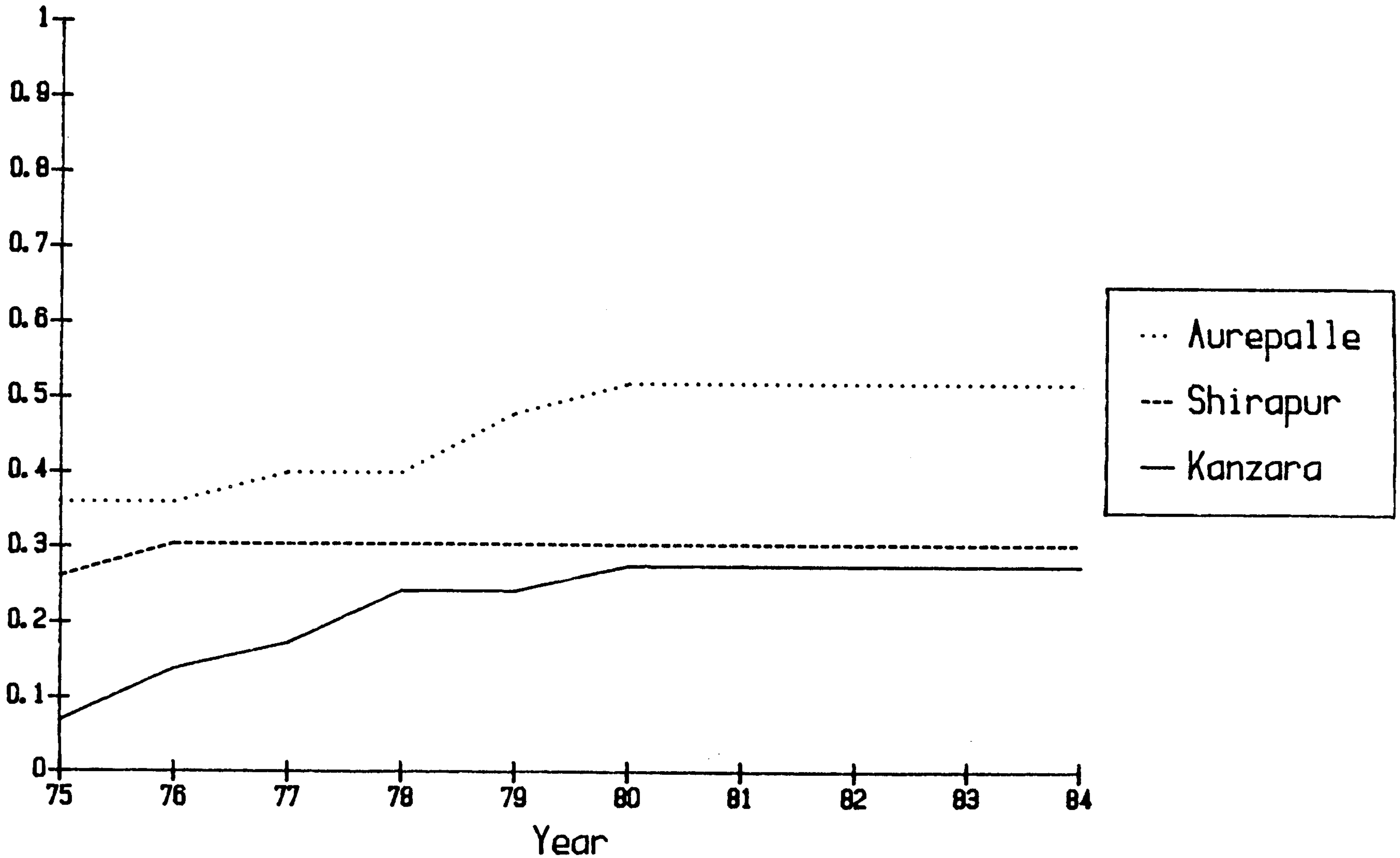
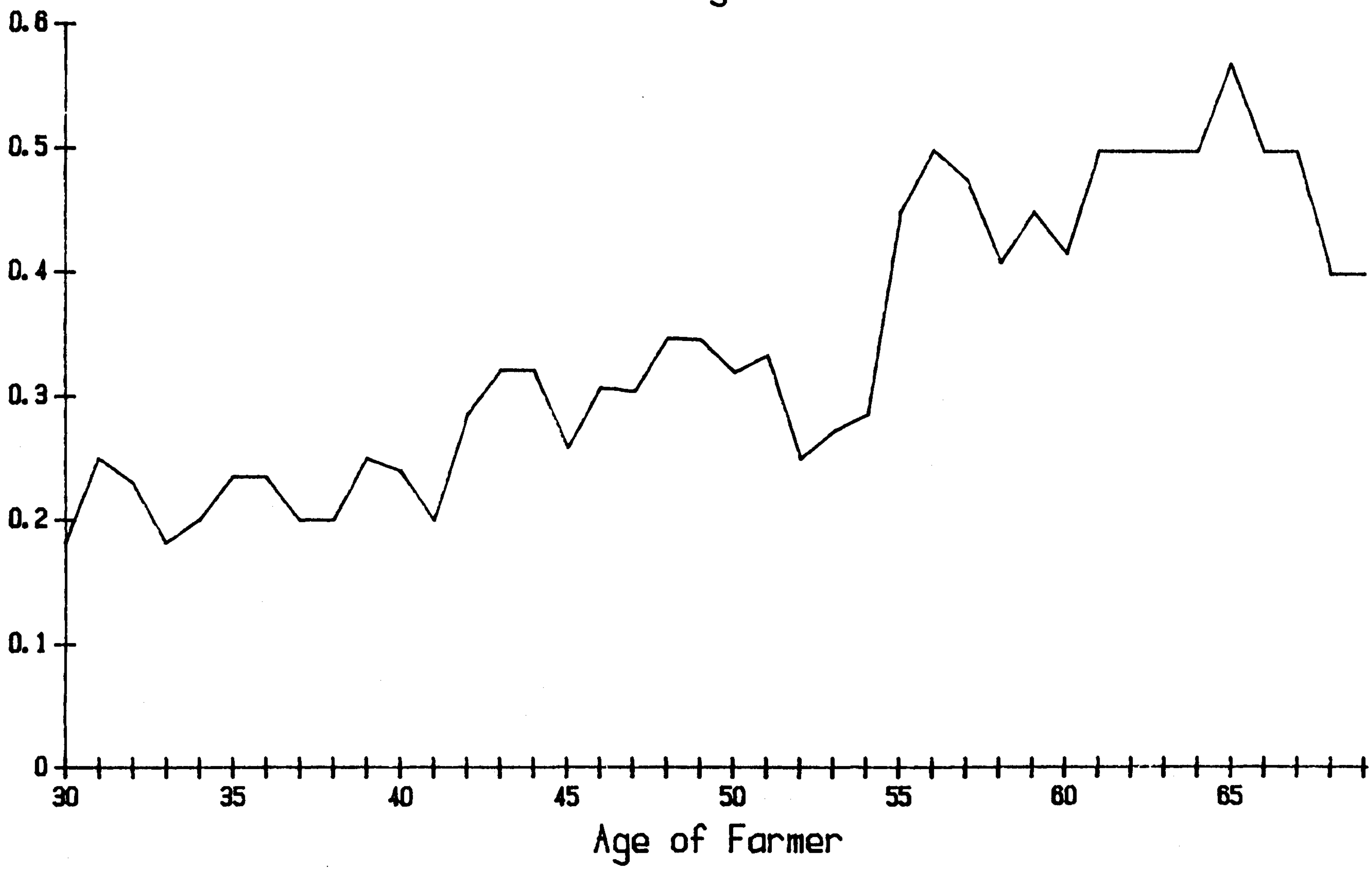


Figure 4

Proportion of Farmers Owning a Pumpset in Three ICRISAT Villages, by Age



tillable) and the optimal sowing date. Not only is the use of bullocks necessary for production in the semi-arid tropics but the uncertainty of the monsoon onset date, the short period of time during which tillage and sowing operations take place, and the high positive covariance in the timing of the demand for animal traction make it almost impossible for farmers to rely on a bullock rental market. Ownership of work animals is thus required to insure the timeliness of pre-harvest farm operations.

That there is turnover in bullock stocks does not necessarily mean that bullocks are used to smooth consumption. To see if purchases (sales) of bullocks respond positively (negatively) to income, as would appear to be implied by a consumption-smoothing model, we estimated a version of equation (2) from the ICRISAT data, in which we also incorporate information on whether the farmer owned a pump. Because of the discreteness of the bullock variable, we ordered the net purchases of bullocks into seven discrete categories, the lowest being the sale of three or more bullocks (in a year) and the highest the purchase of three or more bullocks.

The maximum-likelihood ordered probit estimates of net bullock sales are presented in the first column of Table 3. These estimates indicate that net purchases are significantly more likely to occur when income is high than when income is low, consistent with what appears to be an implication of a consumption-smoothing motive. In columns two and three of the table we confirm that not only does the probability of a purchase rise with income, but the probability of a sale declines; there is divestment when income is low. Finally, in the last column of Table 3, we report maximum-likelihood probit estimates for the purchase of pump, based on a sample of farmer-observations in which a pump is not already owned. Not surprisingly, the probability of a pump purchase rises as well with income, though there is no

Table 3

Estimates of Approximations to Farmer Decision Rules: Net Additions, Gross Additions and Divestments of Bullocks and Purchases of Pumps in Crop-Year

Variable/ Estimation Procedure	Net Additions of Bullocks Ordered Probit	Addition of Bullocks Probit	Divestment of Bullocks Probit	Purchase of Pump Probit[c]
Profits ($x10^{-4}$)	.882 (9.80)[a]	.824 (5.42)	-.645 (4.17)	.913 (2.55)
Number of bullocks at beginning of year less bullock deaths in year	-.385 (13.6)	-.246 (4.71)	.376 (7.55)	.324 (2.76)
Whether own a pump at beginning of year	-.271 (2.41)	-.272 (1.66)	.260 (1.70)	-
Small farm	-.0627 (0.41)	-.354 (1.92)	-3.50 (1.84)	.424 (0.84)
Medium farm	.0062 (0.05)	-.106 (0.63)	-.166 (1.02)	.657 (1.48)
Age of farmer	.0238 (1.01)	-.0054 (0.18)	-.0527 (1.72)	-.0385 (0.51)
Age of farmer squared ($x10^{-3}$)	-.230 (1.01)	.0723 (0.24)	.524 (1.79)	.112 (0.14)
χ^2(d.f.)[b]	123.8(9)	48.6(9)	107.9(9)	39.1(8)
n	788	788	788	545

a. Absolute values of asymptotic t-ratios in parentheses in column.

b. Specification includes three dummy variables corresponding to villages in sample.

c. Sample of farmers without a pump.

divestment.

