Volume Title: Education, Income, and Human Capital

Volume Author/Editor: W. Lee Hansen, editor

Volume Publisher: NBER

Volume ISBN: 0-870-14218-6

Volume URL: http://www.nber.org/books/hans70-1

Publication Date: 1970

Chapter Title: Notes on the Role of Education in Production Functions and Growth Accounting

Chapter Author: Zvi Griliches

Chapter URL: http://www.nber.org/chapters/c3277

Chapter pages in book: (p. 71 - 127)

NOTES ON THE ROLE OF EDUCATION IN PRODUCTION FUNCTIONS AND GROWTH ACCOUNTING • ZVI GRILICHES • HARVARD UNIVERSITY

I INTRODUCTION

THIS paper started out as a survey of the uses of "education" variables in aggregate production functions and of the problems associated with the measurement of such variables and with the specification and estimation of models that use them. It soon became clear that some of the issues to be investigated (e.g., the relative contributions of ability and schooling to a labor quality index) were very complex and possessed a literature of such magnitude that any "quick" survey of it would be both superficial and inadvisable. This paper, therefore, is in the form of a progress report on this survey, containing also a list of questions which this literature and future work may help eventually to elucidate. Not all of the interesting questions will be asked, however, nor all of the possible problems raised. I have limited myself to those areas which seem to require the most immediate attention as we proceed beyond the work already accomplished.

As it currently stands, this paper first recapitulates and brings up to date the construction of a "quality of labor" index based on the changing distribution of the U. S. labor force by years of school completed. It then

NOTE: The work on this paper has been supported by National Science Foundation Grants Nos. GS 712 and GS 2026X. I am indebted to C. A. Anderson, Mary Jean Bowman, E. F. Denison, R. J. Gordon, and T. W. Schultz for comments and suggestions.

surveys several attempts to "validate" such an index through the estimation of aggregate production functions and reviews some alternative approaches suggested in the literature. Next, the question of how many "dimensions" of labor it is useful to distinguish is raised and explored briefly. The puzzle of the apparent constancy of rates of return to education and of skilled-unskilled wage differentials in the last two decades provides a unifying thread through the latter parts of this paper as the discussion turns to the implications of the ability-education-income interrelationships for the assessment of the contribution of education to growth, the possible sources of the differential growth in the demand for educated versus uneducated labor, and the possible complementarities between the accumulation of physical and human capital. While many questions are raised, only a few are answered.

II THE QUALITY OF LABOR AND GROWTH ACCOUNTING

ONE of the earliest responses to the appearance of a large "residual" in the works of Schmookler [50], Kendrick [39], Solow [56] and others was to point to the improving quality of the labor force as one of its major sources. More or less independently, calculations of the possible magnitude of this source of economic growth were made by Schultz [53, 54] based on the human capital approach and by Griliches [22] and Denison [16] based on a standardization of the labor force for "mix-changes." Both approaches used the changing distribution of school years completed in the labor force as the major quality dimension, weighting it either by human capital based on "production costs" times an estimated rate of return, or by weights derived from income-by-education data.[1]

At the simplest level, the issue of the quality of labor is the issue of the measurement of labor input in constant prices and a question of correct aggregation. It is standard national-income accounting practice

[1] Kendrick [39] had a similar "mix" adjustment based on the distribution of the labor force by industries. Bowman [10] provides a very good review and comparison of the Denison and Schultz approaches.

to distinguish classes of items, even within the same commodity class, if they differ in value per unit. Thus, it is agreed (rightly or wrongly) that an increase of 100 units in the production of bulldozers will increase "real income" (GNP in "constant" prices) by more than a similar numeric increase in the production of garden tractors. Similarly, as long as plumbers are paid more than clergymen, an increase in the number of plumbers results in a larger increase in total "real" labor input than a similar increase in the number of clergymen. We can illustrate the construction of such indexes by the following highly simplified example:

Labor Category	Number: Period 1	Number: Period 2	Base Period Wage
Unskilled	10	10	1
Skilled	10	20	2
Total	20	30	

The index of the unweighted number of workers in period 2 is just $N_2 = 30/20 = 1.5$. The "correct" (weighted) index of labor input is $L_2 = \dfrac{10 + 2 \times 20}{10 + 2 \times 10} = \dfrac{50}{30} = 1.67$. The index of the average quality of labor per worker can be defined either as the ratio of the second to the first measure or equivalently as the "predicted" index of the average wage rate, based on the second period's labor mix and base period wages: $\overline{w_1} = 1.5$, $\overset{*}{\overline{w_2}} = \dfrac{10 + 2 \times 20}{30} = 1.67$, $E_2 = \dfrac{1.67}{1.5} = L_2/N_2 = 1.113$.

