HUMAN CAPITAL: A SURVEY OF EMPIRICAL RESEARCH

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INTRODUCTION

The idea that acquistion and development of skills embodied in human agents of production could be treated as a form of investment has been in the literature for years (Marshall, 1948). Systematic empirical work originated in the 1920's with Dublin and Lotka's (1946) discounted earnings calculations. These calcuations were updated by Houthakker, (1959) and by Miller (1960), forty years later. In the 1940's, Friedman and Kuznets (1954) used up-to-date methods to investigate acquisiton of professional skills and restrictive practices in medicine. An influential related essay by Rottenberg (1956) on the market for professional baseball players was published later on.

However, the idea came to the professional forefront in the late 1950's and early 1960's with empirical results of Schultz (1961, 1971), Denison (1962) and others showing the importance of education for productivity growth in the U.S. economy. Others strands of interest in the subject can be seen about that time as well. An empirical study by Keat (1960) attributed a large role to education in accounting for secular narrowing of occupational wage differentials. An important study by Mincer (1958) was one of the first to apply human capital concepts directly to the personal distribution of earnings. In addition, the fundamental concepts of human capital were used to analyze slavery by Conrad and Meyer (1958), a natural application of the idea that is a very active area of current research (Fogel and Engerman, 1974). All these developments were organized into a coherent theoretical structure by Becker (1964), a landmark work which raised virtually all the major questions and which in turn stimulated an incredible number of studies in the general area.

The main substantive impact of this work has been to turn attention toward life earnings rather than current wage rates as the empirical constructs of primary interest for a number of problems in labor economics. The theory of human capital is at heart a theory of "permanent" earnings, and its emphasis on lifecycle decisions has been as revolutionary as were earlier lifecycle developments in the analysis of consumption decisions (Modigliani and Blumberg 1954; Friedman, 1957).

It is this development which will be pursued here. The unifying theme is the inherently unobservable nature of human capital, another point of parallel with the modern theory of consumption, in the present case leading to problems of censored data and self-selection.

The literature of human capital has become so vast that a comprehensive survey is not possible in the space alloted. This rules out including the development literature, for example. Hence a more selective survey will be offered, highlighting several important features and controversies as well as trends and gaps in those studies relating human capital concepts to the personal distribution of earnings. For the most part, studies using U.S. data will be surveyed. The simplest possible lifecycle model framework, a "pure" schooling model, is discussed first. Various forms of this model have been the workhorse around which most empirical work has been organized. More complex models, including informal job related learning phenomena, are discussed after that. As will be seen, the latter have a marked similarity to the analysis of optimal economic growth.

THE RATE OF RETURN TO EDUCATION

Life aspects of educational decisions are most clearly brought out by thinking in terms of rates of return to educational investments, a concept fundamental to the theory of human capital. Consider an individual who can pursue two courses of action, one yielding an earnings stream $\{x_t\}$ and the other yielding a sequence $\{y_t\}$. For example, if decisions are being incurred upon high school graducation, x might represent the decision to enter the labor market and y might be the decision to go to college. Let $z_t \equiv y_t - x_t$ and suppose $z_t < 0$ for some values of t so that the decision problem is not trivial. Define net present value V_t as

$$V_t = \sum_{\tau} z_\tau/(1+r)^\tau \tag{1}$$

where r is a rate of interest. An action is chosen to maximize net present value. Hence y is the better course if V > 0 and x is better if V < 0. Define the internal rate of return, *i*, by setting the sum in (1) equal to zero, after replacing *r* by *i*. Then, with the well-known qualifications regarding multiple roots, the same criteria is embodied in the statement: *y* or *x* is better according as $i \gtrless r$.

There is a clear sense in which the (internal) rate of return summarizes the whole life-earnings process in a single statistic. Until very recently, it has been the statistic most studied, undoubtedly because it is easy to compute: Capital values are not observable in free labor markets and there is no obvious market interest rate to use for imputing capital values. Early estimates of rates of return were used to demonstrate that it was possible and sensible to think about educational decisions in investment terms (Hansen, 1963) and to make some normative judgments regarding optimal allocation of investment between human and nonhuman capital (Becker, 1960). There are now so many calculations in the literature that it is difficult to keep track of them. However, a study by Hanoch (1967) using 1960 Census data remains among the best and most careful of this type. For no obvious reason, similar analysis of more recent data has not appeared. Also, internal rate of return computations have been the primary instruments for analyzing program effectiveness of manpower training, giving rise to a vast literature in its own right (*e.g.*, Somers, 1968; Borus, 1972).

While the conceptual basis for rate of return computations is straight forward enough, empirical applications have been surrounded by controversy from the beginning. There are two sets of problems at issue, to be considered in turn. First, most data provides limited panel information and there are many practical difficulties in extrapolating lifecycle developments ($\{x_t\}$ and $\{y_t\}$ in equation (1) from it. Second, there is a question of an appropriate comparison group, since the data represent expost classifications. In principle it is easy to contemplate what the consequences of investing might be, but such counterfactual behavior cannot be observed once the subject has undertaken the decision. Either $\{x\}$ or $\{y\}$ is observed for a particular person, not both. If the comparison group really is appropriate in differing only in the decision to invest, there must have been some other force that induced them to behave differently: There is a problem of self-selection.

DATA PROBLEMS

(i) *Cross-Section Projections*. The usual procedure for estimating lifecycle earnings patterns is to use cross-section age-earnings profiles to set relative patterns of earnings across age groups, up to a geometric growth factor. The growth rate of real wages is used to set the growth factor and the relative cross-sectional values are inflated to estimate a lifecycle profile. Even panel sources follow individuals for a limited time period and a modified version of the above always is required. Cross-sectional age-earnings patterns by educational classes have remained relatively constant in the 1940–1970 Censuses, as evidenced by the relative constancy of rate of return to schooling computations in each of those years (Griliches, 1970). More direct evidence is available in a study by Miller and Hornseth (1971), who examined successive age cohorts from a lengthy series of CPS surveys and found that the use of a constant geometric growth factor described above was a good approximation to actual experience, ex post. The question of ex ante expectations cannot of course be known. Short-term macroeconomic factors tend to confound estimates of costs and returns from educational decisions, as it is well known that wages and unemployment rates among various age, skill and educational groups follow systematic patterns over the course of business cycles. This makes trend extrapolation more dificult, as seen in a recent study by Freeman (1975) showing that the rate of return to college education using the most recent "great recession" cross-section data is substantially smaller than it was in the 1940–1970 period. Of course these problems become even more severe as the group investigated becomes more narrowly defined, and calculations dealing with particular occupations and narrowly defined training programs must be viewed with caution. Changing relative occupational, regional and industrial wage patterns and business cycle factors loom large here.

In addition, cross sections invariably mix up cohorts experiencing vastly different labor market events. For example, the data include generations whose work experience included the Great Depression and major wars. For some, military service substituted for direct labor-market experience. The theory implies that such events have lasting effects on earnings capacities of workers, but little research has gone into investigating their consequences. Some studies have examined the transferability of skills acquired in the military to the private sector, but no general conclusions can be drawn as yet.

(ii) *Classification Difficulties*. This issue might be labeled problems of *invariant classification*. Many years ago, Friedman and Kuznets (1954) stressed that the rate of return on a particular educational investment should be computed as an average over all people who undertook training, irrespective of their subsequent activities. For example, many graduates of professional schools do not actually pursue those lines of work for their whole life after graduation, if at all. This problem becomes especially severe when particular types of training are considered, because people not actually registered in the professsion tend to get censored out of the data.

An example of this problem is an often cited study by Wilkinson (1966), who computed rates of return for detailed occupational classifications. His estimates are of limited value until it can be established that the occupational classifications used are lifetime invariant. There is surprisingly little data available on occupational mobility (Blau and Duncan, 1970; Theil, 1972), but extensive new panel information may help resolve this problem.[1]

Another problem of cross sections arises even when dealing with broad aggregate classifications such as years of school completed. School completion levels are not invariant classifications across cohorts. Schools partially serve as informational and knowledge transfer mechanisms, and the content of school changes across chronological time. Also, schools process certain raw material and the content of that material may change. Schools may become more or less selective over time. In effect, there is a possibility of vintage effects, raising difficult issues for growth accounting and measurement of "effective" labor input. Similar difficulties arise in the productivity accounting literature with respect to physical capital (Jorgenson and Griliches, 1965; Gordon, forthcoming; Denison, 1957), but little work has been done on it for labor inputs. Griliches (1970) standardized simple manhour labor input measures by years of school, but no good measure of human capital vintage effects are available and the necessary refinements cannot be made.

