HUMAN CAPITAL: EDUCATION
AND AGRICULTURE

by

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Abstract [*]

This chapter presents a review and synthesis of effects of education in agriculture, summarizes major contributions, and suggests major research gaps in the literature. Although growth in knowledge enables skill acquisition and specialization of labor, which generally raises labor productivity, and technical change, the dominant effect on agriculture has been technical change. A puzzle remains why schooling does not have broader direct impacts in agriculture. Furthermore, as we proxy education or general intellectual achievement by schooling in our empirical research, this has led to biased interpretations of impacts when general intellectual achievement of school graduate changes over time and perhaps in nonlinear ways.

Key words: education, schooling, agriculture, human capital, impact analysis

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Human Capital: Education and Agriculture

by Wallace E. Huffman[*]

Education is widely considered to be the most important form of human capital (Becker 1993, p.1-13). A major part of formal education or general intellectual achievement is obtained in elementary and secondary schools and in colleges/universities. Although there are differences in exactly what these institutions teach in different parts of the world, common components are skills, knowledge, and a method of analyzing problems (Schultz 1963, p.1-19; Becker 1993, p.1-13; Bishop 1989). Investments of students' and teachers' time and other inputs are used in the schooling process, and schooling of an individual beyond the permanent literary level, which is generally 3 to 4 years of formal schooling, has lifetime impacts on almost all of his or her activities. These are widely accepted to include labor productivity and wage rates, but also include choices of occupation, geographical location, information acquisition, and technology. In agriculture, the returns to schooling seem to increase substantially as a country goes from traditional agriculture to modernizing, which creates a dynamic technical and economic environment requiring information acquisition, technology evaluation, and adjustments to change (Schultz, 1964; Schultz 1975; Becker 1993, p.1-13).

The objective of this paper is to present a review and synthesis of the broad effects of education on agriculture and to summarize where major contributions lie and where major gaps exist in the literature. The first section presents a conceptual framework for education's contribution. The second section reviews and synthesizes the empirical evidence which is organized around the topics of (1) choices about where to work, (2) technology adoption and information acquisition, (3) agricultural production, (4) agricultural productivity decomposition, and (5) household income. The third section presents a summary of major contributions and research gaps in the literature.

A Conceptual Framework

Overview

Growth in knowledge seems to be a major factor causing the long-term rise in labor productivity, real wage rates, and per capita incomes in market economies. First, as the stock of knowledge grows, the opportunities for individuals to invest in specialized knowledge (e.g., schooling, training) that raises their productivity occurs (Becker and Murphy 1993; Jones 1998,

p.71-87). Hence, the returns to labor's specialization arise through workers taking on narrower and more specialized tasks, but to get output produced, this means that a group of workers having different skills must cooperate together. "Team production" within or across firms raises special incentive problems (Gibbons 1998; Becker and Murphy 1993). As the degree of specialization of labor and tasks increases, the number of different tasks and specialists that must be coordinated increases. For the continuation of this growth process emphasizing knowledge accumulation and specialization, an economy must find new ways to reduce team-labor coordinating costs. Economies that have high coordination/ transaction costs because of a weak economic exchange system (i.e., absence of private property, weak contracts, suppressed prices and markets) reduce the incentives for workers and firms to specialize, given any stock of knowledge, and reduce labor productivity and per capita incomes (Williamson 1985).

Second, as the stock of knowledge grows the opportunities to produce new technologies that become embodied in new capital goods (e.g., Romer 1990) and intermediate goods (see Jones 1998, p.88-107; Huffman and Evenson 1993) occur. These innovations are frequently adopted in manufacturing, agriculture, and other sectors. Considerable evidence exists for the United States that unskilled labor and capital services are substitutes in manufacturing, but skilled labor and capital services are complements (see Orazem et al. 1997; Griliches 1969, 1970). More generally, capital services and labor become less substitutable as the skills of labor increase, and labor and capital services eventually become complements, especially for college trained labor. This means that as knowledge and technology advance, the demand for skilled (more highly educated) labor grows relative to the demand for less skilled (educated) labor, and the potential exists for a rise in the real (and relative) wage of skilled labor.

Production on farms is one of biological processes, but major differences exist between crop and livestock production. The seasonal and spatial nature of crop production place severe constraints on large scale or specialized units and mechanized production. With plant biological (clocks) processes sequenced by day-length and temperature, little opportunity exists to use mechanization to speed up the production processes, even on large farms. Because planting and harvesting for any given crop must occur within a narrow time window at any location, a major limit to size of specialized enterprises occurs. Crop rotation, or nonspecialized production, has historically been one important method for controlling pest and disease problems in crops and balancing soil nutrient availability with plant nutrient needs. Chemical and biological control of pests and chemical fertilizer applications are relatively new technological alternatives to crop rotation, and they have facilitated crop specialization.

Because plants occupy fixed land area as they grow, machines suitable for mechanization of crop production must be mobile and move across the fields or through plant materials that are fixed in location. Furthermore, machines must be small relative to plot or field sizes. Thus, a special type of mechanization is required for crops. This contrasts with industrial (and livestock) production where the production plant is fixed and materials move through it. The latter type of production permits workers to become specialized in one phase of the total production process

and this has aided labor productivity in the industrial sector of developed countries. It is difficult for workers in crop production to be fully employed and to specialize in any phase of production.

Livestock production is relatively free of constraints due to seasonal and spatial attributes. It is economically feasible to speed up or slow the rate of production by changing the diet and activity level of animals and poultry during the growing and finishing phases. Production can be organized in sequential phases where all phases from birth to finishing occur on one farm or where different farms specialize in different phases. Advances in animal health products, animal feeding, housing and equipment, and management have made it technically possible to speed up the growing and finishing phases by using large confined animal production systems which greatly increase animal densities and populations. To further reduce disease problems in large animal confined systems, animals of different ages can be segregated and raised apart in "all-in, all-out" systems. With the growing and finishing of animals and birds in a facility in phased groups, livestock production becomes similar to production of industrial goods where workers have the opportunity to specialize in a particular phase of production.

When firms are heterogeneous within a sector or have some specialized resources! e.g., land, climate, knowledge! the potential impact of new technologies will differ across them.   It is costly for entrepreneurs to acquire information, evaluate the available technologies, and adopt only the new ones that are expected to make them better off. Considerable evidence exists that schooling of entrepreneurs becomes a valuable skill when the technology is changing, for example when agriculture undergoes a transition from traditional to modernizing (Schultz 1975; Becker 1993; Huffman 1998).[1]

Agricultural Household Models

The behavior of agricultural households has been modeled from different perspectives depending on the central issue researchers are considering. If human capital investment decisions! e.g., how much schooling, informal training, and information to obtain or whether to adopt a new technology! are the central focus, models of multi-period household utility maximization with human capital production or innovation have provided a useful guide to empirical models. If household members have obtained their human capital, e.g., formal education, and the impact of this human capital on other outcomes! e.g., occupational choice, hours of work, purchased input use, wage rates, income! are the central focus, one-period static agricultural household models have provided a useful guide to researchers about which variables are expected to affect behavior or outcomes and how they might be related. In particular, behavioral models provide one useful guide to researchers for deciding which variables should be treated as endogenous, e.g., choices, and which are exogenous or causal variables.

In the following two subsections, two representative agricultural household models are outlined. One is a multi-period dynamic agricultural household model, and the other is a single-period static agricultural household model.

A Three-Period Model with Human Capital Production and Investment. Building on the multiperiod household decision model of Ghez and Beeker (1975), the human capital (e.g., education) investment model of Ben-Porath (1967) and Mincer (1974, p.14-15), and the one-period agricultural household models of Singh et al. (1986) and Huffman (1991b), a multiperiod agricultural household focused on consumption, human capital production, farm production, and human capital service allocation is presented. To capture the main economic issues in human capital investment decisions but yet to keep the model simple enough that many of its implications are easily interpretable, I assume that the household is risk-neutral and has a three-period planning horizon or lifetime.

In each period, the farm household is assumed to consume human capital services (i.e., leisure, L_{1j}, j=t, t+1, t+2) and goods (X_{1j}), and to have a well-behaved intertemporal utility function:

$$U = U(L_{1t}, X_{1t}, L_{1t+1}, X_{1t+1}, L_{1t+2}, X_{2t+2}). \tag{1}$$

The household faces technology constraints on the production of human capital and farm output. First, the production of the human capital in each period, i.e., the investment, is assumed to use two variable inputs: human capital services (L_{2j}) from an individual's initial human capital endowment or past human capital investment, a purchased input (X_{2j}), and a fixed individual or household specific genetic or innate ability factor (A_2):

$$Z_{2j} = F_2(L_{2j}, X_{2j}, A_2), \quad F_2(0, X_{2j}, A_2) = 0, F_2(L_{2j}, 0, A_2) \geq 0. \tag{2}$$

$F_2(\cdot)$ exhibits decreasing returns to scale in L_2 and X_2. Hence, when the input prices of L_{2j} and X_{2j} are fixed to the household, the assumption of decreasing returns implies that marginal cost is rising with added Z_{2j}. For schooling, this assumption reflects the upper limit on mental capacity of an individual to learn in each period.

Second, the production of farm output is assumed to use two variable inputs and one fixed input. The variable inputs are human capital services of household members (L_{3j}) and purchase inputs (X_{3j}), and the fixed input is technology and agro-climatic conditions (A_3):

$$Z_{3j} = F_3(L_{3j}, X_{3j}, A_3). \tag{3}$$

The farm production function is assumed to exhibit decreasing return to scale in L_3 and X_3 in the region of an optimal solution, e.g., due to natural limitations placed on the production process by agro-climatic conditions.[2]

To facilitate the modeling, human capital investments are assumed to change the quantity of human capital services available, but they do not affect the wage rate per unit of human capital service. Hence, this is a model where human capital investments augment the effective number of units of human time that are available each period rather than raising the wage per unit of actual

time worked. The later approach is the one taken by the hedonic wage literature, e.g., Mincer (1974) and Willis (1986).

The household has an initial human capital endowment K_t^o; human capital is permitted to depreciate over time at a rate $*$, $0 \# * < 1$ due to obsolescence or wearing out, and the human capital services available to the household in each period are:

$$L_j \ ' \ " K_j \ ' \ " \left\{ \sum_{j'\,t}^{t\%2} \left[(1\&*)^{j\&t} K_t^o \% ((1\&*)^{j\&t\&1} Z_{2j\&1} \right] \right\} \tag{4}$$

where $"$ (> 0) is the time invariant rate of conversion of human capital stock to services and $($ equals 1, adjusting human capital investment (a flow) to a stock. The available human capital services are allocated among four activities: leisure (L_{1j}), human capital production (L_{2j}), farm production (L_{3j}), and wage work (L_j^w):

$$L_J \ ' \ L_{1j} \% L_{2j} \% L_{3j} \% L_j^w, L_{2j}, L_{3j}, L_j^w \$ 0. \tag{5}$$

Because human capital services allocated in any period j to human capital production, farm productions, and wage work can be zero, a non-negativity constraint is imposed on these choices.

The household faces a multiperiod cash budget constraint:

$$\sum_{j'\,t}^{t\%2} \left[\frac{P_{3j}^{(} Z_{3j} \% W_j L_j^w}{(1\%r)^{t\&j}} \right] \ . \ \sum_{i'\,1}^{3} \sum_{j'\,t}^{t\%2} \left[\frac{P_{ij} X_{ij} \% C_j}{(1\%r)^{j\&t}} \right] \tag{6}$$

where $P_{3j}^{(}$ is the (expected) price of farm output and P_{ij} is the (expected) price of the purchased consumption goods, inputs into human capital production, or inputs into farm production, respectively. The (expected) wage rate per unit of human capital services is W_j; $C_j \$ 0$ is any fixed cost associated with the household's production or consumption activities, e.g., on licenses or fees; and r is a fixed discount rate.