Note that we have said nothing about what happened to actual relative wages in the second period. If they changed, then we could have also constructed indexes of the Paasche type which would have told a similar but not numerically equivalent story. It is then more convenient, however, and more appropriate to use a (chain-linked) Divisia total-labor-input index based on a weighted average of the rates of growth of different categories of labor, using the relative shares in total labor compensation as weights.[2] To represent such an index of total labor input,

[2] See Jorgenson and Griliches [37], from which the following paragraph is taken almost verbatim, for more detail on the construction of such indexes, and Richter [48] for a list of axioms for such indexes and a proof that they are satisfied only by such indexes.

let L_l be the quantity of input of the lth labor service, measured in man-hours. The rate of growth of the index of total labor input, say L, is:

$$\frac{\dot{L}}{L} = \Sigma v_l \frac{\dot{L}}{L_l}$$

where v_l is the relative share of the lth category of labor in the total value of labor input.[3] The number of man-hours for each labor service is the product of the number of men, say n_l, and hours per man, say h_l; using this notation the index of total labor input may be rewritten:

$$\frac{\dot{L}}{L} = \Sigma v_l \frac{\dot{n}_l}{n_l} + \Sigma v_l \frac{\dot{h}_l}{h_l}.$$

The index of labor input can be separated into three components—change in the total number of men, change in hours per man, and change in the average quality of labor input per man (or man-hour). Assuming that the relative change in the number of hours per man is the same for all categories of labor services, say $\dot{H}/H$,[4] and letting N represent the total number of men and e_l the proportion of the workers in the lth category of labor services, one may write the index of the total labor input in the form:

$$\frac{\dot{L}}{L} = \frac{\dot{H}}{H} + \frac{\dot{N}}{N} + \Sigma v_l \frac{\dot{e}_l}{e_l}.$$

Thus, to eliminate errors of aggregation one must correct the rate of growth of man-hours as conventionally measured by adding to it an index

[3] Where the $\dot{x}$ notation stands for dx/dt, and $\dot{x}/x$ represents the relative rate of growth of x per unit of time; and $v_j = p_j L_j / \Sigma_i p_i L_i$. In practice one never has continuous data and so the Laspeyres-Paasche problem is raised again, albeit in attenuated form. Substituting $\Delta L = L_t - L_{t-1}$ for $\dot{L}$, one should also substitute $v_{jt} = \frac{1}{2}(v_{jt} + v_{jt-1})$ for v_{jt} in these formulae. This is only approximated below by trying to choose the p_i's in the middle of the various periods defined by the respective Δe_i's.

[4] This assumption of proportionality in the change in the hours worked of different men, allows us to talk interchangeably about the "quality" of men and the quality of man-hours. If this assumption is too restrictive, one should add another "quality" term to the expression below, $\Sigma v_i \dot{m}_i / m_i$, where $m_i = h_i / H$ is the relative employment intensity (per year) of the ith category of labor.

TABLE 1

Civilian Labor Force, Males 18 – 64 Years Old, per cent Distribution by Years of School Completed

School year completed	1940	1948	1952		1957	1959	1959[a]	1962[a]	1965[a]	1967[a]
Elementary 0–4	10.2	7.9	7.6		6.3	5.5	5.9	5.1	4.3	3.6
5–6 or 5–7[b]	10.2	7.1	6.6	11.6	11.4	10.4	10.7	9.8	8.3	7.8
7–8 or 8[b]	33.7	26.9	25.1	16.8	16.8	15.6	15.8	13.9	12.7	11.6
High School 1–3	18.3	20.7	19.4		20.1	20.7	19.8	19.2	18.9	18.5
4	16.6	23.6	24.6		27.2	28.1	27.5	29.1	32.3	33.1
College 1–3	5.7	7.1	8.3		8.5	9.2	9.4	10.6	10.6	11.9
4+ or 4	5.4	6.7	8.3		9.6	10.5	6.3	7.3	7.5	8.0
5+	–	–	–		–	–	4.7	5.0	5.4	5.5

[a] Employed, 18 years and over.