While obsolescence of skills and the knowledge explosion have been topics of some concern in recent years (*e.g.*, Dublin, 1971; Link, 1971), most evidence on this matter is no more than anecdotal. Some notable recent exceptions are studies by Johnson and Stafford (1974) and by Weiss (1975), using NSF register survey data on academic professions. This data has a difficulty noted above, since only current members of professional societies were surveyed. But given that caveat it is a useful sample in identifying year of degree, age and years of professional experience. Further, several cross sections are available. Hence it is then possible to use methods similar to the construction of hedonic price indexes. Both studies find positive vintage effects, but the estimates are not precise enough to allow cross-field comparisons. Furthermore, the time period spanned by the data are rather short and there is considerable collinearity between age and year of degree. In cases where individuals of the same age received their degrees at different chronological dates, there is a clear danger that there was some underlying cause not related to vintage effects at all, but rather to uncontrolled differences in personal characteristics. Weiss does attempt to deal with some of these questions. However, there still is some distance to go.[2]

A recent study by Welch (1973) incidentally provides estimates of vintage effects by regressing (log) earnings on school years completed for several age cohorts in 1959 and 1967. The marginal impact of schooling decreases with year of labor-force entry and is of similar magnitude in each cross section. The estimates imply a vintage growth rate of 2.5 percent for whites males (and much larger for black males, relative white-black differences being the main point of the paper). This kind of evidence will become more definitive as more data comes available. As it stands, Welch has found interactions between schooling and labor-market experience in Census type data. Others have found such interactions in this data as well. To attribute the estimates to a true vintage effects remains problematic at this point, until school selectivity factors and specific cyclical labor market events across cohorts can be filtered from the data.

(iii) *Adjustments of Earnings*. Early rate of return studies based on (1) made additional computational refinements, adjusting observed earnings for survival probabilities, labor-force participation and income taxes. Roughly speaking, the pre- and post income tax adjusted estimates are identified with "social" and "private" rates of return. Problems of forward extrapolation for labor-force participation and income taxes are especially severe, but it is not obvious how existing methods can be improved. More recent studies have employed a regression method (described below) that ignores the entire issue, however. In these studies, (log) earnings of individuals are regressed on schooling and other variables. Few existing data sets report individual income taxes and gross earnings must be used. It is well-known that effective income tax rates roughly are proportional over a broad range. If that proportionality holds with respect to earned income as well, the nature of the bias from ignoring taxes is obvious. However, the subject hardly has been studied, and the facts of the matter are unknown. Further, in the regresssion studies, nonzero earned income is a precondition for sample eligibility and this does not at all face the difficult issues revolving around the proper treatment of labor-force participation; that is, the data are censored. Finally, virtually all studies use earnings and not a more comprehensive notion of compensation. Some investigators have made crude corrections for nonpecuniary aspects of work (Taubman, forthcoming), but most often they are ignored. I know of no studies outside the military (Gilman, 1976) that have adequately treated other portions of the pay package in this connection, such as deferred pay, pensions, insurance and the like, which will be increasingly important in the future. Again, the problem is not a conceptual one, but rather lack of adequate data. Nevertheless, these omissions must always be clearly in mind in evaluating empirical results.

(iv) *School Quality*. Readily available data gives information on years of school attended. This is a crude empirical proxy for "education," because the quality of schooling among members of the same cohort undoubtedly has large variance. An interesting line of research into this question was initiated by Hunt (1963) and later followed up by Welch (1966), who used school expenditures as an empirical measure of school quality and adjusted rates of return to school years completed accordingly. This work was extended by Johnson and Stafford (1973) to a sample of urban males. They included a measure of state per-pupil school expenditure in the earnings-schooling relation and found a significant positive effect of school quality. Wachtel (1974) pursued this method, including per-pupil school expenditure in the county of residence of persons in the NBER-Thorndike sample. Wachtel also finds a strong positive effect of school quality, close in magnitude to that found by Johnson and Stafford. Using the same NBER-Thorndike data, Taubman (forthcoming) included a rough measure of college quality in an earnings regression and also found positive effects, though not as strong as those found by Wachtel. Wise (1975) also found very strong school-quality effects on earnings and promotion probabilities of male workers in a large firm.

The conceptual dilemma in school-quality studies lies in avoiding measurement error on the one hand, but at the cost of possible specification error on the other. Use of state or county educational expenditures as an empirical proxy for quality involves measurement error, since actual experience of individuals in the sample differs from the mean experience in the state or county. Yet as one tries to measure educational quality more accurately one is lead to question why some individuals received better quality than others. The Coleman Report (1966) indicates immense collinearity among school quality, neighborhood and family background indicators. Hence precise measure of school quality may well proxy some other unmeasured personal attributes that affect earnings and conversely. Wise (1975), in a generally excellent study, had admission-standards measures of college quality attended by persons in his sample, but could not control for "ability." Is it "school quality" that is measured here? Findings such as Coleman's lead one to expect that a whole host of family-background related measures may be among the best available proxies for school quality (Welch, 1974; Griliches and Mason, 1972). After all, school conscious parents, typically with higher social-economic status, instill similar values in their children and tend to purchase higher quality education for them. Furthermore, it may well be rational for parents of more able students to send their children to better schools. But all this immediately leads to a host of self-selection problems that deserve separate treatment.

EDUCATION AND SELF-SELECTION

The literature discussed so far relates to observed statistical relationships between earnings and schooling. Clearly one does not need a grand theory of human capital to predict associations between earnings and schooling: most parents have known it all along. Rather, the theory of human capital has some behavioral implications that rest on the earnings-schooling relationship, just as the theory of the firm only begins with a statement about the nature of technology. Once a systematic earnings-schooling relationship is specified, whatever its source, it rationally implies some behavioral rules that can be contradicted, in principle. A simple behavioral rule is discussed in this section.

Again, the fundamental conceptual contribution on educational choice is by Becker (1967). It does not seem unfair to say, however, that several of Becker's followers, including himself, have not stuck to the letter of this model in empirical applications. The following account is more closely related to observable variables and also to standard capital theory, and I hope illustrates the empirical problem more clearly.

Start with a deterministic relationship between earnings, y, and years of schooling s:

$$y = f(s;A) \tag{2}$$

where A is a person specific variable such as "ability" that shifts the earnings-schooling function, but is exogenously given to the individual at the time schooling decisions are made. School-quality choice, hours of work and nonschool investments associated with work experience have been ignored for purposes of simplification. The first is incorporated with only slight difficulty, whereas the others involve considerably more complex issues and are discussed below. Units of measurement are such that $(1/y)(\partial y/\partial s) = f_s/f \equiv i$ has dimensions comparable to an interest rate. That is, i(s,A) is the marginal internal ("own") rate of return to additional schooling, and is a function of both s and A. We will require i(s,A) to be non-negative and decreasing in its schooling argument.

To simplify, assume schooling is a full-time activity with students supplying no labor to the market. Then age-earnings profiles would be step functions with an initial phase, during school years, when y = 0. The height of the step at the point of entry into the market is determined by length of schooling and "ability." Assuming school is provided free of charge, the discounted value of future income (at "birth") is

$$V(s) = \int_s^N y(s;A)\, e^{-rt}dt = y(s;A)\,(1/r)\,(e^{-rs} - e^{-rN}) \tag{3}$$

where r is a fixed rate of discount, and N is the age of retirement from the labor market, both taken as exogenous. Thus the only decision variable affecting human capital value is *s* in this simple model, since A is exogenous. What determines s? The theory provides a simple rule: Choose the value that maximizes V(s). The rule is easily found. Set V′(s) equal to zero and simplify to obtain

$$(1-e^{-r(N-s)})\,(y'/y) = r \tag{4}$$

Investment is pushed to the point where the marginal, finite life-corrected, internal rate of return equals the rate of interest. When the schooling period is lengthened, the individual foregoes income that could have been earned had he gone into the market: marginal cost of schooling is y(s). The marginal gain from staying in school a bit longer is $y'(s)$, which has capital value of $(y'/r)(1-e^{-r(N-s)})$, the discounted marginal returns from additional schooling. Rules such as (4) are familiar from the capital theory of Wicksell (1934) and Jevons (1871): when to cut the tree or sell the wine. At heart then the theory of human captial is a generalized harvesting problem: when should a person stop school and enter the market?[3]

We can relate the above to observed data very easily. Assume for expository convenience N sufficiently large that e^{-rN} vanishes. Then approximately $V = ye^{-rs}/r$ and $\ln(y) = \ln(rV) + rs$ defines a family of lines in the $(\ln y, s)$ plane with slope r, parametric on V. $\ln y = \ln f(s;A)$ is given from the market-constraint (2) and defines a curve in that plane. The optimal policy is characterized by a point of tangency between the two. Only there is V maximized, as in Wicksell's problem. Data in this model are y, s and possibly indicators of A and r across individuals in the labor market. Interpersonal differences in A shift the constraint, whereas interpersonal differences in r change the slope and intercept of the objective function. Hence market observations on $\ln(y)$ and *s* alone represents alternative points of tangency between these curves among various people in the sample, in general reflecting both interpersonal differences in the constraint and objective functions and identifying neither.