The results in Table 3 also indicate that the current level of own stocks, net of income, influence negatively the probability of a subsequent purchase, a result which suggests that there is some targeting of stock levels. Clearly to understand more fully bullock investment behavior, more than just the ad hoc "model" of equations (1) through (3) is required, at the very least because the determination of income needs to be modeled, inclusive of the technology of production and the value (cost) of the assets.

2. The Structural Model and Estimation Strategy

a. The model

To understand more fully the dynamics of bullock stock adjustment behavior we formulate a structural dynamic model. There are a number of salient features of the agricultural environment that we incorporate. The most important elements of the model are: (i) farmers wish to smooth their consumption, (ii) bullocks contribute to agricultural output and income, (iii) output and income are stochastic, resulting from the existence of both farmer-specific and aggregate (weather) shocks, and (iv) bullocks can be purchased and sold. The partiability of inheritance in the Indian context, in which the death of the household head results in the transfer of a share of family assets to each male heir, each of whom subsequently resides in a separate household, also suggests that a finite-horizon model is relevant, although one incorporating a bequest motive. The finiteness of life is one possible reason why bullock stocks exhibit an age-pattern, as seen in Figure 2. However, we also incorporate in the model the possibility that agricultural productivity depends on farmer age, reflecting the returns to farming experience (Rosenzweig and Wolpin, 1985).

The farmer is assumed to maximize the present value of expected lifetime utility over a finite horizon inclusive of bequests. Utility at any age t, $u(C_t-C_{min})$, depends on the consumption of a single non-storable aggregate commodity, C_t, above minimum subsistence consumption, C_{min}. The farmer owns a fixed amount of land, A, which can neither be divested nor added to, but can accumulate animals used in production (bullocks) through purchases and/or via self-production. The farmer can also purchase a pump for crop production, which, unlike bullocks, has no resale value. The utility from bequests at the last age, $\beta(A,B_{T+1}+n_{T+1}+n_T+n_{T-1},M_{T+1})$, depends on land owned (which is automatically transferred), the sum of the stock of adult bullocks, B_{T+1}, and of young bullocks (calves) at each of their first three years of life, where n_{T+1} is a newborn calf, n_T is a one-year old, and n_{T-1} a two-year old, and on the ownership of a pump, M_{T+1}. Bullocks, calves and pumps are the only intergenerationally transferable assets which are within the farmer's choice set, because there is no land market. The farmer therefore maximizes

$$(5) \quad E_0 \sum_{t=0}^{T} \delta^t u(C_t-C_{min}) + \beta(B_{T+1} + \sum_{j=T-1}^{T+1} n_j,\ M_{T+1})$$

where E_0 is the expectations operator given the information set at the age of inheritance, and δ is the subjective discount factor.

The farmer's income is derived from crop production, which is a two-stage process which we denote as planting and harvesting. In the planting stage, the stock of bullocks (including net purchases from previous-period profits) and the fixed amount of land are combined with variable inputs such as seeds, fertilizers, and labor. The crop available for harvesting, i.e., the potential yield from the planting stage, depends as well on the realization of a stochastic shock. The harvesting stage uses only variable inputs, primarily labor. All variable inputs are paid out of current period profits. We assume that variable planting input decisions are made prior to the realization of the shock, while harvest input decisions occur after the realization.

Farm profits at t are thus given by

$$(6) \quad \Pi_t = p_t^y Y_t(B_t, M_t, A, \underset{\sim}{Z}_t{}^p, \underset{\sim}{Z}_t{}^h, v_t) - \Sigma \underset{\sim}{p}_t{}^z \underset{\sim}{Z}_t - mB_t$$

where $B_t \epsilon \{0,1,\ldots,\bar{B}\}$ is the adult bullock stock, $M_t \epsilon \{0,1\}$ is the ownership of a pump, A is land size, $\underset{\sim}{Z}_t{}^p$ and $\underset{\sim}{Z}_t{}^h$ are variable input vectors used in the planting and harvesting stages respectively, m is the maintenance cost per bullock, v_t is the random shock to production, composed of a farmer-specific shock and an independent shock common to all farmers in an environment, p_t^y is the product price, and $\underset{\sim}{p}_t{}^z$ is the vector of variable input prices. We subscript the production function to allow for the possibility that farm productivity is age-dependent.

While the farmer can accumulate and divest assets (bullocks), we assume that he cannot borrow. Any intertemporal stochastic consumption model with borrowing constraints must deal with the problem that income may fall short of minimum consumption even when all assets have been divested. This is particularly true in our case because agricultural profits are not infrequently very low; ten percent of the farmer-year observations among small- and medium-size farmers in our sample are characterized by profits of 200 rupees or less. We employ the assumption that the farmer must sell his animals to maintain minimum consumption in each period. If minimum consumption cannot be achieved with full divestiture, then we assume that consumption equals minimum consumption. Thus, we assume that the farmer has a form of disaster insurance. One example is transfers from non-resident family members, which have been shown to be important in the environment we are studying (Rosenzweig, 1988; Rosenzweig and Stark, 1989; Caldwell et al., 1986) and in other low-income environments (Lucas and Stark, 1985).

Because we assume that there are no opportunities to borrow and the only asset that can be sold is bullocks, consumption must equal farm profits net of the purchase or sale of adult bullocks, the purchase cost of a pump if one is purchased, and the breeding cost of a calf if one is bred as long as the consumption minimum is met. That is,

$$(7)\quad C_t = \Pi_t - p^b b_{t+1} - p^m m_{t+1} - c n_{t+1} \geq C_{min}$$

$$C_t = C_{min} \text{ if } \Pi_t + p^b B_t \leq C_{min} ,$$

where p^b, p^m, and c are the real price of an adult bullock, the real price of a pump, and the real cost of breeding respectively; b_{t+1} is the net number of adult bullocks purchased, with $neg(b_{t+1}) \leq B_t$ if $b_{t+1} < 0$; m_{t+1} indicates the purchase of a pump, and n_{t+1} indicates the breeding of a calf. Although bullocks and/or pump transactions as well as breeding take place at t, they have no effect on profits and thus decisions until t+1, which accounts for the subscript convention in (7).

The bullock stock evolves according to

$$(8)\quad B_t = B_{t-1} + b_t + n_{t-3} - d_{t-1}.$$

The bullock stock at t equals the stock in the previous period plus net purchases and the number of calves born three periods before less bullock deaths during the period. For simplicity, we assume that only one birth and only one death can occur in any period regardless of the size of the bullock stock. The probability that an adult bullock dies is q_d. The equation of motion for pump ownership is

(9) $M_t = M_{t-1} + m_t$

where M_t, $m_t = \{0,1\}$ and $m_t = 0$ if $M_{t-1} = 1$. Thus, only one pump can be purchased and owned.

At the end of period t the farmer must decide, prior to the realization of next period's production shock v_{t+1}, how many bullocks to buy or sell (b_{t+1}), whether or not to breed a bullock (to be born in the next period, n_{t+1}), whether or not to buy a pump (if one is not already owned, m_{t+1}) and how much of each planting variable input $\underset{\sim}{Z}^p_{t+1}$ to purchase. After the realization of the shock, variable harvest inputs $\underset{\sim}{Z}^h_{t+1}$ are purchased. Solving the optimization problem described above for all of these choice variables is not tractable in the context of estimation, i.e., where the problem must be solved repeatedly at alternative parameter values. If there were no planting-stage (pre-shock) variable inputs, then variable input decisions could be separated out from the dynamic problem, because post-shock harvesting inputs would be allocated to maximize single-period profits. A (restricted) profit function conditional on stocks held at the beginning of the period could then be estimated to retrieve the technology parameters. It is sufficient for separability that planting variable inputs are used in fixed proportions to the fixed input land and/or to the predetermined inputs (bullocks, pump). We also assume that all variable input prices and the product price are completely determined by an average village-level output shock (contained in v in equation (6)). Thus there is uncertainty, of a particular form, about output, variable input prices and product price. The restricted or conditional profit function, under these assumptions, takes the form

$$(10) \quad \Pi_t = \Pi_t(B_t, M_t, L, w_t+\epsilon_t)$$

where $v_t = w_t+\epsilon_t$ is decomposed into village-level (weather, w_t) and farmer-level time-varying (ϵ_t) shocks.

The optimization problem can be solved numerically by backwards recursion using Bellman's equation. Specifically, expected lifetime utility is given by

$$(11) \quad V_t(B_t, d_t, M_t, n_t, n_{t-1}, n_{t-2}, w_t, \epsilon_t)$$

$$= \max_{\{b_{t+1}, n_{t+1}, m_{t+1}\}} \left\{ u(\Pi_t(B_t, M_t, L, w_t, \epsilon_t) - p^b b_{t+1} - p^m m_{t+1} - cn_{t+1}) + \delta E\max\{V_{t+1}(B_t+b_{t+1}+n_{t-2}-d_t,\ d_{t+1},\ M_t+m_{t+1}, n_{t+1}, n_t, n_{t-1}, w_{t+1}, \epsilon_{t+1})\} \right\}$$

$$\text{if } t < T$$

$$V_T(B_T, d_T, M_T, n_T, n_{T-1}, n_{T-2}, w_T, \epsilon_T)$$

$$= \max_{\{b_{T+1}, n_{T+1}, m_{T+1}\}} \left\{ u(\Pi_T(B_T, M_T, L, w_T, \epsilon_T) - p^b b_{T+1} - p^m M_{T+1} - cn_{T+1}) + \beta(B_T+b_{T+1}+n_{T-2}-d_T,\ n_{T+1}, n_T, n_{T-1}, M_T+m_{T+1}) \right\}.$$

The expectations operator in (11) is taken over the joint distribution of d, w and ϵ which is known by the farmer.