If equation (3) is substituted into equation (6), then the farm production and multiperiod budget constraints are combined into one constraint:

$$\sum_{j'\,t}^{t\%2} \left[\frac{P_{3j}^{(} F_3 (L_{3j}, X_{3j}, A_3) \% W_j L_j^w}{(1\%r)^{j\&t}} \right] \ . \ \sum_{i'\,1}^{3} \sum_{j'\,t}^{t\%2} \left[\frac{P_{ij} X_{ij} \% C_j}{(1\%r)^{j\&t}} \right]. \tag{7}$$

The household can now be viewed as making multiperiod consumption, human capital production, farm production, and labor supply decisions by maximizing equation (1) subject to equations (7), (2), (4), and (5), including nonnegativity constraints. The Kuhn-Tucker first-order conditions are

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$$\partial N/\partial L_{1j} = \partial U/\partial L_{1j} - \beta_j/(1+r)^{j-t} = 0, \quad j = t, t+1, t+2 \tag{8}$$

$$\partial N/\partial X_{1j} = \partial U/\partial X_{1j} - P_{1j}/(1+r)^{j-t} = 0, \tag{9}$$

$$\partial N/\partial L_{2t} = \lambda\left[PV_{Z_{2t}}^t \cdot MP_{L_{2t}}^{Z_2} - \beta_t\right] \le 0, \; L_{2t} \ge 0, \; L_{2t}\left[PV_{Z_{2t}}^t \cdot MP_{L_{2t}}^{Z_2} - \beta_t\right] = 0, \tag{10}$$

where $PV_{Z_{2t}}^t = \dfrac{P_{3t+1}^(}{(1+r)}\dfrac{\partial Z_{3t+1}}{\partial L_{3t+1}}\dfrac{\partial L_{3t+1}}{\partial Z_{2t}} + \dfrac{P_{3t+2}^(}{(1+r)^2}\dfrac{\partial Z_{3t+2}}{\partial L_{3t+2}}\dfrac{\partial L_{3t+2}}{\partial Z_{2t}} + \dfrac{W_t''}{(1+r)} + \dfrac{W_{t+1}''(1-\star)}{(1+r)^2},$

and $MP_{L_{2t}}^{Z_2} = \partial Z_{2t}/\partial L_{2t}, \; MP_{x_{2t}}^{Z_2} = \partial Z_{2t}/\partial X_{2t},$

$$\partial N/\partial X_{2t} = \lambda\left[PV_{Z_{2t}}^t \cdot MP_{X_{2t}}^{Z_2} - P_{2t}\right] \le 0, \; X_{2t} \ge 0, \; X_{2t}\left[PV_{Z_{2t}}^t \cdot MP_{X_{2t}}^{Z_2} - P_{2t}\right] = 0, \tag{11}$$

$$\partial N/\partial L_{2t+1} = \lambda\left[PV_{Z_{2t+1}}^t \cdot MP_{L_{2t+1}}^{Z_2} - \beta_{t+1}/(1+r)\right] \le 0, \; L_{2t+1} \ge 0, \tag{12}$$

$$L_{2t+1}\left[PV_{Zt+1}^t \cdot MP_{L_{2t+1}}^{Z_2} - \beta_{t+1}/(1+r)\right] = 0$$

where $PV_{Z_{2t+1}}^t = \dfrac{P_{3t+2}^(}{(1+r)^2}\dfrac{\partial Z_{3t+2}}{\partial L_{3t+2}}\dfrac{\partial L_{3t+1}}{\partial Z_{2t+1}}$

$$\partial N/\partial X_{2t+1} = \lambda\left[PV_{Z_{2t+1}}^t \cdot MP_{X_{2t+1}}^{Z_2} - P_{2t+1}/(1+r)\right] \le 0, \; Z_{2t+1} \ge 0, \tag{13}$$

$$X_{2t+1}\left[PV_{Z_{2t+1}}^t \cdot MP_{X_{2t+1}}^{Z_2} - P_{2t+1}/(1+r)\right] = 0,$$

$$\partial N/\partial L_{3j} = \lambda P_{3j}^(\cdot MP_{L_{3j}}^{Z_3} - \beta_j/(1+r)^{j-t} \le 0, \; L_{3j} \ge 0, \tag{14}$$

$$L_{3j}\left[\lambda P_{3j}^(MP_{L_{3j}}^{Z_3} - \beta_j/(1+r)^{j-t}\right] = 0,$$

$$\partial N/\partial X_{3j} = \lambda P_{3j}^(\cdot MP_{X_{3j}}^{Z_3} - P_{ij}/(1+r)^{j-t} = 0, \tag{15}$$

$$\partial N/\partial L_j^w = \left[-\beta_j + W_j\right]/(1+r)^{j-t} \le 0, \; L_j^w \ge 0, \; L_j^W\left[-\beta_j + W_j\right] = 0 \tag{16}$$

plus equations (7), (2), (4), and (5), where $\theta_j/(1+r)^{j-t}$ is the marginal utility of human capital services in period ,j and . is the marginal utility of discounted cash income.

A little interpretation of the first-order conditions is enlightening. Equations (8) and (9) imply the standard condition for optimal mix of consumption goods in each period. The ratios of the marginal utilities of the two goods should equal the ratio of their respective marginal cost or shadow price, i.e., $MU_{L_{1j}}/MU_{X_{1j}} = \theta_j/P_{ij}$. Equations (10), (11), (12), and (13) imply that the production of human capital (investment) in each period occurs at minimum cost, i.e., $MP_{L_{2t}}/MP_{X_{2t}} = \theta_t/P_{2t}$, $MP_{L_{2t\%1}}/MP_{X_{2t\%1}} = \theta_{t\%t}/P_{2t\%1}$. Equations (14) and (15) imply that the production of farm output is at minimum cost in each period, $MP_{L_{3j}}/MP_{X_{3j}} = \theta_j/P_{3j}$.

Because of the human capital focus of this chapter, equations (10) through (14) have special meaning. First, they provide the information about the optimal size of the human capital investment in each period. It is the quantity or rate where the present value of the marginal return from a unit of Z_2 equals the present value of the marginal cost. For period t this implies $PV_{Z_{2t}}^t = MC_{Z_{2t}} = (\theta_t/MP_{L_{2t}}^{Z_2}) = (P_{2t}/MP_{X_{2t}}^{Z_2})$.

Second, insights about the tendency for investing in skill to weaken or strengthen ties to farming are obtained by examining the present value of the marginal return for Z_2. There are two effects! the change in the present value of the additional farm production that results from allocating part of an incremental unit of human capital services to this activity, and the change in the present value of the additional labor market earnings that results from allocating the remaining part of an increment of human capital services to nonfarm wage work.

The allocation of an increment in human capital services between farm production and off-farm work is quite sensitive to the relative impact of human capital on the marginal product of labor in farm and non-farm work or to the elasticity of demand faced by the individual for human capital services. If the marginal product of human capital services is low, perhaps zero, in farm production but relatively large in nonfarm wage work, and it is optimal to invest in human capital, then an agricultural household will increase the share of employed human capital services allocated to nonfarm wage work. This outcome might be expected in countries where skills are rewarded in the nonfarm labor market but where new technologies for agriculture are being developed slowly. Alternatively, wage rates in the nonfarm labor might be unaffected by skill, e.g., due to the physically demanding nature of the work or institutional factors, but agriculture might be receiving a steady stream of new technologies that require skill to use them effectively. In this scenario, an increment of schooling will not affect an individual's nonfarm wage but will raise his marginal product at farm work. Hence, if an investment in an increment of human capital is optimal, an agricultural household will increase the share of its employed human capital services that is allocated to farm work. In this case, investing in schooling for farm people would not be expected to necessarily cause an exit of schooled individuals from farms to the cities for work.

Third, given the three-period lifetime, a comparison of the present value of the marginal return to an investment in period t and t+1shows that delaying the investment from t to t+1 significantly reduces the present value of the marginal return. Hence, it is optimal for agricultural households to make large human capital investments early in an individual's life rather than later. Furthermore, it is never optimal in this model for a household to invest any resources in human capital production in period t+2 because there is cost but no return.

Fourth, because the marginal cost of human capital production is increasing, it will frequently be optimal for an agricultural household to spread its human capital investment in an individual over more than one period, even with finite life and associated reduced present value of the marginal return. Spreading the investment over time is a good decision when the cost saving exceeds the reduction in returns due to delaying (see Figure 1). Fifth, if the length of life were to be extended to four periods, e.g., due to better public health measures, this would increase the demand for human capital investment, and other things being equal, increase life-time human capital (e.g., schooling) investment per individual.

At an interior solution, except $L_{2t+2} = X_{2t+2} = 0$, the model implies that human capital services are allocated in t and t+1 such that at the margin $MU_{L_{1j}}/. ' PV_{Z_{2j}^t} @MP_{L_{2j}} ' P_{3j}^(MP_{L_{3j}}^{Z_3} ' W_j$. Given the finite planning horizon, the optimal allocation of human capital services in t+2 is such that at the margin $MU_{L_{1j}}/. ' P_{3j}^(MP_{L_{3j}}^{Z_3} ' W_j$. In these two scenarios, farm production decisions are separable from household consumption, human capital production, and labor supply decisions, i.e., farm input/output decisions are static profit maximizing decisions with W_j as the price of L_{3j}. Furthermore, given that life is finite and that investment in human capital early in life increases the total available human capital services available for allocating later in life, a likely scenario in the initial period t is that optimal $L_t^w ' L_{3t} ' 0$, i.e., none of an individual's human capital services is to farm and nonfarm work, and available human capital services are allocated to consumption and human capital production. In this case, the opportunity cost of human capital services used in human capital production (consumption) is its marginal value in foregone leisure (future labor productivity increases).

As a guide to empirical researchers and research, this model has as endogenous or choice variables in each period the following: the quantity of goods for consumption, leisure, and purchased inputs; inputs for human capital production (investment); human capital services and purchased inputs; inputs for farm production, human capital services and purchased inputs; and supply of labor (human capital services) to the nonfarm labor market. An upper limit to the set

of relevant exogenous variables is the following list: W_t, $W_{t\%1}$, $W_{t\%2}$, P_{1t}, $P_{1t\%1}$, $P_{1t\%2}$, P_{2t}, $P_{2t\%1}$, $P_{2t\%2}$, $P_{3t}^($, $P_{3t\%1}^($, $P_{3t\%2}^($, P_{3t}, $P_{3t\%1}$, $P_{3t\%2}$, C_t, $C_{t\%1}$, $C_{t\%2}$, A_2, A_3, $"$, $*$, and r.

A One-Period Static Model. Drawing upon the agricultural household models of Singh et al. (1986) and Huffman (1991b; 1996b), the farm household is assumed to make resource allocation decisions for any production cycle by maximizing utility subject to resource and technology constraints. The farm household is assumed to derive utility from a home-produced good (Y_1) and from leisure (L):

$$U = U(Y_1, L). \tag{17}$$

First, the household faces a technology constraint from the farm-household production or transformation function:

$$F(Y_1. Y_2, Y_3, H, X, A, E) = 0, \ Y_3 \$\ 0, X \$\ 0 \tag{18}$$

where Y_1 is output of the home good, and Y_2 and Y_3 are outputs produced for sale. Output Y_3 may or may not be produced, so a non-negativity constraint is imposed. H is hours of farm-household work by members, and X is purchased variable inputs, which might not be used, so a non-negativity constraint is imposed. "A" is technology and agro-climatic conditions, and E is an education index of household decision makers. The production function permits adopting new inputs (and discarding old ones) and expanding or reducing the number of outputs produced. It also accommodates substitute or complement relationships between variable inputs, and schooling of the decision maker(s) can enhance technical efficiency. For model development, an asymmetric form of the transformation function is used:

$$Y_2 = f(Y_1, Y_3, H, X, A, E), \ Y_3 \$\ 0, X \$\ 0. \tag{19}$$

Second, the household faces a human time constraint:

$$T = L + H + H_m, \ H_m \$\ 0 \tag{20}$$

where total available time per production cycle T is allocated among leisure (L), farm-household work (H), and off-farm wage work (H_m). A non-negativity constraint is imposed on H_m because it may be zero.

Third, the household faces a cash income constraint:

$$I = P_2Y_2 + P_3Y_3 + W_mH_m + V = W_xX \tag{21}$$

where P_2 and P_3 are the market prices of Y_2 and Y_3, W_m is the market wage rate for off-farm work, V is household nonfarm-nonlabor income net of any fixed costs associated with farm-household production, and W_x is the market price of X. All prices are assumed to be given to households, but the off-farm wage rate depends on human capital (E) and local economic conditions (N), i.e., $W_m = W(E, N)$.

If equation (19) is substituted for Y_2 in equation (21), then two of the three constraints facing the household are combined:

$$P_2 f(Y_1, Y_3, H, X, A, E) + P_3 Y_3 + W_m H_m + V = W_x X. \tag{22}$$

The household can now be viewed as making consumption, production, and labor supply decisions (i.e., choice set C: Y_1, L, Y_3, H , X, and H_m) by maximizing equation (17) subject to equations (22) and (20), including the non-negativity constraints. The Kuhn-Tucker first-order conditions are:

$$\partial U/\partial Y_1 \ = \ -\varepsilon_1 P_2\, \partial Y_2/\partial Y_1 \tag{23}$$

$$\partial U/\partial L \ = \ \varepsilon_2 \tag{24}$$

$$\varepsilon_1 [P_2\, \partial Y_2/\partial Y_3 - P_3] \leq 0, \ Y_3 \geq 0, \ Y_3(P_2\, \partial Y_2/\partial Y_3 - P_3) = 0 \tag{25}$$

$$\varepsilon_1 P_2\, \partial Y_2/\partial H - \varepsilon_2 = 0 \tag{26}$$

$$\varepsilon_1 [P_2\, \partial Y_2/\partial X - W_x] \leq 0, \ X \geq 0, \ X(P_2\, \partial Y_2/\partial X - W_x) = 0 \tag{27}$$

$$\varepsilon_1 W_m - \varepsilon_2 \leq 0, \ H_m \geq 0, \ H_m(\varepsilon_1 W_m - \varepsilon_2) = 0 \tag{28}$$

plus equations (22) and (20) where ε_1 is the marginal utility of cash income and ε_2 is the marginal utility of human time. With an interior solution, equations (23), (24), and (28) imply optimal marginal rate of substitution between home goods (Y_1) and leisure (L) of $\dfrac{\partial U/\partial Y_1}{\partial U/\partial L} = -\dfrac{P_2\, \partial Y_2/\partial Y_1}{W_m}$, or the ratio of their opportunity costs ($\partial Y_2/\partial Y_1 < 0$). If production of Y_3 is to occur, the value of the marginal reduction of Y_2 to produce Y_3 must equal the price of Y_3 (i.e., $-P_2\, \partial Y_2/\partial Y_3 = P_3$). At an interior solution, family labor and purchased inputs are to be used such that the value of the marginal product of an input equals its respective price (equations (26) and (27)).

