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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In this paper we formulate and estimate a finite-horizon, structural dynamic model of agricultural investment behavior that incorporates the major features of low-income agricultural environments: income uncertainty, constraints on borrowing and rental markets, and the use of investment assets to generate income and smooth consumption. The model is fit to longitudinal Indian household data on farm profits, bullock stocks, and pump sets. The estimated structural parameters are used to assess the effects on the life cycle accumulation of bullocks, agricultural profits, and welfare associated with complete markets and bullock liquidity and with second-best policies that provide assured sources of income to farmers and weather insurance.

An essential feature of agricultural populations characterized by incomplete markets is the interlinkage between production and consumption decisions. In particular, almost all the assets held by farmers contribute directly to production, and to the extent that there are asset markets, they can also serve as buffer stocks to smooth consumption when income is stochastically variable and credit markets are incomplete.

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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 (e.g., sharecropping) and of farmer variable input decisions (seeds or fertilizer) generally employ static models of risk behavior that assume the absence of stores of value, credit markets, or 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 1982; Paxson 1992), assumes the absence of borrowing constraints, and studies incorporating this framework have treated income as exogenous to the process of asset accumulation and decumulation. Such studies do suggest, however, a considerable degree of consumption-smoothing behavior.

In this paper we formulate and estimate a finite-horizon, structural dynamic model of agricultural investment behavior that incorporates the major features of low-income agricultural environments: income uncertainty, constraints on borrowing and rental markets, returns to farmer experience, and the use of investment assets both to generate income and to smooth consumption.[1] The model is fit to longitudinal household data on farm profits, bullock stocks, and pump sets from the semiarid tropics of India. By estimating the structural parameters underlying farmer investment decisions, we can thus directly measure risk preferences and better assess the consequences of policy changes for farmer welfare associated with changes in constraints and technology. This approach contrasts with that in which attempts are made to directly elicit risk preferences from experimental games played with actual farmers (Binswanger 1980). It is unclear whether this latter method can separate the influence of preferences from that of constraints.

In Section I of the paper, we provide descriptive statistics on the asset composition of farmers, the role of credit, and the relative turnover rates of the assets in rural India. We show that bullocks are a large share of nonland and building wealth, are bought and sold at

[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) and Deaton (1990) for a review of such studies and Zeldes (1989), Altug and Miller (1990), and Townsend (1991) for examples. The paper by Margiotta and Miller (1991) is a recent exception in that they specifically allow for incomplete markets in a model of managerial compensation containing moral hazard.

considerably higher rates than other assets in well-developed interregional markets, and are sold off when profit realizations are low, suggesting the importance of the consumption-smoothing motivation for these investments and the failure of alternative mechanisms to completely mitigate consumption volatility. Section II contains a description of the structural model and the estimation procedure employed, and Section III reports parameter estimates and both intra- and extrasample tests of the predictive power of the model.[2] These tests indicate that the model fits the data reasonably well for middle-income farmers, from which the model was estimated, and for low-income farmers but not for the wealthiest households, suggesting that the latter group is better protected ex post against consumption variability. In Section IV we use the structural estimates to assess the welfare gain from the liquidity of bullock stocks and the potential effects on the life cycle accumulation of bullocks, agricultural profits, consumption, and welfare associated with complete markets and with second-best policies that (i) provide assured sources of income to farmers and (ii) provide weather insurance. The results indicate that while unsubsidized weather insurance would have little effect on farmer welfare, the availability of certain nonagricultural income has a substantial positive effect on agricultural output and efficiency, suggesting that poverty combined with incompletely insured income volatility is in part a cause of agricultural inefficiency.

I. Bullocks, Farmer Asset Portfolios, and Asset Turnover in India

The importance of animal traction, in particular bullocks, in Indian agriculture compared with other areas of the world is well known and reflects the unique agroclimatic conditions of the country.[3] 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. In the semiarid tropics of India, moreover, the soil, hardened and dried during the nonrainy season, must be tilled in the generally short period of time between the onset of monsoon showers (which are required to render the soil tillable) and the optimal sowing date. Not only is the use of bullocks necessary for production but the uncertainty of the monsoon onset date, the short period of time during which tillage and sowing

[2] Implementations of dynamic, discrete-choice models include Miller (1984), Wolpin (1984), Pakes (1986), and Rust (1987). 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).

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. Indeed, most farmers who own land lease out their land when they have no bullocks.[4] Ownership of work animals is thus required to ensure the timeliness of preharvest farm operations.