Implementation of the model for estimation requires the specification of functional forms for the utility function, the bequest function and the profit function, and assumptions about the joint density of d, w and ϵ. The per-period utility function is assumed to be of the constant relative risk aversion type, namely

$$(12) \quad u(C_t) = \frac{1}{1-\gamma} (C_t - C_{min})^{1-\gamma}$$

where γ is the relative risk aversion parameter. The bequest function is assumed to depend on expected profits of the next generation in its first period after inheritance plus bullock wealth,

$$(13) \quad \beta(\cdot) = (E(\Pi_{T+1} | C > C_{min}) + p_t^b B_{T+1})^{\alpha}.$$

The profit function for a given land class is

$$(14) \quad \Pi_t = \Pi_0 + \sum_{j=0}^{\bar{B}} \Pi_{1j} D_{tj} + \Pi_2 M_t + \sum_{j=0}^{\bar{B}} \Pi_{3j} D_{tj} M_t + \Pi_4 w_t + \epsilon_t,$$

where $D_{tj} = 1$ if the stock of bullocks at time t is j and zero otherwise. Weather is assumed for tractability to be described by a serially uncorrelated two-point distribution; bad weather occurs with probability q_w and good weather with probability $1-q_w$. Weather and bullock mortality are independently distributed from each other and from the idiosyncratic shock, ϵ. The latter is assumed to be i.i.d. normal with mean zero and variance σ_{ϵ}^2.

Although w_t, d_t, and ϵ_t are all random variables, only ϵ_t is assumed to be unobservable to the researcher. The solution of the model yields a vector of critical values of ϵ at each t which divides the real line into regions within which particular choices are optimal for each set of values of the state space. These critical values form the basis of the estimation.

The solution method is similar to that described in Wolpin (1984).

b. The likelihood function

The assumption of quasi-separability permits us to follow a two-step estimation procedure; we first estimate the conditional or restricted profit function parameters and then estimate the remaining parameters of the optimization model. As a consequence, we can estimate the flexible form of the profit function given by (14), which is not parsimonious in parameters. We treat γ, C_{min}, the profit variance, the breeding price, and the pump price as estimable parameters. Although we obtain an estimate of the profit variance from the profit function estimates, we assume that profits are measured with error.

What we observe for an individual farmer is a sequence of pump and bullock stocks beginning at some initial age, the age distribution of calves at the farmer's initial age, a sequence of bullock deaths and a sequence of weather states. In addition, we (and the farmers) are assumed to know q_d, q_w, and p^b. The bullock price is treated as data because we have a more reliable estimate of its value than we do for the pump price or the breeding cost both of which we estimate as parameters. Regressions of the actual village-level prices of bullocks on weather outcomes indicated that there was no statistically significant association between village-level weather shocks, obtained from the profit function estimates described below, and bullock prices. The bullock price is thus fixed at its sample mean value (in 1983 rupees), at 992 rupees.

Because we do not have reliable data on breeding subsequent to the initial age, we need to calculate the following probability statement for each farmer:

(15) $\Pr(B_1, M_1, B_2, M_2, \ldots, B_\tau, M_\tau | B_0, M_0, n_0, n_{-1}, n_{-2})$

$$= \sum_{n_1} \sum_{n_2} \ldots \sum_{n_\tau} P_r(B_1, M_1, n_1, B_2, M_2, n_2, \ldots, B_\tau M_\tau, n_\tau | b_0, M_0, n_0, n_{-1}, n_{-2})$$

where the zero subscript refers to the initial age, and τ is the number of years of data available for the farmer. It should be noted that the initial age is not necessarily the first age at which the farmer is a decision-maker. Thus, the initial condition is not exogenous. However, because of the i.i.d. assumption concerning ϵ_t, the initial condition is statistically independent of future decisions. If ϵ_t was serially correlated or there was farmer-specific unobserved heterogeneity, the estimation method would require modification.

Equation (15) can be rewritten as a product of conditional probabilities, namely as

(16)
$$\sum_{n_1} \ldots \sum_{n_\tau} P_r(B_\tau, M_\tau, n_\tau | B_{\tau-1}, M_{\tau-1}, n_{\tau-2}, n_{\tau-3})$$
$$\cdot \Pr(B_{\tau-1}, M_{\tau-1}, n_{\tau-1} | B_{\tau-2}, M_{\tau-2}, n_{\tau-2}, n_{\tau-3}, n_{\tau-4})$$
$$\ldots\ldots \Pr(B_1, M_1, n_1 | B_0, M_0, n_0, n_{-1}, n_{-2}).$$

Each of these conditional probabilities depends on the cutoff values of the ϵ's derived from the dynamic program, which are themselves functions of the parameters we wish to estimate. Thus, the likelihood function over I farmers is

(17) $L(\gamma, C_{min}, \sigma_\Pi^2, p^m, c | \text{data})$

$$\prod_{i=1}^{I} \sum_{n_1} \ldots \sum_{n_{\tau_i}} P_r(B_1, M_1, n_1, \ldots, B_{\tau_i}, M_{\tau_i}, n_{\tau_i} | B_0, M_0, n_0, n_{-1}, n_{-2}).$$

Maximum likelihood estimates are obtained by iterating between the dynamic program which solves for the cutoffs and the likelihood maximization routine.

3. Results

a. Parameter estimates

As discussed above, we follow a two-step estimation strategy as a means of reducing the scale of the estimation problem. The first-step profit function estimates corresponding to equation (14) are presented in Table 4 for each of three land classes defined in the ICRISAT data set. The first-column estimates for each land class are within-village estimates that include year dummies. The second column reports a restricted version that combines year effects into a dichotomous variable representing good and bad weather states (see notes to Table 4) and that combines village effects when statistically appropriate. In addition to the profit determinants shown in equation (14) the age of the farmer is included to capture age-related changes in productivity.

The estimates in Table 4 provide information on the profit-maximizing level of bullocks and pump ownership status. With respect to the latter, it is clearly optimal in all land classes to own a pump regardless of the size of the bullock stock. For example, a medium size farmer would augment annual profits by 2122 rupees by purchasing and installing a pump, an 85 percent increase at the mean profit level. Despite this high return, as seen in Table 2 only 31 percent of the families in this land class ever owned a pump, and over the ten-year period only 18 percent purchased a pump.

The profit-maximizing level of bullocks varies by land size. For small-size farmers it is optimal to own two bullocks if the farmer does not own a pump and one bullock if the farmer does own a pump. For medium-size

Table 4

Profit Function Parameter Estimates by Land Class

	Small		Medium		Large[c]	
	Fixed-Effects Village and Year	Restricted[a]	Fixed-Effects Village and Year	Restricted[b]	Fixed-Effects Village and Year	Restricted[d]
Number of bullocks owned						
1	590	609	668	680	-416	-145
	(1.84)	(1.98)	(1.10)	(1.20)	(0.15)	(0.06)
2	1757	1692	-	-	2132	2349
	(7.16)	(7.31)			(1.49)	(1.87)
2 or more	f	f	1656	1838	-	-
			(4.54)	(6.06)		
3	f	f	f	f	1242	1230
					(0.68)	(0.74)
4	f	f	f	f	1993	1914
					(0.74)	(0.78)
Pump	1786	1677	1825	2122	2474	2557
	(4.02)[e]	(3.83)	(3.27)	(6.18)	(1.16)	(1.85)
Number of bullocks x pump						
1	1781	2061	f	f	1993	1914
	(2.45)	(2.95)			(0.21)	(0.27)
2	132	356	f	f	2245	1984
	(0.22)	(0.63)			(1.10)	(1.05)
2 or more	-	-	492	-	-	-
			(0.66)			
3	f	f	f	f	5351	5862
					(1.47)	(1.79)
4	f	f	f	f	10433	10317
					(2.60)	(2.84)
Farmer's age	1.68	30.1	105	97.7	1188	1139
	(0.03)	(0.58)	(1.76)	(1.70)	(2.54)	(2.60)
Farmer's age squared	.0911	-.157	-1.13	-1.07	-14.0	-13.5
	(0.18)	(0.31)	(2.45)	(1.99)	(2.65)	(2.72)
Bad year	-	-761	-	-1294	-	-1433
		(3.72)		(4.30)		(1.46)
Aurepalle village	-	-1036	-	-	-	-
		(5.99)				
Constant	-	160	-	-365	-	-19745
		(0.12)		(0.24)		(2.12)
R^2	.564	.507	.395	.335	.569	.559
F	8.72	30.9	4.45	22.4	4.22	7.59
Total parameters	36	9	35	6	20	12
Degrees of freedom	243	270	238	267	64	72

a. Year effects are combined to form a dichotomous variable representing "good" and "bad" profit years based on the year-effect estimates. Bad years were 1980 and 1981 for Aurepalle; 1977 for Shirapur, and 1980 and 1982 for Kanzara. The hypothesis that the good-bad differential in profits was identical across villages was not rejected. Profit levels, net of stocks, were statistically significantly lower in Aurepalle village, however.

b. Year effects are treated similarly as described in (a) above. Bad years were 1975, 1976, 1980 and 1981 for Aurepalle; 1977, 1978 and 1983 for Shirapur, and 1977, 1978 and 1979 for Kanzara. The joint hypothesis that the good-bad profit differential and profit levels, net of stocks, were identical across villages was not rejected. Therefore, the restricted model includes no village-specific effects.

c. Sample includes only large farms in Shirapur village.

d. Year effects were treated similarly as in (a) above. In 1980 profits, net of stocks, were significantly lower.

e. Absolute value of t-ratios in parentheses.

f. No observations in cell.

farmers it is optimal to own two bullocks and for large farmers four bullocks, in each case regardless of pump ownership. As seen in Table 2, however, the average number of bullocks owned is only 0.49 for small farmers, 0.94 for medium farmers and 2.72 for large farmers, all of which fall substantially short of the respective profit-maximizing levels. Note also that the existence of substantial returns to bullock ownership is consistent with the conventional wisdom that the bullock rental market, a market we assume to be absent in estimating the full dynamic model, cannot adequately provide farmers with animal traction when they most need it.

The effect of bad weather on profits is 761 rupees for small-size farmers, 1294 rupees for medium-size farmers, and 1433 for large-size farmers. The profit loss in bad weather is particularly large for the small- and medium-size farmers relative to average profits. Table 4 also reveals a statistically discernible age-pattern in profits for medium- and large-size farmers. In both cases profits first rise with age, peak at approximately age 45, and then decline. Although we stress an uncertainty motive for savings, the existence of a profit-age relationship reveals the potential for a life-cycle smoothing motive as well. Our model incorporates both motives.