As a guide to empirical research and researchers, this static model has a slightly different configuration of endogenous and exogenous variables than the three-period model. The endogenous or choice variables are home-produced goods (Y_1) and leisure (L), production of Y_1, Y_2, and Y_3, purchase of variable inputs X, and hours of on-farm and off-farm work by household members. The upper limit to set of exogenous variables driving these decisions includes P_1, P_2,

P_3, W_x, W_m, V, A, and E. In particular, at an interior solution, the farm production decisions can be separated from the household consumption and labor supply decisions. Farm input decisions are then profit maximizing decisions where the price of family labor is the off-farm wage. Furthermore, if the household has a "garden" rather than a farm, the agricultural household model is applicable to most rural and some urban households.

More About Agriculture

Schooling and experience may be productive or unproductive in agriculture depending on economic conditions, but in economies with freely mobile resources, agriculture must compete with other sectors for skilled (and unskilled) labor. The wage to similarly skilled labor need not be equal across sectors, but in equilibrium the marginal compensation, including monetary value of nonmonetary attributes of the farm and nonfarm work, will be equal. Recently the U.S. farm-nonfarm compensating differential has been small (Huffman 1996a). Although agriculture can in some cases compete with the nonfarm sector on rate of technical change, the opportunities for raising labor productivity in agriculture through task specialization and coordination or teamwork may be modest compared to the nonfarm sector, i.e., the skilled individual may face a more inelastic demand for his services on a farm than in a large nonfarm business. Also, the agricultural sector may in some cases face small market size and high coordination costs that put it at a disadvantage.

Formal schooling is part skill creation, part local culturalization, and part screening. The composition differs across countries and through the grade levels within a country. Skill creation generally receives most of the attention in economics, and skill creation fits neatly into a human capital framework. Primary schooling, which emphasizes literacy, numeracy, and problem solving skills for its graduates, creates basic skills that are generally productive to farm people and provide a foundation for secondary and higher education. Secondary schooling encompasses a range of skills, sometimes being mainly college preparatory and at the other extreme being quite utilitarian. In the U.S. before 1890, high schools were primarily college preparatory, located in cities, and were not teaching skills generally useful to farm people. Starting about 1900, secondary schools in America were transformed into a new and generally useful institution for the masses, including farm people (Goldin 1998; Goldin and Katz 1999a, 1999b). The new high schools had a new curriculum centered around English, geometry, algebra, accounting, and typing, that could serve as a useful terminal degree providing skills for life's work or as college preparation. These schools were "open," admitting all students who had completed the requirements of public elementary schools. From 1910 to 1940, U.S. high school enrollment and graduation rates grew rapidly, especially in the Great Plains, West, and Midwest where agriculture was relatively important.   Higher education becomes potentially useful to farm people when successful decision making in agriculture requires depth of understanding of science and business or when farm people need to prepare for an occupation outside of agriculture.

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In some agricultural environments, experience rather than schooling may be a more important form of human capital, while in other environments, schooling has a major advantage over experience (Schultz 1964; Becker 1993, p.1-13; Huffman 1991a, 1985). In a static (political, economic, technical) environment, accumulated experience seems to be a better investment than schooling. Information accumulated through experience in farming or working in the household does not depreciate when the environment is unchanging. Work experience is a relatively valuable form of training, e.g., farmers can learn much that is useful for decision making from their own and others' experiences. However, when the political and economic environments are changing in a market economy, or new technologies are regularly becoming available, skills obtained from formal schooling have an advantage over on-the-job training. Most new agricultural technologies are geo-climatic or land-specific, and changing technologies cause rapid depreciation in land-specific human capital. Being able to make good decisions on information acquisition and technology adoption is valuable. Hence, a changing agricultural environment is expected to increase the expected returns to formal schooling and possibly to reduce the opportunity cost of schooling for farm male youth (reduce the expected payoff to farm-specific human capital) (Foster and Rosenzweig 1996). These are all arguments for allocative efficiency effects of human capital. Schooling and experience may also enhance the technical efficiency at agricultural production activities, but for enhancing technical efficiency, experience seems likely to be a more important form of human capital in both static and dynamic environments.

For farmers to have access to new technologies, they must have either a successful national research and development (R&D) system or access to international technologies. In all cases, some special attention must be given to adaptive research to meet local agricultural conditions. Farmers in developed countries have access to locally, nationally, and internationally developed technologies, but the technologies available in developed countries are frequently limited to the output of the national public agricultural research system and possibly the international agricultural research centers.

Empirical Evidence

Choices About Where to Work

Worldwide about one-half of the labor force works in agriculture (The World Bank 1997, p.220-221). A large majority are unpaid farm workers--the farmers who make decisions and work, and other farm family members who work generally without direct compensation--and a minority are hired (nonfarm family) workers. Hired workers are generally of two types: regular full time and seasonal. Seasonal labor demand variation arises largely from the definite seasonal pattern to biological events in plants, which creates unusually large labor demand at planting, weeding, and/or harvest time. The supply of seasonal agricultural labor generally has a local component and a migratory component (see Emerson 1984).

Over the long term the share of the labor force employed in agriculture has declined dramatically in what are now developed countries, but slowly or not at all in low-income or developing countries (Johnson 1997; OECD 1995). Decisions on schooling by families and communities are an important factor determining whether individuals work in agriculture or elsewhere. Even in developed countries where farmers are relatively well educated, hired farm workers have significantly less education. For example, in the United States, hired farm workers have about 50 percent as much schooling as farm operators (Huffman 1996b), and in 1990, 53 percent of seasonal crop workers had less than 8 years of schooling (Gabbard and Mines 1995). In this latter group, about 60 percent were foreign born and 40 percent undocumented.[3] This subsection examines the impact of schooling on individuals' choices of where to work in a free society.

Choosing agriculture. Whether to work in agriculture or in another industry is an important decision worldwide. In India and China, which account for about 40 percent of the world's population, and in other low-income countries, about 65 percent of the labor force in 1990 was employed in agriculture. In western Europe, less than 10 percent of the labor force was employed in agriculture, and in the United States the share was only 3 percent. In noncentrally planned countries, individuals make a choice of an occupation/industry for work.

Orazem and Mattila (1991) have examined occupational choices for U.S. high school graduates. Graduates are assumed to choose the occupation that maximizes their expected lifetime utility, where indirect utility depends primarily on the mean and variance of earnings and income independent of occupational choice. Their model is similar to the three-period conceptual model presented in the previous section, and goes beyond and is superior to the (lifetime) earnings maximization models (e.g., Ben-Porath 1967). Schooling is also permitted to produce different amounts of occupation-specific human capital, i.e., schooling is not equally productive across occupations. This occupation-specific human capital is a function of the intensity with which a student invests in school (attendance rate) and school (teacher) quality.

They then use the model to examine the choices of Maryland high school graduates (1951-69) among eight activities: six occupations (including farming, fishing, and mining) and two college options. They found that increasing the mean of the earnings distribution (or reducing the variance) for an occupation/activity i increases the probability that activity i is selected by high school graduates. The quality of secondary schooling is shown to affect graduates' activity choices differentially, suggesting that schooling has an activity-specific and a general training component. In particular, increasing schooling quality reduces the proportion of high school graduates going into farming, fishing, or mining relative to other occupations, or continuing with college. Hence, parameters of occupational-earnings distributions and school quality seem to affect occupational choices of rural youth in free societies, but there is considerable potential here for future research on occupational choice involving agriculture.

Perloff (1991) has examined wage workers' industrial choice of work (in agriculture versus nonagriculture) and wages by industry for U.S. low-educated nonurban workers. Workers

are assumed to choose the industry that gives them the largest total current benefit, i.e., wage adjusted for the monetary value of the (dis)utility of work. The probability of wage-work in agriculture is then a function of individual, family, and regional attributes. Wage equations by industry are then a function of workers' attributes and regional/state location of work.

To focus on the population for which working in agriculture seemed most relevant, Perloff limited his sample to nonurban male wage workers who were age 16 or older, had 9 years or less of schooling, and were working 15 or more hours per week. The sample is from the 1988 U.S. Current Population Survey. The results showed that a year of additional schooling increased the probability of working in agriculture for workers having less than 5 years of schooling, but reduced the probability for those having more than 5 years. An additional year of post-schooling experience increased the probability of choosing agriculture only for workers having more than 32 years of experience. A worker being Mexican, non-Mexican Hispanic, or black increased his probability of choosing agriculture.

Using a hedonic wage equation, Perloff found significant differences in the agriculture and nonagriculture wage structures. An additional year of schooling had a (small) positive effect on the wage in agriculture up to 5 years but no significant effect on the nonagriculture wage. An added year of post-schooling experience had no significant effect on the wage in agriculture but a (small) positive effect on the nonagricultural wage up to 33 years. In agriculture, Mexicans, other Hispanics, and blacks earned significantly more than whites, but in nonagriculture, the blacks earned 15 percent less than whites, and Mexican and other Hispanics had wage rates that were not significantly different from whites' (with the same education and experience). Controlling for demographic differences, the agriculture wage differed significantly across regions and states, but for nonagriculture, no difference across regions and states existed, except in California, where wages were higher. Perloff then fitted a structural participation equation using the predicted agricultural-nonagricultural wage differentials adjusted for selectivity, and found strong positive effects of the agriculture-nonagriculture wage differential on the probability of working in agriculture. He concluded that low-education nonurban male wage workers are quite responsive to the agriculture-nonagriculture wage differential.[4]

Migration. As economic conditions change in interconnected labor markets, workers in free societies invest in migration to improve their future economic welfare (see the three-period model in the previous section), which tends to reduce or eliminate inter-market wage differences. This complicates the problem of explaining migration because individuals are acting on anticipated wage rate differences rather than the ex post values. Schooling has been hypothesized to play a significant role in these adjustments or reallocations because of its effect on both the costs and returns to migration.

Migratory agricultural workers incur moving costs in exchange for a higher expected wage in a new location. Emerson (1989) examines the earnings structure for migratory and nonmigratory work and the probability of migration for 559 domestic males in a survey of Florida farm workers. A migrant, an individual who has earnings in two or more states during the survey

year, is hypothesized to have a different earnings structure for nonmigratory work. He finds that the expected earnings difference between migratory and nonmigratory work increases significantly as the probability of a worker being migratory increases. For these workers, the mean schooling completion level was 6.5 years, and worker's schooling had a positive but not significantly different from zero (5 percent) effect on being migratory.

Perloff et al. (1998) examine the migratory responsiveness of seasonal agricultural service labor to geographical wage differences using the National Agricultural Workers Surveys 1989-1991. They define migration as a worker traveling at least 75 miles for perishable crop work during a survey year. They test and confirm the hypothesis that workers who have the largest expected gain to migration are the ones who actually migrate for work. In a probit equation explaining the probability of a worker migrating, they find the worker's amount of schooling has no significant effect. However, a worker's U.S. farm labor market experience and a worker being female had significant negative effects on the probability of migration.

Taylor (1986, 1987) examined the decisions of rural Mexican households to allocate adult labor to work in Mexico or to work as undocumented labor in the United States. Mexican households are assumed to employ adults so as to maximize expected (source) household income. If the adult migrates as an undocumented worker, his or her contribution to Mexican source household income is expected remittances net of migration costs, and the probability of successful undocumented migration is assumed to be a function of individual and family attributes. Net remittances and Mexican income from work are each assumed to be a function of individual and source household attributes.

Taylor (1987) fits his model to data for randomly chosen households in a rural Mexican village 2,000 kilometers from the U.S.-Mexican border. In a (reduced-form) equation explaining the probability of undocumented Mexico-U.S. migration, he found that an adult's age has a significantly positive effect up to 36 years for men and 32 years for women, one added year of experience as an undocumented Mexico-U.S. migrant has a significantly positive effect up to 9 years, but an added year of worker schooling has a significantly negative effect. The latter result arises because more educated rural Mexican adults have relatively better labor market opportunities in Mexican cities than in the United States. A Mexican household having a migration kinship network, i.e., family contacts in the United States, has a significantly positive effect on the probability of undocumented Mexico-U.S. migration. The reason put forth in the network reduces the costs to a potential immigrant of crossing the border and finding a job. Hence, Taylor presents evidence which many researchers would find counterintuitive: an individual's schooling reduces rather than increases his or her likelihood to migrate internationally. Migration kinship networks seem to be highly substitutable for educators in understanding Mexico-U.S. migration. Finding collaborative evidence in other parts of the world would seem to be a useful activity.

He also reports results for fitted income equations, one for Mexico-U.S. migrant remittances and one for income contribution by working in Mexico. He found that a worker's

education has a positive and significant effect on his or her Mexican income but no significant effect on remittances to Mexico. U.S. experience as an undocumented migrant has a significantly positive effect on remittances and on Mexican income, but Mexican experience as a migrant in Mexico has a positive effect only on Mexican income. Thus, U.S. work experience seems to produce a type of general human capital, but work experience in Mexico seems to produce country-specific skills.

