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The Role of Agriculture and Human Capital in Economic Growth: Farmers, Schooling and Health

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This paper examines the important role played by agriculture and human capital of farmers and farm people in economic growth and development. In particular, we place great emphasis on the importance of positive technology shocks to agriculture for igniting what may become long-term economic growth with increased food production per capita, an improved standard of living, migration of labor from the farm to the nonfarm sector and the rise of cities.

The objective of this paper is to provide a critique of the existing literature, to identify the contributions of schooling, health and agriculture to economic growth and development of the poor countries, and to provide recommendations about gaps and puzzles that exist. We place the analysis in the context of long-term economic growth, starting from an economy and labor force that is primarily agricultural (Johnson 2000) and then consider productivity shocks to agriculture as an essential event before modern economic growth with industrialization can occur. We show that human capital in schooling and health of farmers and farm families are important to the whole process. In particular, as the economy is transformed, the farm sector becomes a major source of labor for the nonfarm sector, but inter-sector and occupational mobility require a

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skilled-labor force. Also, the skills of women, even if they work primarily as unpaid workers or in housework, are an important source of human capital production as they nurture children and families. We first present a conceptual framework and then summarize a variety of empirical evidence. Finally, some conclusions are formulated.

A Conceptual Framework

A two-sector model is first outlined and then we turn to a 3-period agricultural household model with human capital investment. Some concluding implications are presented.

A Two-Sector Model: Agriculture and Non-agriculture

As shown in Jorgensen (1965) and Huffman (1977), a two-sector model of the linkages between the farm and nonfarm sectors can generate many insights into the role of agricultural productivity in fostering economic development. In poor countries, trade barriers are frequently ubiquitous, and they do not have sufficient foreign exchange to regularly purchase large quantities of food from abroad. Hence, useful insights can be obtained from a two-sector model (where there is one world or an economy is closed to trade).

The following 2-sector model allows us to quantify the linkages and adjustments to shocks in domestic demand due to real income growth and to domestic supply from technical change. Define $X_i^d = D_i (P_1,P_2,Y)$, i =1,2, as the demand function for farm output (i=1) and for nonfarm output (i=2). P_i, i =1,2, is the price of farm and nonfarm output, respectively, and I is total income of domestic demanders. In the supply equation, $X_i^s = AS_i(P_i)$, i=1,2, where "A" is the coefficient of disembodied technical change.

Because we are concerned with growth, the two-sector model is expressed in time-rate of change form:

$$(1)\ x_i^d = \varepsilon_{11}p_1 + \varepsilon_{12}p_2 + \eta_i y, \quad \varepsilon_{ii} < 0,\ i = 1,2 \ \text{(demand equation)}$$

$$(2)\ x_i^s = \varphi_{ii}p_i + a_i,\ \varphi_{ii} \geq 0, \quad i = 1,2 \ \text{(supply function)}$$

Where $x_i = \frac{dX_i}{dt}\frac{1}{X_i}$, $p_i = \frac{dP_i}{dt}\frac{1}{P_i}$, i = 1,2 are the percentage rates of change in the output of sector i and of the price of output of sector i, respectively. The response elasticities are own-price demand elasticity, $\varepsilon_{ii} = \frac{dX_i}{dP_i}\frac{P_i}{X_i}$; cross price demand elasticity, $\varepsilon_{ij} = \frac{dX_i}{dP_j}\frac{P_j}{X_i}$, i,j = 1,2; and the income elasticity, $\eta_i = \frac{dX_i}{dY}\frac{Y}{X_i}$, i = 1,2. In addition, $a_i = \frac{dA_i}{dt}\frac{1}{A_i}$, i … j, i, j = 1,2 is the rate of disembodied technical change in sector i.

We assume that the two markets are initially in equilibrium, $X_i^d = X_i^s$, i = 1,2, i.e. the markets clear, and we maintain the neoclassical assumption that markets clear even when shocks to demand and (or) supply occur:

$$(3)\begin{cases} \varphi_{11}p_1 + a_1 = \varepsilon_{11}p_1 + \varepsilon_{12}p_2 + \eta_i y & \text{(farm sector)} \\ \varphi_{22}p_2 + a_2 = \varepsilon_{21}p_1 + \varepsilon_{22}p_2 + \eta_2 y & \text{(nonfarm sector)} \end{cases}$$

$$(4)\begin{cases} (\varepsilon_{11}\text{-}\varphi_{11})\ p_1 + \varepsilon_{12}p_2 = a_1 - \eta_1 y = c_1, \\ \varepsilon_{21}p_1 + (\varepsilon_{22} - \varphi_{22})\ p_2 = a_2 - \eta_2 y = c_2, \end{cases}$$

Now equation (4) is arranged to emphasize that income growth (y) and disembodied technical change (a_1, a_2) are driving changes in the prices of farm and nonfarm output, p_1 and p_2. This set of equations can be solved for the equilibrium rate of change in the prices of the farm (X_1) and nonfarm (X_2) outputs due to $c_i = a_i - \eta_i y \neq 0$:

$$(5)\ p_1 = \frac{(a_1 - \eta_1 y)(\varepsilon_{22} - \varphi_{22}) - (a_2 - \eta_2 y)\varepsilon_{12}}{(\varepsilon_{11} - \varphi_{11})(\varepsilon_{22} - \varphi_{22}) - \varepsilon_{12}\varepsilon_{21}}$$

$$(6)\ \ p_2 = \frac{(a_2 - \eta_2 y)(\varepsilon_{11} - \varphi_{11}) - (a_1 - \eta_1 y)\varepsilon_{21}}{(\varepsilon_{11} - \varphi_{11})(\varepsilon_{22} - \varphi_{22}) - \varepsilon_{12}\varepsilon_{21}}$$

Therefore the rate of change in equilibrium market prices of farm and nonfarm output due to income growth and technical change are a function of the two own-price elasticties (ε_{11}, ε_{22}), two cross-price elasticities (ε_{12}, ε_{21}), two-income elasticity's (η_1, η_2) and two rates of technical change (a_1, a_2).

Now assume both farm and nonfarm outputs are normal goods ($\eta_i > 0$, i = 1, 2), and the income elasticity of farm output is less than for nonfarm output ($\eta_1 < \eta_2$). If the rate of disembodied technical change is the same in the two sectors, ($a_1 = a_2 = a$) and if the cross-price elasticities of demand are zero ($\varepsilon_{12} = \varepsilon_{21} = 0$), then $a - \eta_1 y > 0$ and $a - \eta_2 y < 0$ and this implies that:

$$(7)\ \ \text{sign}\ (p_1 - p_2) = \text{sign}[(a-\eta_1 y)(\varepsilon_{22}-\varphi_{22}) - (a-\eta_2 y)(\varepsilon_{11}-\varphi_{11})] < 0.$$

So that equal rates of technical change in the two sectors will cause the relative price of farm output to decline.

If the cross-price elasticities of demand are of opposite signs and the other conditions hold, then condition (7) still holds. If they are of the same sign but $* \varepsilon_{12}\ \varepsilon_{21} * < *(\varepsilon_{11}-\varphi_{11})\ (\varepsilon_{22} - \varphi_{22})*$, then condition (7) also holds. If we impose homogeneity of degree zero in prices and income so that $\varepsilon_{11} + \varepsilon_{12} + \mathbf{0}_1 = \varepsilon_{21} + \varepsilon_{22} + \mathbf{0}_2 = 0$, then the denominators in (5) and (6) can be shown to still be positive and so (7) remains satisfied. Thus, if the income elasticity for nonfarm output is larger than for farm output, positive growth of income (or technical change) causes the relative price of farm output to decline under very general conditions. The result in (7) becomes even stronger if TFP growth is faster in the agricultural than in the non-agricultural sector, as has been found by Jorgenson and Stiroh (2000) for the U.S..

Consistent with this simple theoretical argument and evidence of relative farm and nonfarm productivity growth, economic development in the United States since 1900 has generally been accompanied by falling relative prices of farm commodities. This pattern has held generally as economic development has occurred in other countries also. This has profound implications for the proportion of the population engaged in farm production over the long run. Assume that labor is the only variable input in the farm and nonfarm sectors and that farm and nonfarm labor markets are in equilibrium. Then, the real wage or its equivalent is approximately equal across the two sectors. Again assume that the rate of disembodied technical change and population growth is the same in both the farm and nonfarm sectors. With the farm output price falling relative to the nonfarm sector, the real cost of food will fall. To maintain equilibrium real wages rates between sectors, labor must be transferred from the farm to the non-farm sector. If the population grows faster in the farm than the nonfarm sector, the rate of exit of labor from the farm/agricultural sector must be even faster. These migrants become a potentially important source of labor for a growing nonagricultural e.g., industrial and service, sectors. See Floyd (1967) for a detailed framework

The recent paper by Gollin (2000) reemphasizes that the labor force which is self-employed, working on own account or unpaid family is largest in most developing countries. Furthermore, Gollin et al (2002) also provides supporting evidence for growth in agriculture being central to economic growth and development.

A Multiperiod Agricultural Household Model

The decisions of agricultural households have been modeled from different perspectives depending on the central issue researchers are emphasizing. When human capital investment decisions are the central focus (e.g., schooling, informal training, information search, technology adoption, good health), multiperiod household utility maximizing models provide a useful guide for empirical work. Once household members have obtained their human capital and the focus is on choice of occupation, hours of work, purchased-input use, wage rates, or income, one-period static agricultural household models provide a useful guide to researchers (Singh et al., 1986). In particular, behavioral models provide one useful guide to researchers for deciding which variables should be treated as endogenous and which are to be held exogenous or causal.

Consider a risk-neutral household living three periods. In each period, the farm household consumes human capital services and purchased goods that give utility. The production of human capital investment uses human capital services from the existing stock, purchased inputs, and a fixed individual household-specific genetic or innate ability factor and exhibits decreasing returns to scale in production (see Ben Porath, 1967). The production of farm output uses variable inputs of human capital services of household members and purchased inputs and is conditional on technology and agro-climatic conditions. The farm production technology exhibits decreasing returns to scale in the variable inputs (see Huffman, 2001 for details).

This modeling strategy treats human capital investment as changing the quantity of human capital services available for all uses but does not change the real wage for a unit of human capital services. Human capital depreciates at some constant rate, and available human capital services in each time period are allocated among leisure, human capital production, farm production, and wage work. The household faces a multiperiod discounted cash income constraint in maximizing its intertemporal utility function.

The following important results follow from this model. First, the optimal size of the human capital investment in each period is the quantity or rate where the present value of the marginal return from a unit equals the present value of the marginal cost. Increases in the cost of borrowing will cause the household to lower its current investments in human capital.

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 to investment in human capital. 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 of 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 nonfarm 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 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.

Third, given the three-period lifetime, a comparison of the present value of the marginal return to an investment in period t and t+1 shows 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 resources in human capital production in the final period (t+2), because there is cost but no return (see Figure 1).

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 reduction in the present value of the marginal return due to delaying the investment. Spreading the investment over time is a good decision when the cost saving exceeds the reduction in returns due to postponement (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 (see also Huffman, 2001).

Some Implications

Schooling and learning-by-doing 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 for 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, 1996). Although technical change in agriculture is frequently at least as large as in the nonfarm sector, the opportunities for raising labor productivity in agriculture through task specialization and coordination may be modest compared with the nonfarm sector. On a farm, the skilled individual may face a more inelastic demand for his/her services than in a large nonfarm business. Also, due to poor infrastructure and institutions, the agricultural sector may in some cases face small market size and high coordination costs that put it at a disadvantage.

In some agricultural environments, informal learning rather than schooling is the most important form of human capital, but in other environments where information processing about new technologies, schooling may have high payoffs (Schultz, 1964; Huffman, 1985, 1991; Becker, 1993, p. 1-13; Johnson, 2000). For example, in a traditional environment that is static in technology and relative prices as exists in some low-income countries, accumulated experience is a better investment than schooling. Information accumulated informally does not depreciate when the decision-making environment is static. However, in a market economy where the political and economic environments are changing and new technologies are regularly becoming available, skills obtained from formal schooling provide an important foundation for later informal post-school learning. Most new agricultural technologies are geo-climatic and (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 a valuable skill. Hence, a changing agricultural environment increases the expected return to formal schooling through allocative efficiency effects, which seem likely to be more important than technical efficiency effects.

Empirical Evidence

We present a variety of evidence, some from stylized facts over the past two thousand years and econometric evidence.

2000 Years of Economic Growth: Stylized Facts

The world population and per capita gross domestic product data from year 0 to 1998 AD, as reported by Madison (2001), are plotted against time in Figure 2. For the first 1,700 years of the series, world population hardly grew at all. From a base of approximately 231 million world inhabitants in year 0, which was the time of the first Roman Census, the world population in 1700 stood at approximately 603 million—a net increase at an average of 0.06% per year. In the subsequent 300 years, the world population has increased ten-fold, rising at an average rate of 0.8% per year. Most of the growth has occurred during the 20th century when world population growth averaged 1.4% per year. The population would have grown even more rapidly were it not for the two world wars. After World War II, world population growth averaged 1.8% per year.

The very slow growth of the world population for the first 1,700 years coincided with an even slower growth of GDP per capita that averaged 0.02% per year. Using GDP per capita as a rough indicator of labor productivity, it appears that workers in 1700 were no more than 1.4 times more productive than workers in year 0. Over the next 300 years, GDP per capita grew at 0.8% per year—roughly comparable to the population growth rate. However, the timing of the population and per capita GDP growth after 1700, differed. Before 1900, the world population grew faster than GDP per capita (0.50% vs. 0.35%) but slower thereafter (1.4% vs. 1.6%). Nevertheless, the consistency between the growth of population and the growth of output per capita suggests that the two series are structurally interrelated.

In 1750, over 90 percent of the world's labor force was engaged in agriculture. By 1830, France and Germany had reduced their labor force in agriculture to about 50 percent. The U.K., the most advanced industrial country at this time, had less than 25 percent of its labor force in agriculture. At the same time, the U.S. had about 65 percent of its labor force in agriculture (Grübler, 1994), a share that is equal to that of India and China today (World Bank).

The great wealth of today's industrialized nations and remarkable improvement in the wellbeing of people in developed countries have been made possible by farm people aided by organizational, institutional, and scientific advances. Farmers and farm people have played a central role in this transformation process. Change was possible because farmers could produce a surplus over and above their own consumption and it could be exported to the cities. Advances in the science of agriculture also contributed greatly to the early economic development of the currently developed countries (Johnson 2000).

Fogel (1994) and Johnson (2000) have laid out the reasons why improvements in agricultural productivity were a necessary condition before early economic growth could occur. Fogel begins his explanation with an examination of time series data on death rates between 1550 and 1975. The rise in population growth rates after 1700 corresponded to a secular decline in death rates that has been observed in European church records. Before 1700, the Malthusian prediction that the population expanded to consume any available increases in food production was essentially correct, as evidenced by the absence of appreciable growth in per capita output. For 1,700 years, the economic conditions for the average person in the world hardly improved. What is less apparent is that the average income or food production level over that period was too low to energize the labor force for hard work, meaning that the low levels of per capita income also led to persistently low levels of labor productivity.[1]

Depending on the weather and an individual's size, gender, and age, we can estimate the minimum caloric intake necessary to support productive labor over a full working day. Given the average stature of men and women in Europe in the 1700s, Fogel estimated that at least 2,000 calories per person would be necessary to support productive work. In England and France in the latter part of the 18th century, food production was high enough to meet this target on average, but food was not equally distributed in the population. About 40% of the French males and 20% of the British males did not attain even this minimal level of nutrition, meaning that

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[1] This observation leads to models of efficiency wages which will be covered later in a later section.

they were too undernourished to perform a full day of work.[2] Moreover, even those who attained the minimal level of nutrition on average, "were so stunted and wasted that they were at substantially higher risk of incurring chronic health conditions and of premature mortality."