Given the estimated profit function parameters, the rest of the model's parameters can be estimated using the bullock and pump data as described in the previous section. It is important to note that the estimation procedure requires that the dynamic program be solved separately for farmers whose returns to investments or whose prospects of weather shocks differ. To minimize the computational burden, we estimated the remaining parameters of the model only using observations on medium-size farmers. As shown in Table 2, medium-size farmers are the most homogenous in actual land size so that the marginal profitability of an additional bullock and of pump ownership is least likely for this group to reflect unmeasured land- size effects. Moreover, village effects are completely absent for the medium-size group. Indeed, for the large-size group not only do average profits net of inputs differ across the three villages but bad weather effects also differ by village. For this reason we obtained and reported in Table 4 profit function estimates for only a single village (Shirapur), the one with the least land size variation within the large-size farms. However, even if large farmers were homogeneous, we believe the model may not be as appropriate to this relatively wealthy class of farmers, who appear to exhibit less risk-averse behavior (Rosenzweig and Binswanger, 1989). We test this hypothesis below. The cost of restricting the estimation to the class of medium-size farmers in the three villages is reduced sample size and a concomitant loss in estimation precision. An offsetting advantage is the ability to perform extra-sample tests of the model with the small- and large-farm class data.

An important limitation of the data is that we could not estimate profits for all possible combinations of bullocks for each land class. For the middle-level farmers, in particular, in only two periods were any farmers holding as many as three bullocks and none were holding four or more. It was thus not possible to determine with any precision the profit consequences of holding more than two bullocks for these farmers. Because in each period the farmer must consider all feasible alternatives and their consequences, the absence of information on the profitability of owning more than two bullocks

led us to restrict $\bar{B}$ to be two. Thus, farmers were assumed to place a zero probability of owning more than two bullocks and, of course, could not hold more than two. To ascertain if this restriction had serious consequences for our estimates, we searched for the minimum reduction in profits that would make the probability of actually holding three bullocks zero if farmers were free to do so, given our parameter estimates. We found that this amount was 600 rupees, which corresponds closely to the average annual maintenance costs of a bullock. We do not think, therefore, that this restriction importantly affects our results (recall that medium-size farmers on average hold less than one bullock).

Table 5 reports the maximum-likelihood estimates of the preference function, price and profit variance parameters. The relative risk aversion parameter is estimated to be 0.90 which implies that there exists a strong motive for consumption smoothing among these farmers. The estimated consumption minimum is 2584 rupees which appears somewhat high relative both to average profits and average food consumption as shown in Table 2. It is noteworthy, however, that average food consumption is almost identical in small- and medium-size farm households, which is consistent with a high consumption floor. The price of a pump is estimated to be 6007 rupees and the breeding price 717 rupees. The estimated standard deviation in profits (net of weather effects) is 2267 rupees which is almost identical to the regression estimate, implying that profits are measured quite accurately.

b. Tests of fit

To assess the validity of the model we performed a number of goodness-of-fit tests both for the sample of medium-size farmers from which the estimates were obtained and the small- and large-size farmers who are presumed to face the same markets and to have the same preferences. Table 6 provides chi-square goodness-of-fit statistics for medium-size farmers by year based on the actual stock of bullocks owned in the previous year. As

Table 5

Maximum Likelihood Estimates[a]

Parameter	γ	C_{min}	c^b	p^M	$\sigma_\pi{}^c$
Estimate	.904	2584	717	6007	2267

a. The discount factor δ is set at .95. The probability of bad weather q_w is .3, the probability of bullock mortality is .15, and the purchase (and sale) price of a bullock is 992 rupees (1983 rupees), the sample average over all bullock transactions.

b. The breeding price was constrained to be less than the price of an adult bullock.

c. The profit variance was constrained to be less than the estimate obtained from the regression function reported in Table 4, 2269.

Table 6

Within-Sample Goodness-of-Fit Tests: Distribution of Medium-Size Farms by Year and Bullock Stock[a]

Year	No Bullocks		One Bullock		Two Bullocks		χ^{2b}
	Actual	Predicted	Actual	Predicted	Actual	Predicted	
76	14	14	1	2.7	9	7.3	1.42
77	13	13.6	3	2.5	8	7.9	0.14
78	11	14.2	1	2.4	12	7.4	4.41
79	13	12.9	1	2.3	10	8.9	0.84
80	11	11.7	3	2.5	10	9.9	0.16
81	12	11.3	2	3.0	10	9.7	0.37
82	11	11.7	2	2.7	11	9.6	0.44
83	12	10.5	3	2.8	9	10.6	0.47
84	14	12.9	1	2.8	9	8.4	1.27

a. Sample includes only farmers with ten years of information; n=216.

b. $\chi^2(2)=5.99$ at .05 significance level.

seen in that table although there is a tendency to underpredict the ownership of two bullocks and overpredict the absence of any bullocks, none of the chi-square statistics exceed the critical value at the five percent level. We cannot reject, for any year, the hypothesis that the distribution of bullock stocks predicted by our model is identical to the actual distribution.

A more stringent within-sample test is provided in Table 7. In that table predicted bullock stocks in all years are based only on information on the initial (1975) stock. Although the fit is generally worse than that obtained using period-by-period information, as expected, in only one year does the chi-square statistic imply rejection of the model. However, a model which predicted that bullock stocks would not change over time generally has lower chi-square statistics. The data do not contain enough year-to-year variation in bullock stocks to distinguish between models which predict (realistically) only small year to year changes.

Another test is to examine the conformity of the predicted age pattern of bullock stocks to the actual pattern. The actual life-cycle pattern of bullock ownership, as already discussed, has approximately an inverted u-shape. As Table 8 shows, the predicted pattern has a similar shape. However, the number of farmers owning two bullocks is severely underestimated for the 31-40 and 41-50 age groups,with the associated chi-square statistics exceeding the critical value.

The extra-sample goodness-of-fit tests using the small-size farmers are shown in Tables 9 and 10 based on actual lagged and initial (1975) bullock stocks respectively. In the former, the fit test rejects the model in only two of the years, while in the latter rejection occurs in six of the years, with the fit much worse in the later years. To ascertain if the model

Table 7

Within-Sample Goodness-of-Fit Tests Based on Initial Stocks Only:

Distribution of Medium-Size Farms by Year and Bullock Stock[a]

Year	No Bullocks		One Bullock		Two Bullocks		χ^{2b}
	Actual	Predicted	Actual	Predicted	Actual	Predicted	
75(initial stocks)	15	-	1	-	8	-	
76	14	13.8	1	2.8	9	7.4	1.5
77	13	14.1	3	2.8	8	7.1	0.21
78	11	15.3	1	2.5	12	6.1	7.7
79	13	15.9	1	2.4	10	5.7	4.6
80	11	13.7	3	2.6	10	7.6	1.4
81	12	13.6	2	2.5	10	7.9	0.86
82	11	13.3	2	2.6	11	8.1	1.6
83	12	12.5	3	2.5	9	9.0	0.13
84	14	13.8	1	2.4	9	7.8	0.46

a. Sample includes only farmers with ten years of information; n=216.

b. $\chi^2(2)=5.99$ at .05 significance level.

Table 8

Within-Sample Goodness-of-Fit Tests Based on 1975 Initial Stocks Only:

Distribution of Medium-Size Farms by Age-Group and Bullock Stock[a]

Age Group	No Bullocks Actual	No Bullocks Predicted	One Bullock Actual	One Bullock Predicted	Two Bullocks Actual	Two Bullocks Predicted	χ^2 [b]
21-30	14 (.67)[b]	14.7 (.70)	1 (.05)	2.1 (.10)	6 (.28)	4.1 (.20)	1.5
31-40	14 (.45)	18.1 (.55)	0 (.00)	3.7 (.12)	17 (.55)	9.1 (.29)	11.4
41-50	27 (.38)	38.3 (.52)	4 (.05)	8.1 (.11)	42 (.58)	26.6 (.36)	14.2
51-60	37 (.66)	35.4 (.63)	6 (.11)	6.2 (.11)	13 (.23)	14.3 (.26)	0.19
61-70	19 (.54)	19.6 (.56)	6 (.17)	2.9 (.08)	10 (.29)	12.5 (.36)	3.19

a. Sample includes only farmers with ten years of information; n=216.

b. Proportion of farms in category in parentheses.

Table 9

Extra-Sample Goodness-of-Fit Tests: Distribution of Small-Size Farms by Year and Bullock Stock

Year	No Bullocks		One Bullock		Two Bullocks		χ^{2a}
	Actual	Predicted	Actual	Predicted	Actual	Predicted	
76	22	22.9	3	3.4	4	2.6	0.20
77	23	24.1	1	3.9	5	1.0	0.30
78	23	24.0	0	3.5	6	1.5	0.24
79	21	23.2	3	4.1	5	1.6	1.14
80	16	21.7	5	3.5	6	1.7	7.97
81	15	21.0	4	3.7	8	2.3	7.71
82	16	17.1	6	4.7	4	4.2	0.21
83	15	19	6	3.5	5	3.5	3.13
84	18	17.8	1	3.5	7	4.7	0.01

a. One and two-bullock categories aggregated to compute the test statistics. Critical $\chi^2(1)=3.84$ at .05 significance level.