He then fits a structural probit to explain Mexican-U.S. undocumented migration. He uses the fitted remittance and Mexican worker income equation, corrected for selection, to estimate for each worker the difference between his or her predicted migrant remittance and predicted Mexican worker income. This difference in income is then shown to contribute positively to the probability of undocumented Mexico-U.S. migration while leaving the effects of a migrant's U.S. experience, migration kinship network, and age largely unchanged from the reduced-form equation.

Barkley (1990) presents economic evidence on the determinants of net migration of labor out of U.S. production agriculture, 1940-1985. This is an especially interesting period because employment in U.S. agriculture declined about 300 percent. He hypothesized and found that labor was responding to a significant decline in the expected payoff to working in agriculture relative to other industries. A higher return to labor in nonfarm work relative to farm work increased the net exit rate from agriculture. Higher real land prices, which raises the wealth position of farm labor that owns land, however, tended to reduce the migration of labor out of agriculture. Government program payments which clearly affect farm income did not affect migration, except perhaps through the land prices or returns to farm labor. Being a farmer creates location-specific information about the land, climate, and input supplies, and Feridhanusetyawan and Huffman (1996) have shown that being self-employed or a farmer causes a significant reduction in the likelihood of an adult male experiencing interstate migration. But formal schooling which creates general skills was shown to have a strong positive effect on the likelihood of migrating.

Huang and Orazem (1997) applied a human capital model, similar to the three-period model, in their examination of the underlying causes of growth and decline in U.S. rural county populations by decade, 1950-90. They examined population growth rates for 306 southern and midwestern counties and tested for human capital and labor market opportunity effects. They found that rural counties that had a higher average adult schooling level at the beginning of a decade had a higher rate of loss of population over the following decade. When a county was farther from a large city, had more concentrated employment by industry, had a larger share of population on farms or share of population who were black, it had a larger rate of population loss over the following decade. Over their study period, schooling yielded higher returns in urban than rural areas. Hence, in rural U.S. counties that invested more in schooling of children, the rate of net export of human capital to other countries was larger. Because of positive, expected geographical spillover effects of rural schooling, a significant part of the cost should be borne by areas that expected to benefit--e.g., state and federal sources (Olson 1969, 1986).

In contrast to the human capital approach taken by Huang and Orazem to modeling annual county population growth rates, Goetz and Debertin (1996) rejected a human capital approach. They employed a rather *naive* empirical economic model for explaining rural county population growth rates over 1980-90. It placed all the emphasis on *actual* characteristics of counties at the beginning of the period, e.g., average characteristics of farms, average earnings in farming and other occupations, and total employment across industries, and the net birth rate from 1980 to 1990. The authors argued that individual characteristics, e.g., education and age, are unimportant, and ignored information about the expected commuting distance to work and earning prospects elsewhere. Also, they apparently considered birth rates to be an uneconomic decision. Another deficiency is their use of actual characteristics of counties in 1980 to explain population growth: Individuals presumably use as information for migration decisions anticipated rather than actual characteristics, although past values do represent naive expectations formation.

Off-farm work. Although farmers or cultivators tend to be tied to the land and to be geographically immobile, off-farm work of farmers is a relatively common international phenomenon. Since the 1950s and 1960s aggregate demand for operator and family farm labor in all of the developed countries has declined (see OECD 1995), the demand for housework in farm households has generally declined as family sizes have declined and labor-saving household technologies have been adopted (Bryant 1986), and the real nonfarm wage has generally increased. Faced with needing to make adjustments in labor allocation, farm households in the developed countries have frequently chosen to continue in farming but also to supply labor of some of its members to the nonfarm sector (e.g., see Hallberg et al. 1991).

Most empirical studies of off-farm work participation of farm household members have used an agricultural household model similar to the static conceptual model presented in the previous section. In this framework, an individual's schooling has been an important determinant of off-farm work participation in middle- and high-income countries. In all the published econometric studies of off-farm work participation of farm operators in the U.S., Canada, and Israel, the operator's schooling has been shown to have a positive and statistically significant effect on his probability of off-farm work (see Table 1). Fewer studies have examined off-farm work decisions of farm wives, but a farm wife's schooling has a positive and significant effect on her probability of off-farm work too (see Huffman and Lange 1989, Gould and Saupe 1989, Tokle and Huffman 1991, Lass and Gempesaw 1992, and Kimhi 1994). Cross-person schooling effects between spouses are mixed in sign and generally statistical significance. Where wage equations have been part of these econometric studies, an individual's schooling always has a positive and significant effect on his or her off-farm wage, and an individual's experience also has been a significant predictor of the wage.

Overall, the review of the literature has shown that the quantity and quality of an individual's schooling affects their choice of where to work. In the U.S., higher secondary school quality seems to reduce the likelihood of an individual choosing an occupation in agriculture. For less-educated wage workers, say less than 5 years, added schooling increases the likelihood of working in agriculture. U.S. domestic and undocumented migratory farm workers seem to

function relatively well with low levels of schooling. For individuals in developed countries who are farmers and continue farming, additional schooling increases the likelihood that they will participate in off-farm wage work, but not necessarily for those in Green Revolution areas of developing countries. Higher schooling levels are in general associated with a population that is more geographically mobile.

Technology Adoption and Information Acquisition

The decision to adopt new technologies is an investment decision because significant costs are incurred in obtaining information and learning about the performance characteristics of one or more new technologies and the returns are distributed over time. Furthermore, only a small share of the new technologies that become available will be profitable for any given farmer to adopt. This means that there is a large amount of uncertainty facing farmers, and additional schooling may help them make better adoption decisions and increase farm profitability. Because additional schooling affects the amount of knowledge that a farmer has about how technologies might work and his or her information evaluation skills, additional schooling may affect his or her choice of the type and amount of information to acquire. Hence, a model similar to the three-period model of the previous section provides a useful guide to the empirical literature. Also, see Besley and Case (1993) for examples of particular choice-based empirical models of farmer's technology adoption.

When technology is new and widely profitable, farmers' schooling has been shown to be positively related to the probability of adoption. When a technology has been available for an extended period (e.g., several years) or it is not widely profitable, farmers' schooling is generally unrelated to adoption/use of the technology. Schooling has been shown to affect choice of information channels about new technologies.

Huffman and Mercier (1991) examined the adoption of microcomputers and/or purchased computer services by a 1982-84 sample of Iowa farmers. Farmers' schooling has a positive and statistically significant effect on the probability of adopting a microcomputer, adopting purchased computer services, and adopting both a microcomputer and computer services. As farmers become older, they have fewer years to capture returns from changing, and farmers' age has a negative and significant effect on adopting all combinations of computer technologies. Although arguments can be made for off-farm work releasing credit constraints and giving exposure to computer use and usefulness, a higher probability of off-farm work by these farmers reduces (significantly) the probability of adopting a microcomputer, and tends to reduce adoption of purchased computer services.

Putler and Zilberman (1988) examined computer use by a 1986 sample of (Tulare County) California farmers who had relatively high schooling completion levels. Forty-six percent of these farmers had completed a college bachelor's (4-year) degree, and of them 11 percent had also completed a graduate degree. They found that farmers who were college graduates, i.e., individuals who had completed bachelor's and graduate degrees, had higher probabilities of

computer adoption than farmers who completed only elementary or high school. However, individuals who completed some college but did not receive at least a four-year degree had adoption probabilities that were similar to individuals who had completed only elementary or high school. Thus, the effective use of a computer in California agriculture seems to require high levels of education. They also found that farm size has a positive and significant effect on computer adoption. Farmer's age had a quadratic effect on computer adoption, peaking in the 36-40 age range. Their evidence on type of software owned is generally weaker than for computer adoption, but they concluded that it is influenced primarily by the type of farm products produced, the size of the farming operation, ownership of a farm related business, and education of the farm operator.

Wozniak (1984) examined the adoption of two interrelated cattle feeding technologies-- one new and the other mature (available for several years)--for a 1976 sample of Iowa farmers. The new technology was the use of Rumensin which enhances natural microbial activity in rumens, and it became available to farmers about one year before the survey. The mature technology was implanting growth hormones, which is a technology that had been available for several years. Wozniak found that farmer's schooling and frequent contact with agricultural extension information sources had positive and statistically significant effects on the probability of adopting the new technology (Rumensin) but no effect on the probability of adopting the mature technology (implanting). He also found a positive and statistically significant effect of scale/size of the cattle feeding operation on the probability of adopting both feeding technologies. These results suggest that education and extension are important to assessing new innovations and explaining early adoption but not for diffusion or use of mature technologies. Also, the results imply that if an innovation is compatible with current technology, it is more likely to be adopted than if it displaces it.

Rahm and Huffman (1984) examined the adoption of reduced tillage for row crop (corn) seedbed preparation and the efficiency of the adoption decision for a 1976 sample Iowa farms. Reduced tillage technology refers to seedbed preparation without the aid of a moldboard plow, e.g., chisel plows, field cultivators, primary tillage disks, or no-till planting. Reduced tillage significantly reduces field preparation time and retains crop residue on the soil surface, which has the potential to decrease soil loss from wind and water erosion. It also lowers springtime soil temperatures and decreases evaporation. The profitability of reduced tillage over moldboard plow technology depends on soil characteristics, annual precipitation, cropping system, and other management practices, and it is not profitable for all cropland. They found that the probability of a farm operator adopting reduced tillage was not related significantly to his schooling. A large corn enterprise size (acre of corn planted) had a positive and significant effect on a farmer's adoption of reduced tillage, and the cropping system of the farm and soil association of the farmland significantly affected the probability of adoption.

But Rahm and Huffman (1984) also examined the efficiency of a farmer's adoption decision, which is defined as the absolute difference between actual and predicted adoption behavior. Here, farmers who had more education (years of formal schooling) had greater

efficiency of reduced tillage adoption. Also, if the farm operator used media sources of information published or marketed by the private sector or if the farm operator or spouse attended short courses, conferences or meetings at Iowa State University, the efficiency of a reduced tillage adoption was increased. However, a farm operator's active years of experience farming or participation in meetings, field days or demonstrations sponsored by the extension service did not have a significant effect on the efficiency of reduced tillage adoption.

Soule et al. (1999) have extended the Rahm and Huffman model of adoption of conservation practices. They develop a multiperiod model of the adoption decision, focusing on possible differences that might be associated with different land tenure arrangements, and fit a probit specification of the adoption decision to data from the 1996 Agricultural Resource Management Study survey. They find that if a farm operation has some college education he is more likely to adopt (short term) conservation tillage practices than if he has less schooling. They, however, found no significant effect of the farm operator having some college education on the probability of adopting medium-term practices, e.g., contour farming, strip cropping, establishing grassed waterways.

We turn next to some adoption evidence for developing and transition economies. New high yield wheat and rice varieties became available in the mid-1960s. Foster and Rosenzweig (1996) consider the probability that a sample of Indian farm households had ever adopted high yielding seed varieties by 1971. Schooling completion is low in these households; only 49 percent of households had someone who had completed primary school and 21 percent had someone who had completed secondary schooling. They found that farm households containing at least one adult who had completed primary schooling were significantly more likely to have adopted the new seeds by 1970-71 than households having no adult who was a primary schooling graduate. Schooling beyond the primary level tended to not significantly affect adoption of high yield varieties (HYV). Households that had more acres of owned land and were located in villages with an agricultural extension program were also more likely to use HYV seeds.

In another study, Foster and Rosenzweig (1995) examined the adoption of high yielding seed varieties in a national panel sample of Indian rural households pertaining to the crop years 1968-69, 1969-70, and 1970-71. Here they focused on the importance of prior experience with HYV on current rate of use. They found that farmers who had more prior experience with HYV seed had a significantly higher current rate of use of the new seed. They also found that farmers in villages that had more prior experience with HYV also tended to have higher current rates of use of HYV seed. Their results suggest positive learning-by-doing (or own experience effects) and positive learning-from-neighbors (or experience spillover effects) occur. Because of the fixed-effects specification of their econometric model, farmers' schooling, which does not change over time, does not have an identifiable effect on HYV adoption.

Lin (1991) examined the adoption of high yielding rice varieties for a 1988 sample of Chinese farmers (Hunan Province). Although China did not have a market economy, a new household-based (rather than collective-based) farming system was introduced to the study area in

1981-82. The average years of formal schooling completed by the household head was 5.5 years, and 93 percent had less than 10 years of schooling. Hybrid rice seeds were released to farmers in 1976, but the price of the seed was set relatively high (10 times conventional seed), although the seeding rate was one-third to one-fourth of conventional rice's seeding rate. Controlling for 16 other variables, Lin found that schooling of the head of the farm household had a positive and significant effect on the probability of adopting middle or late hybrid rice seed. Increasing the land area cultivated by a household also increased the probability of hybrid rice variety adoption. Household head's experience in farming had a positive effect on adoption (at the 10 percent significance level).

