

## Technical Change and Human Capital Returns and Investments: Evidence from the Green Revolution

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In this paper, we use newly-available longitudinal household data from a large national probability sample of over 4000 rural households in India (rural households represented 82% of all households in India as of 1961 and 76% in 1981) covering the period 1968-1981, merged with supplementary area-specific data on crop-yields and schools, to estimate the effects of economic development and investments in schools on the returns to human capital and schooling investments. In particular, we use the longitudinal data to test whether exogenous technical change increases the returns to schooling, whether schooling investments respond to changing schooling returns and whether the absence of schools constrains schooling investments.

Although investments in schooling are thought by many to be critical to the achievement of economic growth, it is not clear whether such investments are sufficient to achieve growth even in a policy environment not hostile to markets. While there are several studies (e.g., Psacharopoulos) which purport to show that the rates of return in many low-income countries, at least with respect to primary schooling, are very high, these studies are based on cross-sectional wage data from very unrepresentative and selective samples, and do not appear to explain why high average levels of schooling have been associated with economic stagnation in low-income settings such as Kerala state in India, Costa Rica, and the Philippines.

In another view (e.g., Nelson and Phelps and T.W. Schultz), economic growth increases the returns to schooling. Thus, schooling will have a low return in a stagnant economy, whereas low levels of schooling will deter further development in a potentially high-growth environment. This view has received some support in studies of the U.S. farm population (Welch) and from studies of U.S. industries (Bartel and Lichtenberg and Mincer and Higuchi).<sup>1</sup>

There are two important aspects of the technical change associated with Indian green revolution experience relevant to uncovering the effects of economic growth on schooling returns. First, the technology, embodied in new high-yielding variety (HYV) seeds, was originally imported from outside of India.<sup>2</sup> While over time locally-based breeding programs adapted the imported technologies to the indigenous

characteristics of regions (Evenson), the innovation industries (agricultural research centers) and the direct beneficiaries (farmers) are distinct; thus problems arising from the endogeneity of technical change with respect to the human capital or other characteristics of the beneficiaries are minimized. This situation contrasts sharply with that of industries in developed countries where a substantial component of research and development is undertaken and financed by the firms themselves. A second feature of the green revolution in India is that the ability to exploit the new seeds profitably was substantially different across India because of (exogenous) differentials in local soil and weather conditions. Thus, households in different areas of India were exposed differentially to changing productivity frontiers.

In section 1 we briefly describe the spatially differentiated aggregate trends in agricultural productivity, schooling and school growth during the Indian green revolution and the household data sets that we use in the subsequent analyses. We also present preliminary estimates of the relationships between schooling, by level, and the adoption of the new seeds in the early stages of the green revolution. In section 2 we set out the method by which we identify the extent to which the returns to schooling (and other factors of production) are altered by technical change when income growth may be affected by both schooling and other productive investments. Section 3 presents the estimates of area-specific rates of technical change and their effects on factor returns for two periods for which we have comparable data, 1968-71 and 1971-82. Both sets of estimates indicate that rates of return to primary schooling increased as a consequence of the green revolution, rising at significantly higher rates in areas experiencing high rates of increase in technology levels. In section 4 we test the hypotheses that schooling enrollment in rural farm households rose most in areas where technical change was i) most advanced and ii) most rapid based on our estimates of area-specific rates of technical change. These results indicate that enrollment rates responded significantly to the increases in returns to schooling induced by technical change in areas where these changes occurred. The estimates also suggest that increases in the proximity of schools played an independent role in increasing the level of schooling investment.

## **1. The Green Revolution in India: Aggregate Time-Series and Household Panel Data**

The introduction of new hybrid seed varieties that took place in India in the mid 1960's had substantial effects on agricultural productivity that differed importantly across areas of the country due in part to differences in agroclimatic conditions relevant to the new seeds' productivity. Figure 1 reports the growth of crop yields based on a Laspeyres index for the four major crops affected by technical innovation for 12 (of 17) Indian states for which we also have survey data over the period 1961-1981. This series is constructed using annual district-level data on output and cropped area from Vanneman that we smoothed using locally-weighted scatterplot smoothing (bandwidth=.8) to eliminate noise due to weather fluctuations. The states are arranged left-to right by average rates of growth. As can be seen, states differed considerably in their rates of agricultural productivity change with respect to the potentially high-yielding varieties (HYV) of crops. For example, while yields rose by almost threefold in Karnataka and by almost 2 and a half times in Punjab, yields of these crops rose by less than 20% over the 21-year period in three states, including Kerala which had the highest levels of literacy of any state at the beginning of the period.

In the same twenty-one year period there was also a significant increase in schooling levels in the rural populations of many states. Figure 2 displays the change in the proportion of 15-year old males with at least a primary school education by state and year, where the states are ordered by yield growth as in Figure 1. These schooling rates were constructed from the 1982 rural cross-sectional survey data, described below, based on the age-specific educational achievement information for men aged 15 through 35 in 1982.<sup>3</sup> The figures indicate that while the highest-growth states do tend to have the highest rates of increase in schooling attainment, schooling also increased dramatically in the lowest-growth state - Madhya Pradesh - and in another low-growth state, Rajasthan. This discrepancy between growth rates and human capital investments is in part "explained" by investments in schools, if such investments are viewed as exogenous. Figure 3 displays by state the growth in the number of primary schools, arranged in the same ordering as in Figures 1 and 2.<sup>4</sup> While the highest-growth states appear to exhibit among the highest increases in schools, evidently needed to support the rise in primary schooling in those areas, the number of schools also increased at a high rate in the low-growth states that had high rates of increase in schooling attainment.

The trends depicted in Figures 1 through 3 thus are consistent with the hypotheses that investment in schools increases schooling in the absence of economic growth and that schooling may affect growth, but also suggest that schooling investments do not necessarily lead to economic growth, at least in agricultural populations. However, the intercorrelations between yield growth, schooling attainment and schools cannot precisely provide information on whether or by how much exogenous growth or school investments affected schooling rates, whether school investments were affected by economic growth or how yield rates were affected by schooling investments. The principal problem is that measures of agricultural productivity growth such as that used in Figure 1 reflect technical change as well as the change in productive inputs such as irrigation, schooling, and fertilizer, the use of which may be influenced by technical change, if any. These data thus cannot be used as a measure of technical change. In order to extract estimates of technical change from information on productivity it is thus necessary to control for the changes in productive inputs. One way that this may be done is through estimation of the agricultural technology before and after the onset of the green revolution. Such an approach also permits direct assessment of the effects of technical change on the returns to schooling.