Table 10

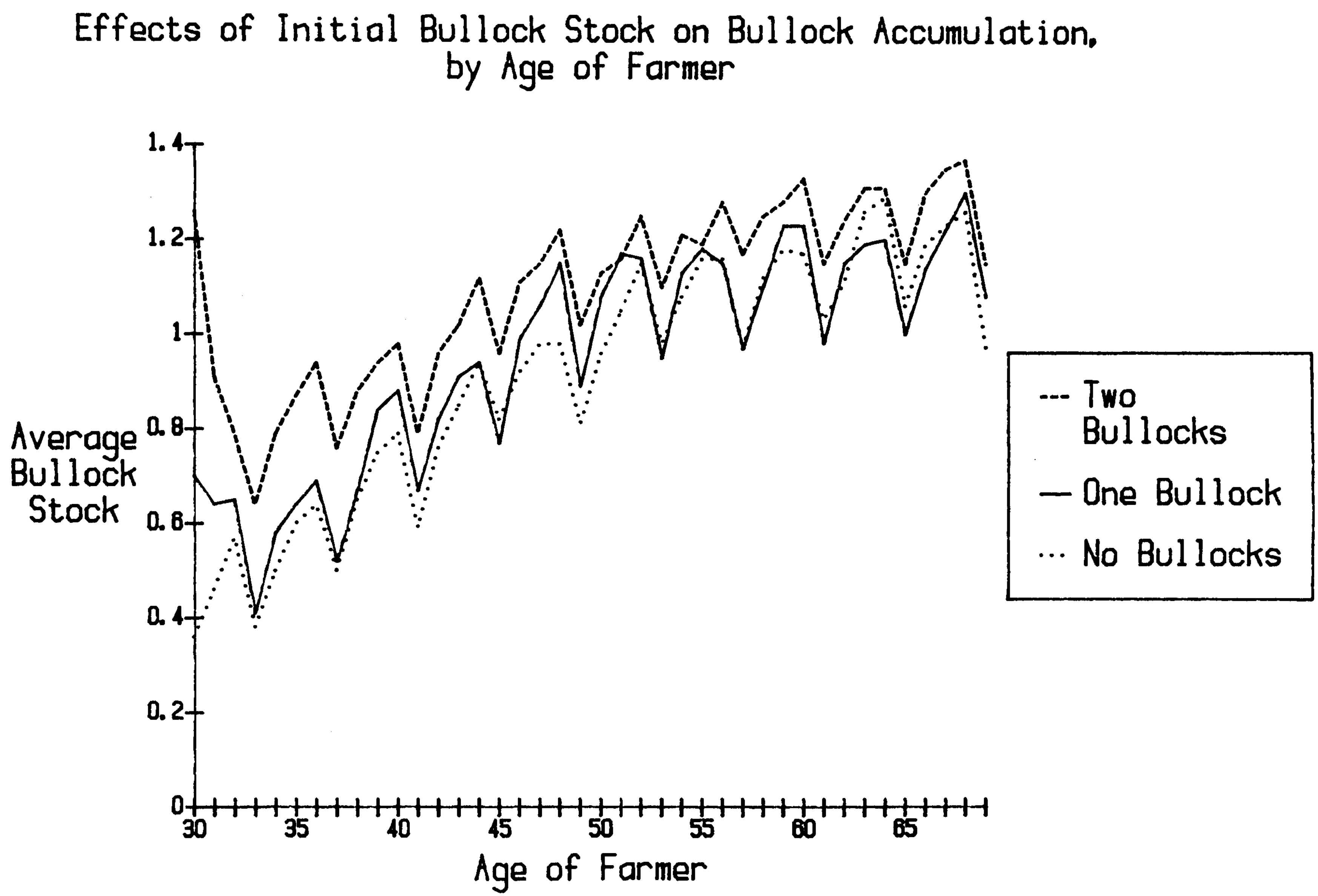
Extra-Sample Goodness-of-Fit Tests Based on 1975 Initial Stocks Only:

Distribution of Small-Size Farms by Year and Bullock Stock

Year	No Bullocks		One Bullock		Two Bullocks		χ^{2a}
	Actual	Predicted	Actual	Predicted	Actual	Predicted	
75(initial)	23	-	1	-	5	-	-
76	22	23.0	3	3.5	4	2.6	0.18
77	23	24.0	1	3.3	5	1.7	0.24
78	23	25.2	0	2.9	6	0.9	1.47
79	21	25.1	3	3.0	5	0.9	4.98
80	16	23.4	5	2.9	6	0.7	17.6
81	15	23.8	4	2.6	8	0.6	27.5
82	16	22.6	6	2.7	4	0.6	15.5
83	15	23.6	6	1.8	5	0.6	34.0
84	18	23.4	1	1.9	7	0.7	12.5

a. One and two-bullock categories aggregated to compute the test statistics. Critical $\chi^2(1)=3.84$ at .05 significance level.

Figure 5


Effects of Initial Bullock Stock on Bullock Accumulation,
by Age of Farmer
Average Bullock Stock
1.4
1.2
1
0.8
0.6
0.4
0.2
0
30
35
40
45
50
55
60
65
Age of Farmer
Two Bullocks
One Bullock
No Bullocks

incorporating such severe borrowing constraints also successfully predicts the behavior of the large farmers, we performed goodness-of-fit tests using the information on this group from the village from which we estimated the profit function reported in Table 4. Because we only estimated a profit function for large-size farms from a single village, there are not enough observations to perform annual chi-square tests. However, a cumulative test over all of the years reveals that the model performs quite poorly in predicting bullock stocks for this group. When the actual lagged bullock stock is used the overall chi-square statistic is 21.7 and when the initial (1975) stock is used the statistic is 102. Interestingly, while the model underpredicts the extent to which two bullocks (the profit-maximizing level) are owned in the case of both small- and medium-size farmers, the model significantly overpredicts the ownership of four bullocks (the profit-maximizing level) in the case of large-size farms. The poor performance of our estimated model in predicting the behavior of the large-size farmers based on the medium-size farmer data suggests that the former may have alternative means of consumption-smoothing, although it is notable that our profit-function estimates suggest that the large farmers are still not "efficient" in their average holding of bullocks.

c. Experimental simulations based on the estimated parameters : policy effects

The structural parameter estimates, which appear to provide good fits to the actual data describing the mid-size farmers, can be used to generate the effects of changes in the economic environment on the life-cycle accumulation of bullocks, on profits and on consumption and welfare for this group. Our profit function estimates, obtained independently of the structure of the behavioral model, imply that there is considerable underinvestment in bullocks, presumably due to borrowing constraints. It is therefore useful to ascertain if there are interventions, or circumstances, that might induce or allow farmers to hold more bullocks and thus to increase farmer efficiency apart from direct interventions in credit markets. We consider four possible policies: changes (reductions and increases) in the price of bullocks, the provision of weather-insurance and increases in opportunities for alternative and assured income flows for farmers.[4]

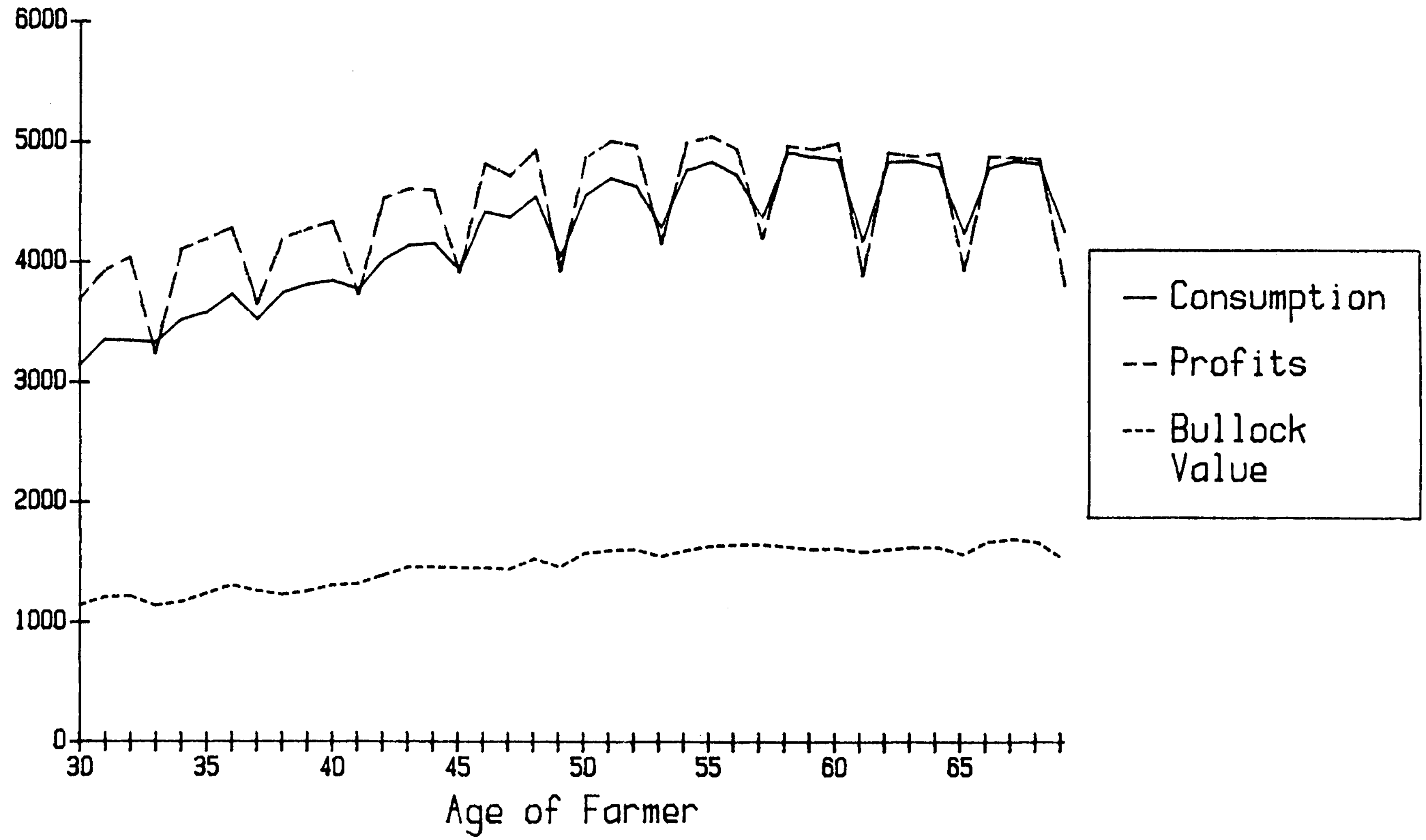
We perform the simulations by drawing 40 values of the idiosyncratic profit shock, one for each age beginning at age 30, from a (normal) distribution characterized by the estimated profit variance. These draws are superimposed on weather shocks, which are assumed to occur once every four years (the sample probability is .30) and to decrease profits by the estimated amount reported in Table 4. The age-specific profit draws then generate life-cycle bullock purchases, sales and breeding decisions, solved out from the model. These experiments are repeated 1000 times and results are averaged over all sets of draws by age. The average values generated thus correspond to what would be observed in the aggregate in an economic environment experiencing a particular time-series of weather draws and in which 1000 farmers, all of the same age, also experienced uncorrelated profit shocks.

Figure 5 reports the average life-cycle accumulation of bullock stocks generated by model simulations for initial bullock stocks of none, one and two. The large paralleled spikes in the three line-plots reflect the effects of the quadrennial weather shocks on bullock holdings. The most important feature of Figure 5, however, is that initial conditions do not matter much. Farmers who begin with the profit-maximizing level of two bullocks, on average sell off bullocks initially prior to the first bad weather draw, reflecting their desire to smooth consumption and the necessity of achieving the consumption floor. That is, farmers already holding two bullocks and with good draws do not buy additional bullocks, because of their unprofitability, while such farmers experiencing bad shocks sell some of their bullocks. Farmers beginning with no bullocks on net purchase bullocks prior to the first bad weather year, reflecting the perceived profitability of bullocks as production factors. After the first bad-weather year bullocks are accumulated on average by all three types of farmers, a consequence in part of the rise in farmer incomes due to age effects and the accumulation of pumps. However, on average, bullock stocks never reach the profit-maximizing level of two bullocks even for farmers who begin their life with two bullocks. In subsequent simulation experiments we set initial bullock stocks at one, reflecting the approximate sample average for the middle-level farmers.