Strauss et al. (1991) examined the adoption of cultural practices by upland rice and soybean farmers from survey information collected from 161 central-west Brazilian farms in 1985-86. Both soybeans and upland rice technologies began to be introduced in the region after 1980. The educational distribution of the farmers in the survey is: < 4 years, 56.8 percent; 4-8 years, 29.0 percent; and > 8 years, 14.2 percent. They found that better educated farmers were more likely to do soil analysis and use fertilizer on both rice and soybean plots, but farmers' education did not significantly affect the probability of using treated soybean seeds, certified rice seeds or rice blast control. Farmers in areas with more experienced extension agents were more likely to use treated soybean seeds and certified rice seeds, but extension did not have a significant effect on adoption of other practices. Clearly these are a mixed set of results.

Pitt and Sumodiningrat (1991) examined the determinants of rice seed variety choice (HYV vs. traditional variety (TV)) for a 1980 national sample of Indonesian farm households. High yielding varieties became first available at least a decade earlier. They found that farmer's schooling had a positive but statistically insignificant effect on HYV adoption, holding relative profitability of HYV to traditional varieties constant. Higher expected profitability of HYV and higher quality irrigation for a farm household also had positive and significant effects on the probability of HYV adoption.[5]

Although successful adoption of innovations clearly requires information, few studies have considered the important joint decisions of information acquisition and new technology adoption. This seems to be a fruitful area for new research. When several information sources exist, early adopters might prefer sources that facilitate faster learning about the innovation. The information channels for early adopters might also be different from those for late adopters.

Wozniak (1993) is an exception in that he examined farmers' joint decisions on information acquisition and technology adoption. He considered the adoption of two technologies--one new (Rumensin) and one mature (implanting)--and four channels of information--one active and one passive information channel for both extension and private sector information providers. In the study, he found that farmers' education significantly increased the probability of adopting new and mature technologies and of acquiring information from extension by talking with extension personnel (passive) and attending demonstrations or meetings (active) about the use of new products or procedures sponsored by extension. Farmers' education did not

have a statistically significant effect on acquiring information by talking with private industry personnel or attending demonstrations or meetings on the use of new products or procedures sponsored by private companies. Farmers were more likely to be early adopters if they acquired information actively or passively from private industry information providers than if they acquired information from extension. For both new and mature innovations, positive and significant interaction effects existed between farmers acquisition of information from public and private sources, i.e., public and private information acquisition seems to be complementary.

In addition, he found that scale has a positive and significant effect on adoption of new and mature technologies and on the likelihood of acquiring information from extension actively or passively, but no significant effect on likelihood of acquiring information from private sector firms. Farm operators who had larger off-farm wage income had a lower probability of adopting the new technology and lower probability of talking with private sector information providers. He concluded that off-farm work seems to impact adoption not by easing credit restraints but by reallocating operator's time away from farm-related activities of early technology adoption and gathering technical information.

Klotz et al. (1995) examine California dairy farmers' awareness of recombinant bovine somatotropin (rbST) and its adoption using survey data over a four-year period 1987-1990. They argue that information acquisition costs per cow decline as the size of a cow herd increases leading to scale bias to large producers. Empirically they fit a bivariate probit model to explain awareness and adoption of rbST. They find that farmers' schooling has a positive and significant effect on both the probability of awareness and adoption. In addition, they find that as the size of the dairy herd increases the probability of a farmer's awareness and adoption increases.

Bindlish and Evenson (1997) have undertaken an extensive study of information acquisition and its impacts in agriculture of two poor African countries. They use econometric techniques to examine whether the Training and Visit (T&V) system of extension led to earlier and greater awareness, testing, and adoption of improved farming practices in Burkina Faso and Kenya than would have occurred otherwise. They pay particular attention to the effects of endogenous T&V participation by farmers in their analysis. They found that farmers having more schooling had a high probability of participating as T&V contact farmers or members of contact groups. Holding the probability of T&V participation constant, additional T&V extension had a positive and significant effect on farmers' testing 10 of 12 recommended practices and on adoption of 9 of them. They also found positive externalities or spillover effects of T&V participating farmers on the probability that other farmers would test and adopt recommended practices. Farmers having more schooling (and more land) were more likely to learn from other farmers and to test and adopt new technologies.

In Kenya, the findings were less clear cut. However, T&V extension had a positive effect on the probability of adoption of all recommended practices and a statistically significant effect on most. Higher schooling levels of farmers led to more and earlier awareness and adoption of recommended practices.

Antle and Pingali (1994) considered an interesting pesticide choice and production problem where farmers' education might be expected to matter for acquisition of information and choice of technology. They integrated farm-level survey data with health data collected from the same population of Philippine farmers to measure the impacts of pesticide use on farmer's health and the impact of farmer's health on rice production. They, however, indicate that their sample contained too little variation in farmer's education to find a significant effect on either pesticide use or production. However, an alternative interpretation of their results is that they included "choice variables" as regressors in these equations, e.g., the pesticide use equation contains as regressors the number of applications of particular pesticide toxicity and dummy variables for farmer's smoking and drinking, which themselves seem likely to be (partially) determined by farmer's schooling. Welch (1970) and others (see later section) have shown that when the effects of education are channeled through farmers' choices, one cannot expect to hold the "choices" constant in a regression sense and also find a significant effect of education.

Overall, the review of the literature has shown that additional schooling of farmers increases the rate of early adoption of useful agricultural technologies in developed and developing countries. A surprisingly small amount of research, however, has examined farmers' joint decisions on information acquisition and technology adoption, and this is an area for much needed new research. Furthermore, care must be taken in empirical modeling so they are built on a solid choice-based foundation and permit schooling to affect outcomes.

Agricultural Production

Education of farm labor has the potential for enhancing agricultural production as reflected in gross output/transformation functions, see equations (3) and (18), and in value-added or profit functions. These effects are frequently referenced as technical efficiency effects, allocative efficiency effects, or economic efficiency effects of education. When the effects of schooling on production are considered in a gross output-complete input specification, the marginal product of education, a measure of technical efficiency, is limited by the other things that are held constant. A value-added or profit function representation of production accommodates a much broader set of effects that farmers' education may have on production through affecting choices or allocative efficiency--the adoption of new inputs in a profitable manner, the allocation of land (and other quasi-fixed inputs) efficiently among alternative uses, the allocation of variable inputs efficiently, and the efficient choice of an output mix. The hypothesis is and the empirical evidence has shown that the productivity of farmers' education is enhanced by a wider range of choices. Welch (1970) is generally given credit for delineating these substantive differences.

First, some evidence and findings are presented for developed countries, and second, for developing countries. U.S. studies of agricultural production before the 1960s did not focus on farmers' schooling being a potentially important contributor to production, e.g., see Heady and Dillion (1961). Griliches (1963a) presented one of the first studies of the contribution of education to agricultural production. He included an index of the education of farm labor as an input in an aggregate Cobb-Douglas-type production function. The production function was

fitted to data for 1949 on aggregate output and inputs for 68 U.S. agricultural regions. Six inputs, including a man-days measure of farm (hired and unpaid family) labor, were included in addition to education. Education per worker was derived from the educational distribution of the rural population and income weighted. Griliches (1963a) found that schooling of farm labor had a positive and statistically significant effect on production and that the coefficient of education was similar in size to the coefficient of farm labor. Griliches (1964) also applied a similar methodology to U.S. state aggregate per farm data for 1949, 1954, and 1959, and obtained similar results for the contribution of education of farm labor to production. His interest in education of workers in agriculture arose primarily from a concern about labor quality and a hypothesis that labor quality was an important input for explaining output.

Huffman (1977, 1981) applied a production function approach to assessing the effects of labor quality in U.S. agriculture, using county data. Huffman (1976a, 1976b) focused on the quantity and quality of farm husband and wife labor allocated to own-farm work. A Cobb-Douglas type production function was fitted to 1964 county data for Iowa, North Carolina, and Oklahoma, where effective labor input was measured as days of work multiplied by a schooling index. The value of the marginal product of husband and wife labor was shown to be larger than the average wage received for off-farm work by farm husbands and wives in these states. However, the implied marginal return in agricultural production to husband's and wife's schooling was generally lower than the average off-farm return to schooling.

Huffman (1981) presented estimates of productivity differences on black- and white-operated farms in the U.S. South (North and South Carolina, Mississippi, and Alabama). Results from fitting a modified Cobb-Douglas production function to 1964 county data showed that the quantity and quality of farmers' education and extension were the primary sources of productivity differences on black- and white-operated farms. The *quantity* differences in schooling and extension on black- and white-operated farms were shown to be *more important* than *quality* difference for explaining black-white farm productivity differences.

Welch (1970) laid the conceptual foundation for broadening the examination of education's contribution to agricultural production, especially allocative effects of farmers' education, but his empirical evidence addressed the issue only indirectly. His model, however, stimulated considerable new research on the topic. Khaldi (1975) and Fane (1975) focused on identifying the contribution of farmers' schooling to allocative efficiency by comparing hypothetical minimum cost of producing realized output to actual cost. For both, hypothetical minimum cost was inferred from an estimated aggregate production function. Khaldi's observations were state average per farm values for all U.S. states for 1964, and Fane used county averages for four Midwestern states for 1959 and 1964. Both studies found that the proportional difference between *actual* cost and *hypothetical* cost declined significantly as the average schooling level of farmers increased (for preferred specifications).

Huffman (1974, 1977) pursued a different route to testing for allocative efficiency effects. He focused on Corn Belt farmers' production of corn and nitrogen fertilizer use in county

aggregate average data for 1959 and 1964. This was a period when the price of nitrogen fertilizer fell significantly relative to the price of corn (22-25 percent), and new hybrid seed corn varieties, which could respond well to higher nitrogen fertilizer use, were being developed and marketed by commercial seed corn companies. He found mixed results for the contribution of farmers' schooling to output per acre or technical efficiency. The production function for corn in 1959 and 1964 was shown to be different due to technical change, and schooling's effect was positive and significantly different from zero in Huffman (1974) but not significantly different from zero in Huffman (1977) which used a different set of counties. The next step was to examine changes in nitrogen fertilizer usage. He computed a partial adjustment coefficient showing the actual change in nitrogen fertilizer use as a fraction of the change necessary to reach a hypothetical optimum rate of use, and then related the speed of adjustment to farmers' schooling, extension input, and size. He found a positive and statistically significant relationship between the average education of farmers and the speed of adjustment. Extension and size (of the corn production enterprise) were shown also to be positively related to the speed of adjustment. Hence, both studies found that farmers' schooling increases allocative efficiency.

Huffman and Evenson (1989) examined the effects of farmers' education and other variables on optimal mix of outputs and inputs for multi-output multi-input U.S. cash grain farms. They fitted a system of output supply and input demand equations derived from a profit function to state aggregate per farm data for 42 U.S. states pooled over census years 1949-74. They found that an increase in farmers' schooling biased production decisions on cash grain farms away from fertilizer, labor, and fuel input use, and toward machinery input use and toward wheat output and away from soybean and feed grain outputs. Moreover, the relative bias-effects caused by farmers' schooling have been larger among outputs than inputs. They also found that additional agricultural extension biased production decisions in the same direction as farmers' schooling for fertilizer, fuel, and machinery inputs. However, the effects of extension on the other four choices were in the opposite direction as those caused by farmers' schooling.

Some recent agricultural profit function studies, however, have ignored the effects of farmers' education. Weaver (1983) and Shumway (1983) also fitted a system of output supply and input demand functions derived from a profit function to aggregate per farm data for North and South Dakota, 1950-70, and Texas data, 1957-79, respectively, and omitted education (and extension) from their models. This omission could cause the estimated coefficients of other included variables to be biased and to miss some important effects of education on agriculture. At least the potential effects of farmers' schooling should be carefully examined before deciding that they are insignificant.

Turning to some developing country evidences, Hayami and Ruttan (1985) and Jamison and Lau (1982) summarize much of the early evidence. Few early studies found a positive and statistically significant effect of farmers' schooling on farm output. This seems to have several sources. First, researchers were exploring technical efficiency but not allocative efficiency effects. Second, schooling levels may have been too low to be productive. Third, variance in schooling levels may have been too small. Later studies have had more success.

Pudasaini (1983) chose to examine the effects of education in two regions of Nepal, one undergoing modernization and the other traditional due to its hill country isolation. The average level of schooling was 5 years in the modernizing region and 4.2 years in the traditional region. He fitted yield response, gross sales, and value-added production functions to farm level data. He found that farmers' schooling had a positive but insignificant effect on crop yields in both regions, but farmers' schooling had a positive and statistically significant effect on the gross sales and value-added for both regions. In the modernizing region, the estimated coefficient of education was 66 percent larger for the value added than the gross sales equation, but in the traditional region, the coefficient of education was only 10 percent larger. The marginal contribution of farmers' schooling to value-added output was about two times larger in the modernizing than in the traditional region. In contrast, he did not find any significant effects of agricultural extension. Hence, this study showed that allocative effects of farmers' education were more important than worker effects, and that allocative effects were quite large in the modernizing region.

Foster and Rosenzweig (1996) used longitudinal Indian rural household data and area-specific information on crop yields and schools to test whether Green Revolution technical change increased the returns to farmers' schooling and whether schooling investments responded to changes in the return to schooling. They argued that the Green Revolution technologies were developed outside of India and imported so the availability of the technologies can be treated as exogenous to rural Indian economic conditions. However, the ability of different regions and households to exploit the new technologies was argued to differ because soils and climates differed regionally and farmers' schooling differed.