[b] 5–6 and 7–8 for 1940, 1948 and the first part of 1952, 5–7 and 8 thereafter.

SOURCE: The basic data for columns 1, 3, 4, 5, and 6 are taken from U.S. Department of Labor, *Special Labor Force Report*, No. 1 "Educational Attainment of Workers, 1959." The 5–8 years class is broken down into the 5–7 and 8 (5–6 and 7–8 for 1940, 1948, and 1952) on the basis of data provided in *Current Population Report*, Series P–50, Nos. 14, 49, and 78. The 1940 data were broken down using the 1940 *Census of Population*, Vol. III, Part 1, Table 13. For 1952 the division of the 5–7 class into 5–6 and 7 was based on the educational attainment of all males by single years of school completed from the 1950 *Census of Population*. The 1962, 1965, and 1967 data are taken from Special Labor Force Reports Nos. 30, 65, and 92 respectively.

of the quality of labor input per man. The third term in the above expression for total input provides such a correction. Calling this quality index E, we have

$$\frac{\dot{E}}{E} = \Sigma \nu_l \frac{\dot{e}_l}{e_l}.$$

For computational purposes it is convenient to note that this index may be written as follows:

$$\frac{\dot{E}}{E} = \sum \frac{p_l}{\Sigma p_l e_l} \dot{e}_l = \Sigma p'_l \dot{e}_l,$$

where p_l is the price of the lth category of labor services and p'_l is its relative price. The relative price is the ratio of the price of the lth category of labor services to the average price of labor services, $\Sigma p_l e_l$.

In principle, it would be desirable to distinguish as many categories of labor as possible, cross-classified by sex, number of school years completed, type and quality of schooling, occupation, age, native ability (if one could measure it independently), and so on. In practice, this is a job of such magnitude that it hasn't yet been tackled in its full generality by anybody, as far as I know. Actually, it is only worthwhile to distinguish those categories in which the relative numbers have changed significantly.[5] Since our interest is centered on the contribution of "education," I shall present the necessary data and construct such an index of input quality labor for the United States, for the period 1940–67, based on a classification by years of school completed of the *male* labor force only. These numbers are taken from the Jorgenson-Griliches [37] paper, but have been extended to 1967.

Table 1 presents the basic data on the distribution of the male labor force by years of school completed. Note, for example, the sharp drop in the percentage of the labor force having no high school education (from 54 per cent in 1940 to 23 per cent in 1967) and the sharp rise in

[5] To adjust for changes in the age distribution, one would need to know more about the rate of "time depreciation" of human capital services and distinguish it from declines with age due to "obsolescence," which are not relevant for a "constant price" accounting. See Hall [29] for more details on this problem.

TABLE 2

Mean Annual Earnings of Males, Twenty-Five Years and Over by School Years Completed, Selected Years

School year completed	1939	1949	1956	1958	1959	1963	1966
Elementary 0–4	$ 665	$1,724	$2,127	$2,046	$2,935	$2,465	$2,816
5–6 or 5–7	900	2,268	2,927	2,829	4,058	3,409	3,886
7–8 or 8	1,188	2,693 2,829	3,732	3,769	4,725	4,432	4,896
High School 1–3	1,379	3,226	4,480	4,618	5,379	5,370	6,315
4	1,661	3,784	5,439	5,567	6,132	6,588	7,626
College 1–3	1,931	4,423	6,363	6,966	7,401	7,693	9,058
4+ or 4	2,607	6,179	8,490	9,206	9,255	9,523	11,602
5+	–	–	–	–	11,136	10,487	13,221

NOTE: Earnings in 1939 and 1959; total income in 1949, 1958, 1963 and 1966.

SOURCE: Columns 1, 2, 3, 4, H.P. Miller [42, Table 1, p. 966]. Column 5 from 1960 *Census of Population*, PC(2)–7B, "Occupation by Earnings and Education." Columns 6 and 7 computed from *Current Population Reports*, Series P–60, No. 43 and 53, Table 22 and 4 respectively, using midpoints of class intervals and $44,000 for the over $25,000 class. The total elementary figure in 1940 broken down on the basis of data from the 1940 *Census of Population*. The "less than 8 years" figure in 1949 split on the basis of data given in H.S. Houthakker [34]. In 1956, 1958, 1959, 1963 and 1966, split on the basis of data on earnings of males 25–64 from the 1959 1-in-a-1000 Census sample. We are indebted to G. Hanoch [31] for providing us with this tabulation.