The identification problem is straightforward. If everyone has the same discount rate, interpersonal differences in A map out the objective function. A regression of $\ln(y)$ on s identifies the common value of r. However, the regression contains no information on how additonal schooling affects earnings of any particular person, so long as $\partial i/\partial A \neq 0$. If individuals in the sample are of similar abilities, with financial terms differing among them, the observations on $\ln(y)$ and s identify $\ln f(s)$, conditional on the value of A in the population, yielding information on the constraint function (2).

Now suppose that some indicators of A and r are available, such as test scores, family background, patental wealth and social-economic status. Then the model is recursive and exactly identified. It consists of the earnings constraint $\ln y = F(s,A)$ and the inverse of the stopping rule, $s = G(r,A)$. However, there is one more restriction implied by the theory, namely a connection between G and F coming from the stopping rule $r = F_s(s,A)$. Much empirical work has investigated $F(s,A)$, and some research has gone into $s = G(r,A)$. But almost none has ever exploited or tested the connections between the two. In other words, schooling regressions seldom properly incorporate financial incentives to go to school! To do so, however, is not easy because the functional form interdependence is indirect. Also one must recognize that any empirical measures proxy A and r with error; and the errors in the variables analysis resulting is exceedingly complicated.

Further progress requires some consideration of demand. Two polar views will be discussed.

First, suppose "labor" can be converted into homogenous efficiency units, so that persons with more schooling and/or ability have more efficiency units of labor to rent in the market. In this case curvature of (2) may be due to diminishing returns of schooling in producing embodied skills, and A may index either initial stock effects and/or interpersonal differences in learning efficiency. In this case competiton will establish a single market rental price per efficiency unit of labor. Then, if all workers were exactly alike, everyone would rationally stop school at the same age. Both the variance of observed schooling and of earnings among members of the labor force would be zero. If there is variance in the population distributions of A and r, the previous analysis carries over intact. The point is that, with efficency unit assumptions, observed earnings and schooling inequality fundamentally are due to inequality in the distributions of "abilities" and school financial constraints ("opportunity"). Inequality in earnings cannot be attributed to inequality in the distribution of schooling *per se*, because the distribution of schooling is a result of the joint distribution of A and r.

A second interpretation is possible, however, (Mincer, 1970). Suppose that labor cannot be measured in efficiency units, that each level of education is associated with different kinds of skills and works activities that are imperfect substitues for each other in production. In this case curvature of (2) is also due to different market rental values of skills produced at various levels of schooling. The paramenter A might still index interpersonal differences in school-skill production efficiency, but it also might index differences in natural talents toward various work activities. Consider again the case where all individuals are alike with respect to both A and r (again ignoring nonpecuniary aspects of work). Then relative supplies of labor to alternative occupations must be completely elastic, determined only by the financial opportunity costs of entry associated with education. That is, supply factors adjust relative wages in each occupation so that present values of associated earnings streams are equalized everywhere. In terms of the previous discussion we have assuming N is infinite, $V(s) = y(s)e^{-rs}/r = V_0$ for *all* s. Hence $y(s) = E_0 e^{rs}$, where $E_0 = rV_0$ is determined by total supplies of labor and capital. In this case everyone has the same human wealth and is indifferent to the schooling level chosen. However, though everyone is equally well off from a lifetime point of view, observed earnings in any particular year are not equally distributed. Those with more schooling earn more: the earnings distribution is "equalizing" on opportunity costs of schooling. This is the sense of Mincer's original thesis (Mincer, 1958) and much subsequent work by him (1974), Chiswick (1972, 1974) and others.[4]

In this case we have $\ln(y) = \ln E_0 + rs$, the fundamental empirical relationship upon which much empirical work rests. Semi-log linear earnings-schooling regressions are common in the literature (Heckman and Polachek, 1974), and the above argument is the justification for them.

For those taking the first, labor-in-efficiency-units approach, casting everything in terms of schooling is unsatisfactory because there are rents in the system. Ability cannot be untied from the human agent; and earnings reflect both the "normal" rate of return on educational investments plus a special return to scarce natural talents and abilities. The point is reinforced by existence of interpersonal differences in interest rates. Then the earnings-school relationship is the result of moving points of tangency between both shifting constraint functions (2) and shifting objective functions. One may still fit a curve to data on log earnings and schooling, and the dimensionality of the regression coefficient retains the units of an interest rate or rate of return, but the relationship has no structural significance. Nor is it a reduced form. The complete model in this case again is the recursive structure outlined above.

For those holding the equalizing difference view, a semi-log earnings schooling equation is indeed a structural relationship. It reflects market equilibrium, given the assumptions. The equalizing difference hypothesis basically sets a bench mark for observed earnings inequality and it is certainly appropriate to ask how well one can do with the equalizing difference assumption. If the hypothesis (suitably modified for on-the-job training and so forth—see below) can account for most of the variance in observed earnings, then other, unobserved factors may not be of great importance.

Detailed studies of individual earnings data indicate that no particular hypothesis does very well, in the sense of proportion of variance explained by measurable factors. There is enormous variation in earnings among individuals that the data say are identical. It is observations such as these that have led some investigators (Jencks *et. al*, 1972) to conclude that education cannot contribute much to reducing observed income inequality. Whether or not one accepts that particular view, it seems clear that the simple equalizing differences framework is not tenable on this evidence. In recognition of this, the equalizing-differences school abandons that fundamental assumption. Now the semi-log relationship is treated as an identity: $\ln(y_i) = E_{0i} + \hat{r}_i s_i$ for person *i*, with the interpretation of $\hat{r}_i$ as the *average* rate of return for person *i*. Treated in a simple regression context across persons, estimated values of E_0 and r are interpreted as interpersonal averages in the population studied, with all other interpersonal differences impounded in the residual. But once differences among persons are recognized, we are, strictly speaking, back to the analytical issues addressed in the efficiency units model. The regression is not a structural relation, since it is marginal values that determine behavior, not averages, and the fitted function only summarizes observed equilibrium points. Further, the average rate of return for each person is affected by his own ability and financial constraints, which in turn determine investment. That is, $\hat{r}_i$ and s_i in the expression above are not distributed independently of each other. Consequently s_i is not distributed independently of the error term in a cross-section regression, undoubtedly biasing the estimate of the population average rate of return. We are led back to the recursive model in any case.

SCHOOLING, ABILITY AND EARNINGS

The model described above offers a convenient framework for classifying existing empirical studies. Most of them have examined equation (2) directly, a smaller number have looked into the determinants of school enrollment and a few are based on variants of the recursive structure.

1. *The Determinants of Schooling*

Many studies have attempted to correct rate of return calculations for differences in ability between "treatment" and "control" groups. This subject has been controversial from the inception of rate of return calculations, since schooling systems use grades and require successively higher minimum entrance credentials at each level. Higher levels of schooling select entrants on the basis of past performances, and students tend to get sorted out by "ability." A few studies have documented this kind of behavior. For example Olson (1975) used a multinomial logit model relating probabilities of enrollment in various types of schools to personal characteristics, including a measure of ability, and wage rates. Differences in personal characthristics affect either the productivity of different kinds of schooling or financial constraints on alternative choices among people, as in the model above. Though it is not linked directly to the returns function (2), as a full treatment of that model would require, Olson finds significant hierarchical effects with respect to ability and also significant family-background effects that go in the expected directions.

2. *Schooling and Ability*

Studies of school enrollment are interesting, but inconclusive for the point at issue; and most effort has been put into direct estimation of the marginal effects of schooling and ability on earnings. There is now a sufficient number of such studies to reach something of a consensus that the effects of left-out ability measures biases rates of return to schooling, but the bias probably is less than 30 percent and may be substantially less than that.

Becker's old computation of the rate of return to college (Becker, 1964) recognized that a typical college graduate would have earned more than the mean earnings of typical high school graduates and conversely, that typical high school graduates would have ended up in the lower tail of college graduates' earnings distributions had they chosen to continue schooling. On the basis of some rather skimpy evidence, he adjusted the opportunity costs for each group accordingly, reducing the unadjusted rate of return computations by about one third. Becker's adjustments were hampered by an inadequate pool of studies on which he could draw, and the subject has received much more attention since that time without overturning the general conclusion that there remains a substantial true effect of schooling on earnings.

There has been some opinion that academic performance in college is not clearly related to future labor-market success, based on a review of several studies by Hoyt (1965). More recent evidence by Weisbrod and Karpoff (1968) and by Wise (1975) goes in the opposite direction. Data on this issue are scarce and these two studies do have some limitations, because they are based on samples of employee experience in large firms. Thus they are subject to the censoring-selection problem mentioned above, as people who left the firms are not sampled. Given that limitation, these studies show quite convincing effects of college quality and class rank on earnings. For example, Wise found that school-quality and class-rank variables do not affect initial salary determination, but are highly significant in determining salary *growth* rates. Also, the effect of education level has a significant level effect on initial salary, but not on the rate of growth. As mentioned previously, class rank and school quality undoubtedly are correlated with personal "ability," but their inclusion does not knock out school-years effects. Similar results were found by Weisbrod and Karpov (1968) using less extensive data.