They used a large sample of households to explain change in farm level profit 1969-1970 to 1970-1971. With fixed-effects instrumental-variable estimates, they showed that the profitability of HYV acreage was significantly increased by a farm household member having completed primary schooling (relative to less than primary schooling). The profitability of HYV acreage was also increased significantly by the share of HYV land irrigated. For primary-schooled farm households having 100 percent irrigated HYV acreage, they concluded that farm profit was 39 percent higher (compared to having less than primary schooling and no irrigation). Their results confirmed positive allocative effects of schooling in Indian farming.

Foster and Rosenzweig (1996) then explained the 1971-82 change in household-specific school enrollment rates for children aged 5-14 using a subset of their sample of rural households. They found that primary school enrollment rates were positive and significantly related to the growth of crop yields in the area, but yield growth had a significantly smaller impact on school enrollment for children in nonfarm than farm households. The results suggested that the expected return to primary schooling in India was higher for farm than nonfarm households, and that the difference was associated with the steady change of technologies associated with the Green Revolution.

Subsistence peasant households in the Peruvian Sierra provided Jacoby (1993) with evidence for the contribution of schooling to agriculture of poor Latin American farm households.

The sample was from a sizeable survey conducted in 1985-86 from households that reported harvesting some crops and with at least one adult male and female who worked on the family farm during the survey year. The mean schooling of male heads in these households was only 2.9 years. Farm output was defined as the value of crop and livestock production. Jacoby fitted Cobb-Douglas and translog specifications of a farm production function. He found that the head's schooling increased farm output. However, the head's age (as a proxy for experience) did not statistically affect farm output. In these households, work effort (hours of farm work) among adult males and females seemed to respond positively to their productivity, which suggested the opportunity cost of not working was higher for more educated individuals.[6]

Evenson and Mwabu (1997) examined the impact of agricultural extension and farmers' schooling on crop yields of poor African farmers. They pooled 1981-82 and 1990 samples of Kenya farm households. The average level of schooling of these farmers was very low: 47 percent had less than 2.5 years of schooling (only one was a high school graduate). They applied a quantile- regression technique for investigating productivity effects of schooling over the conditional distribution of crop yields. Farmers' schooling (measured qualitatively as greater than or less than 2.5 years) had a positive and significant impact on yields only at the bottom of the yield distribution. Agricultural extension (number of field extension workers per farm) had a generally positive impact on crop yields, but in contrast to schooling, the marginal product was largest at the top end of the yield distribution.

A few studies have also examined the effect of schooling in non-democratic and emerging market economies, especially for China. The opportunities for schooling to contribute to farm production in China were very limited under the collective farming system but seem to have increased after 1984 with the change to household-responsibility system and opening input markets. Fleisher and Liu (1992) used a large 1987-88 survey of Chinese farm households located in six different geographical regions to test for diseconomies associated with small scale and multiple plots and effects of schooling and experience of household heads on productivity. Farm output was defined as weighted "rice-equivalence" of "field crops" produced (which excluded largely vegetables and fruits). They fitted a Cobb-Douglas-type production function and found positive, but not significantly different from zero effects of schooling and experience of the household head on farm production.

In another study, Yang (1997b) examined effects on production of alternative measures of education in an attempt to strengthen the connections between education and agriculture on small Chinese farms. He choose a value-added measure of farm output so as to capture allocative effects. Although farmers' choices may still be somewhat restricted in China, he hypothesized that the allocative effects would be larger than the worker effects. He considered alternative measures of education that might be expected to affect farm production, including years of schooling of the household head, highest year of schooling completed by any household member, and average schooling of all farm labor. The sample mean values of these variables were 5.6, 7.3, and 6.0 years, respectively. He fitted several different specifications of a Cobb-Douglas type production function. The head's education had a positive but insignificant effect on farm

production. Farm workers' education had a positive and significant effect on farm production, but education measured as the highest level completed by *any* farm household member performs *best*. In addition, he found that farm workers' experience (post-schooling experience weighted by farm work participation) also had a positive and significant effect on value added. Yang concluded that the schooling evidence from his sample of small Chinese farms showed allocative effects of education to be more important than worker effects. Furthermore, on these farms, the beneficial effects of schooling were obtained from an individual who frequently did not report any farm work. This seems possible only when farms are small and allocative decisions are relatively simple. The allocative benefits for these small farms were attainable with one well-schooled person per household.

The frontier production and profit function literature also provides evidence of the contribution of farmers' education to increased efficiency. Abdulai and Huffman (1999) showed that schooling of Ghana rice farmers reduces significantly profit inefficiency, which implies enhanced technical and allocation or economic efficiency. The empirical evidence for farmers' education reducing production or technical inefficiency is mixed, e.g., Belbase and Grabowski (1985) and Flinn and Ali (1986) found significant schooling effects but some other studies have found insignificant effects (see Bravo-Ureta and Pinherio 1993).

Overall, in developing, transition, and developed countries, the review of the literature shows that farmers' schooling has generally greater value through allocative than technical efficiency effects. The positive allocative effects are, however, closely associated with a farming environment where technologies are changing and relative prices are changing. Farmers' schooling has infrequently been shown to increase crop yields or gross farm output because technical-efficiency gains from skills provided by farmers' schooling seem generally to be small. Farmers' schooling has also been shown to change the optimal mix or composition of farm inputs and outputs where production is multi-input and multi-output.

Total Factor Productivity Decomposition

Productivity statistics, measuring output per unit of input, started in the 1950s showing seemingly costless increases in output. Schultz (1953), Kendrick (1961), and Denison (1962) started to search for underlying sources of productivity for these increases. Their work focused on the general economy and on agriculture where the data were better. Three main classes of methods have been applied in sources of productivity analysis: (1) imputation-accounting methods, (2) statistical meta-production function methods, and (3) statistical productivity decomposition methods (Evenson, this volume). In all of these methods, there is considerable investment in data construction, especially trying to accurately account for quality and quantity of inputs and outputs. Schooling enters primarily at two places: (1) schooling of agricultural labor can reasonably be expected to enhance labor quality or the effective units of labor, and (2) schooling of the farmer or decision maker may more generally increase productivity by enhancing economic efficiency in agriculture.

The best known early studies of sources of total factor productivity (TFP) change in U.S. agriculture are by Griliches (1963a, 1963b, 1964). In Griliches (1964), an index of education of farm labor was found to have a coefficient in an aggregate production function fitted to state average per farm data for 1949, 1954, and 1959 that was positive and not significantly different from the coefficient for farm labor (person days). This result has frequently been used by other researchers as a justification for constructed quality-adjusted farm labor input measures for TFP measures (e.g., see Ball 1985; Jorgenson and Gollop 1992; Ball et al. 1997). When Griliches (1964) then conducted an analysis of differences between unadjusted and adjusted residual agricultural output growth, 1949-59, education of farm labor accounted for about 14 percent of the explained difference.

Huffman and Evenson (1993) assessed research and education's contribution to TFP through statistical decomposition of state agricultural TFP levels. In their TFP measure, farm labor was measured as person-hours of unpaid farm family and hired labor, but no adjustment of education (or experience) was made. They derived TFP measures by state, 1950-82, for a crop sector, livestock sector, and aggregate farm sector. They then used public and private research, farmers' schooling, extension, and government commodity program variables to econometrically explain TFP in an analysis of 42 pooled states, 1950-82. To attain consistency of interpretation they impose some coefficient restrictions across the three productivity equations. They however found that farmers' schooling made a positive and statistically significant contribution to state TFP levels. Their results implied a positive marginal product of farmers' schooling and a relatively large social rate of return (19-40 percent). They concluded that farmers who have more schooling have an advantage in being able to understand scientific advances in the public and private sector, to draw inferences from results and make successful adaptation to their own particular farming operation, and to quickly adapt superior technologies, economic organizations, and management practices (Huffman and Evenson 1993).

They also found that farmers' schooling and agricultural extension interact negatively in explaining TFP levels. The marginal product of aggregate crop and livestock extension is positive, and the marginal product is larger in the crop than the livestock sector. For the livestock sector, the marginal product of extension was negative or zero. They, however, obtained evidence that farmers' schooling and extension were substitutes. Over the study period, the average level of farmers' schooling increased by about 4 years which greatly reduced the marginal product of extension by the end of the period.

In some North American studies of agricultural TFP, authors surprisingly have chosen to totally ignore the effects of education. This seems puzzling, but see Capalbo and Denny (1986), Antle and Capalbo (1988), and Chavas and Cox (1992). It is, however, more common to ignore labor quality adjustments in TFP analyses for developing countries where schooling completion levels are low and data are poor.

Rosegrant and Evenson (1993), however, are an exception in their TFP research for India and Pakistan. They constructed TFP indexes for the crop sectors for 271 districts in 13 states of

India (1956-87) and for 35 districts in 3 states of Pakistan (1955-85) and then conducted a statistical decomposition analysis. The empirical models were similar for the two countries. Average schooling completion levels for farmers in these districts of India and Pakistan were low, perhaps averaging 2 years. They chose to measure farmers' education as the literacy rate. They found that the literacy rate made a positive and statistically significant contribution to crop sector TFP in both countries. In India, agricultural extension (expenditures per farm) also made a positive and significant contribution to TFP.

A few studies have examined the effects of education on agricultural productivity across many countries. Hayami and Ruttan (1970) examined agricultural labor productivity, rather than TFP, differences for 38 developed and developing countries. (See Hayami (1960) for presentation of preliminary results for the same countries.) They assumed that a meta-production function (the envelope of all known and potentially discoverable production activities) exists across countries at a given point in time and over time in a given country. They fitted a Cobb-Douglas type production function to average per farm data. Output was measured as gross (net of feed and seed), and the labor input was measured as the *number* of male workers active in agriculture. In the 1960 data (which seems to be better than for 1955 or 1965), they found a positive and statistically significant effect of the rural literacy rate and of agricultural technical education (graduates from agricultural education facilities at above the secondary level per farm worker) on farm output per worker. They concluded that about one-third of the difference in agricultural labor productivity across the 38 countries was due to differences in human capital (education).

In a related study, Kawagoe, Hayami, and Ruttan (1985) expanded the set of countries to 43 (22 less developed) and focused on data for the years 1960, 1970, and 1980. They used the same methodology as Hayami and Ruttan (1970), but the education variables did not perform as well. Positive and significant effects of the literacy rate and agricultural technical education on farm output per worker were obtained from the data pooled across the three years for the less developed countries. For the developed countries, the two education variables did not perform well. This may be due to literacy rates having little variation across developing countries, and to agricultural college graduates frequently taking nonfarm employment rather than working on farms.

Craig et al. (1997) have attempted to push the labor productivity analysis further by expanding the number of countries to 98, making crude adjustments for input quality, and including proxies for rural infrastructure and agricultural research. Conventional agricultural labor is measured as the number of workers, i.e., the economically active agricultural population. No measure of work intensity, i.e., annual hours of work per worker, is included, but they included two labor quality measures, the literacy rate for the population over 15 years of age and life expectancy of the overall population at birth. They fitted a meta-Cobb-Douglas labor productivity equation, including the above adjustments, to the observations on 98 countries pooled over six observations per country (obtained by creating five-year averages from thirty years of annual data). Surprisingly, the coefficient of adult literacy is negative, and sometimes

significant, in all reported regression equations. In contrast, the coefficient of life expectancy is positive and significant. The poor performance of literacy seems likely to be due to its very crude measure of schooling, perhaps failing to capture dimensions of schooling that affect production, and no adjustment for intensity of work.

The authors can be criticized for trying to stretch their inferences by including the USSR, Central European countries, and China. From both an economic and econometric perspective this seems highly questionable. First, over the study period, the choice of where and when to work, range of choices available to farm managers or farmers, availability of variable inputs, and incentives to perform were very different in these centrally planned non-market economies than in the market-oriented largely free countries. Little evidence exists that centrally planned economies produced agricultural output at anything like cost-minimizing input combinations. Hence, the methodology applied by Craig et al. (1997) made an unnecessarily heterogenous sample.

Overall, it seems that some dimension of schooling contributes to TFP or labor productivity, but the current evidence is mixed. In U.S. agricultural productivity data sets, the incorporation of labor quality adjustments have not been uniform. One strand of the literature, started by Griliches and continued by Ball at USDA, emphasizes effective units of labor, which is the product of agricultural labor quantity (days or hours) and an index of labor quality. Another strand of the literature places labor quality effects in the productivity index (residual), and uses an education index, generally for farm operators, to explain TFP levels. When the latter approach has been followed, farmers' schooling has generally had a positive and significant effect on agricultural productivity. In cross-country studies of agricultural labor productivity, it has been difficult to obtain a satisfactory empirical measure of schooling. Consequently, the weak effects of education in cross-country studies seem most likely to be due to data problems than absence of real effects. Although the progress may be slow, this is an area where progress can be made.