In a stationary environment with complete markets, we would expect to observe no purchase or sale of productive assets (except for replacement) after the initial period of life. Two data sets describing in detail farm households in India suggest that farmers have considerable difficulty in transferring purchasing power across periods. A national probability sample of all rural households surveyed in the crop year 1970–71 indicates that while 13.7 percent of farmers received loans for consumption purposes, almost 10 percent sold livestock, chiefly bullocks (National Council of Applied Economic Research [NCAER] Additional Rural Income Survey, third round).[5] Moreover, in areas in which crops were adversely affected by weather conditions, the probability that a farmer sold livestock was higher by 34 percent ($\chi^2 = 5.13$).

"Distress" sales of bullocks would not be observed, even when consumption credit is constrained, if farmers were able to accumulate alternative nonproduction assets to use as buffer stocks or were able to borrow for consumption purposes. A second data set, from a longitudinal survey of 30 farmers (and 10 nonfarmers) undertaken by the International Crops Research Institute for the Semi-arid Tropics (ICRISAT) from 1975 to 1984 in each of 10 villages located in five districts in the semiarid tropics of India, provides detailed information on the accumulation and decumulation of assets by farmers (Singh, Binswanger, and Jodha 1985). The 1983 round of this survey suggests that farmers own few financial assets. For all three land size classes, immobile capital—land and buildings—makes up the major portion (approximately 85 percent) of total wealth. Bullocks represent the greatest share of non–real estate wealth for all three land classes, representing almost half of this wealth component for the small farmers, over a third for midsize farmers, and slightly over 27

[4] In a survey of 10 villages in the semiarid tropics of India in the period 1975–84, described below, 71 percent of farmers leasing out land owned no bullocks; among those not leasing out land, only 37.6 percent did not own bullocks ($\chi^2 = 141.1$). Maximum-likelihood, fixed-effects conditional logit estimates based on 1,476 farmer-year observations from these data indicated that when a typical farmer did not have a bullock he was 63 percent more likely to lease out land than when he owned at least one bullock (asymptotic t-value = 12.5).

[5] Over 20 percent of farmers received loans for production purposes, chiefly the purchase of inputs such as seeds and fertilizer. Another 11 percent received a loan for the purpose of making capital improvements, purchasing a house or land.

percent for large farmers. Only a very small or trivial share of wealth lies in financial assets, less than 5 percent even for the large-size farmers. Crop inventory stocks, inclusive of fodder, are approximately a quarter of nonland wealth, but they reflect a need to smooth consumption and maintain bullocks within the year, given the seasonality of production.

Farmers in all three groups are able to accumulate a sizable proportion, approximately 19 percent, of their nonland wealth in the form of jewelry. However, the ICRISAT data on asset transactions over all the survey years indicate that sales of bullocks were 3.5 times as prevalent as sales of jewelry. Indeed, the longitudinal data from the three ICRISAT villages with the most years of information indicate that for the top two land classes, over 86 percent of farmers bought or sold bullocks over the 10-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 the observations were characterized by an irrigation pump purchase for any land class. Land and farm implements also exhibit little turnover: the NCAER data indicate that only 1.5 percent of farm households sold land in the survey year, less than one-sixth the number that sold bullocks, and less than 0.1 percent of all farmers sold irrigation equipment, the major component of nonland farm capital.

The high incidence of bullock turnover, despite the critical role of bullocks for farmers' capabilities to produce income (to be tested below), reflects not only farmers' evident inability to accumulate financial assets but the extensive nature of the bullock market. The villages are not closed or autarkic economies: over 60 percent of bullock sales in all the ICRISAT villages went to buyers outside of the village, with 10 percent of such sales going to buyers located more than 20 kilometers from the village (average distance was 10 kilometers).[6] The ability to move bullock capital, in contrast to land, renders bullocks particularly valuable as buffer stocks in the face of the spatially covariant production shocks that characterize agriculture.

We can ascertain directly whether purchases (sales) of bullocks respond positively (negatively) to income, as would appear to be implied by a consumption-smoothing model, by estimating a simple stock adjustment model from the ICRISAT data. 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.

[6] The bullock market is in fact well organized since there are regionally centralized bullock "fairs" held at specific times during the year.

TABLE 1

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 (1)	Addition of Bullocks Probit (2)	Divestment of Bullocks Probit (3)	Purchase of Pump Probit* (4)
Profits ($\times 10^{-4}$)	.88	.824	−.645	.913
	(9.80)	(5.42)	(4.17)	(2.55)
Number of bullocks at beginning of year less bullock deaths in year	−.385	−.246	.376	.324
	(13.6)	(4.71)	(7.55)	(2.76)
Whether own a pump at beginning of year	−.271	−.272	.260	. . .
	(2.41)	(1.66)	(1.70)	
Small farm	−.0627	−.354	−3.50	.424
	(.41)	(1.92)	(1.84)	(.84)
Medium farm	.0062	−.106	−.166	.657
	(.05)	.63	(1.02)	(1.48)
Age of farmer	.0238	−.0054	−.0527	−.385
	(1.01)	(.18)	(1.72)	(.51)
Age of farmer squared ($\times 10^{-3}$)	−.230	.0723	.524	.112
	(1.01)	(.24)	(1.79)	(.14)
χ^2 (degrees of freedom)†	123.8 (9)	48.6 (9)	107.9 (9)	39.1 (8)
Number of observations	788	788	788	545

NOTE.—Absolute values of asymptotic t-ratios are in parentheses.
* Sample of farmers without a pump.
† Specification includes three dummy variables corresponding to villages in the sample.