Several studies directly have addressed the question in a regression framework, incorporating measures of ability in earnings-schooling regressions. The methodology is pretty much the same in all of them. First the marginal effect of education is computed without other measures. Then ability and other variables are entered in the regression and any change in the marginal effect of education is noted. Some of the more widely known studies of this type are as follows:

(1) Taubman and Wales (1974) and Taubman (1975) updated Thorndike's sample of air force-veterans, a select group of individuals of high measured intelligence. Hence there is a real question of the extent to which their results can be extrapolated to the population at large. However, they are among the very few studies using several dimensions of measured intelligence. Of the ability measures used, mathematical ability had the most important effect on earnings. Inclusion of all ability measures in the regressions reduced the marginal impact of education by some 30 percent. These studies had earnings measures at two different points in time (1955 and 1967) and found no diminution of the effects of measured ability on earnings in that 12-year interval, which tends to strengthen their conclusions.

(ii) A study by Hansen, Weisbrod and Scanlon (1970) examined a special group of military rejects that were followed up by the Census (CPS) in 1964, a sample with quite opposite characteristics from Taubman. In this case, inclusion of ability, age, race and family-background variables reduced the marginal impact of schooling by a factor of more than two thirds, confirming Weisbrod's earlier benefit-cost calculation of keeping high school dropouts in school (Weisbrod, 1957). The study did indicate significant effects of vocational training on earnings even when ability measures were included, as might be expected of this sample.

Extrapolating these results to the population as a whole again is difficult, given the high proportion of nonwhites in the sample and truncation on the ability measure.

(iii) Hause (1972) noted that a semi-log functional form of (2) would imply no correlation between ability and school years completed (given perfect capital markets), since the marginal condition $r = f_s/f$ implies school effects on earnings are independent of ability if (s,A,) is exponential in s and A. Yet there is a positive association between measured ability and school completion, an observation that could be otherwise accounted for by a negative correlation between ability and interest rates. Hause tested for the presence of schooling-ability interaction in the semi-log specification in several samples and found some rather weak evidence for it. Also, in all samples inclusion of ability measures reduced the marginal impact of education by rather small amounts.

3. *More Complete Models*

Several studies of recent origin have estimated recursive structures (Bowles, 1972; Hauser, 1973; Griliches and Mason, 1972). All find positive associations among school-completion levels, ability and family-background measures, as expected. But these are secondary to their main purpose, which is to adjust simple rate of return estimates for left-out variables.

The best of these studies is by Griliches and Mason, who used a followup survey of post World War II veterans. This may be the most representative sample of all studies listed here but still is not a random sample of the population. Griliches and Mason utilize data on pre- and post military schooling and intelligence test scores at the time of entry into the military. They argue that simple incorporation of ability measures in an earnings-schooling regression removes some of the bias of schooling effects that would occur without it, but also introduces another bias because of the correlation between ability and school quality. A partial cure may be worse than the disease. Their data on incremental schooling undertaken after military service is uncorrelated with ability and family-background measures (proxies for quality), so the omitted quality variable is not a problem with regard to that increment. They find, as might be expected on other grounds, that the marginal earnings effect of post-military incremental schooling is larger than that of the pre-military schooling levels; and, in support of their statistical argument, inclusion of the ability measure reduces the effect of the increment much less than that of the pre-military schooling level. The estimated reduction in the marginal impact of schooling is quite small, on the order of 10 percent, and comparable to the result found by Hause.

A paper of recent origin by Griliches is a fine summary of the state of the art of earnings, ability and schooling investigations (Griliches, 1975). This work is particularly notable for coming closest to incorporating financial return considerations into the school completion equation, as the theoretical model would require. While the functional form restrictions of the simple model are not completely imposed, the payoff to schooling is treated statistically by instrumental variables methods. Amazingly enough, this is no left-out ability bias in the earnings equation under this procedure. Griliches' sample is a very special one, but his results nevertheless point out the possibilities of exploiting more of the restrictions in the theoretical model.

4. *Ability and Unobserved Components*

In almost all studies mentioned here, and in many more besides, inclusion of ability measures as a determinant of earnings reduces the marginal effect of schooling somewhat. But direct effects of measured ability always turn out to be rather small, immediately raising questions of what intelligence test scores actually measure. For example, Griliches and Mason attempted to correct for "measurement error" in test scores by instrumental variables techniques (Griliches and Mason, 1972). But their method required the heroic assumption that measured scores linearly proxy human capital stock with error. Indeed in almost all studies (exceptions are: Taubman and Wales, 1974; Taubman, forthcoming), earnings are linearly related to test scores, even though IQ scores are ordinal measures and have no inherent units of measurement.

A completely open question is what kind of measurements would be desirable, in principle, to get closer to a human capital concept. In a well-known study, Gintis reviewed the literature and concluded, on the basis of small direct effects of measured ability on earnings, that schooling does not effect cognitive skills very much (Gintis, 1971). He conjectured that schooling is more related to affective skills (being a good citizen, relating to group norms, etc.). This would come as no surprise to educators, but is a rather different kind of human capital than crude notions of labor efficiency and skill that underlie most empirical work. The fact is that test scores were designed without any human capital concept in mind. They are used in earnings studies because they happen to exist, and for little other reason.

At least two dimensions of ability must be distinguished conceptually. First is some notion of a stock of latent skills, such as cognitive and/or affective traits. The relationship between IQ and this concept is indirect, to say the least. A second concept relates to the learning process itself, namely, the efficiency with which a person can acquire additional skills. Here IQ scores may be more interesting, since, after all, intelligence tests originally were designed to predict school performance (and serve that function quite well).

It is easy to construct a theoretical argument accounting for the small direct effect on earnings, on the hypothesis that test scores proxy learning capacity rather than earning capacity. People with a comparative advantage at learning can acquire human capital at less cost. Hence net returns from learning in the market should be greater for them and they should engage in more intensive (informal) learning activities. But such activities involve opportunity costs, earnings foregone, rendering observed earnings relatively smaller than earnings capacities for such people (see below). In this sense Hause might have been looking for the wrong interaction to test his hypothesis, for this argument would lead one to expect an ability-labor market experience interaction as well as, or maybe even instead of, an ability-schooling interaction. In all samples including test scores, however, the age range of individuals is truncated severely, rendering such tests difficult if not impossible on a direct basis.

In sum, available measures of ability are nebulous at best. For this reason some recent and promising investigations have abandoned direct measurement altogether, adopting instead statistical methods suitable for that purpose: unobserved variance components and factor analysis.

Taubman has analyzed earnings data on twins attempting to allocate its variance among unobserved genetic (G), common environment (N_1) and specific environment (N_2) components, to ascertain the extent to which economic success is strictly inherited or acquired (Taubman, 1975). Earnings of identical (MZ) twins and fraternal (DZ) twins are examined using analysis of variance methods and assumptions that population distributions of G and N are the same across both types of twins. The fundamental assumption on which the results rest is that genetic components are identical for MZ pairs. Hence the within MZ twin variance of earnings only reflects environmental factors. The model is underidentified, but restrictions on the population covariance matrix narrows down the range of possibilities. Taubman estimates that genetics could account for as little as 5 percent of the total variance of earnings or as much as 50 percent. It would be interesting to compare these estimates across countries to shed light on international differences in social mobility and the social mobility picture U.S. citizens are so fond of. More sophisticated unobserved component methods are found in Behrman and Taubman (1975).

Chamberlain and Griliches (1975) also use unobserved components methods to analyze a model similar to Griliches and Mason (1972). The earlier model is augmented by another equation relating Social Economic Status (a rather dubious variable presumably proxying nonpecuniary income) to ability and other things. Ability is treated as an unobserved factor with a common family component and an individual component. The presence of the same unobserved components in several behavioral relationships along with possibilities of computing between and within family covariances yields restrictions on the reduced form covariance matrix sufficient to identify most parameters of interest. In the limited sample actually used, exclusion of ability does not bias estimated effects of schooling on earnings. However, the constructed ability variable is badly behaved (having negative effects on earnings) implying that there are other factors at work here.

In a sense these studies are investigating systematic "people effects," stressing the fact that individuals are different from each other. Most effort has been put into interpersonal differences in ability, and, as mentioned above, somewhat less in differences in school quality. Of course the two are related. But there are other obvious differences that have been ignored. Chief among them are things that go by the common names of "drive," "motivation" and "ambition," and that are almost but not quite summarized in economists' jargon as "tastes for leisure." This factor has not been investigated at all. Again, it is likely to be related to ability and may well be a substitute for it. While there may be few meaningful "ambition indexes" in the psychology literature there are several indicators, such as hours worked, that may be useful in getting at this component of individual differences.