Household Income

In the first section, the three-period model has household utility derived from leisure and purchased consumption goods. In that model, household (net) cash income is spent on purchased consumption goods and on purchased inputs for human capital production. Within this model, the optimal life-cycle path of purchased consumption goods will be less concave than net cash income because of the incentive to invest early in human capital and to reduce consumption early and to raise it later in life (Ghez and Becker 1975). Furthermore, in both the three-period and single-period models of agricultural household resource allocation, cash income in each period is determined by the household's initial human capital endowment, past net investments in human capital, and current allocation decision for human capital services between leisure and work, farm production decisions, and wage rates and prices. Hence, these models imply that household cash income is *not* an *exogenous variable*, but rather a variable that is the result of current and past decisions of the household, given market wage rates and prices. Hence, household income should not be treated as an exogenous variable in econometric studies of consumption, labor supply, and welfare analyses.

This subsection will focus on the narrower issue of the impacts of education on incomes of agricultural workers and farm households. The impact of schooling on incomes of hired agricultural labor seems to be small in developed countries and insignificant in other countries. Emerson (1989) examined the earnings structure for migratory and nonmigratory work of 559 domestic males in a 1970 survey of Florida farm workers. In fitted annual earnings equations (adjusted for selection), he found a very small positive and significant effect of workers' schooling on earnings (1.4 percent per year for migrants and 1.6 percent per year for nonmigrants, holding weeks worked per year constant). He also found a quadratic effect of worker's experience on earnings. The coefficients for experience were about 50 percent larger for migrants than for nonmigrants. Furthermore, he found that these domestic farm workers sorted or self-selected themselves into migratory and nonmigratory groups in a manner that was consistent with the theory of comparative advantage--i.e., migrants earned more as migrants than they would as nonmigrants, and nonmigrants earned more as nonmigrants than they would as migrants.

Ise and Perloff (1995) employed a hedonic wage equation and static labor supply model to examine the effects of an agricultural worker's legal status on wage earned and hours of work or labor supply. Legal status of a worker was hypothesized to be determined by an individual's demographic attributes. The model was fitted to a random sample of seasonal agricultural service workers from the National Agricultural Workers' Survey. They found that an individual being an English speaker and having more schooling increased the odds of having a preferred legal status. For seasonal agricultural service workers, work experience had a positive and significant effect on the hourly wage in all equations, except for workers having unauthorized status. However, a worker's education did not have a significant effect on the wage. In the labor supply equation for workers having Amnesty or Green Card status, additional schooling reduced significantly weekly hours of work. They concluded, not too surprisingly, that agricultural workers who work in the U.S. legally earned substantially more per hour and per week than those having unauthorized status. Thus, investing in obtaining a preferred legal status becomes another form of human capital with highly relevant cost-benefit calculations for potential immigrants and significant effects on workers' incomes.

The attributes of farm work, of farm workers, and employers affect the type of pay system used, e.g., time or piece rate. A piece-rate system is not workable in many circumstances, e.g., due to quality control or no easily defined output, but it is frequently the pay system for harvest labor. A piece-rate system is incentive pay for speedy work, a skill that seems likely to be unrelated to schooling. Rubin and Perloff (1993) examined workers' choice of pay system and hedonic wage equations for both pay systems in a small 1981 sample of harvest workers (in Tulare County, California).[7] The average schooling level for time-pay workers was 4.9 years and for piece-rate pay workers, 4.1 years. They found that the probability of using/choosing the piece-rate system was strongly related to the age of the workers, where young and older workers who have unproven skills are more likely to choose the piece-rate pay system than prime age workers, holding the expected pay differential constant. The lowest probability of piece-rate pay occurred for a 34-year old worker. In the hedonic wage equations, adjusted for sample selection, Rubin and Perloff (1993) found that *workers' schooling had a small positive* and statistically

significant effect on the *time-rate of pay wage but not on the piece-rate wage*. Experience, proxied by age and age-squared, had a statistically significant effect on the wage rate in both pay systems, and the age at which the peak occurred was about 39 years. The coefficients were, however, larger by a factor of two for the piece- than for the time-rate system, suggesting more exaggerated effects of experience for the piece-rate than for the time-rate pay system. Hence, these results suggest that a worker's pay is not related to his or her schooling when the work is piece-rate, but the return is small when it is time-rate of pay.

In a developing country, transportation and communication are relatively expensive, schooling is minimal, and housing in a new location may be difficult to find. Hence, workers tend to be less geographically mobile than in the United States, and rural labor markets less integrated. Rosenzweig (1980) used data from a 1970-71 national sample of rural households in India to examine several labor issues, including hedonic wage equations for casual workers employed on a monthly or daily basis. In his sample, mean schooling of male and female landless workers was 1 year and 0.5 year, respectively. The wage equation (adjusted for selection) included individual and local village attributes, and separate equations were fitted for men and women. He found that schooling of males had a small positive (3.9 percent) and statistically significant effect on their wage, but schooling had no significant effect on the female wage. Also, potential experience (as represented by age, and age-squared) had no significant effect on male or female wage rates. Rosenzweig, however, concluded that human capital variables *were not significant predictors of the wage rate for casual labor* in India, and village attributes that affect local labor demand and supply were relatively important.

For farm or landed households, the effects of schooling on income arise primarily from impacts on farm profit or value added and off-farm earnings.[8] In the third subsection, evidence was summarized showing that farmers' schooling increased farm profit in an environment where technology and relative prices are changing. In other agricultural environments where technology and prices are not changing, or where farmers' schooling is below the permanent literacy level, farmers' schooling seems unlikely to have a significant impact on farm profit, value added, or household income.

Huffman (1991b) provides an extensive survey and critique of agricultural household models that have proved useful for examining off-farm labor supply. In U.S. studies of off-farm work, a male farm operator's schooling increases his off-farm wage by 4 to 13 percent (see Sumner 1982, Jensen and Salant 1985, Gould and Saupe 1989, and Huffman and Lange 1989). The direct effect of a male operator's education on his off-farm hours, holding his wage constant, has sometimes been significant and positive (e.g., Huffman 1980, Lass and Gempesaw 1992), and, when only the operator works off-farm, significant and negative (e.g., Jensen and Salant 1985), and sometimes insignificant (e.g., Sumner 1982, Huffman and Lange 1989). Given that the wage elasticity of off-farm hours has been positive (an exception is Lass and Gempesaw 1992), schooling of farm operators who work off-farm makes a positive contribution to household income in the United States.

The effects of schooling on off-farm income of farm households may be different in developing countries than in the United States. In a 1970-1971 national sample of rural households, in India, Rosenzweig (1980) found that an individual's schooling and experience were relatively unimportant for explaining wage rates for *casual* labor. In his results for landholding households, schooling had a negative and generally significant effect on off-farm work days of both males and females. The implication was that farm households can better employ members with schooling on the farm than in the casual labor market. In the Philippines, Evenson (1978) found a positive and significant effect of a farm husband's market wage on his hours of wage work and implicitly on household income. For a 1990 sample of Chinese farm households, Yang (1997a) found that an individual's schooling and potential labor market experience have a positive and significant effect on the off-farm wage. He also found that the person in these households who had completed the most schooling was the off-farm work participant. In another study, Yang (1997b), showed that the person having the most schooling in these households also made the allocative decisions on the farm. Hence, schooling for one person in the Chinese farm households has positive effects on household incomes that come from farm and nonfarm effects.

Given that there are several channels through which education can affect farm household income, Huffman (1996a) fitted a reduced-farm household income equation to data for U.S. Current Population Survey married couple farm households, 1978-1982. He used as explanatory variables the following: husband's and wife's education, husband's age and race, family size, local labor market conditions, cost of living and locational amenity variables, and agricultural input and output prices and climate. He found that husband's and wife's schooling had a significantly positive effect on farm household income. An added year of husband's schooling increased household income by 1.3 percent and of wife's schooling by about 1 percent.[9]

Overall, the review of the literature has shown that the effects of education on incomes of hired farm workers are mixed. If hired farm workers work piece-rate, schooling doesn't affect their wage but experience may be important if they can acquire skills by specializing in a particular type of work. If they are time-pay wage workers, added schooling may have a small positive impact on their wage. For farm household members in developed and developing countries, the impact of schooling on farm profit or value added is positive when technology is changing rapidly. In developed countries, schooling has been shown to have a positive impact on the off-farm wage and off-farm earnings, but in developing countries the results are mixed, e.g., negative in Indian Green Revolution areas and positive in China. In developed countries, schooling of husbands and wives has a positive effect on farm household (net) income, and in developing countries, the impact is probably positive. Empirical studies, however, have infrequently focused on the effects of education on household or family income.

Summary and Research Gaps

Economists continue to search for a better understanding of the sources and causes of economic growth and development of regions and nations. Schultz (1988) concluded that a significant set of studies show strong empirical regularities between the educational attainment

of a population and their productivity and performance in both market and nonmarket production activities. Furthermore, this chapter has shown that a now sizeable body of empirical evidence has accumulated on the effects of education in agriculture. In particular, the returns to education of farmers increases substantially as a country goes from traditional agriculture to modernizing, which itself becomes a continuing process. First, with modernizing, new technologies are becoming available and the economic environment is changing so that enhanced decision-making skills of farmers (and possibly other family members) are more productive. Second, when the productivity of agriculture increases, the aggregate demand for agricultural labor is reduced and the share of the labor force employed in agriculture declines and in other sectors increases. All currently developed countries have progressed from ones where a very large share of the labor force (over 75 percent) was employed in agriculture (Johnson 1997), but with modernization of agriculture and economic development the share of the labor force in agriculture is less than 20 percent (and for the United States only 3 percent). There is accumulated empirical evidence that individuals' schooling plays a very important role in occupational choice (increasing the probability of working outside of agriculture in developed countries), migration (more educated individuals have greater geographic mobility out of rural areas), and part-time farming (the probability of off-farm work by those who remain in farming increases), which are all important in reallocating human resources among sectors in a growing and developing country but could contribute to the remaining rural population being quite low educated.

There is also accumulated evidence where education seems to be a poor private investment. First, in casual rural labor markets of low-income countries, schooling (and experience) doesn't seem to affect wage rates. In urban labor markets of these countries, the returns to education are better. Second, in high-income countries, schooling of field workers in fresh fruit and vegetable production has a very low return. Some fresh fruits and vegetables have large income elasticities of demand, and high quality fresh produce is possible only with hand harvesting. Thus, in the United States and some other developed countries, there is growth in the demand for relatively unschooled migratory farm labor to work on a piece-rate pay system. For the United States, this labor is supplied largely by legal and illegal immigrants from Mexico and Central America. Interestingly, the accumulated evidence shows that ethnic migration networks or social capital have been an effective substitute for migrants' own schooling in being successful in the U.S. low-skilled migratory labor market. Furthermore, an assumption that hired farm labor and farm operator (and family) labor are homogeneous in agricultural household models should be carefully scrutinized. In modernizing agriculture, the assumption is almost certainly dubious.

It is useful to think critically about the empirical evidence. Schultz (1988) emphasized that outcomes on educational attainment, occupation, location, labor force participation, and social-economic program participation are never random. This opens the door to nonrandom selection of comparison groups and potential sample-selection bias in parameter estimates of econometric models. Techniques have been developed for trying to off-set sample selection bias, and they have been applied in many of the studies reviewed. These techniques are, however, imperfect, and researchers have discovered that identification problems sometimes arise in implementing selection correction procedures (see Nawata and Nagase (1996) and Heckman

(1997)). The identification problem creates another set of serious parameter biases. Researchers must continue to raise data quality issues, promote and pursue good experimental designs for new data sets, and pursue careful analysis where selectivity is likely to be serious.

In our empirical research, we use an individual's years of schooling as proxy for his or her education, but in the U.S. and in many other countries, the quality of this proxy has not been constant over time. Education is really general intellectual achievement (GIA), including developed abilities, e.g., reading, writing, doing mathematics, reasoning, and knowing important facts and principles of science, history, and art (Bishop 1989). These are skills essential for performing many job tasks, the tools for learning new tasks, and the foundations upon which much job-specific knowledge is built. The production of GIA is multi factor: school attendance (years completed), quality of schooling, quantity and quality of out-of-school learning, the general socio-intellectual environment, innate ability, and other things.

Bishop (1989) summarizes how general intellectual achievement in the U.S. rose steadily from 1915 to about 1967. For 12-th (and 8-th) graders, GIA went into a decline over 1967-1980, equaling 1.25 grade equivalents and a 2 grade equivalent deviation from trend. Since 1980, GIA of 12-th graders has been increasing again. Thus, what a year of schooling completed measures has not been constant over time nor does it have a linear trend. Hence, when individuals included in a survey have graduated from high school at different times, complex schooling vintage effects may exist, which complicate using years of schooling completed as a proxy for education in cross-sectional and panel studies, and in interpreting the impact of schooling on social-economic outcomes.