The maximum-likelihood ordered probit estimates of net bullock sales are presented in column 1 of table 1. 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 2 and 3 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 column 4 of table 1, we report maximum-likelihood probit estimates for the purchase of a 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 divestment.

The results in table 1 also indicate that the current level of own stocks, net of income, negatively influences the probability of a subsequent purchase, a result that 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 stock adjustment is required, at the very least because the determination of income should be modeled, inclusive of the technology of production and the value (cost) of the assets. The estimates reported in table 1 also cannot be used to discern the consequences for bullock stocks, profits, or farmer welfare of different market regimes.

II. The Structural Model and Estimation Strategy

A. *The Model*

To understand more fully the dynamics of bullock stock adjustment behavior, we formulate an empirically tractable structural dynamic model that incorporates a number of salient features of the low-income agricultural environment described in Section I. The most important elements of the model are that (i) farmers wish to smooth their consumption but cannot borrow for this purpose; (ii) bullocks, land, and irrigation equipment contribute to agricultural output and income; (iii) output and income are stochastic, resulting from the existence of both farmer-level and village-level (e.g., weather) shocks; (iv) bullocks can be bred, purchased, and sold but not rented; (v) irrigation equipment can be purchased but not rented or sold; and (vi) land can be rented but is not sold or purchased.

The farmer is assumed to maximize the present value of expected lifetime utility over a finite horizon.[7] Utility at any age t, $u(C_t - C_{\min})$, depends on the consumption of a single nonstorable aggregate commodity, C_t, above minimum subsistence consumption, $C_{\min}$. The farmer owns a fixed amount of land, A, which can be rented out but is neither divested nor added to. The farmer can, however, accumulate animals used in production (bullocks) through purchases or via self-production and can purchase a pump for crop production, which, unlike bullocks, has no resale value.[8] Given a constant relative risk aversion utility function per period with respect to discretionary consumption, the farmer maximizes

$$E_t \sum_{t=\tau}^{T} \delta^{\tau-t} \frac{1}{1-\gamma} (C_t - C_{\min})^{1-\gamma}, \tag{1}$$

where E_t is the expectations operator given the information set at age t, δ is the subjective discount factor, and $\gamma > 0$ is the relative risk aversion parameter. The initial period corresponds to the age of land inheritance.

[7] We allowed for a bequest motive in bullocks, land being automatically transferred, but did not estimate it to be empirically important.

[8] Although the pump itself can be resold, the well and to a lesser extent the tubing, which are the major investments, have no resale market.

The farmer's income is derived from crop production, which is a two-stage process denoted 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, that is, 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.[9] We assume that variable planting input decisions are made prior to the realization of the shock, but harvest input decisions occur after the resolution of uncertainty in the period.

At the end of period t, the farmer must decide, prior to the realization of next period's production shock, how many bullocks to buy or sell, whether or not to breed a bullock (to be born in the next period), whether or not to buy a pump (if one is not already owned), and how much of each planting variable input to purchase. After the realization of the shock, variable harvest inputs are purchased. Solving the optimization problem for all these choice variables is not tractable in the context of estimation, that is, where the problem must be solved repeatedly at alternative parameter values. If there were no planting stage (preshock) variable inputs, then variable input decisions could be separated from the dynamic problem, because postshock 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 or to the predetermined inputs (bullocks or a pump). In addition, we assume that villages are small open economies that take all prices as parametric, and we also assume that price uncertainty is small enough to be ignored.[10] The restricted or conditional profit function is assumed, therefore, to take the form

[9] This assumption is consistent with the observed prevalence of noncapital production loans previously noted. Indeed, because we do not allow for the financing of current production costs out of savings from previous periods' profits in order to maintain tractability, it is necessary that credit be used to finance preharvest input purchases. The harvest (and the assured consumption floor scheme described below) is the "collateral" for this form of credit, chiefly provided by the input suppliers.