LEARNING FROM EXPERIENCE

While most empirical research in this field is concerned with effects of schooling on lifetime earnings, some effort has been devoted to investigating chiefly *informal* learning processes associated with work experience. It must be emphasized that most learning in the market occurs on an *informal* basis, and not in formal training programs. The latter must account for a small proportion of learning in the market. Now a distinction that was superflous before must be made between firm specific knowledge and more general kinds of knowledge that has uses to many firms. A lot of skills commonly called specific are not so in this sense. For example, underground coal miners have skills that are specific to the coal industry, but are in small measure specific in any one mining company. These skills are "general" in the terminology used here.

So long as there is a modicum of competition and potential firms have the same technology, the existence of firm-specific knowledge rests primarily on the presence of transactions costs in labor markets. Thus in extreme cases of immobility, such as the lifetime tenure system in Japan, a legal sanction converts what would otherwise be general skills into firm specific ones. Large transactions costs make markets thinly traded, and break the link between current earnings and the amount of skills possessed. If most skills are specific, then the whole of lifetime earnings must be examined, not any particular annual figure. Annual earnings may be arbitrarily distributed over the lifecycle so long as present values are not affected. Clearly, it would be difficult to construct a rigorous and useful theory on such a basis; and the role of other factors, such as bargaining power, come to play a more dominant role.

These ideas have a long tradition in labor economics. Noncompeting groups of Cairnes (1874), "Balkanization" theories (Kerr, 1954) and internal and external wage structure theories (Dunlop, 1957) really make these same distinctions in another terminology. The difference in emphasis rests on an empirical assumption. While aware of transactions costs, economists working in the human capital tradition tend to minimize their importance for the analysis of life-earnings patterns. Firm specific types of human capital and transactions costs generally play a much more important role in short-run business cycle related phenomena and demand behavior by firms. It remains to be seen how these two strands can be successfully integrated, and whether there are great advantages from doing so.

Reconsider the alternative earnings streams $\{x_t\}$ and $\{y_t\}$. Again, letting $z_t = y_t - x_t$, elementary manipulations yield the accounting identity

$$rV_t - (V_{t+1} - V_t) = z_t \tag{5}$$

Simplify for the moment by assuming an infinite horizon. Then, identifying accumulated investment costs ΣC_t with present value, $V_t = C_1 + C_2 + \ldots + C_{t-1}$, and $C_t = V_{t+1} - V_t$. In this definition the value of human capital acquired by pursuing action y always equals its opportunity cost. Hence (5) is equivalent to

$$z_t = r \sum^{t-1} C_\tau - C_t.$$

The observable earnings differential is a return on prior investments minus current investment. $r\Sigma C_\tau$ has the interpretation of (unobserved) earnings capacity, something akin to permanent earnings, whereas C_t is foregone earnings. Another form of (6) is also useful (Mincer (1970)). Define $E_t = r \sum^{t-1} C_\tau$ and $\theta_t = C_t/E_t$.

Then $z_t = E(1-\theta_t)$ and $E_t = E_0 \prod_{\tau=1}^{t-1}(1+\theta_\tau)$, so that as a first approximation

$$\ln E_t = \ln E_0 + r \sum_{\tau=1}^{t-1} \theta_\tau \tag{7}$$

A similar expression holds for $\ln z_t$ with an additional term in $\ln(1-\theta_t)$. θ_t in (7) has the natural interpretation of the proportion of period *t* spent investing rather than earnings. If we associate $\theta = 1$ with periods of formal schooling, (7) becomes

$$\ln E_t = \ln E_0 + rs + r \sum_{\tau=s+1}^{t-1} \theta_\tau \tag{8}$$

for a schooling period of s years. Then t − s is a measure of labor-market experience.

(8) points to a variety of factors influencing earnings distributions—viz., distributions of initial earning capacity, E, "rates of return," r, and amounts of

investment at various points in the life cycle—and has been a useful guide for several empirical studies (surveyed in Mincer, 1970). Generally speaking, gross predictions relating schooling with earnings inequality from this point of view are borne out by the data. One could also turn the results around and say that the data implies the conditions upon which the distributional predictions rest.

However, (6) or (8) is not a good enough basis for a theory because no restrictions are imposed on the data. To see this, consider the formula in a finite life case. Let N be the horizon and define $b_t = 1/1 - (1+r) - (N-t)$, an interest correction factor for finite life. Defining $C_t = b_tC_t$ as the finite life corrected cost of investment, (6) becomes

$$z_t = r\Sigma\hat{C}_\tau - \hat{C}_t \tag{9}$$

and $V_t = \overset{t-1}{\Sigma}\hat{C}_\tau$ still holds true. Becker (1964) and Mincer (1962) use (9) to estimate the unobservable (C_t) from data on (z_t), a procedure that has serious problems. First there are N observations, $z_1, \ldots, z_N$, but N+2 unknown parameters, $C_0, \ldots, C_n$ and r. One natural restriction is $C_N = 0$: No one rationally invests in the last period of work-life since there is no return on such outlay. Still there is one less observation than unknown parameters. The model is under-identified. Only for arbitrary values of r can investment costs be computed.

The internal rate of return is conventionally used to solve the identification problem. Then initial capital value, $V_1 \equiv b_0C_0$ is zero, since $V_1 = \hat{C}_0 = \overset{N}{\Sigma} z_\tau/(1+i)^\tau \equiv 0$ by definition of the internal rate i. In this case there are N observations to compute N unknowns, $i, C_1, \ldots, C_{N-1}$, as C_0 vanishes by the definition of i. Once i is computed, the recursion algorithm (9) estimates (C_t). There are two objections to this procedure (see Rosen, 1973). First, in view of the discussion above, it is not obvious why the internal rate of return should be preferred to any arbitrary interest rate. Second, even if there was some reason for preferring it, the assumption that all investments are exactly worth their cost, $V_t, \equiv \overset{t-1}{\Sigma} C_\tau$, is tantamount to assuming equality everywhere between average and marginal costs and returns on investment, an extreme form of the assumption that *all* human capital investments are compensatory. Again that view has no appeal once interpersonal differences in abilities and interest rates are admitted. For if equality between average and marginal costs and returns in some sense holds true for the average person in the sample, there will be many for whom marginal returns is less than marginal cost. Those people should not invest at all. For others marginal return exceeds marginal cost. For them investment should be unbounded. Of course time constraints preclude the latter, but such considerations destroy the logical basis for equating average costs and average returns anyway.

It is conceptually possible to salvage the formulas in light of these objections. Alter (6) to $z_t = \sum^{t-1} r_\tau \hat{C}_\tau - \hat{C}_t$ where r_τ no longer is identified with the marginal rate of return on investment in period τ, but rather with the average rate of return in that period. Computational identities are preserved, as was true in the pure schooling model as well. But now there are 2N−2 unknown parameters, N−1 terms each in the C_τ's and the r_τ's. Things are hopelessly under-identified. The definition has become extremely complicated and inconvenient. It is almost useless.

A refutable theory must impose restrictions on the unobservables $\{C_t\}$ that have nontrivial implications for the observables $\{z_t\}$. The simplest possible theory comes from the observation that the C_t's eventually must decline. This follows from the fact that returns to investing decline in later years because work life is finite, and also because learning may become more expensive as one grows older. A falling sequence $\{C_t\}$ is consistent with the major stylized fact of observed life-earnings patterns, that earnings rise at a decreasing rate with years of experience in the market. The assumed shape of the "learning curve" $\{C_t\}$ also has a number of conditional implications about earnings inequality (Mincer, 1958; Becker and Chiswick, 1966; Chiswick and Mincer, 1972). The multiplicative structure leads to skewness in the distribution of observed earnings if the distribution of costs and marginal return components are symmetric and uncorrelated. Skewness increases with years of experience, as $r\Sigma C$ gains in relative importance compared with current investment $-C_t$. An interesting implication follows from an equalizing-difference kind of assumption that all investments are compensatory. Then observed earnings equalizes the opportunity cost of every conceivable investment and human capital value is the same for all workers. Following Mincer (see Mincer, 1974; and also, Bowman, 1966), the earnings patterns of those who invest less must be flatter than those who invest more and must also exhibit a larger initial value. At some point in the life cycle, labeled the "overtaking point," earnings of the big investors matches earnings of those who invest less and is larger from there on out. That is to say, earnings inequality should have a U-shaped pattern as a function of time spent in the market, within schooling groups.

Many investigators have exploited declining investment cost restrictions in empirical studies, beginning with Johnson (see Johnson, 1970; and the study reworked with more extensive data in Johnson, 1975), who imposed a linearly declining pattern. While his estimation technique is not well exposited, this is an important paper for showing how prior restrictions on $\{C_t\}$ lead to corresponding restrictions on observable age-earnings profiles.