This information does suggest that a better estimate of the impact or return to a year of schooling can be obtained from U.S. micro-data by including as variables in a regression equation with an individual's years of schooling his or her year of graduation from high school (or grade school, if he or she is not a high school graduate) and a dichotomous variable for graduation after 1967. Given the incentive for individuals to obtain schooling at a young age and to graduate at approximately the same age, at least in developed countries, and that most surveys do not ask about year of high school (or elementary school) graduation, we can obtain almost the same information from an individual's age. Including as regressors an individual's age rather than date of graduation and a dichotomous variable for birth after 1950 contain approximately the same information as the two variables constructed from year of graduation. From the review in earlier sections, recall that human capital wage, labor supply, and adoption equations generally include an individual's age (and age squared) as regressors to take account of finite life or on-the job training effects, but production, profit, and cost functions generally do not. Hence, estimates of impacts of schooling from the latter group might be suspect.[10]

The potential for endogenous or stochastic regressor bias in human capital research area is especially high. For example, in some of the off-farm participation and labor supply studies, farm characteristics like size (acres operated) and presence of a dairy enterprise are used as regressors. Our economic models of farm household decision making (for developed countries), however,

imply that acres operated, presence of a dairy enterprise, and off-farm work participation are farmers' choices (and not exogenous or randomly assigned). Jointly determined variables are not legitimate regressors, even though they seem to have large explanatory power. Similar types of issues also arise with farmers' information acquisition and technology adoption and with variables to explain migration. The solution seems to be careful economic and econometric modeling of behavior and outcomes and using instrumental variables for regressors that may be stochastic because of endogeneity or serious measurement errors (Green 1997, p.435-443).

Some research gaps or potentially fruitful research directions exist. First, skilled labor and (technologically enhanced) capital services seem to be complements in manufacturing. Agriculture in developed countries is relatively capital intensive too, but except for farm operators' education, no good evidence exists on whether skilled labor and capital services are substitutes or complements. Also, empirical evidence is missing on the extent to which workers in agriculture are at a disadvantage (or advantage) compared to workers in other sectors for obtaining productivity gains from greater worker specialization, or whether potential productivity gains from specialization differ across crop and livestock enterprises. Some large-scale broiler, swine, cattle feed lot, and dairy operations seem to have production attributes much like manufacturing plants. A key difference between agriculture and other sectors might be differences in opportunities to increase labor productivity through larger investments in skill and specialization of workers. A closely related issue is how new biotechnology and information systems affect the demand for skilled labor in agriculture.

Second, although farmers' schooling and frequently extension have been shown to enhance successful adoption of new technologies in agriculture where heterogeneity of land and climate are important factors, a set of related management decisions has been largely ignored. They are the joint decisions on technology, information acquisition, and risk-bearing methods, and how farmers' schooling affects these choices. In most agricultural societies, a wide range of options exist for technologies, information, and risk-bearing, but models and empirical analyses have generally focused on only one of these outcomes. This limits our ability to learn about successful management strategies that farmers use internationally as the technical and institutional environments change. It also limits our ability to learn about potentially important public-private substitution possibilities in providing information and risk-bearing instruments for farmers.

Third, general intellectual achievement of elementary and secondary school students is produced both through schooling and out-of-school activities, so the total decline over 1967 to 1980 in GIA cannot be attributed to a decline in the quality of schooling. Huffman (1998), however, summarizes some of the changes in the organization of U.S. schooling starting in the late 1960s that undoubtedly contributed significantly to the decline in general intellectual achievement of students. He and others have concluded that the last 50 years of schooling research provides a weak knowledge base for guiding schools and school administrators. Too little is known about the successful organization of schooling for efficient production of general intellectual achievement, and new rigorous research is needed.

Fourth, although it is widely accepted that schooling creates new skills that increase workers' productivity in market and nonmarket activities, relatively little empirical research has attempted to identify the effects of adults' schooling on total farm family income net of farm expenses. Farm families in most countries have significant nonfarm income, and cash income is used to purchase consumption goods/inputs, schooling, and health care. Empirical studies have largely focused on individual pieces of a much larger story, e.g., effects on farm gross output, farm profit (value added), off-farm wage rates, or off-farm work hours, but this misses some of the important trade-offs that exist. Although farm income is notorious for large measurement errors and farm expenses in developed countries generally receive favorable tax treatment, these do not seem serious enough to prevent useful research. Given that governments generally invest in schooling, research, extension, commodity, and credit programs with some intention of increasing farm families' income, it is interesting to ask which of them have been successful. Although Gardner (1992) concluded that there is no empirical evidence in the literature that U.S. government farm program payments have increased net farm income, it is important for future research to estimate and compare the impacts of these government policies on farm family income.

Overall, this chapter has summarized the impacts of education in agriculture for several different environments, e.g., developing country, transition economy, developed country, technically dynamic, technically static, and concluded that the impacts are positive in some but not all environments. It remains somewhat of a puzzle, however, why schooling in developed countries does not have broader direct impacts in agriculture. One hypothesis is that the dominance of agriculture by biological production processes which are controlled largely by climate and are land surface-area intensive, at least for crop production, greatly limits the potential for raising labor productivity through skill acquisition and specialization of labor that is possible in the non-farm sector. After reviewing the extensive literature cited in this chapter, one should not miss the fact that the dominant effect of education in agriculture of developed countries is to aid and assist farm people with education make the transition to nonfarm work and ultimately to full-time nonfarm occupations. This process has important implications for the composition of the population left behind in agriculture and on the optimal financing of schooling in rural areas.

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Table 1. Summary of econometric evidence: probability of participation in off-farm work.

| | | | | Marginal effect on probability | |
| | | | | Operator's | Spouse's |
Off-farm Participation	Location	Dependent Data Type	Operator's Variable	Schooling	Schooling
Huffman (1980)	U.S. (Iowa, N.C., Okla.)	1964 census ct. aggre. avg.	Log (odds of off-farm work)	+[a]	+[a]
Sumner (1982)	U.S. (Ill.)	1971 farm level	Probit (1,0)	+	!
Huffman/Lange (1989)	U.S. (Iowa)	1977 farm level	Probit (1,0)	+[a]	![a]
Jensen/Salant (1985)	U.S. (Miss., Tenn.)	1981 farm level	Probit (1,0)	+[a]	!
Bollman (1979)	Canada	1971 census 1971 census	Probit (1,0)	+[a]	+[a]
Gould/Saupe (1989)	U.S. (Wis.)	1986 farm level	Probit (1,0)	+	+
Lass, Findeis, and Hallberg (1989)					
Tokle/Huffman (1991)	U.S.	1978-82 household level	Probit (1,0)	+	![a]
Lass/Gempesaw (1992)	U.S. (Pa.)	1985 farm level	Probit (1,0)	+	+[a]
Kimhi (1994)	Israel (1981 census)	1981 farm level	Probit (1,0)	+[a]	![a]

[a] Computed from a coefficient that is significantly different from zero at 5 percent level.

Endnotes

1. Average schooling completion levels of the adult population differ greatly across countries. Barro and Lee (1993) have recently constructed good estimates of schooling completion levels for a set of 125 countries for the period 1960-1985. They report summaries for regional groups of countries. In 1985, sub-Saharan Africa and South Asia had the lowest average schooling completion levels for adults, 2.67 and 2.81 years, respectively. In the Middle East and North Africa, the average schooling completion level was 3.51 years, and in Latin America and the Caribbean the average was 4.47 years. In other regions, the average schooling completion level for adults was higher, 5.19 years for East Asia and the Pacific, 8.88 years for the OECD countries, and 9.17 years for centrally planned economies (excluding China). No similar international data exists on schooling completion of the farm population.

2. If an active rental or asset market in farmland does not exist, then farmland is part of A_3.

3. See Martin et al. (1995) for an extensive review of the use of foreign, including undocumented, workers in U.S. agriculture and an examination of the impacts on U.S. agriculture of the Immigration Reform and Control Act of 1986.

4. Perloff also concluded that if the supply of undocumented workers to U.S. agriculture was to end, the wage rate in agriculture would rise relatively, and significant positive supply response would arise from low-educated nonurban U.S. workers.

5. See Feder, Just, and Zilberman (1985) for a survey of other economic factors affecting adoption of technologies in developing countries. See Birkhauser, Evenson, and Feder (1991) for a review of impacts of agricultural extension on adoption.

6. Benjamin (1992) presents a rigorous modeling and econometric analysis of Java farm household labor use due to household composition and presence or absence of labor markets.

7. The authors, however, ignored the possibility that employers of agricultural workers are also making a decision about which pay system to offer. This could affect the results (Gibbons 1999).

8. The seemingly perverse effect of farmers' schooling on cost of milk production from the U.S. Department of Agriculture 1993 Farm Costs and Return Survey (see Short and McBride, 1996) seems most likely due to the way schooling is defined (as dichotomous rather than continuous variable) and the fact that ability or age of farmers' is not controlled for. Before 1940, ability and schooling completion among rural youth were not positively correlated. With some selection on who chooses to operate a dairy enterprise, a seemingly positive relationship between schooling and cost should not be taken as evidence that schooling of dairy farmers is unproductive. A negative schooling effect on the cost of milk production does not show up in a study using later data (see El-Osta and Johnson 1998).

9.	However, a similar model fitted to data for nonmetropolitan nonfarm household income gave estimated coefficients for husband's and wife's schooling that were about 60 percent larger than for farm households. This model excluded agricultural prices and climate.

10.	See Bishop (1989) for a methodology for constructing vintage of schooling effects in aggregate data.

$MC_{Z_{2j}}, MR_{Z_{2j}}$ ' $PV_{Z_{2j}}^t$

$MC_{Z_2}[W_2, P_2, A_2]$

$MR_{Z_{2t}}$

$MR_{Z_{2t\%1}}$

0

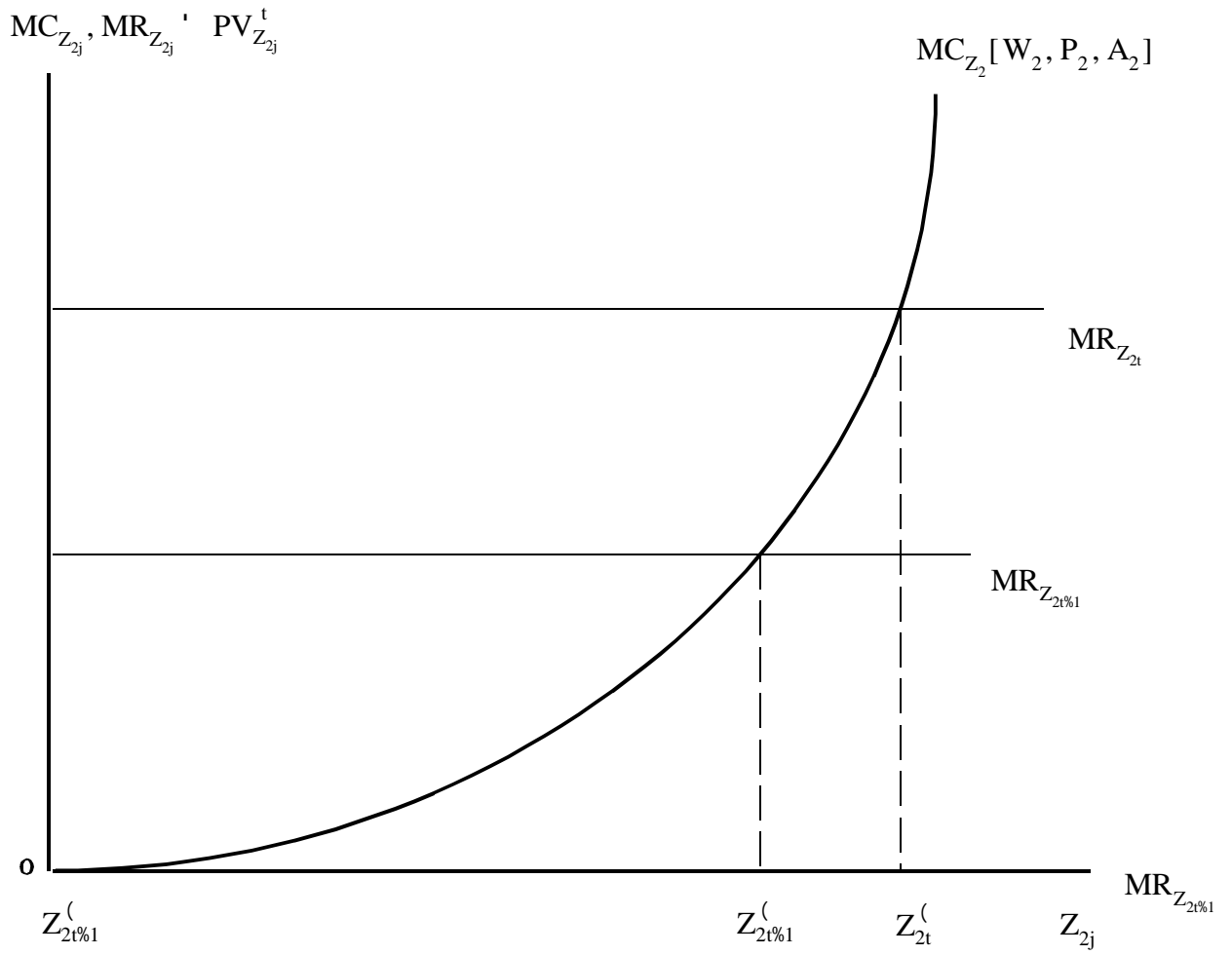$MR_{Z_{2t\%1}}$

$Z_{2t\%1}^($ $Z_{2t\%1}^($ $Z_{2t}^($ Z_{2j}

Figure 1. Optimal Production
of Human Capital