Before 1700 in Europe, land-holdings were under a feudal system. Livestock mingled together as they grazed the “common pastures” and were shepherded by individuals, which was time intensive. These animals were called “common stock” and the genetic potential of these animals was low and static. Enclosure of the “commons” in the U.K. started about 1700 with the transition to private property. Enclosures—fencing private property—made controlled mating of farm animals possible, which was essential for improving livestock genetically. Enclosures also eliminated the need for labor to shepherd livestock, reducing the demand for labor in livestock production. With the spread of the enclosure system in the U.K., farmers starting using nitrogen-fixing legumes in there crop rotations. This helped to boost crop yields. Crop productivity was also increased because crop farmers were largely free of the damage caused by wandering livestock herds (Huffman and Evenson 1993). These were important early changes that increased the productivity of agriculture in Europe in the 18th century and provided the nutrient base for the economic growth that followed.

With private ownership, farmers for the first time took an interest in farm-animal improvement, and improved strains began to appear. Farmers had known that some animals were better adapted to a particular environment than others, and in 1760, Bakewell, an English farmer, is credited with first establishing the pattern of modern animal breeding. He established purified lines, emphasizing selection for visual traits, and began the process of developing

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[2] Fogel (1994, p. 374) suggests that the very high proportion of beggars in cities (perhaps as high as 20% of the population) was related to the fact that the lowest fifth of the population would have caloric intake that was too low to support even a few hours of strolling per day.

purebred animals (Huffman and Evenson 1993). New breeds were generally selected so that they were adapted to local geoclimatic conditions.

Before the Industrial Revolution, craftsmen operating small shops with a minimum of wage labor were the main producers of nonfarm goods. With increased agricultural productivity in the mid-18th century, the U.K. was able to initiate an Industrial Revolution that built on standardization and specialization of activity in the nonfarm sector (Grübler 1994). This industrialization first occurred in textile and iron production. By the early 19th century, Germany was making major technical advances through the application of science in laboratory chemistry. This provided the foundation of a new chemical industry and for further scientific advances to support agriculture. For example, during the 19th century, the U.S. and other countries sent students to Germany for training at the first agricultural chemistry laboratory--one established by Liebig at Giessen. He published his famous agricultural chemistry book, *Organic Chemistry in Its Relation to Agriculture,* in 1840. The early attempts to apply science to agriculture in the United States drew upon the German example for their model of institutional organization and the education of agricultural scientists (Huffman and Evenson 1993).

Although nutrient intake data are not easily available, estimates of per capita GDP are widely available over countries and time. Pritchett (1997) created a conversion between caloric intake and per capita GDP, which allows a rough translation between the two measures of average welfare. He suggests that nutritional subsistence requires an income of about $528 per person in 1990 dollars. Using Maddison's (2001) estimates, therefore, GDP per capita in the world was barely above minimal subsistence in 1700, suggesting that much of the world's population was too malnourished to perform significant work.

Europe began to grow in 1700, at first slowly and then at an accelerated pace (Figure 3). The growth which occurred in Europe in the 18th and 19th century was made possible by improvements in agricultural productivity---increased crop yields and labor productivity. In addition, gains in labor productivity in agriculture freed up labor that could migrate to the nascent urban industrial sector. Furthermore, the improvements in agricultural productivity were large enough to improve the nutritional status of the growing urban population, although a shrinking share of the labor force was devoted to agricultural production.

Today, 50 percent of the world's labor force is engaged in farming, and many developing countries are still at levels of per capita GDP prevailing in Europe in 1700 (Figure 3). In particular, average GDP in Africa in 1998 is only modestly above the 18th century European average, and many countries in Africa have not yet attained that level. For example, in Ethiopia and Uganda, per capita calorie intake is approximately the same as for the U.K three hundred years ago (Pritchett 1997). Hence, the population is stunted and wasted and does not receive enough calories to be able to undertake much work. Increased food availability and nutrition are potential sources of increased short- and long-term labor productivity in Africa and some other areas. For most of these countries, significant advances in per capita GDP will not occur until their agricultural sector undergoes a major transformation that raises farm labor productivity. Lacking the resources required to purchase significant quantities of food in the world market, these countries cannot circumvent the need to raise their own labor productivity in agriculture.

During the past century, the most fundamental and pervasive factors affecting the interaction of farm and nonfarm labor markets have been economic growth and science-based technological change. Referring back to the two sector model, the per capita income elasticity of demand for farm products is (and has been) positive but less than one, so the income elasticity of demand for nonfarm products is larger than one. Thus, domestic growth of real per capita income has caused a more rapid rate of growth of domestic demand for nonfarm products than for farm products. Furthermore, differences in rates of growth of domestic demand have increased as the rate of population growth has slowed. If the supply curve for domestic farm products shifts at least as fast as the supply for nonfarm products, the farm output share of national income and the relative farm output price must fall, provided that foreign demand growth for U.S. products is not offsetting. Even if technical change was so favorable to agricultural labor as being factor neutral and grew at the same rate in farm and nonfarm sectors, the income elasticity differences imply that growth of labor demand in the nonfarm sector must exceed that in the farm sector. If both sectors initially have equal rates of population and labor supply growth, the relative farm-labor wage rate must fall.

With the relative price of food falling, real incomes of the nonfarm population rise. With food quality and nutrition being luxury goods, this means that the nutritional status will improve for the nonfarm population. For labor to be fully employed and farm labor to earn its opportunity return under these conditions, a net transfer of labor to the nonfarm sector must occur. With intersector mobility, wage rates become more equal, and they may approach equality when allowance is made for living cost differences and an opportunity return on moving costs. The geographical distance of agricultural production from most other industries means that relative population density will fall in rural (farming) areas and rise in urban (nonfarm areas).

The transfer of labor occurs in three major ways. First, families may sever farm sector ties by quitting farm jobs, selling any farm capital they own, and taking a nonfarm job, perhaps moving to a city. Second, as children come of age, they may leave agriculture and take nonfarm jobs, but their parents remain in farming until retirement. Third, workers and their families may stay on farms, but some family members take full-time nonfarm jobs (e.g., wife) while others (e.g., husband) continue full-time work. Or some members may reduce their hours of farm work, take a non-farm job, and become multiple jobholders. The relative attractiveness of these alternatives depends on the location of nonfarm job opportunities, the types of skills of the people, and the costs of commuting or of moving to nonfarm jobs. All have been important sources of adjustment.

If the nonfarm real wage rises with economic growth, and if outmigration from the farm sector causes the real wage rate to be bid up there as well, new labor-saving technology may be induced for agriculture. Hayami and Ruttan (1985) suggest that induced innovation has occurred in U.S. agriculture and that it has been labor and land saving. Also the population and labor supply growth rates may initially be larger in the farm than in the non-farm sector as a result of the higher birthrates of farmwomen. Both of these changes increase the net transfer of labor services required to equalize earnings between sectors while maintaining full employment. This, however, provides labor to support a growing nonfarm sector. If, however, rural people do not have equal access to schools and roads and communication systems are poor, this can be a major barrier to increasing labor productivity and inter-sector resource adjustment. Hence, it is critical that farm people have an opportunity to obtain a basic education that will facilitate making good farming decisions if they remain in the rural area or to support their occupational and geographical mobility to the nonfarm sector.

Contemporary Cross-Sectional Comparisons

We show the cross sectional relationship between schooling and GDP per capita across countries in figure 4. These plots use average years of education for women aged 15 and over as the measure of the level of human capital in the population, but the patterns would look similar if we were to use average education levels of males. As a further aid to illustrating the stylized facts concerning per capita output and human capital, we superimpose the results of a log-linear regression of GDP per capita on average levels of female and male schooling and a quadratic term in female schooling. The specification is chosen to correspond to that used commonly in microeconomic analysis of labor earnings. These cross-country regressions covered the years 1960, 1970, 1980 1990 and the most recent available data period. The regressions also included a complete set of year dummies whose coefficients are not reported. The original specification also included a quadratic term in men’s schooling, but the quadratic terms in men's and women's schooling were so highly correlated (0.97) that we only included the one for women. The results illustrate a strong positive correlation between average years of schooling in the population and output per capita.

We conduct a parallel exercise illustrating the relationship between human capital and the proportion of the labor force engaged in agriculture. As discussed in the previous section, modern economic growth has been tied to a decline in the share of the labor force in agriculture for most countries of the world. We can also see that rising levels of education can also be tied to declining agriculture share of the labor force.

Although the agricultural transformation ultimately requires schooling of the masses, the early part of the transition involves more basic sources of improved labor productivity: learning by doing through apprenticeships or work experience; a larger stature that increases physical strength and ability to do work; and human migration. As the society becomes more advanced, formal training of teachers and schooling of children become cost effective, but this usually covers only elementary schooling. Furthermore, advancements are required before investing in high school teachers and devoting child time to high school generate sufficient returns.

What are some of the reasons that the agricultural transition leads to increased human capital investment? First, as the nutritional status of the population rises, expected length of life at birth increases. In the Middle Ages the expected length of life at birth was about 24 years, roughly the expected length of life associated with subsistence levels of per capita GDP (Maddison, 2001). By 1820, life expectancy at birth had risen to approximately 36 years in Europe, 39 years in the United States, and 34 years in Japan, but life expectancy remained near 25 years everywhere else. Since then, countries that raised GDP per capita have experienced increases in life expectancy. As predicted by the three-period human capital investment model, the near tripling of the world average length of life at birth has greatly strengthened the incentive to invest in skills early in life. For the average world resident in the Middle Ages, this incentive did not exist.

The present-day cross-country relationship between life expectancy and human capital is illustrated in Figure 6. Currently, life expectancy at birth stands at about 78 in the OECD countries. It averages only 52 years in Africa, and is actually declining in some African countries. As shown, a strong correlation exists between higher levels of human capital investment and greater life expectancy.

Second, as nutritional status improves, both labor productivity per hour and the number of hours per day an individual could potentially work productively or enjoy leisure increases. Hence, total allocatable time per year rises. As Fogel (1994) shows, during the agricultural transition in the U.K. and France, a disproportionate share of the increased available productive time was allocated to leisure and educational activities. In contrast, in earlier periods when much of the population was malnourished and the intensity of work was reduced, they actually allocated a large share of allocatable time to work.

Third, all the adult population in 1700 were stunted. Besides making them vulnerable to early onset of chronic diseases, their physical ability to do work was reduced by their small size. As schooling is considered a normal good, its demand rose with the rising incomes attributable to improve health of the population.

Fourth, as labor shifted out of agriculture, the need for child labor declined. This freed up children's' time for larger investments in schooling. Current statistics show that the incidence of child labor is much higher in rural than in urban areas, with nine of every ten rural working children engaged in agriculture. As the rise of agricultural productivity helped to support the rise of cities and the shift of labor out of agriculture, it also supported the transfer of children from work to school.

Finally, a large literature exists showing that malnourishment at an early age retards brain development. Studies of the impact of nutrition on cognitive achievement have shown that schooling outcomes raise with nutritional sufficiency. In short, better-fed children do better in school, so the agricultural transformation has a direct impact on the returns to attending school. For all of these reasons, we argue that the agricultural transformation has led to the human capital transformation, which has played such a prominent role in the theoretical and empirical literature on economic growth.

An Overview of Micro- and Macro-Econometric Evidence

*Micro-Evidence for Schooling and Economic Growth***.** One of the most widely investigated empirical relationships has been between schooling and earnings. Mincer (1974) showed that if the cost of schooling is the opportunity cost of time, and if the proportional return per year of schooling is constant over time, then an individual's wage will be well-explained by a function of the form:

$$\text{(8)} \qquad \ln(y_{it}) = \beta_0 + \beta_1 S_{it} + \beta_2 Z_{it} + \xi_i + e_{it}$$

where $\ln(y_{it})$ is the natural logarithm of labor earnings per unit of work time of i-th individual in period t, S_{it} is a measure of years of schooling of the i-th individual, Z_{it} is a vector of other productive human capital attributes of the i-th individual such as work experience and job tenure, and the β s are associated regression coefficients. The coefficient on years of schooling, β_1, is commonly interpreted as the proportional change in labor earnings from a 1 year increase in an individual's schooling attainment.[3] The last two terms are an individual-specific and time-invariant random effect ($>_i$, that is known to the individual and might be ability) and a random disturbance term across individuals i and time periods t, e_{it}, that has a zero mean. If $>_i$ is correlated with S_{it} and/or Z_{it}, then direct estimates of the coefficients in equation (8) will be biased.

Mincerian earnings functions have been estimated using data on individuals in many different countries. The most recent extensive review of estimated private returns to schooling in developing countries is by Psacharopoulos (1994). His results are illustrated in Figure 7. Estimated private returns to schooling are always positive. Furthermore, schooling appears to be subject to diminishing marginal returns. At the lowest schooling completion levels the rate of return is highest and it declines for incremental increases in years of schooling completed. For

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[3] Interestingly, specification tests conducted by Heckman and Polachek (1974) showed that this log-linear specification dominated all other alternatives. More recently, Welch (1999) has shown that a more complex spline-regression performs better when sample sizes are extremely large.

the 57 countries surveyed by Psacharopoulos,[4] he found that on average, private returns to girls' schooling exceeded returns to boys' schooling,

A large literature exists which explores the various sources of biases in estimated returns to schooling. Card (1999) provides a comprehensive review of the topic, so we will touch on it only briefly here. First, S_{it} might be endogenous and jointly determined with ln (y_{it}).[5] Second, reported years of schooling may contain measurement error, e.g., at low years of completed schooling individuals regularly exaggerate years completed, which introduces measurement errors. Data on identical twins has been used to correct for unmeasured abilities.[6] Information on school availability or proximity, truancy laws, and school building projects has been used to correct for measurement error and/or self-selection in school choice.

Card (1999) reports that for industrialized economies, little difference exists between ordinary-least squares estimates and the more econometrically sophisticated estimates, suggesting that estimation bias in naïve models appear to be small or offsetting one another. In developing country settings, there is more variability in school attainment and consequently more potential for self-sorting to matter. Nevertheless, Krueger and Lindahl (2001), concluded that ability bias is approximately offset by measurement error in reported years of schooling for developing countries as well. Instrumental variable estimates are similar to those obtained from ordinary least squares (Psacharopoulos 1994; Duflo, 2001). Where researchers have found differences (Bedi and Gaston, 1999; Bedi and Edwards, 2002), OLS estimates of returns to

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[4] Lam and Schoeni (1993) conducted a detailed examination of how the rate of return to schooling changed as years of school attainment rose in Brazil. They found nearly linear rates of return after controlling for family background variables, but the highest returns were in the first four years of schooling.

[5] If an individual chooses how much school to obtained based upon $>_i$, e.g., abililty, then observed years of schooling (S_{it}) will almost certainly be correlated with it, so the least squares estimate of equation (8) will yield biased coefficients. Furthermore, correlation of $>_i$ with Z_{it} creates a similar problem.