To ascertain the extent to which bullock sales and purchases contribute to consumption-smoothing we examine profit and consumption levels. In order to isolate the influence of optimal bullock turnover from the effect of having an "insured" consumption floor, we generated a truncated set of profit draws such that no farmer's profits dip below the consumption floor. Figure 6 presents the resulting average life-cycle movements in profits, consumption and the values (at the sample price of 962 rupees) of the bullock stocks. Again, the regular large spikes in profits reflect the assumed four-year cycle of bad weather. As can be seen, however, the movements in consumption are always less than those in profits, with considerable savings (net purchase of bullocks) in "good" weather years and dissaving (net sales of bullocks) in eight of the nine "bad" years. An

Figure 6

Simulated Average Life-Cycle Patterns of Consumption, Profits and Bullock Stock Value: No Profit Shocks Below Floor



interesting feature of Figure 6 is that the amplitude of fluctuations in consumption increases relative to that in profits over the life-cycle. As the mean level of profits increases, due to age effects on profitability and to the accumulation of pumps, farmers are evidently more willing to absorb fluctuations in consumption. This reflects declining absolute risk aversion implied by the constant relative risk aversion specification of the utility function (12).

1. Bullock Price Effects

Figure 7 displays the life-cycle accumulation of stocks of bullocks associated with the observed sample price and with bullock prices set at 50 percent above and below the observed price. Figure 8 displays the corresponding paths of consumption. These simulations indicate the following: First, reductions in the price of bullocks increase bullock ownership in the initial period of the life-cycle but lower them, relative to that associated with the baseline or actual price, after age 45. Average bullock stocks over the entire life-cycle period actually decline (by 2.4 percent) in response to a permanent decrease (by 50 percent) in the price of bullocks. Conversely, bullock stocks are lower initially when the price of bullocks is raised above the baseline but then rise above baseline stocks; however, average bullock stocks are also lower compared to the baseline case, by 4.2 percent.

The differences in the life-cycle effects of price changes reflect the operation of borrowing constraints. When income is relatively low, at the younger ages, a reduction in the price of bullocks permits more farmers to accumulate bullocks, as expected. However, a farmer experiencing a bad shock to profits must sell more bullocks under a lower-price regime; when bullock sales prices are low, more farmers "stock out" when there is a

Figure 7

Effects of Changing Price of Bullocks on Life-Cycle Accumulation of Bullocks

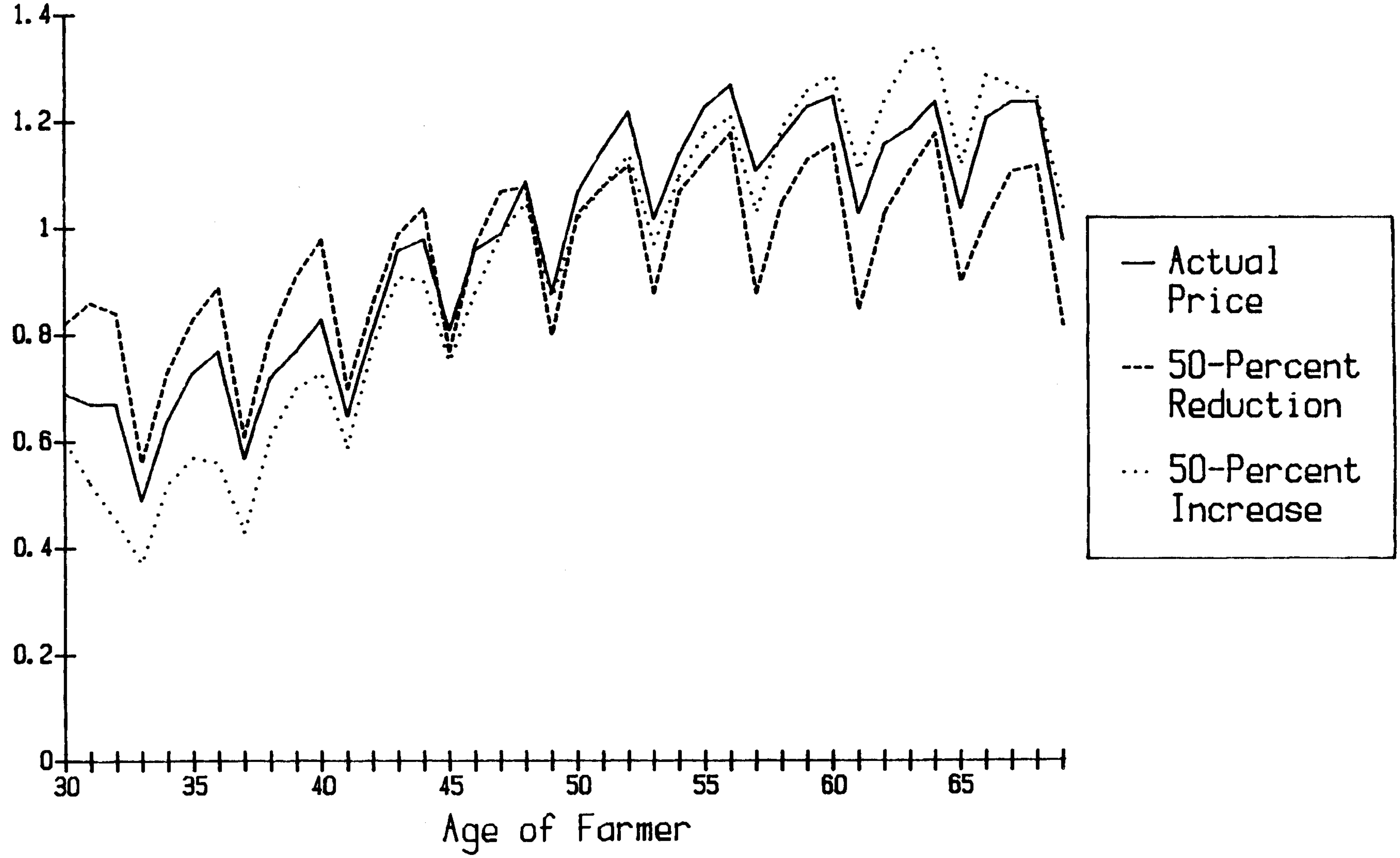
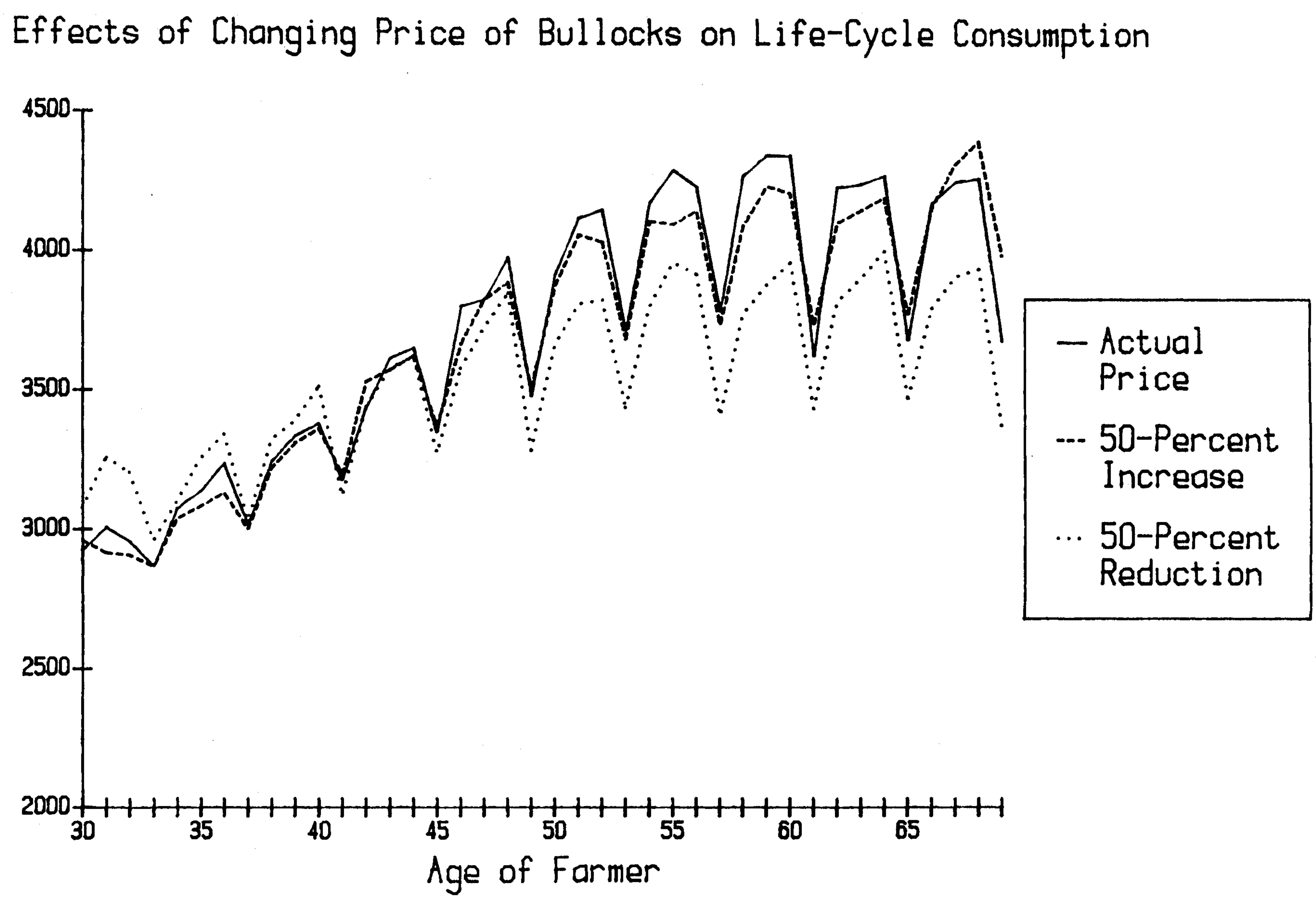


Figure 8


Effects of Changing Price of Bullocks on Life-Cycle Consumption
4500
4000
3500
3000
2500
2000
30
35
40
45
50
55
60
65
Age of Farmer
Actual Price
50-Percent Increase
50-Percent Reduction

common bad shock. As incomes rise, more farmers are able to purchase bullocks under the high-price regime, and under the high-price regime fewer stock out during bad times. After an initial disadvantage, therefore, bullocks accumulate at a faster rate when bullock prices are high. In part this is also due to the increased profitability of breeding bullocks when bullock prices rise. Indeed, in the high bullock-price regime, on average 5.7 percent of farmers hold more than two bullocks (almost ten percent for farmers over 45) even though it is unprofitable (in the static sense) to do so, reflecting the greater value of bullocks as a consumption-smoothing asset. In the lower-price regime, no farmers ever hold more than two bullocks.