[10] For example, 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 village-level bullock prices. As noted, the majority of bullock sales transactions occur outside of the village.

$$\Pi_t = \Pi_0 + \sum_{j=0}^{\overline{B}} \Pi_{1j} D_{tj} + \Pi_2 M_t + \sum_{j=0}^{\overline{B}} \Pi_{3j} D_{tj} M_t + \Pi_4 w_t + \epsilon_t, \quad (2)$$

where $D_{tj} = 1$ if the stock of bullocks at time t is $j = 0, 1, \ldots, \overline{B}$, $M_t = 1$ if the farmer owns a pump at t, and w_t is a village-level and ϵ_t a farmer-level time-varying shock. This functional form allows separate effects on profits of different numbers of bullocks and combinations of bullocks and a pump. We also included in (2) the age of the farmer to pick up potential farming experience effects (Rosenzweig and Wolpin 1985). Note that positive profits with zero bullocks, measured by Π_0, may result from renting out land, a common practice among landowners owning no bullocks, as noted. Thus full divestiture of bullocks to increase current consumption does not necessarily imply only minimum subsistence consumption in the next period.

While the farmer can accumulate and divest assets (bullocks), we assume that he cannot borrow for consumption purposes. Any intertemporal stochastic consumption model with borrowing constraints must address 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.[11] 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 plus $\theta > 0$, θ negligible. Thus we assume that the farmer has a form of disaster insurance.[12] One example is transfers from nonresident family members, which have been shown to be important in the environment we are studying (Caldwell, Reddy, and Caldwell 1986; Rosenzweig 1988; Rosenzweig and Stark 1989) and in other low-income environments (Lucas and Stark 1985).[13]

Because we assume that there are no opportunities to borrow for current consumption 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

[11] 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.

[12] We assume that there is a fixed insurance premium paid each period that is subtracted from Π_t. We do not attempt to estimate the premium, but we assume that it is contained in Π_0.

[13] Given the specification of utility in (5), at $C_{\min}$ the marginal utility of consumption would be infinite, and no voluntary insurance scheme would ever optimally locate there. This accounts for the assumption that consumption after complete divestiture is at least θ above $C_{\min}$. In the estimation we assume that θ is small enough to ignore.

the breeding cost of a calf if one is bred as long as the consumption minimum is met. That is,

$$\begin{aligned} C_t &= \Pi_t - p^b b_{t+1} - p^m m_{t+1} - c n_{t+1} > C_{\min} + \theta, \\ C_t &= C_{\min} + \theta \quad \text{if } \Pi_t + p^b B_t \leq C_{\min}, \end{aligned} \tag{3}$$

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 $\text{neg}(b_{t+1}) \leq B_t$ 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 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 (3).

The bullock stock evolves according to

$$B_t = B_{t-1} + b_t + n_{t-3} - d_{t-1}. \tag{4}$$

The bullock stock at t equals the stock in the previous period plus net purchases and the number of calves born three periods before minus 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 (which for the farmers we consider never exceeds three). The probability that an adult bullock dies is q_d. The equation of motion for pump ownership is

$$M_t = M_{t-1} + m_t, \tag{5}$$

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.

The village-level shock is assumed for tractability to be described by a serially uncorrelated two-point distribution; a bad shock occurs with probability q_w and a good shock with probability $1 - q_w$. The village-level shock and bullock mortality shock are independently distributed from each other and from the idiosyncratic shock, ϵ. The latter is assumed to be independently and identically distributed (i.i.d.) normal with mean zero and variance σ^2_ϵ.

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

$$\begin{aligned} &V_t(B_t, d_t, M_t, n_t, n_{t-1}, n_{t-2}, w_t, \epsilon_t) \\ &= \max_{\{b_{t+1}, n_{t+1}, m_{t+1}\}} \{u(\Pi_t(B_t, M_t, A, w_t, \epsilon_t) - p^b b_{t+1} - p^m m_{t+1} - c n_{t+1}) \\ &\qquad + .95 E \max\{V_{t+1}(B_t + b_{t+1} + n_{t-2} - d_t, d_{t+1}, M_t \\ &\qquad\qquad + m_{t+1}, n_{t+1}, n_t, n_{t-1}, w_{t+1}, \epsilon_{t+1})\}\} \end{aligned} \tag{6}$$

if $t < T$.

At T, because there is no bequest motive, the farmer sells his bullocks in order to maximize current consumption. The expectations operator in (6) is taken over the joint distribution of d, w, and e, which is known by the farmer.

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 that divides the real line into regions within which particular choices are optimal for each set of values of the state space exclusive of ϵ. These critical values form the basis of the estimation. The solution method is similar to that described in Wolpin (1984).