[6] Recent research has, however, shown that "identical" twins are not genetically identical because the expression of certain genes is affected by the environment in which the individual finds him or herself. This weakens much of the economic evidence using identical twins.

schooling appear to be biased downward. Thus, one might want to view the estimates in Figure 7 as a lower bound.

Macro-Evidence. Given the virtually universal demonstrated success of education in generating private returns that meet or exceed returns on alternative investments, it seems clear that investments in education make good economic sense from an individual perspective. However, every country subsidizes education, meaning that the cost of education to society exceeds the marginal cost borne by the individual. For these public investments to make economic sense, a public return from schooling must exist that is not captured by the individual receiving the schooling.[7] To address this question, studies have typically used macroeconomic data that can capture spillover benefits and costs.

Returning to our regression estimates reported in Figure 4, the cross-country relationship reveals a strong positive correlation between average years of male schooling and GDP per capita, averaging 13% growth in per capita GDP for every year of added male schooling attainment. The relationship between female education and GDP is almost 4 times larger than that for male education. Consistent with the Psacharopoulos findings for private returns, the rates of return fall as the level of schooling rises.

The much larger estimates for women than men suggest considerable underinvestment in female education relative to men. In addition, if GDP per capita is interpreted as average income in the country, these rates of return can be interpreted as the social return as opposed to the private return from schooling. These returns from investment in female education are far higher than estimates of private returns, consistent with the view that education of girls generates

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[6] Psacharopoulos (1994) reports estimates of private and social rates of return averaged for country groups. Estimated social returns are uniformly lower than private rates of return, but this result is largely due to the construction of the estimates. Public costs are added in which depress returns, but measures of external benefits from education are not. This would create a downward bias in his estimates of social returns.

greater positive externalities to the society than for men. In contrast, estimated social returns for male schooling are only marginally larger than typical estimates of private returns. Similar findings elsewhere (King and Hill, 1993; Schultz, 2002) have led the World Bank and other international funding agencies to emphasize investments in girls' education as opposed to children's education generally, as a critical development tool (World Bank, 2001, Chapter 2).

The empirically oriented growth literature has concentrated on a first-difference variant of equation (8):

$$(9) \qquad \Delta\ln(y_{it}) = \tilde{\beta}_{0t} + \beta_t S_{it} - \beta_{t\text{-}1} S_{i\,t-1} + \beta_2 \Delta Z_{it} + e_{it}.$$

If returns to schooling are constant so that $\beta_1 = \beta_t = \beta_{t\text{-}1}$, then the impact of schooling can be captured by $\beta_t S_{it}$ - $\beta_{i\,t\text{-}1} S_{it} = \beta_1 \Delta S_{it}$. The vector of regressors ΔZ_{it} is now used to represent per worker changes in physical and other human capital, and the constant term in (9) captures time-specific factors that have common effects on per capita income across countries.[8] Growth can also be linked to the Solow neoclassical growth model where changes in technology and physical and human capital are sources of growth (see Jones 2002, p. 54-62). These factors fit under the ΔZ_{it} term in equation (9).

By adding and subtracting $\beta_t S_{i\,t\text{-}1}$ to the right hand side of equation (9), we obtain:

$$(10) \qquad \Delta\ln(y_{it}) = \tilde{\beta}_0 + \beta_t \Delta S_{it} + \Delta\beta_t S_{i\,t-1} + \beta_2 \Delta Z_{it} + e_{it}.$$

The coefficient on ΔS_{it} is interpreted as the average return to schooling across countries over the sample period, and the coefficient on $S_{i\,t\text{-}1}$ gives the change in the return to schooling over the sample period.

Equation (10) is estimated using (average annual rates of) change in (per worker) income over 5, 10 or 20-year intervals. For example, Benhabib and Spiegel (1994) estimated a human-capital model similar to (10) and found that the change in schooling had virtually no effect on changes in GDP per capita, but that the beginning period or initial level of schooling has a positive and significant effect. They justify this outcome by explaining that higher levels of education in the workforce lead to more rapid assimilation of existing technologies as well as more rapid innovations of new technologies. Topel (1999) argued that the Benhabib and Spiegel results were biased because they used logarithmic measures of schooling rather than the levels as suggested by the Mincerian specification. Krueger and Lindahl (2001) argue further that measurement errors in the international schooling data bias the coefficients. Correcting for these specification and measurement errors, Krueger and Lindahl found that a one-year increase in average schooling raised annualized growth in GDP per capita by as much as 30 percent over a twenty year period. This is consistent with the average of the male and female returns reported in Figure 4. Estimates of larger returns to schooling tend to occur when longer time horizons are used in the averaging process, e.g., 10 year averages versus 5 year averages. Moreover, these estimated returns are higher than the private returns, suggesting that education generates external benefits to the economy as a whole.

It is difficult to tell whether levels of education matter for economic growth because measurement error may be more severe in the level than the change in schooling. Recall also that the coefficient on $S_{i\,t-1}$ is $)\beta_t$, so if returns are constant over time, then $)\beta_t = 0$. Furthermore, Krueger and Lindahl found that the estimate of $)\beta_t$ was sensitive to the inclusion or exclusion of physical nonhuman capital in the vector $)Z_{it}$. Some estimates were negative while others were implausibly large, implying that schooling levels are responsible for all growth in GDP per

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[8] In the differencing process, the random individual-specific effect ($>_i$) is difference out.

capita.[9] Nevertheless, it seems likely that the average level of schooling does affect the rate of growth, even if the effect is not precisely estimated. The reason is that rates of growth in the countries with the highest levels of schooling have consistently outpaced rates of growth of the countries with the lowest levels of schooling, leading to a steady widening of the gap in income between the richest and poorest countries (Pritchett, 1997). While other explanations can be advanced for this result, the role of schooling levels in raising long run growth rates has a strong theoretical appeal (e.g., Romer 1990) that awaits a more definitive empirical test.

If positive externalities to investments in schooling occur, this provides a major justification for public investment in schooling. Returning to Figure 5, we find that as average educational attainment for women rises by one year, the proportion of women engaged in agriculture falls by 19%. Increases in male education also lower agriculture's share of employment, but the effect is half as large. The relationship is nearly linear, so the proportional decline in labor or out-migration from agriculture is constant as levels of education rise. Some have considered this outmigration from agriculture to be a form of "brain drain" from rural areas. This seems to be a misnomer. The education levels of those remaining in agriculture rises as well, but the process of development appears to raise returns to human capital in cities faster than it raises returns in the country-side, a theme to which we will return later.

With improvements in human capital and the shift of labor out of agriculture comes a change in how men and women allocate their time. Much of the academic literature has concentrated on changes in women's time allocation, but it is clear that there are dramatic changes in how men allocated their time as well, in terms of occupational and educational

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[9] The lower bound of Krueger and Lindahl's positive estimates is about 0.003 log points of growth for every year of average educational attainment which would translate to roughly 2.6% growth in per capita GDP per year when evaluated at average world education levels. Average growth over the last 50 years was 2.2%.

choices, residential choices, and time spent in work versus leisure over the lifetime. Nevertheless, the process of development does not affect male labor force participation rates at prime ages, which is not true for women.

The cross sectional relationship between labor supply behavior and women's education is illustrated in Figure 8. Several scholars (Sinha, 1967; Durand, 1975; Psacharopoulos and Tzannatos, 1989; Goldin, 1995; Mammen and Paxson, 2000) have identified a U-shaped pattern in women's labor supply behavior as economic development progresses. The story behind the U-shape is that early in the development process, labor market opportunities expand off-farm rapidly. These opportunities disproportionately raise the value of time of men, either because men are more likely to engage in physically demanding factory work or because male education levels rise faster than that for women. Rising male wages combined with constant value of time for women results in an income effect away from women's work and toward nonmarket activities such as child or home care. Later in the progression of development, women's education also begins to rise, raising their opportunity cost of time. The rise of white-collar jobs as the economy develops and opening of occupations to women appear also to be related to the movement of women into the labor market (Goldin, 1995).

This story hinges on two presumptions that may or may not be correct: that educational and off-farm opportunities rise more rapidly for men than women early in development, and that for women, income effects for leisure are dominated by substitution effects away from leisure as women's wages start to rise. These assumptions may hold in some countries and not others. In addition, variation in women's labor supply behavior out of the home across countries can be strongly influenced by local tastes and customs. Nevertheless, the hypothesized U-shape is supported by the simple data plots. Taken literally, the regression indicates that women's labor supply behavior declines until school attainment reaches 5 or 6 years and then rises thereafter. The U shape is more apparent when following labor supply patterns over time within a country. In the United States, for example, Goldin reports that labor force participation rates for married white women rose from under 15% in 1890 to 50% in 1980, but the change was not smooth or steady over the time period, e.g., major increases occurred during World War I and II which were followed by a post-war decline.

The cross-sectional relationship is also clouded by measurement problems in distinguishing between home production and labor supply in family farm enterprises (Schultz, 1990). For example, women's time in home and farm production activities may be highly complementary and subject to joint products. A woman engaged in tending a family plot may also be tending children at the same time. It is difficult to distinguish between jointly productive activities, e.g., women specializing in plot work versus specializing in children care, and large changes in women’s time allocation may be associated with small changes in incentives. What is clear is that the type of work that women do changes as development progresses. In the poorest countries, female labor force participation approaches 90%. This is well beyond the highest levels reported for industrialized economies. Women in these poorest countries are mainly engaged in unpaid work for family enterprises. In the industrialized economies, most women are engaged in paid work away from home.

Part of the public return from education is in the reallocation of male and female labor across sectors, and in the diversification of the economy, which allows a greater degree of specialization according to comparative advantage. These gains occur in the formal labor market, but significant gains occur in home production as well. One of the avenues by which education can generate external benefits was illustrated in Figure 6 and two others in Figures 9-

10. These gains are related to increases in life expectancy and reductions in infant mortality and fertility. Much of the literature has concentrated on the role of women's education in generating these welfare gains. In fact, development policies have concentrated on stimulating education for girls on the presumption that girls' education generates more externalities than boys' education, an assumption consistent with the higher estimated impact of girls' education on GDP per capita. What has been less commonly discussed is that married men and women may have similar objectives with respect to the number and health of their children, so that male education levels may have similar effects (in sign if not in magnitude) to those of women's education on these welfare indicators.[10]

Both increases in male and female education levels raise life expectancy, but the effect is 3 times larger for women's education than for men. Taken literally, the gains in life expectancy from women's education dissipate after 14 years of schooling, but dissipate at 5 years of men's schooling. Both male and female education lower infant mortality. The impact is one-third larger for women's education than for men's education, suggesting a 19% or a 14% decline in infant mortality for every additional year of schooling for adult women and men, respectively.

The decline in mortality that accompanies the agricultural transition and the improvements in human capital will at least temporally raise the population rate of growth. Without a change in the birth rate, reductions in the death rate would lead to rapid population growth that would threaten to reverse the initial gains in the country's development. Thus, it is

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[10] As an example, Johnson and Skinner (1986) examined whether divorce causes female labor supply or female labor supply causes divorce. Following married couples longitudinally, they found that when both the husband and the wife worked continuously after entering marriage, likelihood of divorce was not affected. Presumably, the husband's and wife's anticipated labor supply behavior was already incorporated into the marriage contract, so the wife's labor supply should not affect the probability of marital dissolution. Similarly, one would expect that number of children and interest in child care would be subjects agreed upon before entering marriage. It should be noted that these marriage contracts are not based on full information. Johnson and Skinner found that women who ultimately divorced were more likely to have entered the labor force 2-3 years before the divorce, suggesting that as the probability of divorce increases, women are more likely to work.

critically important that fertility rates appear to decline as a country develops. An additional year of average schooling for women lowers the fertility rate by 11% in Figure 10. The effect is concave and dissipates at about 15 years of schooling. Equally important is that fertility declines with improvements in male education levels as well, although the effect is about one-third smaller than for women's education.

A common finding in all of these studies is that the measure of external health benefits from women's education is larger than that for men's education, but that the effects are in the same direction. There is generally underinvestment in female education relative to male education. Nevertheless, the positive external benefits arise from boys and girls education.

Production of Health, Nutritional Inputs, and Work

Fogel (2004) has forged more strongly the links between physiological capital, nutritional intake of individuals, and economic growth. Physiological capital is a part of human capital broadly defined and related to health. Human capital was developed to explain differences in earnings by occupation over the lifecycle, by industry and region, by using differences across individuals in education/schooling and on-the-job training. The concept has expanded to include health and information. The health capital concept was developed to explain the demand for goods and services that offset the depreciation rate on the initial endowment of health of an individual over a life cycle. Although the theory behind health capital takes for granted physiological capital, it does not deal with it explicitly. Health capital takes as exogenous an individual’s health stock at birth and considers how later investments in health care can reduce the health stock’s rate of depreciation. It does not address why some individuals are born with a greater stock of physiological capital than others, and it does not recognize the relationship

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between the size of the initial stock of physiological capital and rate of depreciation of physiological capital. Nor does it encompass the effect of an individual's date or country of birth on his or her initial stock or rate of depreciation of physiological capital. Furthermore, the theory of health capital does not confront the issue of how the average initial stock of physiological capital changes from one generation to another or why it differs across countries.

Improvements in physiological capital are reflected in larger stature and improved body-mass index (BMI) of populations over time (Fogel 2004). Variations in height and weight are associated with variations in the chemical composition of the tissues that make up vital organs, in the quality of the electrical transmission across membranes, and in the functioning of the endocrine system and other vital systems. Nutritional status, as reflected in mature height and weight for height, are critical links connecting improvement in technology to improvements in human physiology. The early onset of the degenerative diseases of old age has been linked to inadequate cellular development early in life, including intrauterine development. Fogel's theory of technophysio-evolution (Fogel 2004) implies that health endowments in a given population change (on average improve) over time, and that they differ across countries that are at very different stages of development.

Micro-Evidence. The microeconomic evidence of impacts of malnutrition on health and labor productivity is reviewed. First, consider the theoretical issues associated with estimating a person's or household's health production function. Let H be an individual's true health status, N be a vector of human nutritional intakes, and E be a vector of time investments in health such as exercise and acquisition of health-related knowledge. Z_H is a vector of observable individual and household attributes, μ is an unobservable individual health endowment, and e_H is a random measurement error. An epidemiological health production function can then be written as:

(11) $H = H(N, E; Z_H, \mu, e_H)$.

Many studies have collected data on individual attributes such as sex, race, marital status and education as the elements of Z_H and information on the elements of N and E to estimate the effects of nutritional and exercise choices on measures of health. If information is missing on the health endowment, this will bias the estimated coefficients of the included variables, and often, lead to perverse results.

To see why, we must take explicit account of the individual's decision-making process. Following the pioneering work by Grossman (1972a, 1972b) and the human capital model of section II, we embed the health production function into an individual's utility function:

(12) $U = U(H, L, X)$,

where L is leisure and X is a composite good that is purchased in the market and does not affect an individual's health. His or her time constraint is $T = L + E + h$, where h is hours of work for pay. The individual is assumed to maximize utility, subject to the budget constraint

$$(13)\quad V + W(T - L - E) = \sum_{i=1}^{k} P_i N_i + P_x X$$

where V is nonlabor income, W is an individual's hourly wage (assumed here to be unaffected by health) and P_i and P_x are the prices of nutrients and other goods respectively.