Few data sets contain the detailed time-series information on farm production necessary to consistently estimate the agricultural technology and even fewer of these are sufficiently broad in scope (with respect to space and/or time) to capture differential rates of technical change. The data used in this paper are well suited to this approach, however. In particular, we use two panel data sets from India describing farm households from national probability surveys begun in the crop year 1968-69, soon after the onset of the green revolution, and ending in the crop year 1981-82. The first data set, the National Council of Applied Economic research (NCAER) Additional Rural Incomes Survey (ARIS), provides longitudinal information for 4,118 households pertaining to the crop years 1968-69, 1969-70 and 1970-71 on use of high-yielding seed varieties, household structure, schooling, income, asset divestiture, and agricultural inputs and outputs. Also provided is information on the village infrastructure, including the presence of a school, and information at the village level on adverse weather conditions. The villages (250), districts (96) and states are identified in

the coded data, enabling the merging of these data with other area-level information such as the crop-yield data by district from Vanneman.

In the crop year 1981-82, NCAER conducted a resurvey of the 1970-71 households, the Rural Economic Development Survey (REDS). These data, only recently made available, provide information on a subset of the original 1970-71 households, principally those in which the household head remained the same over the interval, based on the same survey design as in the ARIS. Thus, the ARIS data and the REDS data combined with the 1970-71 ARIS data form two panels, covering the periods 1968-69 through 1970-71 and 1970-71 through 1981-82. The data sources are described in the Appendix.

The 1968-71 ARIS panel data indicate that by 1971 approximately 51% of the cultivating households were using the high-yielding varieties. Simple explorations of the data also suggest that primary, but not higher, levels of schooling are significantly related to the probability that the household had adopted the new varieties. Table 1 reports, for a sample of farmers residing in districts in which at least one sample farmer was cultivating with HYV seeds, maximum-likelihood probit estimates of the relationship between the probability that a farm household ever adopted the new seeds by 1970-71, the highest level of schooling attainment in the household, the amount of owned land, and variables indicating residence in a district with a government program designed to facilitate the adoption of the new seeds, the Intensive Agricultural District Program (IADP), or a village with an extension program. The highest schooling level is divided into two categories - primary schooling and completed secondary schooling. As can be seen from the sample descriptive statistics reported in column one of the table less than half of households had anyone with primary schooling and only slightly more than 20% had anyone with completed secondary schooling.

The probit estimates reported in columns two and three indicate that farm households containing at least one adult who had completed primary schooling were significantly more likely, controlling for land size, to have adopted the new seeds by 1970-71. However, schooling beyond the primary level does not appear to have significantly affected adoption. In accord with other studies (e.g., Rosenzweig, 1990; Besley and Case), farmers with larger owned landholdings are also more likely to have adopted the new seeds by 1970-71. And,

given these farmer characteristics, use of HYV seeds is more likely in IADP districts<sup>5</sup> although not more likely in villages with an agricultural extension program

After the initial introduction of HYVs in the mid 1960s, the technology choice facing farmers in areas conducive to the growing of the high-yielding seeds became a matter of choice among vintages of the new seeds rather than that between high-yielding seeds and traditional seeds. The returns to schooling associated with technical change in this latter period thus accrued primarily from early adoption (and efficient use) of the newest seeds rather than from a shift to HYV from traditional seeds. It is thus instructive to use the ARIS panel, collected in the early period when HYV and "new technology" were isomorphic, to examine whether schooling is associated with the timing of technology adoption. In the fourth column of Table 1 probit estimates are presented of a discrete hazards model that makes use of all three periods of the data; the dependent variable is the probability of adopting in a particular year given that a farmer had not adopted the technology previously. These results indicate that farm households with at least one primary-schooled person, in addition to being more likely to have adopted the seeds at all, were more likely to have adopted the seeds when they first became available. Similar to the cumulative probability probit results in columns two and three, additional schooling beyond the primary level does not appear to have affected the timing of adoption. However, as indicated by the estimates reported in the fifth column the presence of the village extension program and the IADP appear to have accelerated adoption, even though farmers in such areas were no more likely to have ever adopted the new seeds by 1970.

## **2. Identifying the Returns to Schooling and Technical Change**

The estimates in Table 1 are only suggestive of the possibility that the returns to (primary) schooling are complementary with technical change. It is possible that schooling (and land size) are correlated with unmeasured factors that affect technology adoption and its timing, such as land quality or weather conditions. Moreover, the finding that more-schooled farmers in India at the onset of the green revolution were more likely to adopt the new seed varieties provides little insight into the precise role that schooling plays in a regime of technological change. In particular, more schooled farmers may experience higher returns from the

new seeds because they allocate inputs such as fertilizer more efficiently and/or schooling may directly facilitate the more rapid adoption of the technology, given the potential productivity gains of the technology.

In an environment with weather uncertainty, the role of schooling in augmenting productivity can be expressed by including schooling as an input in the production function describing the new technology and relating output  $q_t$  in period  $t$  to inputs used in that period after the resolution of uncertainty:

$$(1) \quad q_t = H_t q(\theta_t, S_t, L_t, F_t, A_t, \mu, \epsilon_t),$$

where  $H_t$  is the amount of land cultivated under the new-technology (HYV seeds),  $\theta_t$  is the level of technology at time  $t$ ,  $S_t$  is the level of schooling,  $L_t$  and  $F_t$  are the quantities of labor and fertilizer allocated per unit of cultivated area in time-period  $t$ ,  $A_t$  represents farm assets at the beginning of the period,  $\mu$  is a vector of time-invariant farm-specific productivity attributes (land quality, farmer ability), and  $\epsilon_t$  is the time-varying stochastic weather shock. If schooling is productive under the new technology, then  $\partial q_t / \partial S_t > 0$ .

To estimate the productivity of schooling under the new technology relative to that under the old, an equivalent approach to directly estimating (1) is to estimate a HYV-conditional profit function, i.e., a profit function that conditions on the use of HYV seeds. This approach exploits the fact that in the first years of the green revolution, farmers used both HYV and traditional seeds. The HYV-conditional profit function  $\Pi^h$ , with output price normalized to one, is given by:

$$(2) \quad \pi_t = \Pi^h(H_t, S_t, A_t, w_t, p_t, \theta_t, \mu, \epsilon_t) = \max_{L_t, L'_t, F_t, F'_t} [H_t [q(\theta_t, S_t, L_t, F_t; A_t, \mu, \epsilon_t) - w_t L_t - p_t F_t] + (\lambda - H_t) [q'(\theta'_t, S_t, L'_t, F'_t; A_t, \mu, \epsilon'_t) - w_t L'_t - p_t F'_t]],$$

where  $w_t$  and  $p_t$  are the prices of labor and fertilizer, respectively,  $\lambda$  is the total amount of land cultivated, and primes denote old (traditional) technology values. The envelope theorem implies that the cross derivative of the conditional (on seed use) profit function with respect to  $H$  and  $S$  provides the difference in the contributions of schooling to output under the traditional and new technologies; i.e.,

$$(3) \quad \partial^2 \Pi_t^h / \partial H_t \partial S_t = \partial q_t / \partial S_t - \partial q'_t / \partial S_t,$$

where  $\Pi_t^h$  denotes the HYV-conditional profit function evaluated at time  $t$ . Estimation of the HYV-conditional profit function (2) thus identifies the relative productivity of schooling across old and new

technologies, conditional on the extent of technology adoption.