B. *The Likelihood Function*

What we observe for an individual farmer is a sequence of pump stocks, bullock stocks, and farmer profits 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 village states (of w's). 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. The bullock price is thus fixed at its sample mean value (in 1983 rupees) at 992 rupees. We also assume that observed profits are subject to an independent additive measurement error assumed to be normal with mean zero and variance σ_u^2. The likelihood function over I farmers is

$$L(\gamma, C_{\min}, p^m, c, \sigma_\epsilon^2, \sigma_u^2, \Pi_{1j}, \Pi_2, \Pi_3 | \text{data})$$

$$\prod_{i=1}^{I} \sum_{n_1} \cdots \sum_{n_{\tau_i}} \Pr(B_1, M_1, n_1, \tag{7}$$

$$\Pi_0^0, \ldots, B_{\tau_i}, M_{\tau_i}, n_{\tau_i}, \Pi_{\tau_i - 1}^0 | B_0, M_0, n_0, n_{-1}, n_{-2}),$$

where the zero subscript refers to the initial age, Π_t^0 is observed profits at t, and τ is the number of years available for the farmer.[14] Maximum-likelihood estimates are obtained by iterating between the dy-

[14] The summations over breeding subsequent to the initial age are performed because we do not have reliable data on breeding. In addition, it should be noted that the initial observed age is not necessarily the age at which the farmer is the 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. Equation (7) can be written as the product of independent conditional probabilities, which each depend on the cutoff values of the ϵ's derived from the dynamic program solution and are themselves functions of the fundamental parameters we wish to estimate.

namic program that solves for the cutoffs and the likelihood maximization routine.

III. Results

A. *Parameter Estimates*

In order to estimate the distribution of village-level shocks, we estimated separately from the input decisions two versions of the profit function, corresponding to equation (2). These estimates are consistent given the quasi-separability assumptions made in deriving (2). The first set of profit estimates, obtained separately for three land size classes, incorporated separate year dummies. A restricted version was derived by combining year effects into a dichotomous variable representing a good and bad village-level state. It was obvious from the unrestricted version which years were good and which were bad.

The estimation procedure requires that the dynamic program be solved separately for farmers who differ in any respect, for example, whose returns to investments or whose prospects of village shocks differ. To minimize the computational burden, we therefore estimated the remaining parameters of the model using only observations on medium-size farmers who are assumed to have the same land size. Indeed, farmers classified in the "medium-size" strata by ICRISAT are farmers who are the most homogeneous in land size holdings. The marginal profitability of an additional bullock and of pump ownership is thus least likely for this group to reflect unmeasured land size effects. Moreover, village profit effects are completely absent for the medium-size group, so that they can be aggregated across villages. By restricting estimation of the model to a subset of the data, we can perform extrasample tests of the model with the small- and large-farm class data.[15]

[15] Nine of the 30 years over the three villages were classified as having bad weather, so that q_w was set to .30. Bad years were 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. An important limitation of the data is that we cannot estimate profits for all possible combinations of bullocks. In only two periods were any farmers holding as many as three bullocks, and none was 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 on owning more than two bullocks and, of course, could not hold more than two. To ascertain whether 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

TABLE 2

MAXIMUM-LIKELIHOOD ESTIMATES

Parameter	Estimated Coefficients	Asymptotic Standard Errors
Preferences and constraints:		
Relative risk aversion (γ)	.964	.00169
Consumption floor ($C_{\min}$)	1,469	28.4
Breeding cost (c^b)	857	8.35
Pump price (p^M)	6,338	37.3
Profit function:		
Constant (Π_0)	−.00248	36.2
One bullock (Π_{11})	326	677
Two bullocks (Π_{12})	1,800	18.5
Pump (Π_2)	1,795	126
Bad shock (Π_4)	−753	14.5
True variance (σ_ϵ^2)	5.26×10^6	2.58×10^4
Measurement error variance (σ_u^2)	1.82×10^5	540
Age	161	.168
Age squared	−1.84	.0113

Table 2 reports maximum-likelihood estimates and asymptotic standard errors of the preference function, price, and profit function parameters.[16] Almost all the parameters are estimated with relatively high precision. The profit function parameter estimates in table 2 provide information on the profit-maximizing level of bullocks and pump ownership status. With respect to the latter, it is clearly optimal to own a pump regardless of the size of the bullock stock. For example, a farmer would augment *annual* profits by 1,800 rupees by purchasing and installing a pump, a 72 percent increase at the mean profit level. Despite this high return, only 31 percent of the families ever owned a pump, and over the 10-year period only 18 percent purchased a pump.

Similarly, although it is profit maximizing to own two bullocks, the average number of bullocks owned is only 0.94. Note that the exis-

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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 the sample farmers, on average, hold less than one bullock).

[16] The estimation proceeded in three steps. As noted, we first obtained consistent estimates of the profit function by estimating (2) alone. For the middle group of farmers, the interactions between the pump and bullocks were not significant and were thus excluded. We then used these "first-stage" technology estimates to obtain initial consistent estimates of the preference and other parameters of the full model. Finally, we calculated one iteration of a Newton-Raphson procedure to obtain asymptotically efficient estimates and asymptotic standard errors for all the parameters.

tence 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 the structural model, cannot adequately provide farmers with animal traction when they most need it.