The increased affordability of bullocks engendered by a decrease in their price is evidently dominated by the loss to farmers due to the decreased value of bullocks as consumption-smoothing assets-- expected discounted utility is lower under the lower-price regime compared to the baseline. Expected utility is also lower under the higher price-regime compared to the baseline because of farmer's lessened ability to purchase bullocks early in their life-cycle. These results thus suggest that (i) reductions in the price of bullocks do not necessarily improve welfare, increase bullock ownership or profits, although they may do so for poorer farmers for whom the problem of affordability, given borrowing constraints, dominates and (ii) increases in the price of bullocks may benefit higher-profit farmers, who hold more bullocks on average, because of the rise in the value of their productive assets. Our estimates suggest, however, that changes in the market values or price of bullocks by as much as 50 percent in either direction only marginally alters average bullock holdings, which remain at levels, on average, 26 percent below profit-maximizing levels, even at the peak of the life-cycle.

2. Weather Insurance

The preceding simulations illustrate that the accumulation of bullocks is substantially impeded by the presence of weather shocks, which induce farmers to sell off bullocks in order to meet their consumption goals (or necessities). It might appear, therefore, that the provision of weather insurance, by smoothing income, might lead to increased holdings of bullocks and to welfare gains. Figures 9 and 10 display the effects of providing farmers with actuarially-fair weather insurance on the life-cycle accumulation of bullocks and pumpsets and on life-cycle consumption . The actuarially-fair premium is calculated as one-fourth of the estimated profit loss due to bad weather, which occurs one-fourth of the time (in this case every four years). Farmers thus pay 400 rupees each year in return for a smoother income path. The figures indicate that the paths of both bullock stocks and consumption lose their weather-induced jaggedness, as expected. However, average bullock stocks and average consumption levels are lower when farmers pay the full cost of weather insurance, due to their having lower incomes net of the premium.

The decrease in the variability of income associated with weather insurance yields a welfare gain, given our finding that farmers are risk-averse. However, our estimates indicate that discounted expected utility is no higher when farmers pay actuarially-fair insurance premiums compared to the baseline regime without insurance. The principle reason is that farmers are already in part insured via the consumption floor. The consumption-floor, which reflects farmers' informal insurance arrangements via transfers and which also exacts a penalty in terms of bullock sales, evidently is almost a perfect substitute for weather insurance. The provision of such

Figure 9

Effects of (Actuarially Fair) Weather Insurance on Life-Cycle Bullock and Pumpset Accumulation

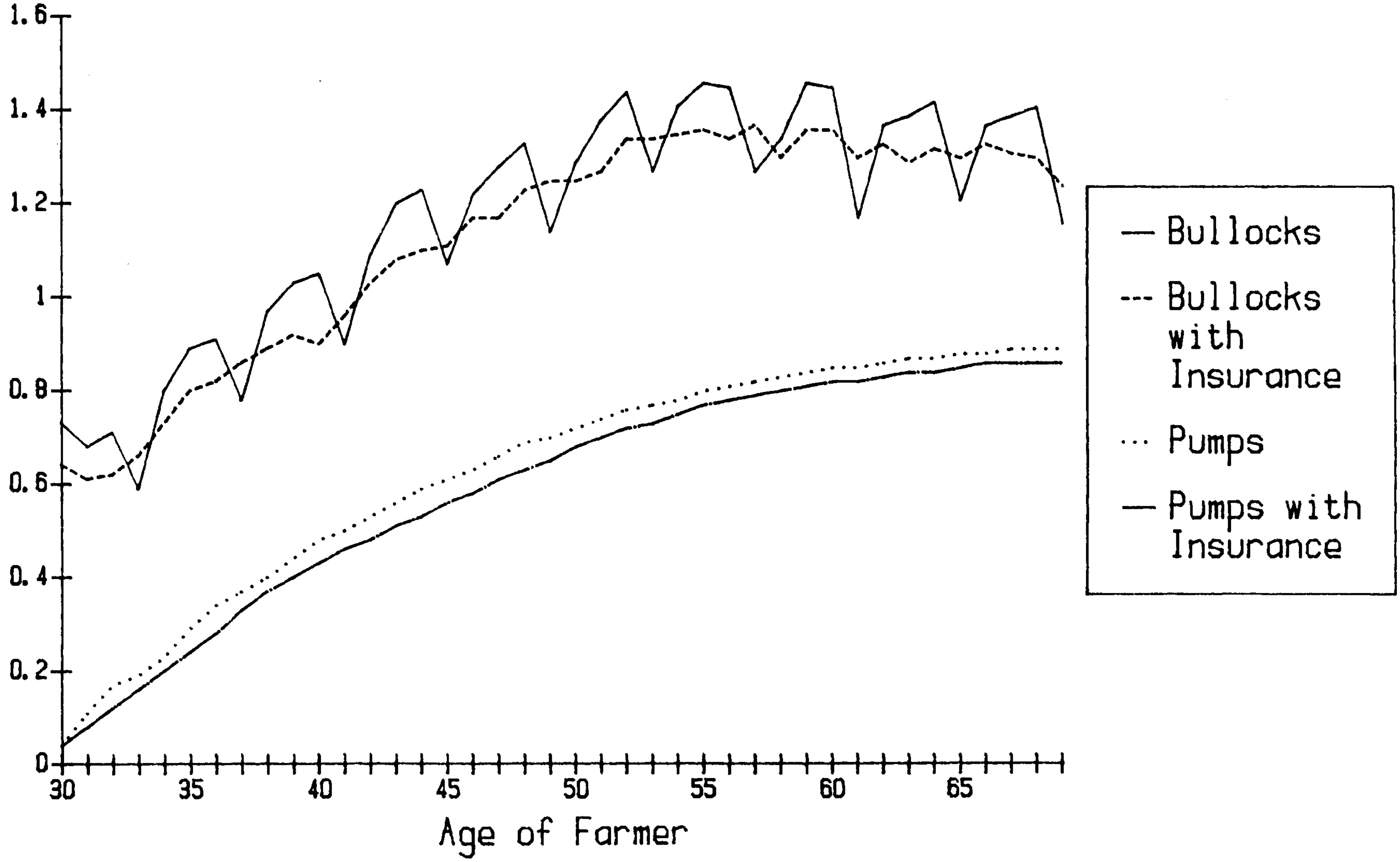
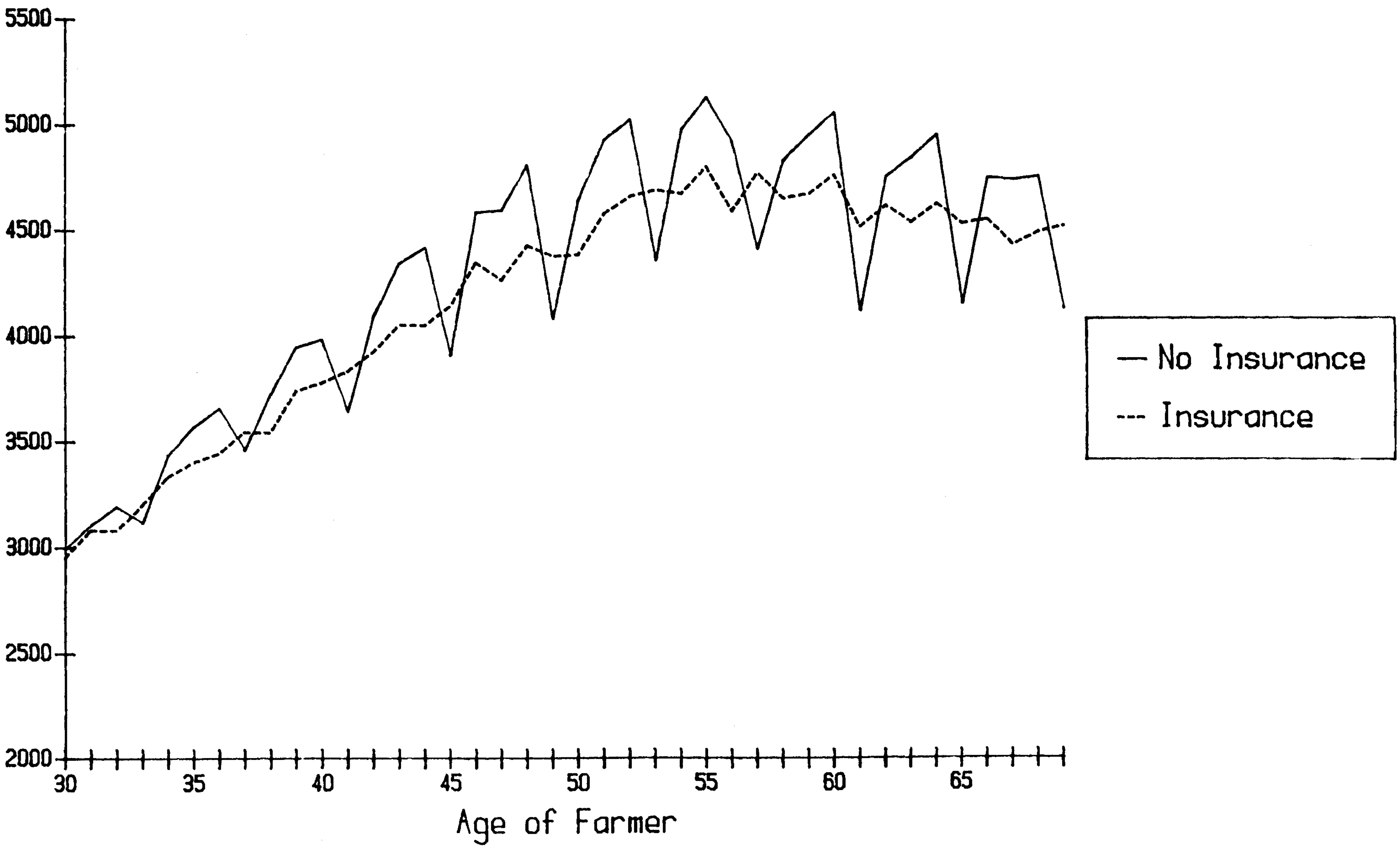


Figure 10

Effects of (Actuarially Fair) Weather Insurance on Life-Cycle Consumption



insurances, fully paid for by the farmers themselves, thus does not raise average bullock holdings or profits gross of insurance premiums and also does not evidently improve farmer welfare, giving existing arrangements. Thus our model and estimates explain the absence of weather insurance.[5]