TABLE 3

Relative Prices,[a] Changes in Distribution of the Labor Force, and Indexes of Labor Input Per Man, U.S. Males, Civilian Labor Force, 1940–64

I. Relative Prices and Changes in the Distribution of the Labor Force

School Years Completed	p' 1939	$\dot{e}$ 1940–48	p' 1949	$\dot{e}$ 1948–52	p' 1956	$\dot{e}$ 1952–57	p' 1958	$\dot{e}$ 1957–59	p' 1958	$\dot{e}$ 1959–62	p' 1963	$\dot{e}$ 1962–65	p' 1966	$\dot{e}$ 1965–67
Elementary														
0–4	0.497	−2.3	0.521	−0.3	0.452	−1.3	0.409	−0.8	0.498	−0.8	0.407	−0.8	.380	−0.7
5–6 or 5–7	0.672	−3.1	0.685	−0.5	0.624	−0.2	0.565	−1.0	0.688	−0.9	0.562	−1.5	.525	−0.5
7–8 or 8	0.887	−6.8	0.813	−1.8	0.796	−3.3	0.753	−1.2	0.801	−1.9	0.731	−1.2	.661	−1.1
High School														
1–3	1.030	2.4	0.974	−1.3	0.955	0.7	0.923	0.6	0.912	−0.6	0.886	−0.3	.861	−0.4
4	1.241	7.0	1.143	1.0	1.159	2.6	1.113	0.9	1.039	1.6	1.087	3.2	1.030	+0.8
College														
1–3	1.442	1.4	1.336	1.2	1.356	0.2	1.392	0.7	1.255	1.3	1.269	0	1.223	+1.3
4+ or 4	1.947	1.3	1.866	1.6	1.810	1.3	1.840	0.9	1.569	1.0	1.571	0.2	1.566	+0.5
5+	–	–	–	–	–	–	–	–	1.888	0.3	1.730	0.4	1.785	+0.1

II. Labor Input Per Man: Percentage Change

	1940–48	1948–52	1952–57	1957–59	1959–62	1962–65	1965–67
Total	6.45	2.50	2.97	2.39	2.36	2.13	1.77
Annual	0.78	0.62	0.59	1.20	0.79	0.72	0.88

[a]The relative prices are computed using the appropriate beginning period distribution of the labor force as weights.

SOURCE: Derived from Tables 1 and 2.

the percentage completing high school and more (from 28 in 1940 to 58 in 1967). Table 2 presents data on mean income of males by school years completed, and Table 3 uses these data together with Table 1 to derive an estimate of the implied rate of growth of labor input (quality) per worker.[6] The columns in Table 3 come in pairs (for example, the columns headed 1939 and 1940–48). The first column gives the estimated relative wage (income) of a particular class and is derived by expressing the corresponding numbers in Table 2 as ratios to their average (the average being computed using the corresponding entries of Table 1 weights). The second column of each pair is derived as the difference between two corresponding columns of Table 1. It gives the change in percentages of the labor force accounted for by different educational classes. The estimated rate of growth of labor quality during a particular period is then derived simply as the sum of the products of the two columns, and is converted to per annum units.[7]

For the period as a whole, the quality of the labor force so computed grew at approximately 0.8 per cent per year. Since the total share of labor compensation in GNP during this period was about 0.7, about 0.6 per cent per year of aggregate growth can be associated with this variable, accounting for about one-third of the measured "residual." A comparison and review of similar estimates for other countries can be found in Selowsky's [52] dissertation and Denison [18].

Note that in these computations no adjustment was made to the relative weights for the possible influence of "ability" on these differentials. Also, while a portion of observed growth can be attributed to the changing educational *composition* of the labor force, it should not be interpreted to imply that all of it has been produced by or can be attributed to the educational *system*. I shall elaborate on both of these points later on in this paper.

It is important to note that by using a Divisia type of index with shifting weights, one can to a large extent escape the criticism of using

[6] These income figures are deficient in several respects; among others: they are not standardized for age, and the use of a common $44,000 figure for the "over $25,000" class probably results in an underestimation of educational earnings differentials. I am indebted to E. F. Denison for pointing this out to me.