The effect of bad weather on profits is estimated to be 753 rupees. We also tried a specification of the profit function (in the first stage of estimation) in which the returns to bullocks and pumps were influenced by adverse weather, but we found no evidence of such interaction effects ($F(2, 264) = .85$). In addition, to ascertain whether local weather influenced the costs of food stocks (fodder) used to maintain bullocks, we tested for interaction effects of bullocks with the previous year's weather. If a poor harvest increases the scarcity value of animal feed consumed over the next crop year, these lagged interaction effects should be apparent, but such effects were also not significantly different from zero ($F(2, 234) = .15$). Thus the selling of bullocks after a bad crop year does not appear to be due to a rise in local bullock maintenance costs, consistent with our assumption of the spatial integration of input markets. Of course, idiosyncratic shocks, which are a large component of uncertainty, should have no effect on market prices.

Table 2 also reveals a statistically discernible age pattern in profits: profits first rise with age, peak at age 43, 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. Finally, in terms of the profit function parameters, our estimates imply that only 3.3 percent of the profit variance is due to measurement error.

The relative risk aversion parameter is estimated to be .96, which implies that there exists a motive for consumption smoothing among these farmers. The estimated subsistence level of consumption is 1,470 rupees, which is 56 percent of mean household food consumption as shown in table 2.[17] The price of a pump is estimated to be 6,340 rupees and the breeding price 857 rupees.

To assess the validity of the model, we performed a number of goodness-of-fit tests. We calculated χ^2 goodness-of-fit statistics by year for the sample of medium-size farmers based on the actual stock of bullocks owned in the previous year. Although there is a tendency to underpredict the ownership of two bullocks and overpredict the absence of any bullocks, none of the χ^2 statistics exceeds the critical value at the 5 percent level. We cannot reject, for any year, the hy-

[17] The estimate of the consumption minimum is remarkably close to that implied by the "preferred" estimates in Ogaki and Atkeson (1991), 1,600 rupees, that were obtained by fitting a model based on the extended addilog utility function to the household consumption information from the ICRISAT survey.

pothesis that the distribution of bullock stocks predicted by our model is identical to the actual distribution.[18]

Extrasample goodness-of-fit tests were conducted using the sample of small-size and large-size farmers based on the separately estimated profit function parameters.[19] In the former sample the fit test rejects the model in only two of the years. For farmers in the large land size group, the profit function parameters differed across villages. We thus performed only a cumulative χ^2 test based on all the years for one village, the one with the largest number of observations (Shirapur). The results indicate, not surprisingly, that the model performs quite poorly in predicting bullock stocks for large farmers: the overall χ^2 statistic is 21.7, with the appropriate critical value equal to 5.99 at the .05 level. The poor performance of our estimated model in predicting the behavior of the large-size farmers on the basis of the medium-size farmer data is consistent with such farmers' superior abilities to obtain consumption loans or to accumulate alternate assets to be used for consumption smoothing, although it is notable that our profit function estimates suggest that even the large farmers are still not fully "efficient" in their average holding of bullocks.

B. *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 midsize farmers, can be used to generate the effects of counterfactual 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 imply that there is considerable underinvestment in bullocks, presumably because of borrowing constraints and the inability of such farmers to both maintain productive stocks and accumulate financial assets given income levels. It is therefore useful to ascertain whether 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 three possible second-best policies: the provision of

[18] A more stringent within-sample test is to predict bullock stocks in all years on the basis of only 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 χ^2 statistic imply rejection of the model. However, a model that predicted that bullock stocks would not change over time generally has lower χ^2 statistics. The data do not contain enough year-to-year variation in bullock stocks to distinguish between models that predict (realistically) only small year-to-year changes.

[19] For details of these tests and the profit function estimates, see Rosenzweig and Wolpin (1989).

actuarially fair and subsidized weather insurance and increases in opportunities for alternative and assured income flows for farmers. These interventions have been those most prominently suggested as alternatives to credit market improvements. Indeed, hundreds of millions of dollars are expended each year by governments in providing subsidized crop and weather insurance, with farmers generally resistant to paying the full cost of such insurance (Hazell, Pomareda, and Valdes 1986). We can use our estimates to assess how much, if at all, farmers' welfare would increase if weather insurance were made available.[20]

We performed the simulations by drawing 40 values of the idiosyncratic profit shock, one for each age of the farmer beginning at age 30, from a (normal) distribution characterized by the estimated true profit variance. These draws were superimposed on weather shocks, which were assumed to occur once every 4 years (the sample probability is .30) and to decrease profits by the estimated amount reported in table 2. The age-specific profit draws generate life cycle pump purchases, bullock purchases, sales, and breeding decisions, solved out from the model. This simulation was repeated for 1,000 "farmers," and results were 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 that is experiencing a particular time series of weather draws and in which 1,000 farmers, all of the same age, also experienced uncorrelated profit shocks.