An estimate of the differential contribution of schooling across old and new technologies, based on the conditional profit function (2), may underestimate the contribution of schooling to productivity augmentation if schooling directly facilitates technology adoption (H). A method for estimating the total contribution of schooling to profitability under technological change is to estimate the unconditional or meta-profit function  $\Pi^m$ .<sup>6</sup>

$$(4) \quad \pi_t = \Pi^m(S_t, A_t, w_t, p_t, \theta_t, \mu, \epsilon_t) = \max_{H_t} \Pi^h(H_t, S_t, A_t, w_t, p_t, \theta_t, \mu, \epsilon_t).$$

Estimation of (4) provides the total effect of schooling on profits,  $\partial \Pi_t^m / \partial S_t$  - the effects of schooling on both the profitability of HYVs and the level of adoption of HYVs.<sup>7</sup> Moreover, estimation of the meta-profit function also provides a way of uncovering the effects of technology on the returns to schooling,  $\partial \Pi_t^m / \partial S_t \partial \theta_t$ , if the level of technology  $\theta_t$  can be estimated.<sup>8</sup>

To identify technology effects on the contributions of specific production factors in (4), we exploit the fact that the potential profitability of the new technology varies exogenously across India due to area-specific differences in suitability to the new high-yielding seed varieties. Prior to the introduction of the new seeds, the level of technology is assumed to be the same in all areas (districts), as is implicitly assumed in empirical studies of production or profit functions based on cross-sectional data. Without loss of generality, technology in this period is normalized to zero ( $\theta_{j0}=0$ ). Thus for any farmer  $i$  in area  $j$  in the pre-growth period 0, a linear, first-order approximation of (4) is:

$$(5) \quad \pi_{ij0} = \sum \beta_k A_{kij0} + \beta_s S_{ij0} + \beta_L W_{j0} + \beta_F P_{j0} + \mu_{ij} + \beta_\epsilon \epsilon_{ij0},$$

where the vector of farm assets  $A$  includes the amounts of irrigated and unirrigated land and the values of farm machinery (e.g., plows, threshers), irrigation assets (e.g., pumps, tubewells), other farm assets (sheds, carts), and animals.

After the onset of technological change, technology grows in each district at different rates, depending on the area-specific endowments. As a consequence, the structure of the profit function changes and becomes differentiated across areas: for example, the return to irrigated land ( $\partial \Pi_t^m / \partial A_{kijt}$  for  $k$ =irrigated)



will rise if the technology is best suited to irrigated land or the cost effect of rising wages ( $\beta_L = -\partial \Pi_t^m / \partial w_t$ ) will fall if the technology is labor saving. Under the assumption that the coefficients  $\beta$  in (5) change differentially across districts as linear functions of the district-specific technology  $\theta_{jt}$ , then in any post technology change period  $t$ , the meta-profit function (5) for district  $j$  becomes:

$$(6) \quad \pi_{ijt} = \theta_{jt} + \sum (\beta_k + \alpha_k \theta_{kijt}) A_{kijt} + (\beta_s + \alpha_s \theta_{jt}) S_{ijt} + (\beta_L + \alpha_L \theta_{jt}) w_{jt} + (\beta_F + \alpha_F \theta_{jt}) p_{jt} + \mu_{ij} \\ + (\beta_\epsilon + \alpha_\epsilon \theta_{jt}) \epsilon_{ijt},$$

where  $\alpha$  expresses how the contribution of a fixed or variable factor to profits differs by the area-specific level of the technology  $\theta_{jt}$ . Note that (6) is a generalization of (5), yielding (5) when  $t=0$  because  $\theta_{j0}=0$ .

Although equation (6) is non-linear in parameters, such parameters are identified because for each asset stock and price in  $\Pi^m$  an increase in the level of technology is assumed to have the same effect in every area (i.e., the  $\alpha$ s are asset- and price-specific but not district-specific). Equation (6) could be thus be estimated using non-linear least squares from cross-section data taken from any period subsequent to the initiation of the green revolution, with the district-specific  $\theta_{jt}$ s replaced by area-specific dummy variables. However, area dummy variables would confound permanent differences across areas in the levels of profitability with different rates of technological change if there are unmeasured permanent characteristics of farms and areas that are reflected in profits ( $\mu_{ij}$ ). With two periods of data, however, the first obtained at the onset of technological change and the second  $t$  periods from that date, the fixed effect could be eliminated using the data in first difference form. Subtracting (5) from (6) yields:

$$(7) \quad \Delta \pi_{ijt} = \tau_{jt} + \sum \beta_k \Delta A_{kijt} + \sum \alpha_k \tau_{jt} A_{kijt} + \sum \beta_s \Delta S_{ijt} + \sum \alpha_s \tau_{jt} S_{ijt} + \sum \beta_L \Delta w_{jt} + \sum \alpha_L \tau_{jt} w_{jt} + \sum \beta_F \Delta p_{jt} \\ + \sum \alpha_F \tau_{jt} p_{jt} + \sum \beta_\epsilon \Delta \epsilon_{ijt} + \sum \alpha_\epsilon \tau_{jt} \epsilon_{ijt},$$

where  $\Delta \pi_{ijt} = \pi_{ijt} - \pi_{ij0}$  and so forth and  $\tau_{jt} = \Delta \theta_{jt} = \theta_{jt}$  because  $\theta_0 = 0$  by assumption.

By estimating equation (7) it is thus possible to identify both area-specific technological change, expressed in terms of profit growth net of the changes in fixed factors and variable input prices, and the key relationship between the returns to schooling and technological change. First, district-level dummies capture variation in technological change  $\tau_{jt}$  in each district. Second, the coefficients associated with the interactions

of the area-specific technology change estimate and the second-period level of each variable reflect the extent to which the return to the variables changed over time as a function of technical change  $\tau_{jt}$  (the  $\alpha$ s). Third, the coefficient associated with the change in each variable reflects its initial, pre-technological growth return  $\beta$ . Thus, with respect to schooling, the hypothesis that more schooled farmers have a comparative advantage in using or implementing new technologies implies that  $\alpha_s > 0$  and, given the stagnation of technology prior to the green revolution, that  $\beta_s \approx 0$ . Similarly, one might expect that the marginal productivity of irrigated land would be increasing in  $\tau$  due to the sensitivity of the new seeds to water control, and that  $\alpha_L < 0$  if high-growth areas are labor-using.