[7] The percentage change so calculated between any two dates, is the same as would be obtained by weighting the two educational distributions by the base (weight) period *i* earnings, aggregating and computing the percentage change.

"average" instead of "marginal" rates (or products) to weight the various education categories. If the return to a particular type of education is declining, such indexes will pick it up with not too great a lag and readjust its weights accordingly. Also, note that I have not elaborated on the alternative of using the growth in "human capital" to construct similar indexes. For productivity measurement purposes, we want indexes based on "rental" rather than "stock" values as weights. It can be shown (see Selowsky [52]), that if similar data are used consistently, there is no operational difference between the quality index described above and a "human capital times rate of return" approach, provided the capital valuation is made at "market prices" (i.e., based on observed rentals) rather than at production costs. For my purposes, the construction of "human capital" series would only add to the "round-aboutness" of the calculations. Such calculations (or at least the calculation of the rates of return associated with them) are, of course, required for discussions of optimal investment in education programs.

III EDUCATION AS A VARIABLE IN AGGREGATE PRODUCTION FUNCTIONS

MUCH of the criticism of the use of such education per man indexes as measures of the quality of the labor force is summarized by two related questions: 1. Does education "really" affect productivity? 2. Is "education" and its contribution measured correctly for the purpose at hand? After all, the measures I have presented are not much more than accounting conventions. Evidence (in some casual sense) has yet to be presented that "education" explains productivity differentials and that, moreover, the particular form of this variable suggested above does it best. There is, of course, a great deal of evidence that differences in schooling are a major determinant of differences in wages and income, even holding many other things constant.[8] Also, rational behavior on the part of employers would lead to the allocation of the labor force in such a way that the value of the marginal product of the different types of labor will

[8] See Blaug [6] and Schultz [55] for extensive bibliographies on this subject.

be roughly proportional to their relative wages. Still, a more satisfactory way of really nailing down this point, at least for me, is to examine the role of such variables in econometric aggregate production function studies. Such studies can provide us with a procedure for "validating" the various suggested quality adjustments, and possibly also a way of discriminating between alternative forms and measures of "education."

Consider a very simple Cobb-Douglas type of aggregate production function:

$$Y = AK^{\alpha}L^{\beta},$$

where Y is output, K is a measure of capital services, and L is a measure of labor input in "constant quality units." Let the correct labor input measure be defined as

$$L = E \cdot N,$$

where N is the "unweighted" number of workers and E is an index of the quality of the labor force. Substituting EN for L in the production function, we have

$$Y = AK^{\alpha}E^{\beta}N^{\beta},$$

providing us with a way of testing the relevance of any particular candidate for the role of E. At this level of approximation, if our index of quality is correct and relevant, when the aggregate production function is estimated using N and E as separate variables, the coefficient of quality (E) should both be "significant" in some statistical sense and of the same order of magnitude as the coefficient of the number of workers (N).[9] It is this type of reasoning which led me, among other things, to embark

[9] The E measure as used here is equivalent to the "labor-augmenting technical change" discussed in much of recent growth literature. I prefer, however, to interpret it as an approximation to a more general production function based on a number of different types of labor inputs. Allowing changing weights in the construction of such an E index implicitly allows for a very general production function (at least over the subset of different L types) and imposes very few restrictions on it. An interpretation of E as an index of embodied quality in different types and vintages of labor, fixed once and for all and independent of levels of K, would be very restrictive and is not necessary at this level of aggregation.

TABLE 4

Education and Skill Variables in Aggregate Production Function Studies

Industry, Unit of Observation, Period and Sample Size		Labor Coefficient	Education or Skill Variable Coefficient	R^2
1. U.S. Agriculture, 68 Regions, 1949	a.	.45		.977
		(.07)		
	b.	.52	.43	.979
		(.08)	(.18)	
2. U.S. Agriculture, 39 "states," 1949–54–59	a.	.43		.980
		(.05)		
	b.	.51	.41	
		(.06)	(.16)	.981
3. U.S. Manufacturing, states and two-digit industries, N=417, 1958	a.	.67		.547
		(.01)		
	b.	.69	.95	.665
		(.01)	(.07)	
4. U.S. Manufacturing, states and two-digit industries, N=783, 1954–57–63	a.	.71		.623
		(.01)		
	b.	.75	.96	.757
		(.01)	(.06)	
	c.	.85	.56	.884
		(.01)	(.16)	

NOTE: All the variables (except for state industry, or time dummy variables) are in the form of logarithms of original values. The numbers in parentheses are the calculated standard errors of the respective coefficients.