The reduced-form demand equations for nutrients, time investments in health, hours of work for pay will be of the form

$$N = N(P_1, P_2, \ldots, P_k, P_x, V, W, Z_H, \mu)$$

$$(14)\quad E = E(P_1, P_2, \ldots, P_k, P_x, V, W, Z_H, \mu)$$

$$h = h(P_1, P_2, \ldots, P_k, P_x, V, W, Z_H, \mu)$$

Without information on the unobservable health endowment, it is now clear why direct estimation of (11) is problematic without information on the unobservable health endowment. The endogenous variables N and E depend on μ. If μ is excluded from (11), the error term will include μ which will be correlated with the observed health inputs. Consequently, the estimated coefficients from the epidemiological production function will be biased.

Missing information on the health endowment can lead to bizarre findings in cross-sectional estimation of health outcomes. For example in a sample of young adults, Miller (1986) found that smokers tended to have larger than average lung capacity relative to nonsmokers. The reason is that asthmatics and others with poor pulmonary health endowments never started smoking. Conversely, those individuals who started smoking at a young age typically had stronger lung capacity when they first start smoking. Holding the initial health endowment fixed, the adverse consequences of smoking are more apparent in longitudinal studies that show that lung capacity declines with every additional year of cigarette smoking.

Similarly, epidemiological studies have frequently failed to find a positive impact of early prenatal care on the health of newborn babies. Rosenzweig and Schultz (1983) found that this odd result was due to the fact that pregnant women who were healthier were more likely to delay visiting the doctor, while women who had poor health endowments used doctors more intensively. When endogeneity of a woman’s doctor visits is taken econometrically into account, the expected positive effect of doctor’s visits on the baby’s birth weight, a measure of infant health, occurs.

In the United States, empirical evidence shows that when farmers produce pork using confined housing for farrowing and finishing, they have increased incidence of short-term respiratory problems. However, it is difficult to find evidence of longer-term loss of pulmonary function (Hurley et al, 2000). The reason is that those producers who have the lowest ability to adapt to the environmental hazards associated with pork production either never enter the sector or else exit once adverse health outcomes are experienced. Hence, when individuals self-sort into occupations based on their initial health status, farmers who select confined hog production disproportionately come from the tail of the health endowment distribution that can best accommodate the adverse consequences without becoming seriously ill.

Randomized experiments, in which nutrient intake and/or time investments in health are exogenously varied, are a methodology that will insure unbiased estimates of the impact of N and E . It is, however, difficult to extrapolate from such laboratory studies to actual behavioral outcomes. The primary reason is that the unconstrained choices of consumers in the market may not reflect the constrained choices dictated by the experimental design. Constraining the choices of consumers by, for example, limiting consumption of red meat will generally lead to increased consumption of other foods, which may have their own negative health consequences.

In developing countries, one method by which the level of N can be varied is by the deployment of government programs aimed at influencing health outcomes. Such deployments are partial rather than complete and are common because a government cannot afford to make universal implementation, or because the deployment is conducted in stages. Such programs include the installation of public health clinics, sanitation systems, tube wells or other improvements to water supplies, nutritional supplements, vaccination programs, and health educational programs. By locating these programs in some locations but not others, one can estimate the impact of the government intervention by comparing health outcomes in areas receiving the program against health outcomes in places in which the program is not yet (or never to be) deployed.

These quasi-experimental designs are rarely randomized because the government naturally wants the program to be deployed where it will have the largest effects (Rosenzweig and Wolpin, 1986). Alternatively, the households, who would benefit greatly from the program, may relocate to take advantage of the new program (Rosenzweig and Wolpin, 1988). Either of these problems makes the occurrence of the health intervention conditional on unobservable health endowments at either the individual household or community level, recreating the endogeneity problem we were trying to sidestep in the first place.

The problem of human migration from the control to the treatment areas can be overcome, but it requires that researchers create a good baseline estimate of health outcomes in the target population before the policies are announced and implemented. Then, one can difference-out the unobserved health endowment effect by examining changes in the health outcome from data before and after project's implementation date. The problem of strategic choice of treatment areas is more difficult to correct. However, if the criteria used for selecting an area for program implementation are known, they can be used to correct for the nonrandom selection of the treatment areas for program implementation.

The most ambitious experimental application of health interventions is the Progresa program recently implemented in Mexico. This program combines a health and nutrition program with a targeted income transfer program that is conditional on children being in school, not working, and attending a health clinic. The enhanced income improves child nutrition. Preliminary empirical findings suggest that children in the program have improved health outcomes.

A nonexperimental alternative for resolving the endoegeneity problem is to find instruments that affect N or E but not H directly. The reduced-form demand equation (4) provides several plausible instruments, namely V, W, P_i, and P_x. The role of an individual's income and wage data is somewhat problematic. A strong positive correlation exists between income and caloric intake. Ray's (1998) survey of 26 studies covering 15 countries found universally positive effects of household income on caloric intake. However, the proper instrument should not be actual household income, which depends on the endogenous hours of work decision. In addition, an added problem of potential simultaneity exists when income is measured by aggregate household expenditures in households where a large fraction of total expenditures are for food. A better instrument is nonlabor income. Also, when the instrumental variable procedure is used, standards errors can be adjusted for heteroscedasticy caused by individual time-invariant effects by using White standard errors (Wooldridge 2002).

Good instruments are food prices, which are exogenous to individual households and have no direct impact on health. Strauss (1986), Sahn and Alderman (1988), and Chen et al (2002) have used food prices to successfully identify nutritional inputs. Alternatively, time costs such as distance to health-service providers have been used sometimes to identify the use of health clinics (Behrman, 1996), and Chen et al (2002) successfully used wages to identify time spent in exercise.

An alternative way to illustrate the importance of the unobserved health endowment is to derive a proxy measure of the endowment, μ, and then to estimate its impact on the choice of health inputs. Rosenzweig and Schultz (1983) proposed deriving an estimate of μ from the residuals of the reduced-form epidemiological health production function

$$(15)\quad H = H(P_1, P_2, \ldots, P_k, P_x, V, W, Z_H, Z_U; \mu)$$

where μ will be in the error term. If the instruments are truly exogenous, they will be uncorrelated with μ.[11] The error term will include μ as well as random measurement error in H that are orthogonal to the regressors in (15). This noisy estimate of μ can then be inserted into an estimated form of equation (15) to derive an estimate of the impact of μ on N or E. Naturally, the random error in the estimate of μ will bias its impact toward zero, so this procedure is more suggestive than definitive. Nevertheless, they do yield reasonable implications. In the original Rosenzweig and Schultz study, mothers who had better health endowments do not consult doctors as early in their pregnancies, have more children, and have more children at an older age. In a recent application of this methodology, Chen et al. (2002) found that individuals who had better health endowments (as measured by low blood pressure) also engaged in more exercise and purchased fewer medicines.

Effects of Nutrition on Physical and Mental Development. Dasgupta (1993, Chpts 14, 15) and Fogel (2004) review the epidemiological evidence relating early malnutrition to health. Malnutrition in the first three years of life and illnesses associated with malnutrition can permanently affect physical stature at maturity. Mild malnutrition causes children to play less and sleep more. Over time, persistent undernourishment will retard development of motor skills. There is evidence that nutritional rehabilitation can reverse the adverse effects of malnutrition in more mild cases, although the process is slow. In more severe cases, the damage may be irreversible. For example, severe malnutrition leads to wastage of heart muscle mass and it can retard brain development.

Few studies of early child nutrition have explicitly confronted the endogeneity of food choices. Nutritionally stressed households must, however, choose how to allocate calories across

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[11] If the wage and nonlabor income are a function of health, they will need to be excluded.

the household members. In such households, some children may be favored at the expense of others. For example, in parts of South and West Asia, survival rates are higher for boys than girls. This is contrast to the typical case where the girls are less frail than boys. The enhanced relative survival rates for boys in these areas have been tied to differential access to food, medicine and parental care between boys and girls (Schultz, 2001). The survival advantage for boys, however, decreases in regions where a stronger labor market exists for females.

For older children, malnutrition has been associated with poorer schooling outcomes (Behrman, 1996). In theory, child health and child schooling are jointly determined by parents, so the ordinary-least-squares (OLS) estimate of the effect of health or nutrition on school achievement will be subject to simultaneity bias. In addition, measured health indicators such as height-for-age or body mass are invariably subject to the measurement error, $e_{H,}$ which will also cause bias in estimated regression coefficients of measured health on schooling. The direction of these two biases is unclear, but instrumental-variables methods can be used to correct for both the endogeneity and measurement-error problems (Greene, 2003). In practice, the instrumental-variables method has proven to have large effects on the magnitude of the health or nutrition coefficients.

Glewwe and Jacoby (1995) found that malnourished children in Ghana were more likely to delay entry into school, but that instrumenting nutrition with food prices reduced the effect by 40 percent. In their study of child achievement in the Philippines, Glewwe and King (2001) found that a similar price-based correction for endogeneity raised the impact five-fold. Alderman et al (2001) found that in Pakistan, correcting for endogeneity raised the effect of nutrition on enrollment three-fold. While there have been too few studies to determine the

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direction of these biases, correcting for endogeneity and/or measurement error has not reversed the sign of the estimated OLS results. The general conclusion from both OLS and instrumental-variables estimation is that enhanced nutritional status increases investment in and returns to schooling. Nevertheless, the large impact on the estimates suggests that researchers must take these problems into account.

Nutrition and Labor Productivity: Micro Evidence. In the previous section, we assumed that wage rates did not depend on a worker's health or nutrient intake. However, if an individual's nutrition raises his or her human physical and(or) mental capacity, then his or her marginal product will increase. Numerous empirical studies have investigated this presumption, and Strauss and Thomas (1998) and Behrman (1999) offer detailed reviews of this literature. We summarize their findings and refer the interested reader to those papers for the details.

Studies differ by choice of dependent variable; some use a direct measure of production (output, profit, net revenue), and others use the market wage as a measure of marginal product. Studies also differ in choice of the primary regressor of interest; it might be a direct measure of health (H) or health inputs (N). Because an individual's income is causally related to his or her nutrition and health, a regression of his or her income or wages on health will be subject to simultaneity problems. In addition, measurement-error problems are associated with the use of H or N. Once again, it seems that instrumental-variable methods should be used to derive valid inferences regarding the impact of nutrition or health on labor productivity and standard errors should be adjusted for unobserved heterogeneity using the White standard errors (or t-values). See Wooldridge 2002).

Height at maturity has been used as a summary indicator of long-term health status. Height, however, is positively correlated with educational attainment. Both health and education are human capital investments that are positively affected by a low rate of time preference for inter-temporal consumption choices. Furthermore, better nutrition while young leads to both better physical and better mental development. Concentrating on empirical studies where results were statistically significant, the effect of an individual's height on his or her wage or output is positive in almost every study surveyed by Behrman (1999). The effect of an individual's height goes beyond its impact on his or her physical strength to do work. Strauss and Thomas report that the steepest relationships between individuals' wage and height are for the more educated groups in Brazil and the United States. Similar results were obtained when body-mass index (BMI) is substituted for height as the summary measure of good health. The latter measure, however, is presumed to be nonlinear as weight rises relative to height.[12] Consequently, it is possible to obtain negative as well as positive wage elasticities with respect to BMI.

A major advantage of height and weight measures is that they are relatively easy to take, requiring simple measurement device and only a small amount of training to obtain high quality data. Hence, they have relatively small measurement errors.[13] Caloric intake is a measure of nutrition, and it is typically collected using a respondent's one-to-three days of information from recall. This method requires conversion of food availability into calorie levels. Given the heterogeneity of intake across days of the week and months of the year, caloric intake data have relatively large measurement errors. Furthermore, the elasticity of an individual's wage or output with respect to caloric intake tends to be small compared to elasticities with respect to height or BMI. Nevertheless, they are usually positive, supporting the conjecture that improved nutrition makes workers more productive.

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[12] BMI is defined as weight (in kilograms) divided by the height squared (in centimeters).

[13] In the U.S., women uniformly under-report their weight. Men, however, at less than 220 pounds over-report, while those over 220 pounds tend to under report (Lakdawalla and Philipson 2002).

If employers take the impact of higher wages on nutrition (and thus productivity) into account in setting pay, it is possible that wages will be set above the market clearing level. Leibenstein (1957) raised this possibility first for developing countries, but it came into prominence as a rationale for Keynesian fixed-wage and unemployment in developed country contexts of the 1980s.[14] To make the story more precise, let a worker's effort or energy be given by $e(w)$, where the worker's consumption of nutrients, $P_N N$, is a positive function of the wage rate. The presumption is that the added energy associated with a higher wage comes from the physics of work (Fogel 1994)--added physical strength is fueled by larger nutritional intake.

The firm's short-run revenue function can be written $p \cdot q(\ell \cdot e(w))$ where P is the output price and ℓ is the number of workers. Assume that workers have a value of time outside the firm, or opportunity wage, equal to ν. The firm chooses ℓ and w so as to maximize profit $\pi = p \cdot q - w \cdot \ell$. The first order conditions are:

(16a) $e(w)pq' - w = 0$

(16b) $\ell pq'e'(w) - \ell = 0$

By solving for pq' in (16a) and substituting into (16b), the optimum choice is characterized by $e'(w) = \frac{e(w)}{w}$ so that the marginal product of the wage is set equal to the average product of the wage. This condition does not depend on R, p or q', which implies that if $w \geqq \nu$, the wage is set independent of current product demand for q and fluctuations in the output price will not affect the optimum wage. More importantly, even if the wage is above the outside value of time ν, the firm will not lower the wage rate. This means that the wage may be set

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[14] See reviews by Akerlof and Yellen (1986) and Stiglitz (1987).

above the market clearing level, with the balance of the population earning v or being unemployed.

Furthermore, this outcome can only occur if a nonconcave region exists in the work effort function, as illustrated in Figure 11. If work effort is concave in w at all wages, the first- order conditions will be satisfied at w = 0, and the firm will set the wage at v, the opportunity wage of the worker. Although many variants on this theme exist, all have the feature that wages will be rigid in the face of persistent rural unemployment. As Rosenzweig's (1991) review illustrates, no convincing evidence exists of sticky wages in rural areas.

Why do these models fail to fit well? One reason is that the firm may be owned by the workers, e.g., self-employed and unpaid family labor. High levels of self-employment and family enterprise characterize developing countries (Gollin 2000). It is plausible that Pareto-superior resource allocations would be fostered in household enterprises because the unemployed that would prefer to work would surely be allowed to do so.

Nutritional and Labor Productivity: Macro Evidence. Following Fogel (1994, 2004), the labor productivity of poor countries may be related to nutrient intake or availability. For example, FAO provides data on DES, dietary energy supply available from a country's domestic food production. This energy measure is not perfect because it ignores the impact of net food imports and net food inventory change on currently available human energy from food.