The most complete study of this type is the recent work of Mincer (1974), using the multiplicative framework (8) above. Two *a priori* specifications are used. If θ_t is parameterized as $\theta_\tau = a + b\tau$, the log of earnings follows a quadratic in experience. If an exponential parameterization is chosen, $\theta_\tau = Ae^{B\tau}$ the log earnings-experience profile looks like a Gompertz curve. Mincer fits reports a superior fit for the latter. Among the most notable features of this work is to prove the importance of using measures of labor-market experience rather than chronological age as a determinant of earnings and to present evidence on the earnings distributional implications discussed above. Mincer organizes a number of facts and conclusions about earnings distributions that I cannot do justice to here.

OPTIMUM ACCUMULATION OF HUMAN CAPITAL

A more powerful theory must be based on more precise structural specifications. A fundamental contribution of Ben-Porath (1967) pointed the way, using a model that has marked similarities to optimum growth theory and investment models based on adjustment costs. This framework clarified a number of conceptual issues that are obscured in rate of return constructions, by changing the focus of analysis to directly observed earnings rather than unobserved and imputed rates of return. It helped spell out exactly what can and cannot be estimated fron the data and how the estimates relate to the assumptions of the theory.

Optimization models postulate a functional relation between earnings, y(t), embodied knowledge, k(t), and the amount learned (investment), $\dot{k} = dk/dt$:

$$y = F(k,\dot{k}). \tag{10}$$

The simplest forms ignore uncertainty and hours of work decisions and use maximization of discounted earnings as the objective function:

$$V = \max_{k(t)} \int_0^N y(t)e^{-rt}dt \tag{11}$$

where again *r* is a discount rate and *N* is the horizon. (11) is maximized by choice of an optimal learning policy $\dot{k}(t)$ subject to (10) and a predetermined initial stock of skill, $k(0) = k_o$. Embodied knowledge and learning, $(k,\dot{k})$, are treated as latent unobservable variables in this approach. The functional form of (10) and assumption (11) transforms latent behavior into observable consequences in the form of an estimable life-earning trajectory: Optimality conditions consist of a differential equation for k(t) plus boundary conditions. The solution to this equation is substituted into (10) to yield the estimated life-earnings trajectory, whose coefficients are sufficient to identify some parameters of the underlying process. These typically include the discount rate, depreciation rates, initial earning capacity and certain parameters describing learning efficiency. Life cycle human wealth, earning capacity and investment costs may be imputed from knowledge of these coefficients. Each parametric form of (10) implies an earnings path, and for the theory to be useful one must find a parsimonious specification that yields simple and reasonably accurate representations of the data. There are two ways of going about it.

1. *Investment and Self-production*

In Ben-Porath's formulation, an individual is viewed as allocating his time between work and study. Let R be the rental price of a unit of knowledge and assume static expectations. Then earning capacity at time t is Rk(t). Let θ be the fraction of time set aside for study as in (8) above, with θ bounded by 0 and 1.0. $\theta = 1$ is associated with full time school. On the assumption of completely flexible work hours schedules, actual earnings must be

$$y = Rk(1-\theta) \tag{12}$$

with θRk representing foregone earnings, the opportunity costs of learning. Close the model by specifying a learning production function

$$\dot{k} = f(\theta,k) \tag{13}$$

such that the amount learned is an increasing function of both embodied knowledge and the proportion of time spent studying. An optimum policy θ(t) maximizes (11) subject to (12), (13) and the boundary conditions k_0 and $0 \leq \theta \leq 1.0$. For the phase $\theta < 1.0$, (13) may be inverted, $\theta = g(k,\dot{k})$ and substituted into (12) to get a particular form of (10).

2. *Learning-by-Doing*

There is another way of thinking about the process that is especially suited to on-the-job learning. Eckaus (1963) raised the possibility that learning may be an unalterable by-product of work. In response, Bowman (1966) suggested that market clearing adjustments would imply cost and return elements anyway, because differential learning on various jobs would be associated with different earnings patterns. These ideas can be formalized as follows (Rosen, 1972; Millar, 1971): Learning and work are taken to be strict joint-products, with the ratio between the two varying from job to job. Let ξ index the learning content of a job. Firms can design jobs to reflect profit maximizing learning content by devoting resources (*e.g.*, diverting time of skilled personal to teaching rather than direct production) for that purpose. An equalizing wage differential $G(\xi)$ will arise in the market such that

$$y = Rk - G(\xi), \tag{14}$$

with $G(\xi)$ reflecting equilibrium between workers' demand for learning opportunities and firms' costs of providing them. A production function relating amount learned with learning content and embodied knowledge closes the model

$$\dot{k} = h(\xi, k). \tag{15}$$

Here (11) is maximized by choosing $\xi(t)$, subject to (14), (15) and k_0. The individual moves through a progression of work activities with differential learning content ξ to effect the optimum policy. Again, expressing ξ as a function of $\dot{k}$ and k from (15) and substituting into (14) yeilds an equivalent problem in terms of (10) and (11).

Either view is sufficient to justify (10) and whichever one is used, the crucial prior restrictions required are $F_k > 0$, $F_{\dot{k}} < 0$, and $F_{\dot{k}\dot{k}} < 0$: more embodied skill increases earnings, and marginal cost $-(\partial y/\partial \dot{k})$ of learning is positive and increasing. The latter *requires*, in distinction to the accounting approach criticized above, that marginal and average cost of learning are not equal. Otherwise the problem would not be well conditioned and all-or-nothing learning activities would characterize optimal policies. Implied earnings patterns would exhibit discontinuities, inconsistent with observed patterms. Notice also, that in principle no paired comparisons are necessary to implement these models. Information on r, the parameters of $F(k, \dot{k})$ and initial conditions can be extracted from earnings observations of a single person.

Most of the literature has analyzed an additively separable form of (10)

$$y = R[k - a(\dot{k})^b]. \tag{16}$$

(16) is most easily motivated in a time allocation framework. If (13) is Cobb-Douglas, $\dot{k} = (\theta k/a)^{1/b}$, then solving for θ yields $\theta = a(\dot{k})^2/k$. Substituting into (12) gives (16). The parameter a has the interpretation of a neutral learning efficiency

parameter, and b reflects returns to scale. $b < 1$ is necessary for a smooth, interior optimum for the work-life part of the life cycle. Haley (1973) worked out the complete solution of (16) for $b = 2$, also solving for the age at which full-time human capital production (schooling, $\theta = 1$) ceases. I also worked out this case conditional on being in the labor market, and showed how the internal structure of the model leads to "earnings generating function," *i.e.*, differential equations in earnings y(t) whose solution yields a parametric family of earning-experience trajectories (Rosen, 1973). For (16) the generating structure is a linear second-order differential equation with constant coefficients. It appears probable that an "earnings generator" exists for every parametric representation of $F(\dot{k},k)$, though not necessarily linear. Thus one has a choice of fitting closed-form solutions, relating earnings directly to labor-market experience, or alternatively, of fitting the difference equations of y_t consistent with those closed-form solutions.

Several papers have centered on the school-stopping decision in the Ben-Porath model, finding the age at which θ comes off the boundary (1.0) and how it is affected by changes in parameters (Haley, 1975; Wallace and Ihnen, 1975; Johnson, 1975). Borrowing constraints usually are introduced into these models.[4] An objectionable feature of them is retention of a maximum present-value objective, even though consumption and investment decisions logically cannot be separated in the presence of capital-market imperfections. Further, analysis is confined to variants of (16), and experience with dynamic programming stongly suggests the results are not robust to alternative functional form and constraint specifications. These efforts have not had much effect on empirical work as yet, but appear to be far too restrictive to serve as adequate guides for empirical research. For they imply that schooling and on-the-job training stand on the same footing, with the same productivity augmenting skills learned in shcool as on the job. One needs to keep open the possibility that schooling may change the on-the-job learning production function. Schooling may teach one how to learn as well as to earn. This idea has been convincingly put forth by Welch (1970) who presented some evidence for it in the case of farm incomes. The possibility that schooling affects learning capacity has been ignored in optimum control approaches to schooling decisions, but shouldn't be.

The recursive structure of dynamic programming provides a simple way of incorporating schooling. A backward induction applies, because schooling can be shown to optimally precede entry into work-related learning for a wide class of models (Ishikawa, 1975). Thus, solve (10) and (11) conditional on an arbitrary value of schooling, s. Next, specify how s enters the maximum problem, either changing initial capital stock k_0 upon entry into the market, affecting learning efficiency parameters in (10) or both. The maximum capital value determined in the first step becomes a function of s and the best choice of s is obtained by elementary methods, much like the pure schooling model (3) and (4) above. The full model still is recursive and almost all of the previous discussion applies.

Insofar as *s* shifts (10), we expect interaction between earnings patterns and schooling. Insofar as ability shifts (10), interactions between earnings paths and ability are expected. Estimates of work-experience earnings trajectories by school and ability class should provide some clues on how these effects work.

EMPIRICAL STUDIES

Empirical efforts in the optimum-accumulation context has followed three lines of attack.