Estimation of (7) using least squares will still not necessarily yield consistent estimates of the parameters because the shocks in the initial period  $\epsilon_0$  are likely to be correlated with the change in accumulated asset stocks  $\Delta A_{ijt}$  over the interval. In particular, farmers with unusually high profits in the initial period are likely to accumulate more assets over the next and subsequent periods. For example, assume that the farmer problem is:

$$(8) \quad \max E_0 \sum \zeta^t U(c_t),$$

subject to

$$(9) \quad c_t = \pi_t - a_t - p_{st} s_t \text{ and}$$

$$(10) \quad A_{t+1} = A_t + a_t$$

$$(11) \quad S_{t+1} = S_t + s_t,$$

subject to (4), where  $s_t$  and  $a_t$  are the net investments in schooling and assets in the  $t$ th period, and  $p_{st}$  is the price of a unit of schooling. In this model, in which the farmer cannot borrow, the dynamic decision rule for asset accumulation in the  $t$ th period in general form is:

$$(12) \quad a_t = a(A_t, S_t, \lambda, \mu, w_t, p_t, p_{st}, \epsilon_t, \theta_t).^9$$

Given dynamic behavior, it thus is necessary to estimate the non-linear differenced equation (7) using instrumental variables. Given the structure of the model, it is also evident that the history of shocks up to the realization of the shock  $\epsilon_0$  and initial or lagged asset levels affect the farmer's subsequent asset

accumulations but not, net of those, changes in profits. We thus use as instruments to predict asset changes across the panel interval (i) information on the values of inherited<sup>10</sup> irrigated and unirrigated land, farm equipment, farm buildings, consumer durables, and farm animals, (ii) the first-period levels of asset variables and first-period primary schooling, and (iii) lagged indicators of village-level weather, which are assumed to be i.i.d. All of these variables are interacted with the district-specific dummy variables in the first-stage equations.

### **3. Estimates of Technical Change and the Returns to Schooling**

#### **a. Estimates from the 1968-69 - 1970-71 Panel Data**

We first use the 1968-69-70-71 ARIS panel to estimate the HYV-conditional profit function, given the availability of HYV seed information in those data, and to estimate the meta-profit function  $\alpha$  and  $\beta$  parameters. The subset of ARIS households used to estimate the HYV-conditional profit function consists of those households cultivating land in 1969-70 and 1970-71 and also present in the 1981-82 REDS panel, 1517 households.<sup>11</sup> The characteristics of these farming households are reported in the first and second columns of Table 2. All of the farm asset values, farm profits and wage rates were deflated by state-specific, rural consumer price indices and are expressed in 1970 rupees. Based on the results of Table 1 we measured the schooling level of the household by creating an indicator variable for whether or not any individual in the household had completed primary schooling. As can be seen from the sample characteristics, in the last one-year interval of the ARIS panel there was a fourfold increase in acreage devoted to HYV seeds as well as increases in the real value of stocks of irrigation assets and other farm equipment.

To maximize the possibility of identifying area-specific technical change in the 1968-69 through 1970-71 period using estimation of a meta-profit function, we use observations on the farming households from the first and third years of the panel survey, a sample of 1694 households, described in the third and fourth columns of Table 2. The ARIS panel data cannot be used to estimate based on the meta-profit function the (initial) returns to schooling ( $\beta_s$ ) or owned land because schooling information and asset stock data are only available for the last round (1970-71). Using our estimation method the year-specific gross investment

data can be used to identify  $\beta$ s for farm equipment, irrigation assets, and farm buildings (other assets), but the absence of independently-collected initial-period stock information limits the instrument list and thus the ability to identify all of the  $\alpha$ s.<sup>12</sup> Another limitation of the ARIS panel is that there is information on fertilizer use only for the third round. Because fertilizer during the entire period was sold at a fixed, below market price, fertilizer use was rationed. To take this into account, we need to include fertilizer as a direct determinant of profits, rather than include its price. This cannot be done for the specifications based on the ARIS panel.

Columns one through three of Table 3 present the fixed effects-instrumental variables estimates of the HYV-conditional profit equation (2) based on the cultivating households in the ARIS panel, with columns five through seven providing the estimates obtained without the use of instruments. In the linear specification in column one, the estimate of the effect of HYV acreage on profits suggests that on average use of HYV was barely profitable in this early period - one additional acre planted with HYV seeds increased profits by a statistically insignificant 292 rupees, or by 7.5%. The non-instrumented estimate is even lower (column five), but this is likely the result of the correlation of the lagged profit shock and the increase in HYV use - as in the adoption model of Besley and Case farmers experiencing a positive profit shock will likely increase their subsequent use of HYV seeds and in an environment with borrowing constraints add to their stocks of equipment. Because the first period shock is subtracted from that of the second period, this dynamic behavior will result in negative biases in the coefficients. Indeed, the farm equipment coefficients obtained from the non-instrumented estimates (column five) are all lower than the corresponding coefficients obtained using instruments in column one.

In the second specification in which the returns to HYV use are permitted to vary with both schooling and the proportion of land irrigated, it can be seen that, based on the instrumented estimates, the profitability of the new seeds was highly dependent on the use of irrigation and on schooling. Moreover, inclusion of the irrigation and schooling interaction terms results in the constant term becoming insignificant. These interactions thus account for all of the unexplained trend in profits reflected in the statistically significant

constant term in the linear specification. In column three, therefore, the statistically insignificant intercept term is dropped, resulting in slightly larger coefficient estimates.

The point estimates in the third column suggest that among primary-schooled farm households, a minimum of 40% of the land must be irrigated for HYV cultivation to be profitable. Even for farmers with completely irrigated fields, however, those without primary schooling evidently reaped little gain from use of the HYV seeds in this initial period. For primary-schooled farm households with wholly irrigated landholdings, however, HYV seeds were quite profitable, with each acre sown with HYV seeds raising profits by 1538 (1970) rupees, or by 39.5% at the sample means.<sup>13</sup>

The estimates of the unconditional profit function, obtained using non-linear instrumental variables fixed effects, for the 1968-69 - 1970-71 interval are reported in the fourth (instrumented) and eighth (non-instrumented) columns of Table 3.<sup>14</sup> Although the absence of initial-period stock data bars the complete realization of the profit-function methodology and although over this relatively short period technical change is likely to be limited, the positive estimate of the  $\alpha$  for schooling whether or not instruments are used is consistent with the conditional profit estimates, although far less precise when instruments are used. In particular, the estimate of .69 for  $\alpha_s$  indicates that for every rupee increase in real profits due to exogenous area-specific technical change those households with primary schooling in the area experienced an additional .69 rupees profit gain compared with their less schooled neighbors.

b. Estimates from the 1970-71 - 1981-82 Panel

The ARIS-REDS panel permits, as noted, the full implementation of the profit-function methodology over an interval in which differentials in growth rates are likely to have been more pronounced than in the short period covered by the ARIS panel. The ARIS-REDS panel is based on cultivating households in the 1970-71 ARIS and 1981-82 REDS data sets in which the head of the household remained the same, 1788 households, 63% of the 1970-71 cultivating households. These households are described in the last two columns of Table 2. While the ARIS-based panel thus provides information on growth rates only over a three-year interval, the merged ARIS-REDS data provide estimates of schooling returns and area-specific

growth rates net of investment effects for an eleven-year period, a period in which the proportion of households with a primary schooled adult rose from 33% to over 50%. Because stock data are available at both end points of the ARIS-REDS panel, moreover, it is possible to identify both the initial-level of and the change in returns from the meta profit function for all asset variables.