Consider the following modified version of equation (10):

$$(17) \qquad \boldsymbol{)} \ln (y_t) = \beta_0 + \beta_1 \boldsymbol{)} S_t + \gamma_1 \Delta \ln N_t + \boldsymbol{)} \gamma_1 \ln N_{t-1} + \beta_2 \boldsymbol{)} \ln (K/L)_t + e_t$$

where N_t is average nutrient availability of workers in time period t and K/L is the average capital-labor ratio. Although equation (17) permits the impact of nutrition on growth to change between t and t-1, this seems only to be inviting estimation problems, given the quality of the available data. In our reported estimates, $)\gamma_1$ is set equal to zero.[15]

We compiled data from the World Bank and FAO on 43 countries that the World Bank classified as low- or middle-income in 1970. There are 29 low-income countries and 14 middle income countries (Abdulla 2004). These are countries that are at a level of development where human energy availability could be expected to affect growth (Fogel 1994). Dietary energy supply (DES) is derived by FAO through the food balance sheet approach (FAO 1996, p. 40). Total food supply is based on information relating to domestic food production and net exports, food wastage from farm to retail, inventory changes, and nonfood use of food products.[16] Nutrient availability is defined as dietary energy supply (DES) per worker. Rates of growth (or change) of a variable is expressed as decade average rates of growth (or change) over 1961-69, 1970-79, 1980-89, and 1990-1999.

Restricting $)\gamma_1$ to zero and fitting equation (17) to these country aggregate data, we obtain the results reported in table 1. Regressions (1)-(3) are various OLS specifications. In regressions (1) and (2), the change in the literacy rate (schooling) has an estimated coefficient that is significantly positive. When change in dietary energy supply per worker is included but the change in the literacy rate is excluded, the estimated coefficient of energy from food is 0.004, and it is significantly positive at the 5 percent level. When the change in literacy rate is included, the estimated coefficient of the change in energy is reduced to 0.003, and it is no longer

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[15] Several reasons exist. First, the estimate of $)\gamma_1$ will reflect the change in the returns to nutrient availability over time, so if the return is constant, the estimate of this change should be zero. Second, if energy availability is measured with error, the estimate will be biased toward zero.

[16] FAO acknowledges that data on domestic food production and net trade are frequently subject to significant error, but an average over several years is better than a single-year measure.

significantly positive at the 5 percent level. Investment in capital per worker is shown to contribute positively and significantly to per worker income growth in all three specifications.

The 43 countries in our sample seem unlikely to be impacted equally by country-specific random effects, i.e., to possess heterogeneity. Hence, regression equation (4) reports a model with country-specific random effects. The statistical significance of both the changes in the literacy rate and DES is reduced relative to regression equation (1), and neither estimated coefficient is significantly positive at the 5 percent level. Another potential problem is that energy from food contains significant measurement error or is endogenous to the growth process. One common remedy for this problem is to use the instrumental variable estimator (Greene 2003). To test this hypothesis, we instrument food energy and refit equation (17).[17] These results are reported in regression equation (5). Although the size of the estimated coefficient of nutrient availability doubles, it remains statistically weak.[18] Finally, we combine country-specific random effects and instrument food energy and report the results in table 1, regression equation (6). In this equation, neither the estimated coefficient of food energy nor literacy rate is significantly positive at the 5 percent level.[19]

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[17] As instruments to predict energy availability we use the production of corn, rice, wheat and milk per worker at the beginning of each decade. See Abdulla (2004).

[18] Avila and Evenson (2004) report a positive and significant effect of the change in DES per person in agriculture on the change in agricultural sector TFP for a set of 77 poor and middle income countries over 1961-1980 and 1981-2000. It makes little difference whether DES is instrumented in their results.

[19] Recent papers by Arcand (2001) and Wang and Taniguchi (2004) report per capita income growth equations including initial period nutrient availability and per capita GDP. Their specifications are equivalent to setting $\gamma_1 = 0$ and allowing $\Delta\gamma_1 \neq 0$ in (17). These studies seem to miss the dominant result predicted by Fogel (1994, 2004) in an enhanced Solow neoclassical growth model (including human capital and technical change), which is that change in real income per worker should be related to the change in nutrient availability per worker. Arcand and Wang and Taniguchi seem to be fitting some type of empirical growth convergence model (Jones 2002), but their work fails to address the more important issue of the contribution of nutrient availability to steady state growth and some of their regressions include low, middle, and high income countries, which have very different histories of physiological capital development. Furthermore, nutrient availability in a given year can be measured with large error, but the average change in nutrient availability over a decade can be quite accurately measured. Hence, some caution should be used in interpreting the Arcand (2001) and Wang and Taniguchi (2004) results.

We conclude from these results that for poor and middle income countries, education is a more important determinant of growth than dietary energy supply. Furthermore, the estimated impact of nutrient/energy availability is sensitive to model specification. Hence, one should be cautious in drawing inferences about the contribution of dietary energy supply to growth even for relatively poor countries. It is possible that the impact of dietary energy supply would be stronger if the data from which DES is constructed were more reliable. Finding such information seems a tall order, given the available data, especially going back in time.

Obesity (Over-nourished). In some developed countries, e.g., the U.S., Great Britain, Greece, and Australia, average caloric intake has been high and rising and energy expended in work at home and market and transportation has been falling. The net result of long-term energy imbalance is human weight gain. When an individual's body mass index is over 30, he or she is considered to be "obese." For the U.S., the obesity rate for adults was 31 percent in 2001. The rate has risen 15 percentage points over the past two decades. In contrast, in Japan and Norway, the obesity rate is only 6 percent.

Obesity translates with a time lag into future human health problems, including morbidity, mortality and increased demand for health care. Obesity is a major risk factor for diabetes, heart disease and some cancers. Other causes of heart disease include high cholesterol, high blood pressure and smoking cigarettes. In developed countries, food, especially high-fat and high-calorie convenience foods, has become relatively cheap and obesity rates are highest among the poor, low educated, and minority populations (Cutler, Glaeser and Shapiro 2003).[20] Furthermore, at least 50 percent of the health-related obesity costs in developed countries are shifted to the public sector through public medical care and social insurance programs for the poor, disabled and elderly. Thus, obese individuals are imposing negative externalities on society.

We showed earlier that under the most likely scenario, the relative price of food falls and real incomes rise as a country develops. Also, the demand for human energy falls with technical change in the household, market, and transportation sectors (Huffman 2004). These events may happen so rapidly that individuals fail to adjust properly to the new economic environment in which they are living. Hence, successful long term agricultural productivity growth seems to be the source of a new set of health-related problems associated with "over-nutrition." Economic research on obesity and associated issues is in its infancy, and we must wait for further analysis to judge whether future technical change in agriculture will improve the welfare of society in currently developed countries. Also, rising obesity rates may become a serious problem in developing countries that grow very rapidly and in population groups that emigrate from poor to rich countries.

Poverty Traps. Dasgupta (1997) argued that it was less important that the efficiency model was literally true but rather it highlighted the mechanism by which households could be trapped in poverty over several generations. In fact, substantial evidence exists of intergenerational transmission of poverty. Carter and May (2001) showed that 18 percent of the South African population in 1998 were also poor in 1993 and the bulk of these were structurally trapped into poverty. An additional 25 percent of the population were not poor in 1993 but were poor in 1998. Of those who fell into poverty, 85 percent were considered permanently trapped.

There are several plausible mechanisms that would cause intergenerational immobility. Emerson and de Souza (2002) found that parents who worked as children were more likely to

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[20] As opposed to poor countries, the economic conditions in high income countries are such that poor people can

have their children work, other things equal. Jacoby and Skoufias (1997) found that adverse income shocks caused parents to send their children to work. Poorer households are more prone to such adverse shocks than are wealthier households or households with higher levels of education (Glewwe and Hall, 1998; McPeak and Barrett, 2001). Underlying these findings is an explicit or implicit liquidity constraint on the poorest households, which prevents them from using short-term borrowing to smooth income shocks. Alternatively, income shocks prevent the household from repaying past debts, forcing it to devote all its personnel, children and adult, to current income generation rather than human capital investment (Basu, 1997). Poorer households apply higher discount rates to future versus current consumption related to poverty and also face higher borrowing costs. They lower the incentive to invest in schooling and further intergenerational transmission of poverty.

This is the context in which malnutrition can have permanent adverse consequences. If a household is unable to feed its adults adequately, household earning capacity suffers. If it cannot feed its children, the next generation's earnings capacity will also suffer.

Agriculture and Schooling Outcomes

Child Labor and Schooling. We indicated above that the incidence of child labor is much higher in rural than in urban areas, and agriculture is the primary employer of children in rural areas. To the extent that agricultural employment opportunities raise current child wages while leaving returns to schooling unchanged, it will be more likely that rural children work and limit time in school or studying. It is clear that child labor and schooling are not mutually exclusive states—most working children are also enrolled in school (Ravallion and Wodon, 2000). Consequently, modest agricultural demand for child labor may not lower time spent in school.

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purchase foods in large enough quantities to make being over weight and obese a problem.

However, numerous studies have shown that increases in child wages or returns to child time in agriculture lower the probability of a child being in school (Rosenzweig and Evenson, 1977; Levy, 1985; King et al, 2002; Orazem, 1987). Furthermore, even if children are enrolled in school, child labor may reduce the amount of time they attend school, study, or learn per year. Very few studies exist of the impact of child labor on school achievement, except at the secondary level

A recent exception (Sanchez et al, 2002) examined how child labor incidence affected student performance on 3rd and 4th grade tests of mathematics and language in 11 Latin American countries. In all cases, child labor lowered school performance, with the adverse effect increasing in magnitude for children who worked longer hours. If parents are more likely to send their children to work when they are performing poorly in school, child labor is endogenous, i.e., their study cannot be viewed as definitive. Ilahi et al (2002) found corroborating evidence that child labor lowers the production of human capital in schools. Brazilian adults who worked as children received returns to a year of schooling that were 15-20% lower than adults who did not work as children. While it seems likely that child labor will lower human capital production, a definitive conclusion awaits a data that controls for the endogeneity of child labor.

The Choice of Where to Work: Rural-Urban Population Shift and Brain Drain. Worldwide, about one-half of the labor force works in agriculture (World Bank, 2000). 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 frequently has a local component and a migratory component.

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 (Grübler, 1994; OECD, 1995; Johnson, 2000). 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 generally have significantly less education.

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

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 section II), which tends to reduce or eliminate intermarket wage differences. This complicates the problem of explaining migration, because individuals are acting on anticipated wage rate differences rather than the ex post values. Young adults have the longest time-period over which to obtain benefits from migration and hence, they have the highest mobility rates (also see model in section II) Schooling also plays a significant role in these adjustments or reallocations because of its effect on the costs and returns to migration.

Although farmers 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, and the real nonfarm wage has generally increased. Faced with needing to make adjustments in labor allocation, farm households in 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., OECD, 1994; Huffman, 1980).

The simple model of trade across agricultural and nonagricultural sectors demonstrated why even neutral technological change across the two sectors could lead to rising relative marginal revenue products in the nonagricultural sector. Consequently, the process of development will be accompanied by a shift of the population out of agriculture into other sectors and from rural to urban areas. The process of migration has been the subject of several recent reviews (Greenwood 1997; Lucas, 1997; Taylor and Martin, 2001). We touch only briefly on the topic here and refer interested readers to those other papers for more extensive reviews.

It has generally been observed that in both developed countries (Greenwood, 1997) and in developing countries (Schultz, 1982; Williamson, 1988), more educated people are more likely to migrate from rural to urban areas. This process has been labeled the “brain drain.” What's more, migrants tend to be younger, so the average age of city dwellers falls as the average age of rural dwellers rises. As Williamson (1988) demonstrates, this same phenomenon took place in England in the 18th and 19th centuries, and it is taking place in developing countries today. The incentives for younger people to migrate are well understood in the context of the human capital investment model--younger people have more years in which to obtain returns on their migration investment and they have less specific human capital invested in the place of origin. It is harder to explain why the relative returns from migration would be higher for more educated individuals, but the effect is so widespread that it requires an explanation. Nevertheless, this appears to be so, as demonstrated by recent studies in the United States (Mills and Hazarika 2001; Huang et al 2002).

An additional year of schooling may raise worker productivity at off-farm work by more than at on-farm work. Numerous arguments explain why higher returns to human capital exist in cities than in dispersed populations. Human and physical capital may be complements, so if cities are concentrations of physical capital, they will enhance the returns to schooling. Specialized human capital in different areas may be complementary, so that educated labor is more productive when employed where other workers also have education (Becker and Murphy, 1993). Cities may also lower the cost of information flows, making educated labor more productive. To the extent that cities are agglomerations of consumers, it is easier for labor to specialize according to comparative advantage, and so cities offer greater scope for specialization for skilled workers. By agglomerating jobs, cities also lower the costs of job search. If one job disappears, it is relatively easy to switch to another sector, which lowers the individual’s risk of specializing. These and other arguments are presented by Glaeser (1998) and Quigley (1998).

However, the process of agricultural transformation will also change the input shares for educated labor in the countryside. Agriculture appears to be subject to constant returns to land

and capital. Rising wages in the cities require that an educated farmer be paired with increasing levels of other inputs in order to generate sufficient income to match his or her opportunity costs in the city. Limitations on land in the face of this need for larger farms further accelerate the shift of the population out of agriculture. Thus, Kislev and Petersen (1982) and Barkley (1990) found that rising urban wages have been a driving force in raising farm size and lowering the number of farmers.

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 benefits are distributed over time. Huffman and Evenson (1993) summarize how public and private agricultural research has developed new crop varieties for U.S. farmers, and Evenson and Gollin (2003) summarize how public sector and CGIAR research efforts have developed new Green Revolution crop varieties for developing country farmers. For any given farmer only a small share of the new technologies that become available will be profitable 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 schooling of farmers affects the type and channels through which they acquire information and information processing skills it has long term impacts. For optimal schooling decision making, the three-period model of section II provides a useful guide.

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.

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 and one mature, and four channels of information, one active and one for both extension and private sector information providers. In this study, he found that farmers' education significantly increased the probability of adopting new and mature technologies and 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 a farmer's 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 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.

Overall, the review of the literature (Huffman, 2001; Hussain and Byerlee, 1994)) shows 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.

Agricultural Production. Education of farmers and other farm labor has the potential for contributing to agricultural production as reflected in gross output/transformation functions, 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 of farmers' education associated with allocative efficiency. The effects include 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 empirical evidence has shown that the productivity of farmers' education is enhanced by a wider range of choices, and Welch (1970) is generally given credit for delineating these substantive differences.

Overall, in developing, transition, and developed countries, the review of the literature (Schultz, 1975; Huffman, 2001) shows that farmers' schooling has 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, i.e., it is necessary for farmers to adjust to disequilibrium caused by unexpected changes in technology and prices. 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 multiinput and multioutput.

Conclusions and Implications

In undertaking this review and evaluation, we have drawn the following tentative conclusions. The poorest countries of the world continue to have a large share of their labor force in agriculture. GDP per capita is low and stagnant, birth rates and infant mortality are high and life expectancy at birth is low. Real economic growth cannot occur in these countries until they experience a positive agricultural productivity shock followed by steady productivity growth. With an increase in agricultural productivity, per capita incomes can rise and workers can be released from agriculture to work in other occupations. With luck, small-scale nonfarm industry can grow. However, investments in schooling, health, information, and migration are important for farm people. These investments will help lower birth rates, increase life expectancy, increase labor productivity, and facilitate successful rural to urban mobility and nonfarm employment that is necessary for long term economic growth.

More research is needed that attempts to identify the production function for good health. Although the available food supply is undoubtedly important to economic growth of poor countries, the current empirical evidence is weak. The empirical evidence is much stronger that formal schooling contributes positively to growth. Some of the current high income countries are experiencing over-nutrition or obesity, and its causes are still to be identified. As poor countries undergo development or their citizens migrate to developed countries, obesity, rather than malnutrition, promises to become new and important problems of the future.