1. *Approximation Methods*

A natural first attempt is to follow the methods used for stability analysis in growth theory. Consider a general formulation of (10) with requisite curvature properties and take linear approximations to the Euler conditions characterizing the optimal program. This results in familiar unbalanced catenary trajectories (Samuelson, 1965) for $k(t)$ and $\dot{k}(t)$. In the present case the quality of the approximation may be poor because there is no steady state bench-mark solution. Also another round of approximations of $F(k,\dot{k})$ is necessary (*e.g.*, Taylor's series) and resulting closed form solutions for $y(t)$ are highly nonlinear and unwieldy. I produced some reasonable estimates along these lines (Rosen, 1975) for white male high-school and college graduates in 1960, but the empirical specifications are rather complex and difficult to estimate.

Another approach, taken by Lillard (1973) is to work out the nonlinear earnings profile for a precise structural specification and linearize it by Taylor's expansions. There are serious identification problems here and the end result doesn't bear much resemblance to what one starts with. Thus Lillard's estimated earnings function contains high-order polynomials in schooling, measured ability, and years of labor-market experience and their interactions. Many have arrived at a similar formulation without all of the optimal control baggage.

However one views it, Lillard's empirical results are the most complete investigation of school-age-ability interactions available. Lillard confirms the presence of interactions between ability and schooling on earnings patterns in the NBER-Thorndike sample. Differential effects of ability show up late in the life cycle in these data, supporting the hypothesis offered earlier on why estimated effects of ability on earnings are small. People with more ability have steeper earnings-experience trajectories, lower earnings at younger ages (presumably because of more intensive learning activity), but much greater earnings later on in life.

Lillard's data has cohort information and allows him to make the only available comparison between life-earnings inequality and annual-earnings inequality (Lillard, 1975). Discounted life earnings is more equally distributed than annual earnings, because age or experience is an important determinant of earnings. More interestingly, it is possible in these data to partition cohort unexplained (residual) error variance into permanent person-specific and transitory components. The person-specific component accounts for as much as two thirds of the total residual variance. Unobserved person-specific effects maintain workers *permanently* above or below the average life cycle earnings path of those with similar measured characteristics, and are twice as large as transitory year-to-year variations around the adjusted mean. This is the most persuasive evidence yet that human capital investments are far from compensatory. It remains problematic at this point how much of the unobserved person components are due to motivation effects and to unobserved ability effects, because the data do not contain measures of working time.

2. *Earnings Generating Functions*

Several interesting studies have examined effectiveness of manpower training programs using panel information from Social Security work-history records. These data are the only source that record earnings of trainees and a comparison group for lengthy periods both prior and subsequently to training. Nontrainees with similar pre-enrollment earnings patterns as trainees are chosen as a comparison group. While there has been no attempt to fit explicit models of human capital accumulation, the autoregressive structures used are easily rationalized in terms of an earnings generating function appraoch. That is, previous earnings patterns must be among the most powerful controls for reckoning earning capacities, being the end result of the accumulation process itself.

David Farber (1972) originated this research, computing straightforward standardized comparisons of post-training earnings based on the level and time pattern of pre-training earnings. Ashenfelter (1974) fitted more sophisticated autoregressive functions of the form $Y_{t+\tau} = \sum_i a_i Y_{t-i} + bT$, where Y_{t+i} are post-training earnings, Y_{t-i} are pre-training earnings and T is a training dummy. Ashenfelter found a slight positive effect of training on subsequent earnings which depreciated at a rather rapid rate. The latest analysis has attempted to cope with selectivity problems (Jacobson, 1973; Cooley, McGuire and Prescott, 1975), since most trainees (but not the comparison groups) were unemployed prior to program enrollment and those with the worst job prospects might be expected to enroll in such programs. A difficulty is that unemployment is not explicitly reported in the data and must be inferred from unusual aspects of earnings records themselves. Preliminary results indicate that training has stronger positive effects on earnings when comparison is restricted to those with similar pre-training unemployment experience. While not definitive, these studies offer among the best evidence available on the effects of training programs[5] and open up an interesting new line of research.

An implication of control on unemployment is that unemployment experience has permanent consequences for future earning capacity. Lazear (1975) studied this problem on a sample of young men in an earnings-generating function framework, fitting difference equations in earnings growth rates and including measures of unemployment and schooling. He found that unemployment experience has adverse consequences on wage growth. While the result is interesting, it may well be that measured effects of unemployment experience capture as much a person-specific effect as a direct learning-investment effect. Unemployment may in part be a personal attribute connected with characteristics of workers and job turnover (Hall, 1970). These people may have greater tastes for leisure, a possibility that must be dealt with in future studies along these lines.

3. *Exact Closed Form Specifications*

Several recent studies have attempted to fit exact earnings-experience patterns arising out of optimization modes. While these models could be fit to earnings patterns of individuals, panel records are insufficient to do so and some cross-sectional comparison of different aged persons with otherwise similar characteristics is necessary. Hence, vintage and trend effects as well as expectations must be models. Most investigations have been based on the separable form (16). This has the useful property that optimal learning patterns are independent of initial conditions. Therefore interpersonal differences in endowments get impounded in a permanent life cycle residual without otherwise affecting earnings-growth paths. This accords with Lillard's empirical result on the person-specific component of residual variance.

I fitted earnings function implied by (16), assuming b = 2, to the first 20 years of 1960 male age-earnings profiles for separate race and schooling classifications (Rosen, 1973). The estimation method becomes extremely simple if *r* is known. Using alternative values of 10 and 20 percent for *r* yielded plausible estimates indicating larger initial stocks and greater learning efficiency relative to return for higher levels of schooling. However, meaningful independent estimates of *r* could not be produced. Hence investment costs and other imputations could not be made and the model hardly is confirmed by these data.

Brown (1974) extended the model using panel data on young men and better estimation methods in an earnings-growth formulation. When a value of b = 2 is assumed maximum likelihood estimates of *r* are suspiciously close to zero, replicating my own poor result on different data. Brown then dropped the b = 2 restriction and estimated it to be much smaller than 2, in the neighbothood of 1.1. *b* must be greater than 1.0 for existence of an optimum policy, and while Brown's estimate does exceed that bound, the likelihood surface is flat and its standard error is large. Furthermore implied interest rate estimates remain very small, and much lower than would be expected *a priori*.

Haley (forthcoming) estimated a more extensive version of this model on earnings profiles from several census surveys of the 1950's and 1960's separately for male high school and college graduates. This is the most complete investigation of (16) available.[6] Haley's estimates of r fall within a narrow band of .05–.07, comparable to Mincer's latest rate of return estimates, and surprisingly show no systematic pattern across schooling groups. His estimate of b lies within a band of 1.65-1.8 and also shows no systematic pattern across schooling groups, not much different from the restriction $b = 2$ used in the other two studies but much larger than Brown's point estimate. A weakness of Haley's specification is an *ad hoc* treatment of vintage effects and wage expectations. This was necessary to make the estimation manageable, since a thorough-going treatment of these effects would require estimating a linear function of at least four separate exponential functions of age or experience. It is not obvious how this affects the results, except to point out that expectations and wage-growth realizations have important effects on optimal earnings trajectories.

I also analyzed specifications of (10) of the form $y = Rk(1-(\dot{k}/Bk)^2)$ where B is a learning efficiency parameter (Rosen, 1976). Similar fuctions have been used to analyze growth rates of firms (Lucas, 1967). Weiss (1974) also has been looking into variants of this kind of model. Here the optimal policy is stock independent in *rates of growth* of learning and leads to a closed-form solution for $y(t)$ involving the log of earnings, closer to Mincer's models. The earnings pattern turns out to be a simple nonlinear function in this model and identifies interest rates, depreciation, learning efficiency, B and initial earning capacity. Also, it is easy to incorporate vintage and wage expectation effects in this model, in a much more satisfactory way than for (16).

The model above was fitted to 1960 and 1970 Census cross sections for white male high school and college graduates. r is estimated in the range .07-.09. As in Haley's estimates there is no evidence here of a systematic negative relationship between school completion levels and the implicit discount rates. Estimated vintage effects were very small and not significantly different between groups, whereas rental values of initial capital stock upon entry into the labor force are much larger for college graduates. Most interestingly, the learning efficiency parameter B is much larger for college graduates, implying that college graduates are more efficient learners. There is some less convincing evidence that depreciation rates are larger for college graduates as well. The combination of greater learning efficiency and depreciation for college graduates is consistent with the spirit if not the letter of Welch's hypothesis about the effects of schooling.

In a broad sense this kind of work is less restrictive than earlier studies in fitting separate regression regimes to each schooling class and giving a more complete interpretation of estimated parameters. It also takes an agnostic view of the formal schooling mechanism *per se*. An obvious criticism is that it only treats interpersonal differences in initial earning capacity among workers within schooling, race and sex classifications. Investment-cost functions otherwise are restricted to be identical. Of course this is standard econometric practice in production and demand studies and it is not clear what can be done about it in the present context. In that sense these efforts must be viewed as attempting to capture the work-life earnings structure of the "representative person" in each class. Also, life cycle variations in hours of work are ignored. Using wage rates as the dependent variable or adding hours of work as an independent regressor does not dispose of the issue because costs and returns to learning must be affected by hours of work patterns over the life cycle. The only satisfactory resolution is to extend the theory to include choice of working hours as well as human capital production. But then maximization of present value is not the proper objective. Maximization of lifetime utility becomes the objective and the optimal learning path cannot be separated from consumption-leisure decisions.