An important issue in the use of the long-period panel data is the selectivity of the panel and the effects of the sample selection on the estimates. The sample selection rule employed by NCAER in resurveying the initial ARIS households was that either the head remained the same in 1982 or the head had died but the household had remained intact (all sons remained in the same household). We exclude this latter set of households (14.6% of those resurveyed) because continued joint residence of sons after the death of a head is both unusual and not likely to be random (Foster). Thus, the panel data set that we use is almost wholly selected on the basis of the survival of the 1970-71 household head to 1982, as only 4.8% of the original households were not resurveyed because they moved from the village (Vashishtha).<sup>15</sup>

Although it is unlikely that the “frailty” of household heads is uncorrelated with profit levels or schooling, our first differencing procedure sweeps out permanent health differences or survival propensities. The only potential source of selectivity bias in the survival-based panel thus arises from the possibility that profit shocks in the initial period influenced the subsequent survival of the household head. To assess the importance of the sensitivity of adult mortality to income, we used Indian Census Data to construct district-specific (log) rural mortality rates for age 25+ males for the decades 1961-71 and 1971-81 for the 96 districts represented in the ARIS data. We then estimated, using the data in first differences, the effects of crop productivity on adult mortality, using the district-specific productivity measures shown (by state) in Figure 1. The hypothesis that agricultural productivity did not affect mortality could not be rejected at conventional levels of significance. The point estimates also suggest that the effects of productivity on adult mortality were small - adults in areas with productivity one standard deviation above the mean in 1982 were only 3% less likely to die compared to those in an average district.<sup>16</sup>

The non-linear fixed effects instrumental variables estimates of the meta profit function are reported

in column one and the corresponding non-instrumented estimates are reported in column two of Table 4. In columns three and four estimates are reported of the meta-profit function replicating the specification employed, because of data limitations, using the earlier-period ARIS panel. The meta-profit estimates using either specification indicate that there was also a significant increase in the returns to schooling over the period 1970-1982. The point estimate of  $\alpha_s$  from the statistically-preferred full specification suggests that within an area experiencing an exogenous change in profits, net of changes in stocks, that is one standard deviation (2900 rupees) above the mean, the return to primary school increased by 1612 rupees (in real terms). It is also evident that the average return to schooling in the initial period ( $\beta_s$ ) was 368 rupees. These estimates imply that, given that average profits in 1971 were 3500 rupees in districts in which any HYV seeds were used, *ceteris paribus*, primary educated households had 11% higher profits in 1971 compared with uneducated households. By 1982, however, such households had 46% higher profits in districts with growth rates one standard deviation above average. Thus, the differential rise in the returns to schooling associated with technical change was substantial.

Of the other coefficients, those for irrigation assets, for fertilizer and for wage rates are of particular interest. The  $\beta$  and  $\alpha$  coefficient estimates for the irrigation asset variable suggest directly the importance of water control under the new technology regime. The estimates indicate that in the initial period the return to a rupee investment in irrigation equipment was .14 rupees such that an investment in irrigation assets of 1000 rupees would have raised pre-growth profits by 4%. In a district with net profit growth one standard deviation above average, however, the same investment in irrigation assets would have increased profits by 11%. The estimates also indicate that net of the changes in the stock of irrigation assets, the returns to both unirrigated land and to irrigated land fell in the high growth districts. That the average returns to irrigated land fell in high growth areas despite the increased return to irrigation equipment may reflect the placement of less productive land under irrigation. Indeed, increases in the amount of land under irrigation were greatest in districts that our estimates suggest experienced the highest rates of technical change.

In accord with casual observation, the estimated negative  $\alpha$  coefficient for the wage rate indicates

that in high growth areas, the demand for labor increased significantly. The negative estimate of  $\alpha$  for fertilizer, however, would appear to contradict the widely-held view that the new HYV seeds are fertilizer-intensive. However, as noted the reason we treat this variable production input as a fixed factor is that fertilizer was rationed in India during the period. Note that if fertilizer were employed at profit-maximizing levels, the coefficients for both  $\alpha$  and  $\beta$  would be zero in the profit function. The positive  $\beta$  coefficient for fertilizer indicates that in 1970-71 fertilizer use was constrained. The negative  $\alpha$  coefficient suggests that the constraints on fertilizer availability were relaxed more in high growth areas. Indeed, the government IADP program was designed to facilitate HYV use and had as a program component the objective of increasing the availability of fertilizer in areas selected to be most productive for the new seeds. In our data, the IADP districts and districts identified as high-growth based on our estimates of the meta-profit function exhibited above-average increases in fertilizer use from 1970-71 through 1981-82.

#### **4. Technology Shocks and School Enrollment in Farm and Non-Farm Households**

If, as indicated by the estimates of the profit function, the returns to schooling rose significantly in those areas experiencing more rapid technical change, it would be expected that this would have evoked an increase in schooling investments in such areas. The estimates of the district-specific technology growth coefficients  $\tau_{jt}$  enable a test of the responsiveness of schooling investment to technical change-induced increases in rates of return to schooling. To estimate the effects, if any, of technological change on schooling investments, we estimate a linear approximation to the dynamic schooling decision rule of farm households analogous to that for any capital stock, as given by (11). Thus, current ( $t^{\text{th}}$  period) school investment decisions depend (i) on the state variables at  $t$  - the stock of assets, including the human capital (schooling) of family members, (ii) on variables affecting current income, such as the level of technology  $\theta_{jt}$ , wage rates, and the weather realizations (assuming the human capital decisions are at least in part made after the resolution of weather uncertainty), and (iii) on variables affecting expectations about the future.