References

Abdulla, Majd (2004), "The impact of improved nutrition on labor productivity and GDP growth rates in low- and middle-income countries," Iowa State University, Department of Economics, Masters Thesis.

Akerlof, G. A. and J. L. Yellen (1986), *Efficiency wage models of the labor market* (Cambridge University Press, Cambridge).

Alderman, H., J. R. Behrman, V. Lavy, and R. Menon (2001), "Child health and school enrollment: a longitudinal analysis," *Journal of Human Resources 36: 185-205.*

Arcand, J. L. (2001), "Undernourishment and economic growth: the efficiency cost of hunger," FAO, www.fao.org/News/2001/stockholm/arcand.htm

Avila, A. Plavio and R.E. Evenson, "TFP caculations from FAO production data," Economic Growth Center, Yale University, Feb. 27, 2004.

Barkley, A. P. (1990), "The determinants of the migration of labor out of agriculture in the United States, 1940-85," *American Journal of Agricultural Economics* 72: 567-573.

Basu, K. (1997), *Analytical development economics: the less developed economy revisited* (MIT Press, Cambridge, MA).

Becker, G.S. (1993), *Human Capital*, 3rd ed., The University of Chicago Press, Chicago, IL, p. 1-13.

Becker, G.S. and K.M., Murphy, K.M. (1993), The division of labor, coordination costs, and knowledge. In: Becker, G.S., *Human Capital*, 3rd ed., The University of Chicago Press, Chicago, IL., 299-322.

Behrman, J. R. (1999), "Labor markets in developing countries," in O. Ashenfelter and D. Card, eds. *Handbook of Labor Economics* Vol 3B (Elsevier Science B.V., Amsterdam).

Behrman, J. R. (1996), "Impact of health and nutrition on education," *World Bank Research Observer* 11: 23-37.

Bedi, A. S. and J. H. Y. Edwards (2002), "The impact of school quality on earnings and educational returns--evidence from a low-income country" *Journal of Development Economics* 68: 157-85.

Bedi, A. S. and N. Gaston (1999), "Using variation in schooling availability to estimate educational returns for Honduras," *Economics of Education Review* 18: 107-16. relationship," *Journal of the American Statistical Association* 69:350-354.

Benhabib, J and M. M. Spiegel (1994), "The role of human capital in economic development: evidence from aggregate cross-country data," *Journal of Monetary Economics* 34:143-174.

Ben-Porath, Y. (1967), "The Production of Human Capital and the Lifecycle of earnings," Journal of Political Economy 75:352-365.

Card, D. (1999), "The causal effect of education on earnings," in O. Ashenfelter and D. Card, eds. *Handbook of Labor Economics* Vol 3A (Elsevier Science B.V.,Amsterdam).

Carter, M. R. and J. May (2001), "One kind of freedom: the dynamics of poverty in post-apartheid South Africa, "*World Development* 29: 391-409.

Chen, S. N., J. F. Shogren, P. F. Orazem, and T.D. Crocker (2002), "Prices and health: identifying the effects of nutrition, exercise and medication choices on blood pressure," *American Journal of Agricultural Economics* 84: forthcoming.

Cutler, D., E. Glaeser and J. Shapiro. 2003. "Why Have Americans Become More Obese?" *Journal of Economic Perspectives* 17:93-118.

Dasgupta, P. (1997), "Nutritional status, the capacity for work, and poverty traps," *Journal of Econometrics* 77:5-37.

Dasgupta, P. (1993), *An inquiry into well-being and destitution* (Oxford University Press, Oxford).

Duflo, E. (2001), "Schooling and labor market consequences of school construction in Indonesia: evidence from an unusual policy experiment," *American Economic Review* 91: 795-813.

Durand, J. (1975), *The labor force in economic development* (Princeton University Press, Princeton, NJ)

Emerson P. M. and A. P. de Souza (2002), "The intergenerational persistence of child labor," University of Colorado at Denver, mimeo.

Evenson, R.E. and D. Gollin (2003), “Assessing the impact of the Green Revolution, 1960 to 2000,” *Science* 300 (May 2):758-762.

FAO 1996. *The sixth world food survey*. Rome, Italy: FAO of the United Nations.

Floyd, John. (1967), “The effects of farm price supports on the returns to land and labor in agriculture,” *Journal of Farm Economics*, 148-158.

Fogel, R.W. (1994), “Economic growth, population theory, and physiology: The bearing of long-term processes on the making of economic policy,” *American Economic Review* 84, 369-395.

Fogel, R.W. (2004), “Health, nutrition, and economic growth,” *Economic Development and Cultural Change* 52 (April): 643-658.

Gollin, D. (2000), “Nobody’s business but my own: Self-employment and small enterprise in economic development,” Dept. of Economics, Williams College.

Gollin, D., S Parente, and R. Rogerson (May 2002), “The role of agriculture in development,” *American Economic Review*, 160-164.

Glewwe, P. and E. M. King (2001), "The impact of early childhood nutritional status on cognitive development: does the timing of malnutrition matter?" *World Bank Economic Review*, 15:81-113.

Glewwe, P. and G. Hall (1998), "Are some groups more vulnerable to macroeconomic shocks than others? Hypothesis tests based on panel data from Peru," *Journal of Development Economics* 56: 181-206.

Glewwe, P. and H. Jacoby (1995), "An economic analysis of delayed primary school enrollment and child malnutrition in a low income country," *Review of Economics and Statistics* 77: 156-169.

Goldin, C. (1995), "The U-shaped female labor force function in economic development and economic history," in T. P. Schultz, ed. *Investment in women's human capital* (University of Chicago Press, Chicago).

Grossman, M. (1972a), "On the concept of health capital and the demand for health," *Journal of Political Economy* 80: 233-255.

Grossman, M. (1972b), *The demand for health: a theoretical and empirical investigation* (Columbia University Press, New York).

Glaeser, E. L. (1998), "Are cities dying?" *Journal of Economic Perspectives* 12:139-160.

Greene, W.H. (2003). *Econometric Analysis*, 5th edition, Upper Saddle River: Prentice Hall.

Greenwood, M. J. (1997), Internal migration in developed countries," in M.R. Rosenzweig and O. Stark, eds. *Handbook of Population and Family Economics* (Elsevier Science B.V., Amsterdam).

Grübler, A. (1994). "Industrialization: A developing country perspective," in R. Socolow, C. Andrews, F. Berkhart, and V. Thomes, Eds., *Industrial Ecology and Global Change*. New York, NY: Cambridge University Press, pp. 43-68.

Hayami, Y. and V.W. Ruttan (1985). *Agricultural development: An international perspective*. Baltimore, MD: The Johns Hopkins University Press.

Heckman, J. and S. W. Polachek (1974), "Empirical evidence on the functional form of the earnings-schooling relationship." *Journal of the American Statistical Association* 69:350-354.

Huang, T.L., P.F. Orazem and D. Wohlgemuth (2002), "Rural population growth, 1950-1990: the roles of human capital, industry structure and government policy," *American Journal of Agricultural Economics* 83: 615-627.

Huffman, W.E. 1977. "Interaction Between Farm and Nonfarm Labor Markets," *Am. J. of Agr. Econ.* 59:1054-1061.

Huffman, W.E. (1980), "Farm and off-farm work decisions: The role of human capital." *Review of Economics and Statistics* 62:14-23.

Huffman, W.E. (1985), "Human capital, adaptive ability, and the distributional implications of agricultural policy." *Am. J. of Agr. Econ.* 67, 429-434.

Huffman, W.E. (1991), "Human capital for future economic growth." In: Johnson, Glenn L. and Bonnen, J.T. (Eds.). *Social Science Agricultural Agendas and Strategies*. Part III, Michigan State University Press, East Lansing, MI, p. 61-67.

Huffman, W.E. (1996), "Labor markets, human capital, and the human agent's share of production." In: Antle, J.M., Sumner, D.A. (Eds.). *The Economics of Agriculture*, vol. 2 (Papers in honor of D. Gale Johnson), The Univ. of Chicago Press, Chicago, IL, p. 55-79.

Huffman, W.E. (2001), "Human capital: education and agriculture." Chapter in *Handbook of Agricultural Economics*, Gardner, B., Rausser, G. (Eds.). Amsterdam: Elsevier Science, pp. 334-381.

Huffman, W.E. (2004). “Marketizing U.S. production in the post-war era: Implications for estimating CPI bias and real income from a complete-household-demand system,” Iowa State University, Dept. of Economics, Staff Paper 04012. In 2nd round of reviews at *Rev. Econ. & Statist*.

Huffman, W.E and R. Evenson (1993), *Science for agriculture: A long-term perspective*. Iowa State Press, Ames, IA.

Hurley, T. M., J. B. Kliebenstein and P. F. Orazem (2000), "An analysis of occupational health in pork production," *American Journal of Agricultural Economics* 82: 323-333.

Hussain, S.S. and D. Byerlee. (1994), “Education and farm productivity in post-green revolution agriculture in Asia,” Invited paper, XXII International Conference of Agricultural Economists, Harare, Zimbabwe (available through the World Bank

Ilahi, N., P. F. Orazem and G. Sedlacek (2002), "How does working as a child affect wages, income and poverty as an adult?" Iowa State University, mimeo.

Jacoby, H. G. and E. Skoufias (1997), "Risk, financial markets, and human capital in a developing country," *Review of Economic Studies* 64: 311-335.

Johnson, D. Gale. (2000), “Population, food, and knowledge.” *Am. Econ. Rev*. 90, 1-14.

Johnson, W. R. and Skinner (1986), "Labor supply and marital separations," *American Economic Review* 76:455-469.

Jones, C.I. (2002), *Introduction to economic growth*, 2nd edition. New York, NY: W.W. Norton & Co.

Jorgenson, D.W.(1965), “The role of agriculture in economic development: Classical versus neoclassical models of growth,” in C.R.Wharton, Jr., Ed., *Subsistence agriculture and economic development*, Chicago, IL: Aldine Publishing Co, pp.320-348.

Jorgenson, D.W. and K.J. Stiroh (2000). “U.S. economic growth at the industry level,” *American Economic Review* 90(May):161-167.

King, E. M., P. F. Orazem, and E. M. Paterno (2002), "Promotion with and without learning: effects on student dropout," Iowa State University, mimeo.

King, E. M. and M. A. Hill (1993), *Women's education in developing countries* (Johns Hopkins University Press, Baltimore).

Kislev, Y. and W. Petersen (1982), "Prices, technology and farm size," *Journal of Political Economy* 90: 578-595.

Krueger, A. B. and M. Lindahl (2001), "Education for growth: why and for whom?"

Journal of Economic Literature 39: 1101-1136.

Lakdawalla, D. and T. Philipson. 2002. “The growth of obesity and technical change: A theoretical and empirical examination.” NBER Working Paper 8946.

Leibenstein, H. (1957), *Economic backwardness and economic growth,* John Wiley & Sons, New York.

Levy, V. (1985), "Cropping pattern, mechanization, child labor, and fertility behavior in a farming economy: rural Egypt," *Economic Development and Cultural Change* 33: 777-791.

Lucas, R.E.B. (1997), "Internal migration in developing countries," in M.R. Rosenzweig and O. Stark, eds. *Handbook of Population and Family Economics* (Elsevier Science B.V., Amsterdam).

Maddison, A. (2001), *The world economy: a millennial perspective.* Paris: OECD.

Mammen, K. and C. Paxson (2000), "Women's work and economic development," *Journal of Economic Perspectives* 14:141-164.

McPeak, J. G. and C. B. Barrett (2001), "Differential risk exposure and stochastic poverty traps among East African pastoralists," *American Journal of Agricultural Economics* 82: 323-333.

Mincer, J. (1974), *Schooling, experience and earnings* (Columbia University Press, New York).

Miller, A. (1986), *Pulmonary function tests in clinical and occupational lung disease*(Grune and Startton, Orlando FL).

Mills, B. and G. Hazarika (2001), "Migration of young adults from nonmetropolitan counties," *American Journal of Agricultural Economics* 83:329-340.

OECD. (1994), *Farm employment and economic adjustment in the OECD*. OECD, Paris.

OECD. (1995), *Technological change and structural change in OECD agriculture*. OECD, Paris.

Orazem, P. F. (1987), "Black-white difference in schooling investment and human capital production in segregated schools," *American Economic Review* 77: 714-723.

Pritchett, L. (1997), "Divergence, big time," *Journal of Economic Perspectives* 11:3-17.

Psacharopolous, G. (1994), "Returns to investment in education: a global update," *World Development* 22: 1325-1343.

Psacharopoulos, G. and Z. Tzannatos (1989), "Female labor force participation: an international perspective," *World Bank Research Observer* 4: 187-201.

Quigley, J.M. (1998), "Urban diversity and economic growth," *Journal of Economic Perspectives* 12:127-138.

Ravallion, M. and Q. Wodon (2000), "Does child labor displace schooling? Evidence on behavioral responses to an enrollment subsidy," *Economic Journal* 110:158-175.

Ray, D. (1998), *Development economics.* (Princeton University Press, Princeton).

Romer, P. (1990), "Endogenous technological change." *J. of Political Econ.* 98, S71-S102

Rosenzweig, M. R. (1991), "Labor markets in low income countries," in H. Chenery and and T.N. Srinivasan, Eds., *Handbook of Development Economics* (Vol I, elsevier Science B.V., Amsterdam, The Netherlands).

Rosenzweig, M. R. and R. Evenson (1977), "Fertility, schooling, and the economic contribution of children in rural India," *Econometrica* 45: 1065-1079.

Rosenzweig, M.R. and K. J. Wolpin (1986), "Evaluating the effects of optimally distributed public programs," *American Economic Review* 76: 470-487.

Rosenzweig, M.R. and K. J. Wolpin (1988), "Migration selectivity and the effects of public programs," *Journal of Public Economics* 37: 265-289.

Rosenzweig, M. R. and T. P. Schultz (1983), "Estimating a household production function: heterogeneity, the demand for health inputs and their effects on birth weight," *Journal of Political Economy* 91: 723-746.

Rosenzweig, M. R. and T. P. Schultz (1982), "Market opportunities, genetic endowments, and intrafamily resource distribution: child survival in rural India," *American Economic Review* 72: 803-815.

Sahn, D. E and H. Alderman (1988), "The effect of human capital on wages, and the determinants of labor supply in a developing country, " *Journal of Development Economics* 29: 157-184.

Sanchez, M.A., P.F. Orazem, and V. Gunnarsson, (2000), "The effect of child labor on mathematics and language achievement in Latin America," Dept. Economics, Iowa State University, 2002.

Schultz, T.P. (1999), "Productive benefits of improving health: evidence from low-income countries." Economic Growth Center, Yale University.

Schultz, T.P. (1993), “Returns to women’s education.” In: King, E.M. and Hill, M.A. (Eds.). *Women’s education in developing countries*. Baltimore, MD: Johns Hopkins University Press, p. 51-99.

Schultz, T.P. (1997), “Demand for children in low income countries.” In: Rosenzweig, M.R. and Stark, O. (Eds.). *Handbook of population and family economics*, Vol. 1B, New York, NY: Elsevier Science, p. ____.

Schultz, T. P. (2002), "Why governments should invest more to educate girls," *World Development* 30: 207-25.