With complete markets, the midsize ICRISAT farmers would immediately and always hold two bullocks, purchasing bullocks only to replace those that die and selling only those that were bred in excess of two. Simulations of the model (unreported) show, however, that the accumulation or maintenance of bullock stocks is substantially impeded, even among low-income farmers with initial holdings of the optimal number (two) of bullocks, by the presence of weather shocks when there are borrowing constraints, which induce farmers to sell bullocks in order to meet their consumption goals (or necessities) even if they are fortunate in never being forced to the consumption minimum. It might appear, therefore, that the provision of weather insurance, by smoothing income, might lead to increased holdings of bullocks and to welfare gains. Figure 1 displays the effects

[20] These policy experiments are ceteris paribus experiments; they do not trace out the full consequences of each intervention. For example, it is unlikely that introducing weather insurance will not affect informal insurance arrangements. Given the possibility of estimating parameters that describe the technology of both production and preferences, it may also 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.

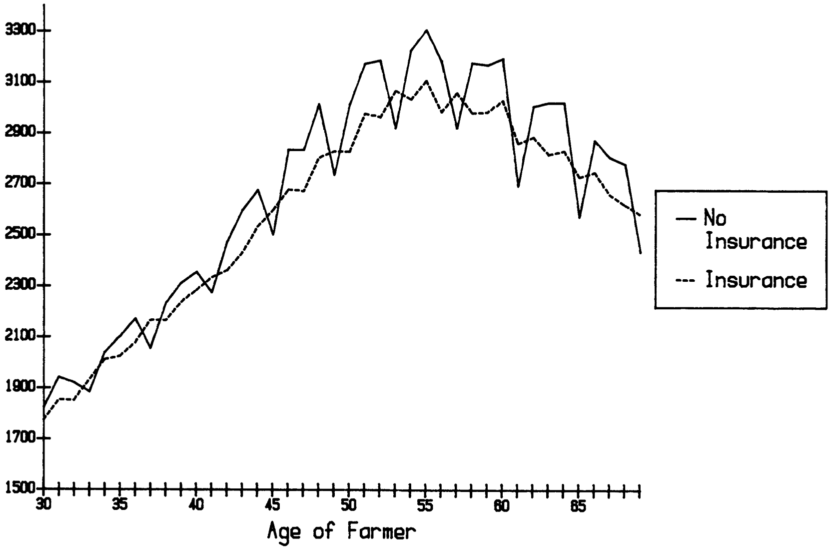

FIG. 1.—Effects of (actuarially fair) weather insurance on life cycle consumption

of providing farmers with actuarially fair weather insurance on life cycle consumption. The actuarially fair premium is calculated as 30 percent of the estimated profit loss due to bad weather, which occurs 30 percent of the time (in this case every 4 years). Farmers thus pay 188 rupees each year in return for a smoother income path. The figure indicates that life cycle consumption loses its weather-induced jaggedness, as expected. However, average consumption levels (and average bullock stocks) are lower when farmers pay the full cost of weather insurance, because of 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 with the baseline regime without insurance. The principal reason is that farmers are already in part insured via the consumption floor, although it is also true that weather shocks are only a part of uncertainty. The consumption floor, which reflects farmers' informal insurance arrangements via transfers and which also exacts a penalty in terms of profits and bullock sales, evidently is almost a perfect substitute for weather insurance. The provision of such insurance, 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, given existing

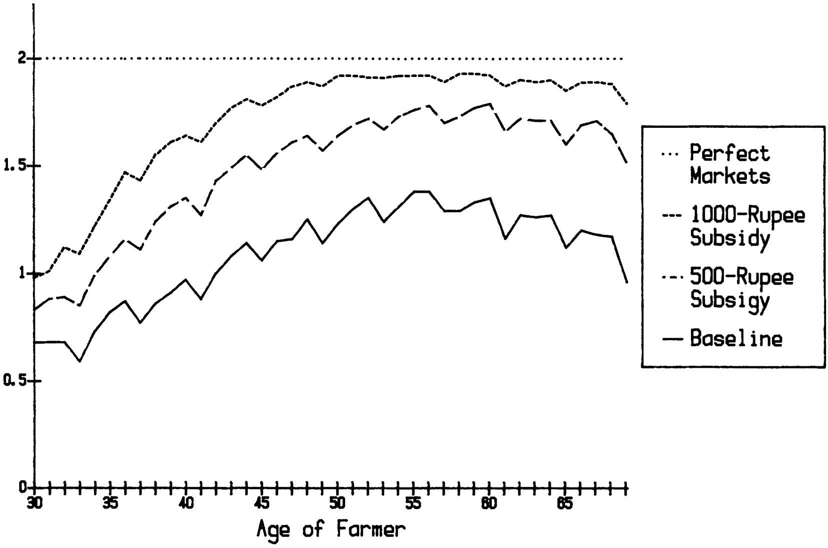

FIG. 2.—Effects of income subsidies on life cycle bullock accumulation compared with actual (baseline) and perfect markets environments.