The variables influencing perceptions about the future include the parameters of the distribution of technology and of weather. These would be impounded in the fixed effect  $\eta_{jk}$  along with agroclimatic



endowments and the ability and preferences of the farmer. In addition, we allow for the possibility that technology shocks provide information about the future because they are autocorrelated. In particular, we assume that technical change in district  $j$  at time  $t$ ,  $\tau_{jt} = \theta_{jt} - \theta_{jt-1}$ , exhibits first-order autocorrelation:  $\tau_{jt} = \rho \tau_{jt-1} + \epsilon_{jt}$ . Assuming  $\rho > 0$ , this expression captures in a relatively simple way the notion that districts that are well suited to the adoption of new seeds in one period are also likely to be well suited to the adoption of seeds that become available in subsequent periods. This notion is consistent with the evidence that in the Indian "green revolution", areas benefitting from early growth exhibited more rapid growth in subsequent periods, a pattern that is evident in Figure 1. If recent technical change predicts future growth and thus higher returns to schooling then, net of the technology level, recent growth should result in higher schooling investment.

If the principal route by which human capital affects productivity is through its impact on entrepreneurial and allocative abilities, we would not expect, in the context of the Indian green revolution, for schooling to be rewarded in off-farm manual labor.<sup>17</sup> For the same reason, we expect that shocks to technology will affect the schooling decisions more for those groups for whom schooling will be used in a managerial capacity. Because the sons of the heads of farm households typically stay on the family's land and will inherit that land at the death of the head, expectations of future technology growth will raise the expected returns to schooling for children in farm households.<sup>18</sup> For children in households that do not own land, who will likely be hired as laborers, the pace of technology only matters to the extent that the future level of technology will affect the demand for labor.<sup>19</sup> Thus, shocks to technology will affect the future incomes of the landless and landed households, but rates of return to schooling will be affected more strongly for children in farming households.

Just as for the profit equations, the presence of the unobservable household fixed effect will lead to biased estimates of the parameters of the schooling investment equation if estimated from cross-sectional data using least squares. For example, if households differ in human capital endowments or preferences (e.g., for risk), their accumulations of assets and human capital will not be orthogonal to the compound disturbance

term. Moreover, schools may have been distributed across areas according to unmeasured human capital endowments (Pitt *et al.*, Rosenzweig and Wolpin, 1986). Using the panel observations on households enables us to purge out the household fixed effect by differencing. Between 1971 and 1982 schools were constructed in 38 of the 235 villages included in the sample.

A consequence of estimating the linearized school investment equation in differenced form is that in the differenced equation only the technology shock (change) variables appear. If we used the estimated district- and period-specific  $\tau$  parameters obtained from the profit function estimates to directly represent the technology growth rates that farmers use to decide on future schooling decisions, such variables would measure the technology shocks with error, which would bias all coefficients. An alternative measure, the growth in HYV-crop yields, reflects more than technical change, such as the effects of endogenous investments in capital. We thus use the two sets of district-specific  $\tau$  coefficients, estimated from the 1968-71 and 1971-82 periods, as instruments for the district-specific yields and the growth rates in HYV yields per-acre in the five-year periods preceding the 1970-71 and 1981-82 survey rounds. The estimated district-specific  $\tau$ 's are valid instruments because their measurement errors should be uncorrelated with both the components of the yield measures that are unrelated to technical change and with the disturbances in the (differenced) schooling equation.

Because the first-period unmeasured random shock (such as to technology) may also influence the subsequent accumulation of wealth, household composition or even the location of schools by a governmental authority, least squares estimates of the differenced enrollment equations may be biased. Accordingly, we again use instruments, using the same criteria as used for the estimation of the profit equations.<sup>20</sup>

To construct a variable corresponding to schooling investment, we use information provided in the ARIS data on the numbers of children ages 5-9 in school and the numbers of boys and girls ages 10-14 in school in each household to construct household-specific enrollment rates for the age group 5-14. Based on the information at the individual level on schooling enrollment in the REDS survey round, we constructed a comparable household-level enrollment rate. The school investment equation is thus estimated for the subset

of farm households from which we estimated the profit functions but which also had school-age children aged 5-14 in each survey round. In addition we add to the sample of these farm households those households who do not own land, using the same selection criteria - the household had at least one child in the requisite age range in both survey rounds. We can thus compare whether or not farm and non-farm rural households respond as strongly to the technology shock.<sup>21</sup> The total sample size is 847 households, of which 152 are non-farm households.

Columns one and two of Table 5 provide the means and standard deviations of the of the sample variables in 1971 and their change from 1971 through 1982. Over this period average enrollment rates rose by 35% and HYV crop yields by 30%. The sample data indicate that enrollment rates rose the fastest in high-growth areas - Figure 4 provides a scatterplot of the district-specific changes in enrollment rates and in the Laspeyres-weighted HYV yields from 1971 through 1982, and the least squares regression line, based on the sample district observations. The positive slope is only moderate, however, and the t-ratio on the coefficient is 1.83. The IV fixed-effects regression results for household enrollment rates are reported in the third column of Table 5. These estimates, which take into account the changing composition of household members and assets as well as changes induced by perturbations to initial schooling, also indicate that in areas with higher (predicted) yield levels enrollment rates are higher, but the effect is considerably stronger than indicated in the simple scatterplot - the slope coefficient is more than double that from the simple regression line in Figure 4 and is 1.7 times the coefficient when the enrollment equation is estimated without instruments, as reported in column five.

The predicted yield growth in the recent period (the technology shock) also has a positive sign but only when instrument are used; the negative coefficient for growth in the set of non-instrumented estimates may reflect the positive effects of unexplained initial-period increases in schooling investments on subsequent yield growth. In the second specification the effects of both the level of and the shock to technology are allowed to differ across farm and rural non-farm households. The instrumented (fixed effects-IV) estimates, reported in the third column, indicate that the level of technology has the same positive effect on enrollment

rates in the two types of households, but that the technology shock only has a positive effect on the school enrollment of children in farm households, as expected; this difference in the growth effect on enrollment between farm and non-farm households is statistically significant.

The point estimates associated with the technology variables indicate that technical change has substantial effects on school enrollment. In areas with an average yield one standard-deviation above the mean in 1970-71 (an additional 918 rupees per acre or 30% higher yields), enrollment rates for all rural households are ten percentage points or 34% higher, using the 1970-71 enrollment rate of .29 as the base. In areas with a recent growth in yields one standard-deviation above mean growth (451 rupees per-acre in the 1969-71 period, approximately double average growth) the enrollment rates in farm households are an additional sixteen percentage points or 53% higher compared with school enrollment rates of farm households in average-growth areas.