Schultz, T. P. (2001), "Women's roles in the agricultural household: bargaining and human capital investments," in B Gardner and G. Rausser, eds. *Handbook of Agricultural Economics* (Elsevier Science B.V., Amsterdam).

Schultz, T. P. (1990), "Women's changing participation in the labor force: a world perspective," *Economic Development and Cultural Change* 38: 457-488.

Schultz, T. P. (1982), "Lifetime migration within educational strata in Venezuela: Estimates of a logistic model," *Economic Development and Cultural Change* 30: 559-593.

Schultz, T.W. (1964), *Transforming traditional agriculture*. Yale University Press, New Haven, CT. (Reprint edition, New York: Arno Press 1976).

Schultz, T.W. (1975), “The value of the ability to deal with disequilibria.” *J. of Econ. Lit*. 13, 827-46.

Sinha, J. N. (1967), "Dynamics of female participation in economic activity in a developing economy," in *Proceedings of the World Population Conference: Belgrade, 1965, Vol. 4* (United Nations, New York).

Singh, I., Squire, L., Strauss, J. (Eds.). (1986), *Agricultural household models*. Baltimore, MD: The Johns Hopkins University Press.

Stiglitz J. E. (1987), "The causes and consequences of the dependence of quality on price," *Journal of Economic Literature* 25:1-48.

Strauss, J. and D. Thomas (1998), "Health, nutrition and economic development," *Journal of Economic Literature* 36: 766-817.

Strauss, J. (1986), "Does better nutrition raise productivity?" *Journal of Political Economy* 94: 297-320.

Taylor J.E. and P. L. Martin (2001), "Human capital: migration and rural population change," in B Gardner and G. Rausser, eds. *Handbook of Agricultural Economics*

(Elsevier Science B.V., Amsterdam).

Topel, R. (1999), "Labor markets and economic growth," in O. Ashenfelter and D. Card, eds. *Handbook of Labor Economics* Vol 3C (Elsevier Science B.V., Amsterdam).

Wang, X. and K. Taniguchi (2004), “Does better nutrition enhance economic growth?” in K. Taniguchi and X. Wang, eds., *Nutrition intake and economic growth: Studies on the cost of hunger*. Rome, Italy: Food and Agriculture Organization (FAO) of the United Nations, 2003.

Welch, F. (1970), “Education in production.” *J. of Pol. Econ*. 78, 35-59.

Welch, F. (1999), “In defense of inequality.” *American Economic Review* 89(May):1-17.

Williamson, J. G. (1988), "Migration and Urbanization," in H. Chenery and T. N. Srinivasan, eds. *Handbook of Development Economics* Vol I (Elsevier Science B.V., Amsterdam).

Wooldridge, J.M. (2002), *Econometric analyses of cross section and panel data*. Cambridge, MA: The MIT Press.

World Bank. (1999), *Knowledge for development. World Development Report 1998/1999*, New York: NY: Oxford University Press.

World Bank. (2000), *Entering the 21st century. World development report 1999/2000*, New York, NY: Oxford University Press.

World Bank (2001), *Engendering development* (Oxford University Press, Oxford).

Wozniak, G. (1993), “Joint information acquisition and new technology adoption: later versus early adoption.” *Rev. of Econ. and Stat*. 75, 438-445.

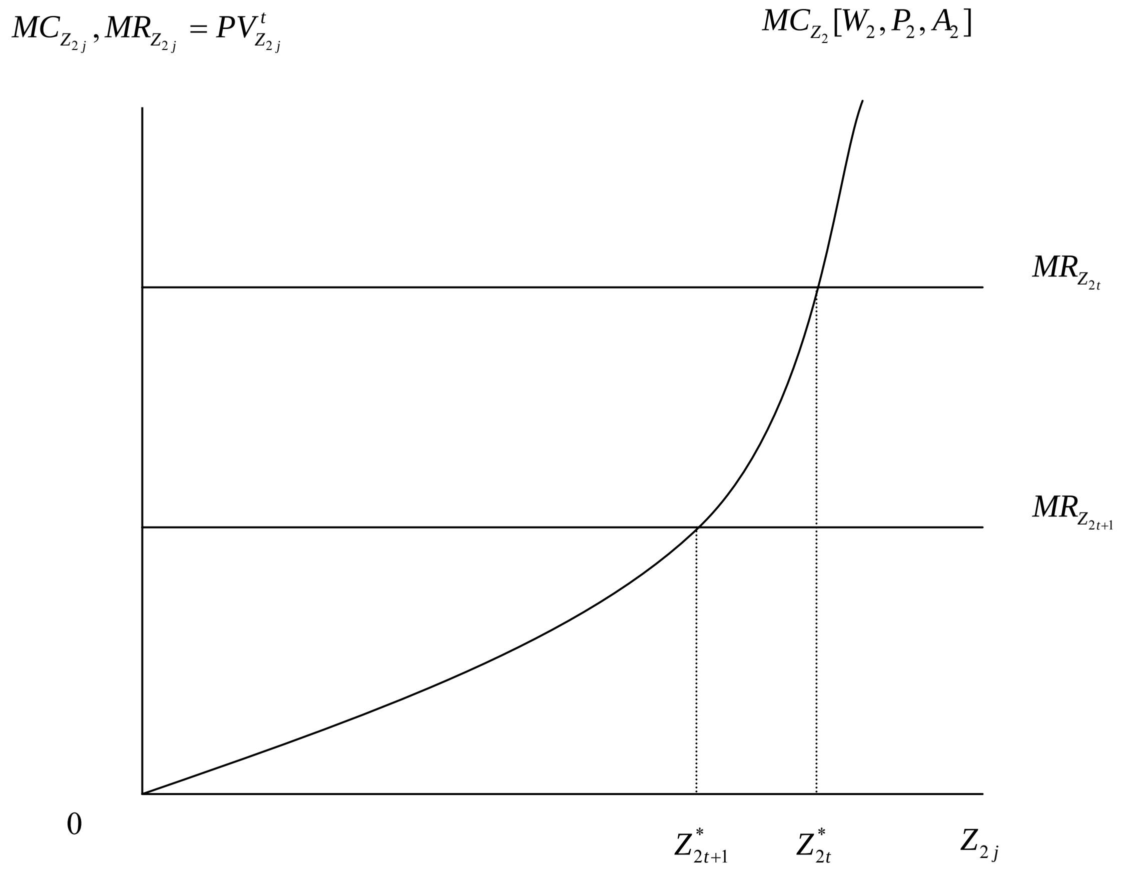


Figure 1. Optimal household decision making: production and investment in human capital investment over the lifecycle.

Source: Huffman (2001, p. 343)

Figure 2: World Population and GDP per Capita, 0-1998
population in millions, income in 1990 U.S. dollars

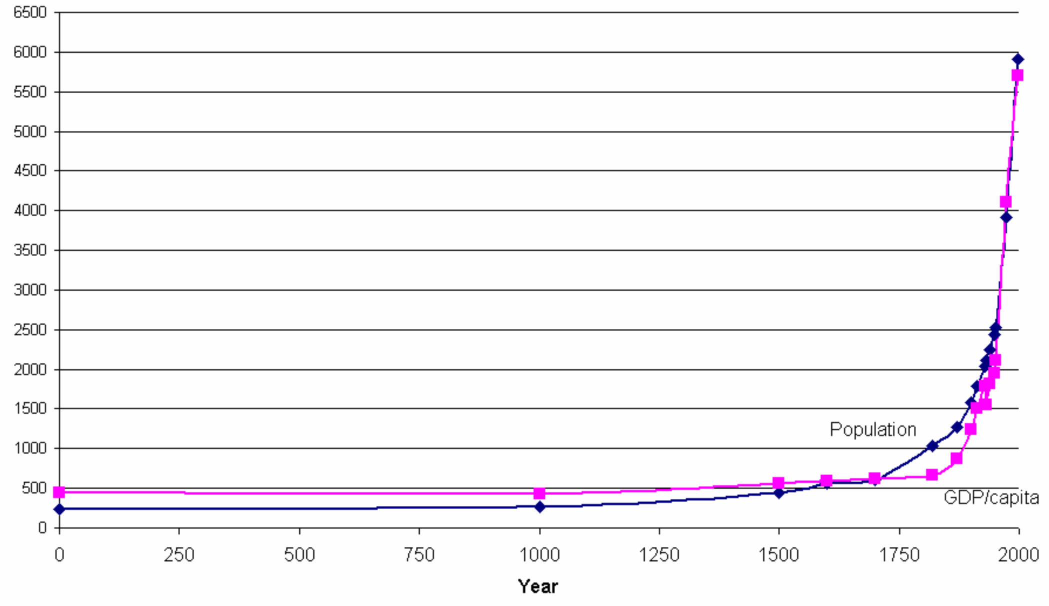


Figure 3: GDP per Capita for various regions, 1600-1998
in 1990 U.S. dollars

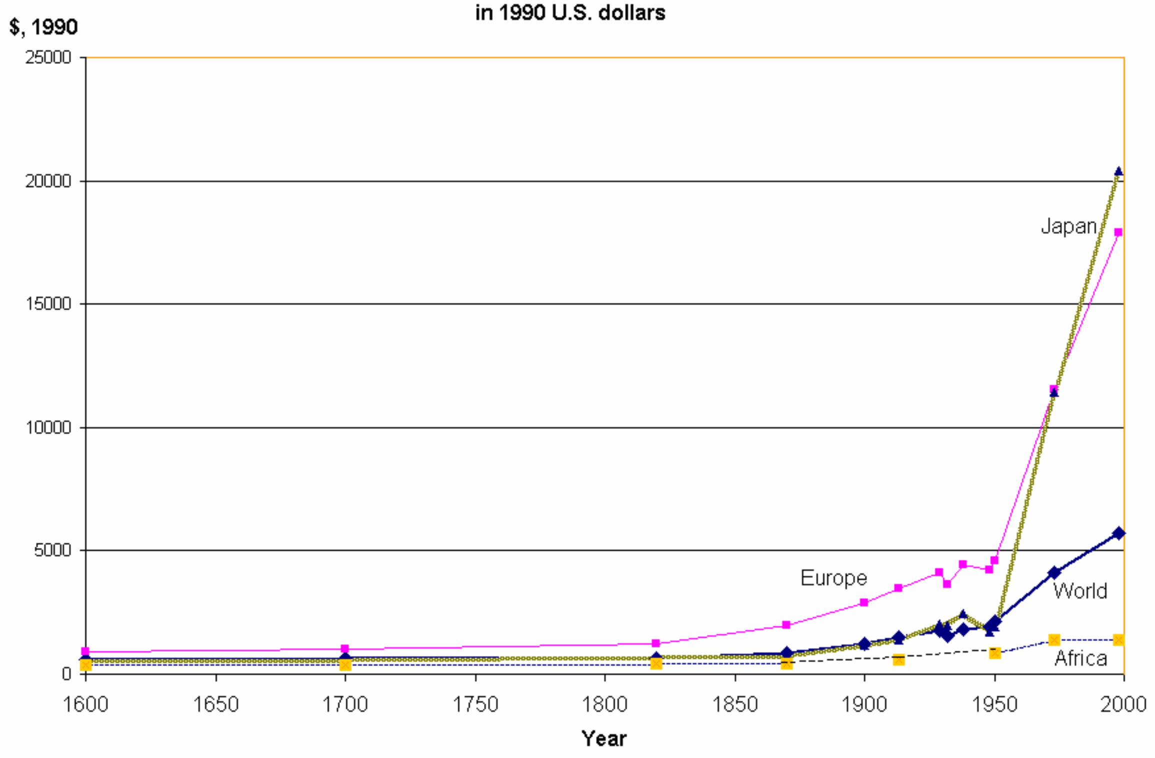


Figure 4: Log Real GNP Per Capita and Average Years of Women's Education. Predicted and Actual Values 1998.

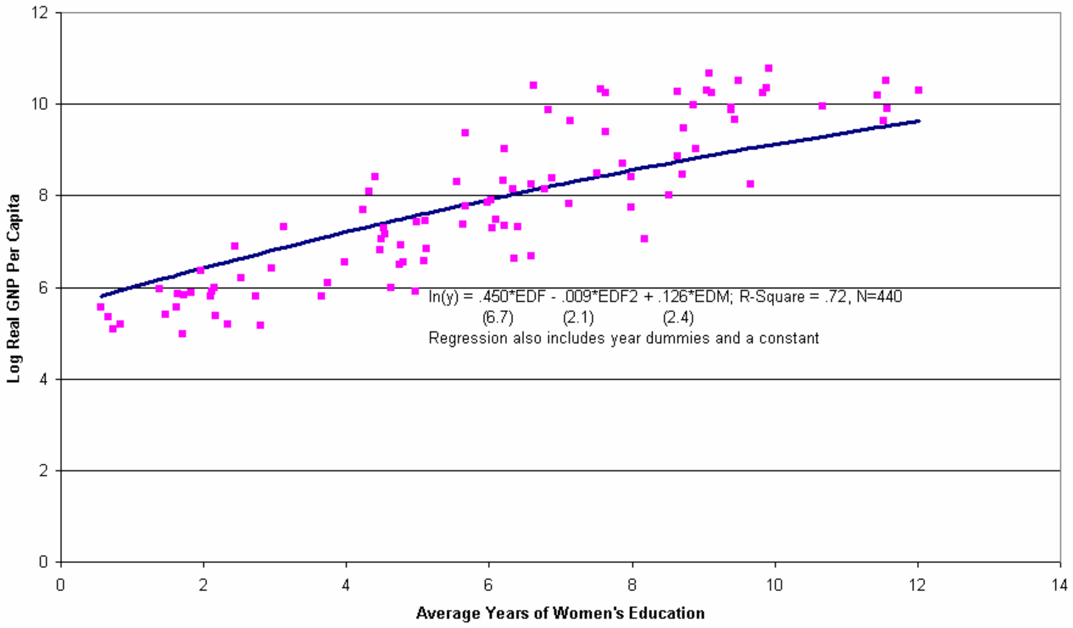
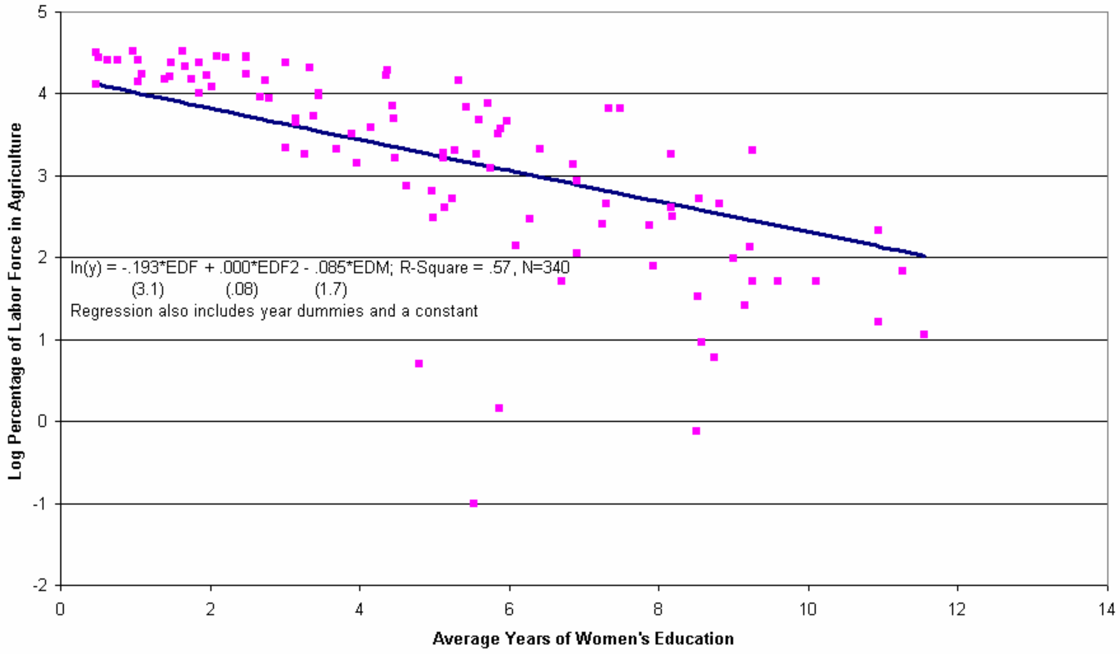


Figure 5: Log Percentage Labor Force in Agriculture and Average Years of Women's Education. Predicted and Actual Values 1990.