arrangements. Thus our model and estimates indicate that the almost universal resistance to nonsubsidized weather insurance schemes among farmers in low-income countries is not due to their being indifferent to risk, but rather may reflect the availability of cheaper (but not cheap) alternative mechanisms of consumption smoothing in an environment characterized by credit constraints and additional nonweather risk sources.[21]

If low incomes combined with borrowing constraints are the primary reasons for underinvestment in bullocks, then improvements in earnings, from whatever source, should increase agricultural profitability by permitting farmers to accumulate larger capital stocks. In figure 2 we present the results of simulations in which we provide farmers with constant 500-rupee and 1,000-rupee income streams. We compare average bullock accumulations under these regimes with those of an empirical baseline (no earnings supplement and no insurance). The importance of income levels, given borrowing constraints, is visible in figure 2. By age 50, farmers with supplementary incomes

[21] 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 setup 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.

of 500 (1,000) rupees are, on average, holding bullock stocks that are within 22 (6.5) percent of the profit-maximizing level of two, compared with the baseline in which at age 50 average bullock stocks are only 58 percent of the profit-maximizing level. Moreover, fluctuations in bullock stocks appear to be substantially smaller for farmers with supplementary incomes. With higher (nonagricultural) incomes, farmers not only are thus able to "afford" higher profits but, because of declining absolute risk aversion (in discretionary consumption), appear to be more willing to maintain farm profitability at the expense of fluctuations in consumption. These results imply that increasing opportunities for members of farm households to obtain jobs that pay assured salaries may also increase the capital intensity of agricultural investments, the efficiency of agricultural operations, and the stability of agricultural output.[22]

IV. Conclusion

In rural settings in which average income levels are low and there are important constraints on borrowing, agricultural resource decisions presumably reflect households' concern to smooth consumption in the face of exogenously variable income. In this paper we have tested this hypothesis by examining investments by Indian farm households in one of the most important production factors in that area of the world, bullocks. These farm assets not only are central to production in the monsoon agricultural economy of India but are a large component of nonland asset holdings and appear to serve a prominent role in smoothing consumption. Indian data from a number of sources indicate that sales of bullocks, which are transacted in well-developed interregional markets, 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.

On the basis of longitudinal data from villages located in the semiarid tropics of India, we have estimated the parameters of a dynamic model of investment in bullocks and irrigation equipment that incorporates 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 averse to risk. Moreover, despite the importance of bullock ownership in producing crops efficiently and its value in mitigating consumption volatility,

[22] 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 (1986) and Benjamin (1992).

the estimates indicate that there is considerable underinvestment in bullocks. Farmers' aversion to risk combined with borrowing constraints and low incomes 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 the life cycle data on bullock accumulations for low- and middle-income farmers, suggested that (i) despite farmers' aversion to risk, the provision of actuarially fair weather insurance would have no little effect on farmer welfare, consistent with the almost universal resistance of farmers to unsubsidized insurance schemes, in part because of farmers' evident ability to insure a minimum level of consumption via informal arrangements and because of the importance of other risk factors; and (ii) increases in opportunities for farm households to receive assured streams of income have a substantial positive effect on agricultural production efficiency and output. Thus credit-constrained farmers appear to be too poor to be efficient in the absence of alternative income sources.

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. Important simplifying assumptions employed were the quasi separability of production, the absence of alternative choices with regard to assets, and the complete absence of credit to smooth consumption across production cycles. We also 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.

The assumption that no credit is available for consumption purposes also does not exactly conform to reality. However, few farmers receive loans for this purpose, and the coexistence of the prevalence of bullock sales and the high profitability of bullocks suggests that consumption-motivated borrowing is importantly constrained. Because we have assumed that all consumption smoothing above subsistence is achieved via bullock turnover, it is likely that when the model is fitted to the actual paths of bullock stocks over time, the parameter estimates obtained understate farmers' motivation for smoothing consumption (because turnover in bullock stocks would be higher where no credit was available for consumption). It is thus likely that our results provide a lower-bound estimate of farmers' aversion to risk, which is thus evidently an important factor in the production decisions of farmers and their institutional arrangements in credit-constrained economies.

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