The estimates also indicate that the (predicted) presence of a school in the village significantly increases school enrollment rates. This result thus suggests that the location of schools can influence enrollment rates. The point estimate indicates that building a school in a village can more than double the enrollment rate for children ages 5 through 14 years of age. Given that schools were evidently built in higher-growth areas (Behrman, Rosenzweig and Vashishtha), school-building policy reinforced the differential effects of growth across areas on schooling. Interestingly, the non-instrumented fixed effects procedure results in an estimated school effect on enrollment which is considerably underestimated. This is consistent with the hypothesis that schools were built in villages in which there were positive initial demand shocks, reflected in above-average 1971 enrollment rates.

The growth effects on schooling investment may in part reflect income effects. However, while the estimates of the effects of wealth on school enrollment are positive, they are not statistically significant from zero whether instruments are used or not. This suggests that the income effects of growth are small or insignificant, although the yield variable may be picking up wealth effects better than the wealth variable to the extent that the prices of land and housing provided in the data are not reflecting fully the increased

profitability of agricultural production. The negative wage coefficient also does not indicate a positive income effect, but this variable also reflects in part the opportunity costs of schooling (Rosenzweig and Evenson, 1977; Rosenzweig, 1990).<sup>22</sup>

Finally, the household composition variables indicate that the addition of a boy 10-14 increases school enrollment by approximately 10 percentage points, while adding a girl in the same age group does not increase enrollment - these effects are statistically significantly different and are in accord with the observed overall higher rates of schooling for boys compared with girls. The presence of adult men with primary schooling, but not adult women, increases significantly (by 10 percentage points) the enrollment rates of the children. This may in part as well reflect income effects.<sup>23</sup>

## **5. Conclusion**

While it has frequently been suggested that education interacts importantly with economic growth, the extent and nature of this relationship are only poorly understood and documented. In this paper we have used panel and time-series data describing the green revolution period in India to measure several components of this relationship: the effects of exogenous technical change on the returns to schooling, the effects of schooling on the profitability of technical change and the effects of technical change as well as school availability on household schooling investment.

The results indicate that the relationship between schooling and economic change is complex. First, the returns to schooling are affected by technical change. Not only did the returns to (primary) schooling increase on average during a period of rapid technical progress, but the returns increased at a higher rate in those areas that grew the most rapidly over the relevant period: educated individuals are either more able to manage new technologies or they become aware of productive innovations at earlier stages of growth than their less educated counterparts. Regardless of which of these two components is responsible the implication is the same: faced with new information, educated individuals are better able to take advantage of technical change. These results also have implications for the effects of schooling levels on the returns to technical change: technical change is likely to have a greater effect on profits in an educated population than an

uneducated one. The initial levels and distribution of human capital thus matter for the subsequent rates of economic growth propelled by technical change and for the resulting distribution of incomes.

Second, as might be expected based on the evidence on the returns to schooling, it is clear that technical change results in greater private investment in schooling. Areas that grew more rapidly than average over the study period also benefitted from greater than average increases in levels of schooling, net of changes in wealth, wages and the availability of schools. Moreover, for cultivating households these effects were more prominent when the economic growth was relatively recent, a result that is consistent with the idea that expectations about future technical change are influenced by technical change in the relatively recent past. The significant difference between cultivating and non-cultivating households with regard to the growth effect suggests that the effects of technical change, at least initially, are primarily driven by the returns to on-farm profitability associated with allocative decisions.

Third, the evidence indicates that increased availability of schools importantly increased levels of schooling in India over the study period. While this result is not especially surprising, it implies that the low levels of schooling in India in 1971 were not entirely the result of low returns to schooling. Coupled with the fact that the returns to technical change are higher in areas with higher levels of schooling this result suggests that public investment in schooling infrastructure can importantly effect economic growth, although perhaps only in areas experiencing rapid technical change.

Finally, the central implication of this paper is neither that investment in schooling is more important than investment in technical change nor the other way around. Instead, the evidence suggests that policies resulting in greater technical change are complementary with those increasing investment in schooling: the returns to investment in technical change will in general be higher when primary schooling is accessible and the returns to investment in schooling will be higher when technical change is more rapid.

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## Appendix

The household data used in this study come from data files produced by The National Council of Applied Economic Research (NCAER) from their Additional Rural Incomes Survey (ARIS) and from their follow-up survey The Rural Economic and Demographic Survey (REDS). The ARIS is based on a stratified random sample of 5115 households interviewed in the crop year 1968-69 meant to be representative of households residing in all rural areas of India in that year excluding Andaman and Nicobar and Lakshadwip Islands. These households were reinterviewed in the crop years 1969-70 and 1970-71. Two data sets constructed from ARIS are used in this study: (i) a merged panel file providing information for each crop year at the household level for the 4118 households that were successfully interviewed in all three rounds and (ii) a file describing the household characteristics for the 4756 households interviewed in 1970-71. A subset of farming households from the merged panel file of 4118 households is used to estimate the conditional profit functions for the 1969-71 period.

Estimates of the production technology and its change from 1971 through 1982 and the effects of technical change on school enrollment are based on data files constructed by merging the 1970-71 ARIS file with data from a subset of the households in REDS. REDS was a resurvey in the crop year 1981-82 of a subset of the 4756 households responding in the 1970-71 round of ARIS - those households for whom the household head remained the same in the crop year 1981-82 and those households in which the head had died but the rest of immediate male relatives of the head had remained together. Only 4.8% of these eligible households were not resurveyed. The number of panel households providing information is 3139. All households residing in Assam and non-intact subsets of households in which the head had died were not included in the panel component of REDS. REDS also included a random sample of non-panel households that included those new households not residing in the villages in 1970-71 and descendants of original (1970-71) households. The 1971-82 panel data constructed for the research reported here uses only the subset of the 1970-71 households in which the head was alive in 1981-82.

The Indian district data set used in this paper was made available by The Data Archives Section of

the Indian Council of Social Science Research and was originally assembled by Reeve Vanneman and Douglas Barnes. This data set includes annual information on yields, prices, and acreage planted by crop and district for the period 1961 through 1981. These data were used to construct an annual measure of HYV-crop productivity over the period 1961-1981. In particular, a Laspeyres index of the value of per-hectare yields from the four major crops affected by technical innovation, wheat, rice, sorghum and corn was constructed for each district as well as for each state. The series for each area was then smoothed using locally-weighted scatterplot smoothing (bandwidth=.8) to eliminate noise due to weather fluctuations. The state-level data are presented in Figure 1 and the district level data were used to estimate the schooling decision rules presented in Table 5.

The Vanneman and Barnes data also includes demographic information from the Indian Population Censuses of 1961, 1971 and 1981. These were used to compute adult mortality indices by district and decade. In particular, the ratio of men aged 35 and above in 1971 to men aged 25 and above in 1961 was used as an inverse measure of adult mortality over the period 1961-1971 and the ratio of men aged 35 and above in 1981 to men aged 25 and above in 1971 was used as an inverse measure of adult mortality over the period 1971-1981.