EFFECTS OF HOURS OF WORK

Proper treatment of hours of work presents conceptual problems for rate of return computations. (See Schultz, 1968, for a useful discussion of the problems.) Work by Lindsay (1971) and Ghez and Becker (1975) has clarified some of the issues in an equalizing-differences framework. Ignoring differences in tastes and abilities, once leisure is considered, life utility rather than present values of net earnings must be equalized across occupations in full-market equilibrium. Hence greater lifetime market consumption allowed by larger money incomes in training-intensive occupations must be offset in utility terms by less lifetime leisure. One implication is that workers in more human capital intensive occupations should tend to work longer hours. The implied positive association between current wages and current hours across occupations is borne out by the data. This gives rise to a routine index number problem in rate of return calculations and an ideal index can be computed only if the utility function is known.

Many rate of return computations have totally ignored the issue however. For example a study by Bailey and Schotta (1972) found that the rate of return to graduate education based on University of California salary schedules was close to zero. This study is seriously marred by the fact that academic salaries typically are on a nine-month basis, whereas the comparison group worked year around. Differential leisure must be correctly valued to get a proper estimate of the return. Several studies in progress (Leffler, 1975) have been reexamining restrictive entry practices in medicine in the light of this framework and seem to be overturning Friedman-Kuznets original conclusion.

An important study by Mincer and Polachek (1974) investigated male-female earnings differences in a human capital framework. The basic idea of this work is the simple point that systematic differences in lifetime labor-market participation between men and women provokes much different incentives to accumulate labor-market skills, because of different roles in home production and the rearing of children. Consequently, women have less incentive to accumulate human capital both at school and in the labor market, since the market return on it is less. The problem is treated empirically by relating earnings of women to time spent in and out of the labor market. The effect of time in the market on earnings is larger for never-married women than for married women; and the effect of labor-market time on earnings of married women alone is larger after the period of child rearing is completed when firmer commitments to the labor market are made. Both findings strongly support the argument. The influence of market time on annual earnings is not as large for never-married women as for men and the difference may be due to discrimination. However, never-married is an expost classification. If never-married women thought they might marry at one time in their life, the expectation would still lead to differential human capital accumulation. Thus it may not be possible to allocate the residual sex differences in adjusted male-female wage differentials between market discrimination and marital expectations. This is a fascinating problem that calls for further research.

Some emerging research has analyzed simultaneous consumption, leisure and human capital decisions in a lifetime utility-optimization context. Some very general theoretical treatments are available in the work of Ryder, Stafford and Stephan (forthcoming) and of Blinder and Weiss (1974). Heckman (1976) has empirically implemented a particular Cobb-Douglas type formulation of these models and estimates much larger implicit interest rates than are found when working hours are ignored. In a sense we have come full circle. I started off this survey by pointing out empirical similarities between human capital and the economics of consumption. Now the two are being linked together. This is an especially promising development for getting at various aspects of "tastes for leisure," a ground for criticism of existing work that has run throughout this survey.

A simplified version of the problem for labor-market behavior, again conditional on prior schooling decisions, runs as follows. Let $U(C,L)e^{-\sigma\tau}$ be the instantaneous utility function, where C is consumption, L is leisure and σ is the rate of time preference. The objective function is max $\int_0^N U(C,L)e^{-\sigma\tau}dt$. Constraints are $y = F(\dot{k},k,L)$ comparable to (10), and $C = rA + y - \dot{A}$, where y, k, $\dot{k}$ and r have their prior meaning, A is the stock of physical assets and $\dot{A}$ is savings. Assuming interior solutions, Euler conditions characterizing an optimum reduce to

$$U_c/U_c = \sigma - r \qquad \text{for physical assets} \tag{17}$$

$$U_cF_L + U_L = 0 \qquad \text{for leisure} \tag{18}$$

$$F_k + rF_{\dot{k}} - dF_{\dot{k}}/dt = 0 \text{ for human capital production} \tag{19}$$

Conditions (17) and (18) are familiar from the standard theory. Notice, however, that the learning optimization rule (19) does not include parameters of U(C,L) and is separable from the rest of the system in that sense. In fact (19) is identical to the condition that would arise from maximizing discounted lifetime earnings *conditional* on an optimal leisure trajectory L(t) over working life. Choosing a functional form for F, (19) may be solved for k(t) and $\dot{k}(t)$ given L(t). Then substitute back into the earnings definition $y = F(\dot{k},k,L)$ as before to arrive at an earnings-experience path that incorporates feedback effects of hours of work behavior on investment decisions. Tastes for leisure are embodied in the conditional trajectory L(t). This suggests an empirical procedure that offers a convenient middle ground between *ad hoc* treatments of hours and having to deal with a complete consumption, leisure, investment model. Fit a curve to observed life cycle work-hours patterns, solve (19) for k(t) with a particular solution coming from the estimated hours function and plug everything back into the earnings definition to obtain an estimatable earnings-experience, hours function. This ignores the simultaneity problem, but related work by Heckman (1976) suggests it may be a workable method. Solving the differential equation (19) is the hard part and the method may require the unhappy prospect of combining numerical solutions and estimation.

CONCLUSION

This survey has been dominated by a search for structural, behavioral relations in empirical applications of the theory of human capital. While much has been accomplished, there is a long way to go. Two strands probably will have major effects on this field in the future. One is the burgeoning literature on unobserved-components statistical models. The other is models of optimal human capital accumulation. Each treats the unobservable concept of human capital in a distinct manner. The first exploits statistical restrictions on population distributions of the unobservables to identify observable behavioral relationships. The second imposes theoretically derived restrictions on the unobserved behavioral relationships to obtain restrictions on observed behavior. One emphasizes populations, the other concentrates on individuals. Some blending of the two approaches is necessary, and will be hampered by the highly nonlinear observational restrictions imposed by the latter approach. The issue can be put in other terms. Some middle ground must be found between purely equalizing difference views of human capital accumulation and homogeneous labor-efficiency-unit views. There is a need to identify the difference between "average and marginal" behavior in the data.

When all is said and done, however, a theory based entirely on unobservables is bound to have limitations. First, recent work on market signaling (Spence, 1974) represents a different basis for rationalizing observed earnings patterns. The *positive* and *behavioral* aspects of signaling and human capital theories appear to be identical (see an example in Riley, 1976), though their *normative* implications differ greatly. Second, in the work discussed above, there is much preoccupation with estimation. Population distributions of underlying ability and motivational factors in the unobserved components approach, or of underlying behavioral parameters in the optimum capital accumulation approach, ultimately may be estimated. But possibilities for meaningful predictions are restricted unless individual's positions in these distributions can be estimated. Ultimately the unobservables will have to be connected with objective data. Third, the theory has to be broadened to other phenomena. The incorporation of leisure decisions is one promising avenue, and possibilities for including occupational mobility patterns is another. Perhaps these broader implications will allow finer distinctions among competing theories. Finally, all these theories are deterministic, and the incorporation of uncertainty into decision making hardly has begun (Levhari and Weiss, 1974). Optimum accumulation models with uncertainty appear to provide a basis for linking the theory of human capital with older stochastic theories of income distribution.

FOOTNOTES

* I am indebted to George Johnson, Glen Cain and Paul Taubman for criticism of an initial draft, and to the National Science Foundation for financial support.

1. Occupational statistics are of little help and an economic rationale for existing or new classifications is needed badly. For some preliminary attempts, see Cain, Hansen and Weisbrod (1967), and Scoville (1972).

2. Citation studies provide more circumstantial, but corroborative evidence. Lovell (1973), found that the half-life of a journal article in economics is about 5.5 years, compared with 4 years in physics and biology and 5.5 years in sociology. We can expect more studies of this sort as citation data improves.

3. To keep things simple, a "perfect" capital market has been assumed. This allows the investment decision to be analyzed independently of consumption decisions. The separation theorem does not apply in the presence of capital market imperfections and the problem becomes more complex, with little change in its qualitative features.

4. A rather different analysis of financial constraints is found in Parsons (1975).

5. Program generated data abounds with censoring and selection problems, making careful analysis all but impossible. Goldstein (1972) estimates that as much as $1.8 billion has been spent on *evaluation* of such programs, with the unhappy result that almost nothing is known about their effects.

6. Ben-Porath (1970) attempted to test this model using investment cost data generated by Mincer (1962). But as explained above, the test is useless, since Mincer's method of generating the data is inconsistent with an optimizing model. Evidently, Ben-Porath reproduced the assumptions of the data.

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