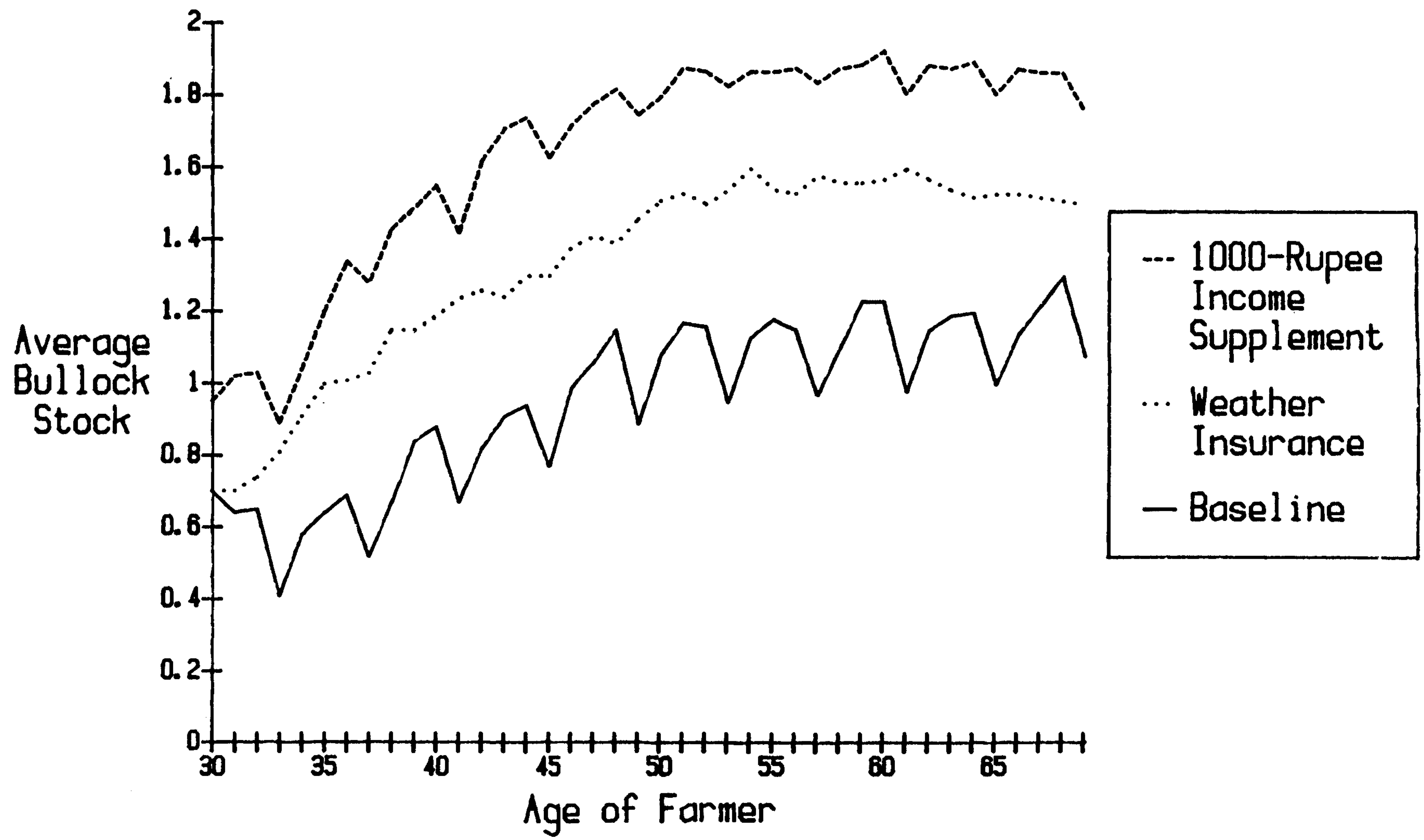
3. Assured Income Opportunities

Our results are consistent with the hypothesis that borrowing constraints combined with low and fluctuating incomes are the primary reasons for underinvestment in bullocks, and neither alterations in the price of bullocks nor the provision of weather insurance are evidently effective in improving farmer profitability or welfare. If low incomes are the cause of lower profitability, then improvements in earnings, from whatever source, should increase efficiency by permitting farmers to accumulate higher capital stocks. In Figure 11 we present the results of simulations in which we provide farmers with a constant 1000-rupee income stream. We compare average bullock accumulations under this regime with those of the empirical baseline and with a regime under which farmers are provided weather insurance at no cost, equivalent to a 400-rupee increase in annual profits but with no weather-induced shocks to profits.

The importance of income and thus borrowing constraints are visible in Figure 11. By age 50, farmers are on average holding bullock stocks that are within five percent of the profit-maximizing level of two, compared to the baseline in which at age 50 average bullock stocks are only 58 percent of the profit-maximizing level. Not surprisingly, the subsidized weather insurance schemes raises bullock stocks to a point intermediate to the 1000-rupee supplement and the baseline. What is of interest is that the fluctuations in bullock stocks after age 50 in the supplemental income case are almost as low as those exhibited under the weather insurance regime.

Figure 11

Effects of 1000-Rupee Certain Income Supplement and of Weather Insurance on Average Bullock Stocks, by Age of Farmer



With higher (non-agricultural) incomes, farmers are both able to "afford" higher profits and, because of declining absolute risk aversion, more willing to maintain farm profitability at the expense of fluctuations in consumption. These results imply therefore that increasing opportunities for farm households to obtain jobs which pay assured salaries may also increase agricultural investments and the efficiency and profitability of agricultural operations.[6]

4. Conclusion

In rural settings in which there are important constraints on borrowing, agricultural investment decisions presumably reflect households' concern to smooth consumption in the face of exogenously-variable incomes. In this paper we have examined investments by Indian farm households in one of the most important production factors in that area of the world, bullocks. These farm assets are not only central to production in the monsoon agricultural economy of India, but appear to serve an important role in smoothing consumption. Data from a number of sources indicates that sales of bullocks increase significantly where weather outcomes are poor, and hence incomes are low, and purchases of bullocks increase when rainfall is ample and incomes are above average, in contrast to all other productive assets, inclusive of land. One consequence of this consumption-smoothing role of productive assets is that agricultural output and incomes are autocorrelated, a feature that is ignored in almost all models of savings decisions purporting to describe behavior in rural areas of low-income countries.

Based on longitudinal data from villages located in the semi-arid tropics of India, we have estimated the parameters of a dynamic model of investment in bullocks and irrigation equipment incorporating uncertainty in agricultural output and in which bullock accumulation via purchases and sales can be used to smooth consumption. Our estimates of the model indicate that farmers are substantially averse to risk. Moreover, despite the importance of bullock ownership in producing crops efficiently and its value in mitigating consumption volatility, the estimates indicate that there is considerable underinvestment in bullocks. Farmers' aversion to risk combined with borrowing constraints thus not only result in output losses and lower incomes but also exacerbate the volatility in incomes.

Simulations of the estimated model, which appeared to provide a reasonable fit to life-cycle data on bullock accumulations, suggested that (i) alterations in the price of bullocks, ceteris paribus, change the life-cycle pattern of bullock accumulations and alter the distribution of bullock holdings across land classes but do not significantly change average holdings of bullocks, (ii) the provision of actuarially-fair weather insurance would, at least in the environment for which we have data, have no effect on farmer welfare, in part because of farmers' evident ability to insure a minimal level of consumption via informal arrangements, and (iii) increases in opportunities for farm households to have assured streams of income have a substantial positive effect on agricultural production efficiency and output. The low level and uncertainty of incomes, in the presence of borrowing constraints, thus appear to be a principal cause of underinvestment and hence agricultural inefficiency.

The model estimated was parsimoniously parameterized in order to maintain computational tractability while allowing for the complexity of dynamic decisions under a regime of uncertainty. Two important simplifying assumptions employed were the quasi-separability of production and the absence of alternative choices with regard to assets. With respect to the latter, we treated the support of a minimal consumption level as an estimable parameter. While there is evidence of the informal, insurance-based transfer arrangements that correspond to such a parameterization, alternative risk-mitigating mechanisms for achieving farmer production and consumption objectives should be modeled as choices. In this regard, it may be feasible to incorporate contractual choice within the discrete choice framework.[7] For households who are "stocked out" with respect to bullocks, given the technological infeasibility of leasing bullocks, a superior alternative to own cultivation is to lease out their land, presumably to farmers with ready supplies of animal traction. A model of tenurial arrangements incorporating productive asset accumulation could be useful in explaining such phenomena as sharecropping and the "tenancy ladder" as well as life-cycle patterns of investments. Finally, given the possibility of estimating parameters describing both the technology of production and preferences, it may be feasible to estimate an equilibrium model of the bullock market, given aggregate data on farmer age distributions and asset holdings by age. Such a model would permit the assessment of the full consequences of various policy interventions.

Footnotes

1. Most tests of the presence of liquidity constraints have involved the search for violations of the conditions implied by models incorporating the assumption of complete markets and not the explicit modeling of consumption or savings decisions when this assumption does not hold. See Hayashi (1987) for a review of such studies, and Zeldes (1989) for a recent example.

2. Implementations of dynamic, discrete choice models include Miller (1984), Pakes (1987), Rust (1987) and Wolpin (1984). See Eckstein and Wolpin (1989) for further examples.

3. For a comprehensive discussion of the role of bullocks in the Indian economy, see Vaidyanathan (1988).

4. These policy experiments are _ceteris paribus_ experiments; they do not trace out the full consequences of each intervention. For example, it is unlikely that a policy-induced change in the price of bullocks will not affect the price of pumps or informal insurance arrangements. Our experiments hold fixed all other prices, however.

5. Note that this result, that weather insurance provides no welfare gain conditional on the existence of informal arrangements, does not imply that weather insurance is inferior to such arrangements. Our model does not include the set-up costs or charges associated with the informal transfer system, nor does the insurance premium reflect administrative costs. Such costs must be known before global comparisons of alternative mechanisms for achieving income security can be made.

6. This assumes that labor markets operate efficiently and that family and hired labor are perfect substitutes. Evidence supporting these propositions is found in Pitt and Rosenzweig (1987) and Benjamin (1988).

7. Modeling the accumulation of financial assets may be more difficult, and not only because of the range of alternative values of this variable. The within-year periodicity of receipts in agricultural settings and the need to smooth consumption over the crop cycle clearly would affect financial asset holdings and would have to also be incorporated in the model.

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