## Footnotes

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1. A significant problem with the evidence from industrial countries on the consequences of technical change for skill demand is the potential endogeneity of technical change. Indeed, relatively strong assumptions have been used to distinguish the effects of technical change on skill premia from the effects of human capital on technical change itself.

2. The principal limitation of the new seeds is that they require an environment with a reliable or controllable supply of water (as well as a high level of fertilizer). Thus, many areas are still unable to exploit the new technologies. The "imported" nature of the technology is indicated in the first rounds of the data. In the 1971 round, the three most-used rice seeds have Asian origins - Taichung-65, Taiwan-3, I.R.-8 (a rice variety from the Philippines International Rice Research Institute) - while the top three wheat varieties have Spanish names - Sonora-64, Lerma Rojo, Sharbati Sonora. No seed variety information is provided in the 1982 round.

3. Because data of this type only provide an accurate measure of schooling for individuals continuing to reside in the state in which they were educated, these figures may be misleading if states differ importantly in the extent to which schooling affects out migration to urban areas or other states. Fortunately, however, rates of rural to urban migration in India are relatively low and male rates of rural-to-rural migration particularly low (Rosenzweig and Stark). That is why we examine only the schooling rates of men in Figure 2. Adult women in the households may have migrated in, via marriage, from other states

4. These data are from Binswanger et al..

5. This should not be interpreted as the effect of the program, as such programs were purposively placed in areas believed likely to be profitable for HYV seeds.

6. Note that the meta-profit function is not "unconditional" in the usual sense of the word as it conditions on asset stocks. It is only unconditional relative to  $\Pi^h(\cdot)$ .

7. It is also possible that the educated will be more likely to adopt HYV because they are more likely to have more precise knowledge of the benefits to HYV use, an effect that we have not explicitly modeled.

8. Of course since the variables in the HYV-conditional profit function will in general be correlated with  $\theta_i$ , the technology term cannot be ignored when estimating  $\Pi^h(\cdot)$ . The difference is that for the HYV-conditional

profit function there is no need to distinguish  $\theta_t$  from  $\mu$  and  $\epsilon_t$  and thus  $\theta_t$  may be treated as an incidental parameter. For a sufficiently short time period estimates of schooling effects on the profitability of HYVs may be obtained by assuming  $\theta_t$  is constant. For the meta-profit function, however, estimates of the effects of technical change on the returns to schooling can only be obtained if there is variation in  $\theta_t$  across regions and/or time.

9. For present purposes we assume that  $\tau_t$  is i.i.d. so that  $\theta_t$  completely summarizes information on future levels and changes in technology. As we will discuss below, if technical change  $\tau_t$  is first-order autocorrelated then  $\tau_t$  will also appear in (12) because recent technical change helps to predict subsequent change.

10. Because the men who become household heads normally do so upon the death of their father and because the panel sample used for analysis was selected so that none of the households experienced a change in the household head, all inheritances occurred prior to the first survey observation in all cases.

11. The sample is restricted to households from REDS because the inherited asset variables, needed for instruments, are only available in those data. We use the last two periods of the data because there is considerably more use of HYV seeds in those years compared to the first.

12. Initial-period (1968) stocks can be constructed from the gross investment (flow) and final-year stock data. However, any measurement errors in the flow variables are carried over to the constructed stocks, rendering them invalid as instruments.

13. We also estimated a specification in which we added an interaction between the presence of village extension service and HYV use to ascertain if extension contributed in the period to the profitability of the new seeds. Although the interaction coefficient was positive, it was approximately one-tenth the magnitude of the schooling coefficient and was not statistically significant. Schooling appears to have played a substantially more important role in enhancing HYV profitability in this period than did extension services.

14. The power of the instruments appears to be good. The lowest F-statistic, for degrees of freedom 187 and 1379, on the excluded instruments was 9.56 (for fertilizer change) and the partial  $R^2$  was .56 which appears satisfactory given the findings in Bound *et al.*

15. This proportion is likely to be even less for the cultivating households (almost all of whom own land) that we use to estimate the profit function.

16. The coefficient estimate was -.0000127, with a Huber t-ratio of 0.35 (N=96).

17. For evidence, see Rosenzweig, 1995.

18. Given positive assortative mating by schooling and by landholdings (Rosenzweig and Stark), incentives to educate girls may also increase with technical change in farm households even though typically daughters leave the household at marriage and do not inherit the family land.

19. In fact, our estimates imply that the green-revolution technology was labor using. If schooling is in part a consumption good favorable technology shocks, by increasing income, would increase the demand for schooling among the landless.

20. In addition to those instruments used to estimate the profit function, we use the first-period (1970-71) stocks of children over age 5 and adults. The members of these age groups were born prior to the 1970-71 shock and their mortality is unlikely to have been affected by shocks in that period. We also use the presence

of a school in the first round as an instrument for whether or not an additional or any school was located in the village in which the household resides over the 1970-71 through 1981-82 period. The ARIS data provides information on the presence of a school, and the REDS data on whether or not a school was constructed in the village since the 1970-71 round.

21. The restriction of the sample to households with children of school age in both rounds may lead to selectivity bias even when fixed effects are purged, but only to the extent that schooling shocks in the initial period cause households to alter their subsequent fertility behavior (or affect child survival). For example, if a shock to schooling in the first period induces higher income growth and if income is negatively related to fertility, our estimates of income effects and of the effects of technology shocks on schooling investment would be biased negatively. However, of those households with at least one child in the 5-14 age group in 1970-71, only 22% did not also have a child in that age group in the 1981-82 round. Because of the possibility of selectivity, however, we do not disaggregate the enrollment measure by sex and age, as this would require much more selective samples. To assess the sensitivity of fertility to income, we used district-specific Indian Census data from 1981 and 1971 on the number of children age 0-5 to estimate, using first differences, the effect of the crop productivity index on (log) fertility. The coefficient estimate was  $-.000162$  with a Huber t-ratio of 1.2. The point estimate suggests that in areas experiencing a one standard-deviation rise in productivity, fertility would be only 1.5% lower compared to a district with average growth.

22. If labor markets were imperfect, the productive assets of the farm such as land, which raise the marginal value product of children in on-farm work, might negatively affect school enrollment, masking any positive wealth effect. However, inclusion of the numbers of children in the 5-9 and 10-14 age groups in the profit function indicated that profits are not affected by the presence of these family members. Moreover, interacting the landless indicator variable with land-housing wealth and with wages indicated that the effects of wages and of wealth on enrollment are not different across farm and nonfarm households. These results are consistent with labor markets working well and with family and hired child labor being perfect substitutes.

23. It does not reflect, as in most cross-sectional studies, unmeasured preferences of the households for schooling, as this is impounded in the fixed effect.