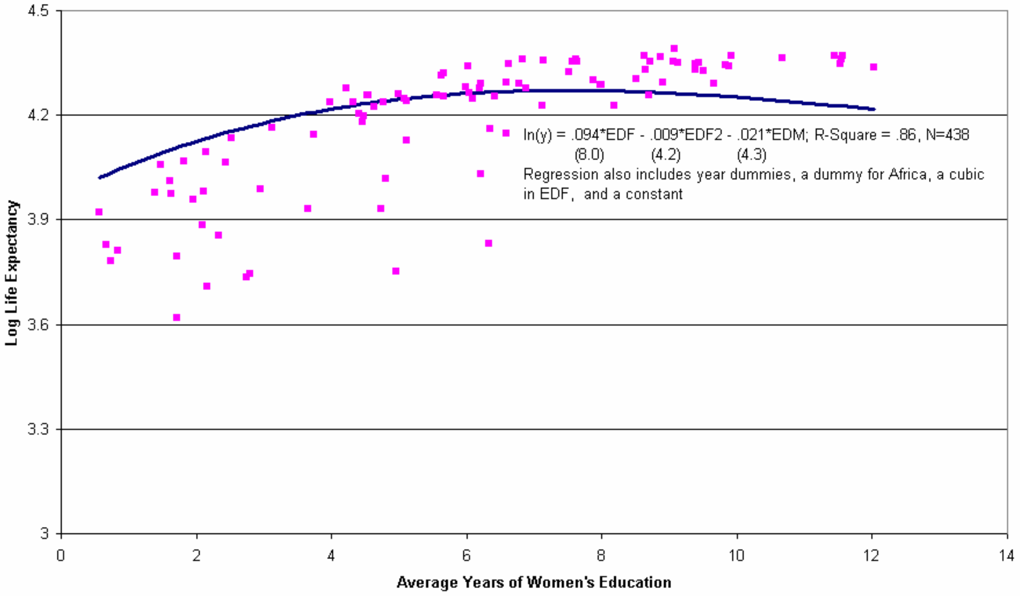


Figure 6: Log Life Expectectancy and Average Years of Women's Education.
Predicted and Actual. 1999

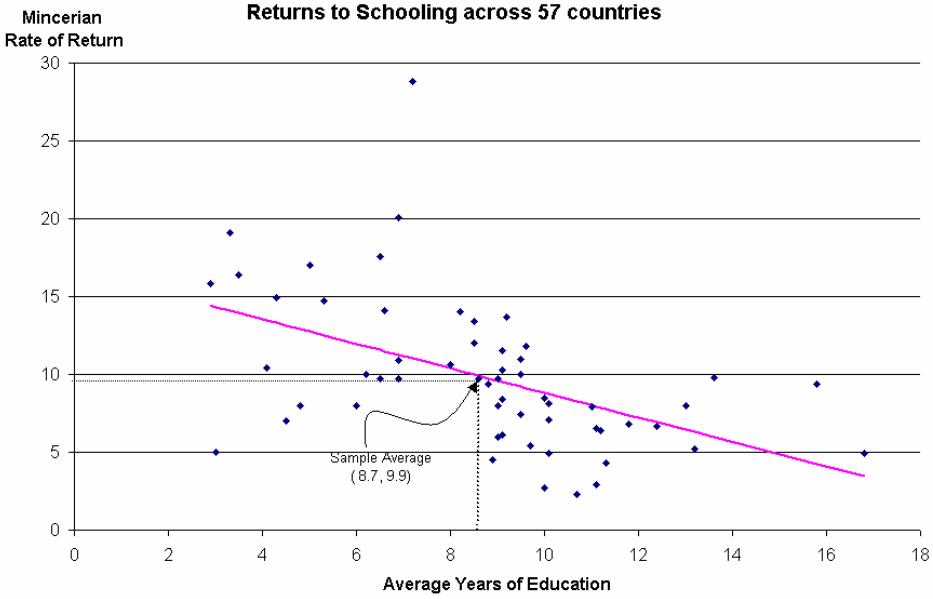


Figure 7: Plot of Psacharopoulos's estimates of Mincerian Returns to Schooling across 57 countries

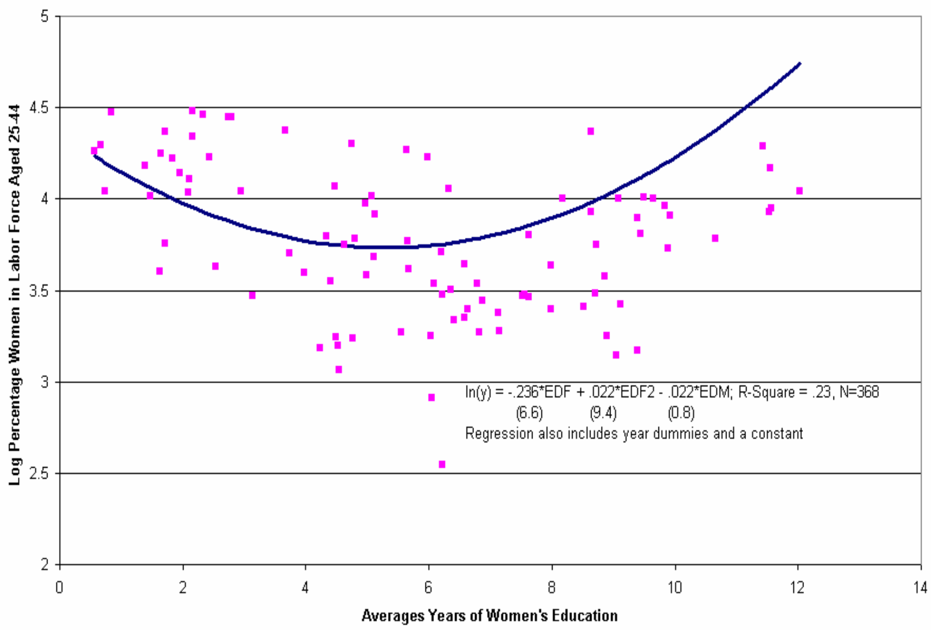


Figure 8: Log Percentage Women in Labor Force Aged 25-44 and Average Years of Women's Education. Predicted and Actual Values 1998.

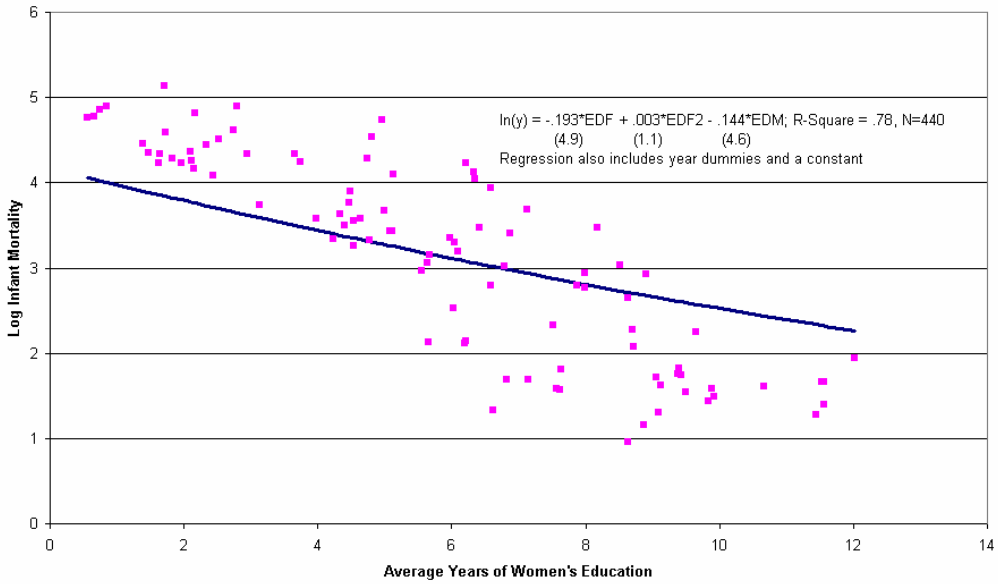


Figure 9: Log Infant Mortality and Average Years of Women's Education. Predicted and Actual Values 1998.

Figure 10: Log Fertility and Average Years of Women's Education. Predicted and Actual Values 1998.

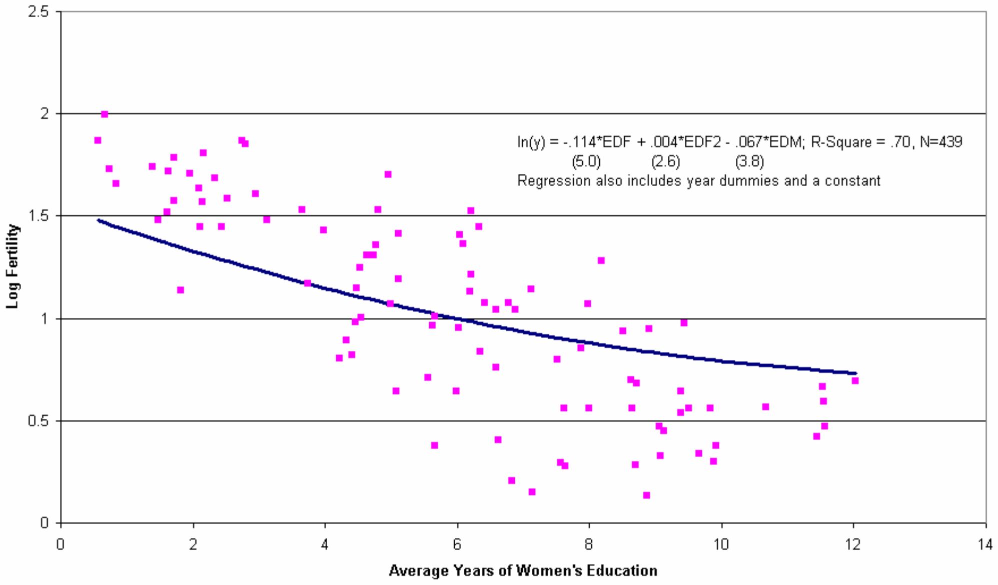


Figure 11: Illustration of the Optimum Wage, w*, in the Efficiency Wage model

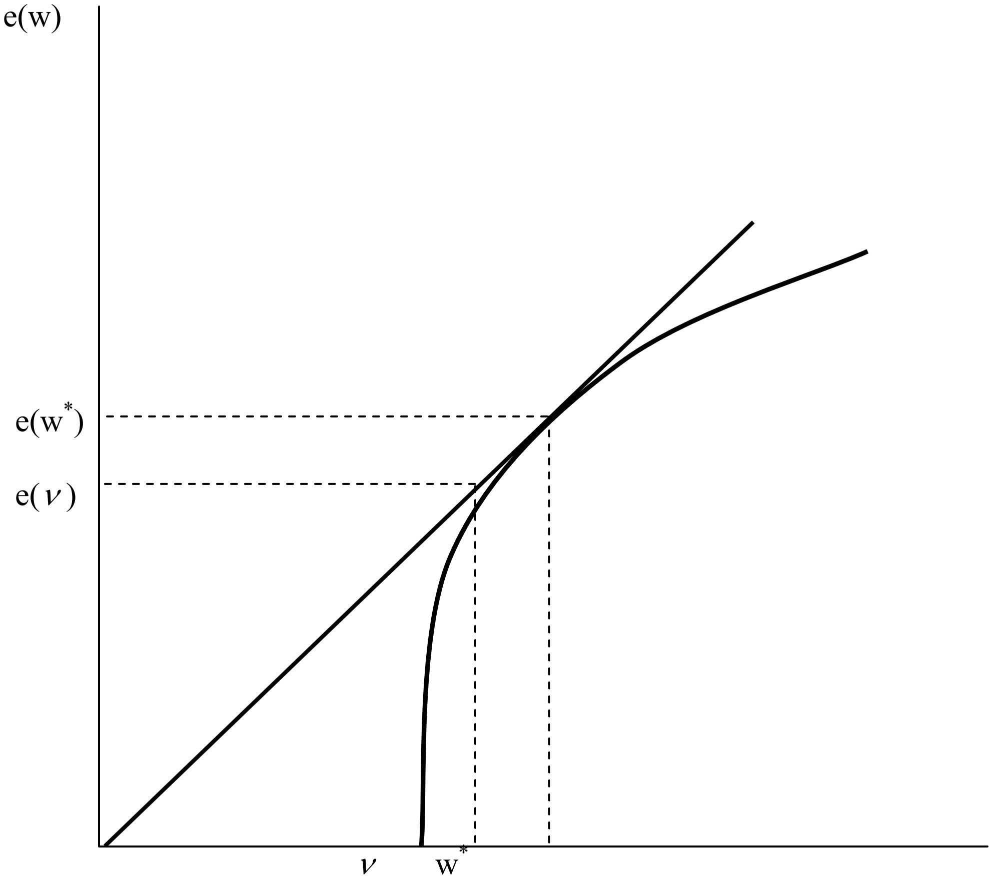


Table 1. Model explaining decade average rates of growth of real GDP per worker, 42 low-and middle-income countries, by decade 1960-1999

Regression/ Equation		Estimated Coefficients							
		Intercept	d (literate)	d ln(DES/worker)	d ln(capital/worker)	d ln(literate)	R^2	N	Estimation Method
1.	d ln y	0.030 (8.86)	0.007 (1.86)	0.003 (1.64)	0.111 (4.03)	----	0.136	168	OLS
2.	d ln y	0.032 (10.29)	----	0.004 (1.81)	0.108 (3.92)	0.121 (0.96)	0.123	168	OLS
3.	d ln y	0.035 (16.6)	----	0.104 (1.85)	0.006 (3.84)	----	0.118	168	OLS
4.	d ln y	0.030 (8.85)	0.007 (1.61)	0.003 (1.18)	0.110 (3.24)	----	0.163	168	Random effects GLS by country
5.	d ln y	0.029 (8.45)	0.007 (1.61)	0.006 (1.18)	0.102 (3.24)	----	----	168	IV [Instrument for d ln(DES/worker)]
6.	d ln y	0.029 (8.42)	0.006 (1.49)	0.008 (1.47)	0.117 (4.35)	-----	----	168	IV [for d ln(DES/worker)] and random effects GLS by country