SOURCES: 1. Griliches [23], Table 1. Dependent variable: sales, home consumption, inventory change, and government payments. Labor: full-time equivalent man-years. "Education" – average education of the rural farm population weighted by average income by education class-weights for the U.S. as a whole, per man. Other variables included in the regression: livestock inputs, machinery inputs, land, buildings, and other current inputs. All variables (except education) are averages per commercial farm in a region. 2. Griliches [24], Table 2. Dependent variable: same as in (1) but deflated for price change. Labor: total man–days, with downward adjustments for operators over 65 and unpaid family workers. Education: similar to (1). Other variables: Machinery inputs, Land and buildings, Fertilizer, "Other", and time dummies. All of the variables (except education and the time dummies) are per farm state averages. 3. Griliches [25], Table 5. Dependent variable: Value added per man-hour. Labor: total man-hours. Skill: Occupational mix-annual average income predicted for the particular labor force on the basis of its occupational mix and national average incomes by occupation. Other variable: Capital Services. All variables in per-establishment units. 4. Griliches [27], Table 3. Dependent, labor, and skill variables same as above. Other variables: a. and b. Capital based on estimated gross-book-value of fixed assets; c. also includes 18 Industry and 20 regional dummy variables.

on a series of econometric production function studies using regional data for U. S. agriculture and manufacturing industries. The results of these studies, as far as they relate to the quality of labor variables, are summarized in Table 4.[10]

In general they support the relevance of such "quality" variables fairly well. The education or skill variables are "significant" at conventional statistical levels and their coefficients are, in general, of the same order of magnitude (not "significantly" different from) as the coefficients of the conventional labor input measures. It is only fair to note that the inclusion of education variables in the agricultural studies does not

[10] The data sources and many caveats are described in detail in the original articles cited in Table 4 and will not be reproduced here. Note that for manufacturing, the quality variable is based on an occupation-by-industry rather than education-by-industry distribution, since the latter was not available at the state level. On the other hand, the first manufacturing study (Griliches [25]) also explored the influence of age, sex, and race differences on productivity, topics which will not be pursued further here.

increase greatly the explained variance of output per farm at the cross-sectional level, while the expected equality of the coefficients of E and N is only very approximate in the manufacturing studies. Nevertheless, this is about the only direct and reasonably strong evidence on the aggregate productivity of "education" known to me, and I interpret it as supporting both the relevance of labor quality so measured and the particular way of measuring it.[11]

There have been a few attempts to introduce education variables in a different way. Hildebrand and Liu [33] considered the possibility that an education variable may modify the exponent of a conventional measure of labor in a Cobb-Douglas type production function. Their empirical results, however, did not provide any support for such a hypothesis, partly because of lack of relevant data. They used the education of the total labor force in a state for the measurement of the quality of the labor force of individual industries within the same state. But the difficulty of estimating interaction terms of the form $E \log L$ implied by their hypothesis, arises mostly, I believe, because there is no good theoretical reason to expect this particular hypothesis (that education affects the share of labor in total production) to be true. Brown and Conrad [13] have proposed the more general (and hence to some extent emptier) hypothesis that education affects *all* the parameters of the production function. They did not, however, estimate a production function directly, including instead a measure of the median years of schooling in ACMS type of time series regressions of value added per worker on wage rates and other variables. Their results are hard to interpret, in part because their education variables are fundamentally trends (having been interpolated between the observed 1950 and 1960 values), and because the same final equation is implied by the very much simpler errors-in-the-measurement of labor model. Nelson and Phelps [46] have suggested that education may affect the rate of diffusion of new techniques more than their level. This would imply in cross-sectional data that education affects the over-all efficiency parameter instead of serving as a modifier of the labor variable. Nelson and Phelps do not present any empirical estimates of their model. Without further detailed specification of their hypothesis, it is not operationally different from the quality of labor view of educa-

[11] Somewhat similar results have also been reported by Besen [5].

tion in a Cobb-Douglas world, since any multiplicative variable can always be viewed as modifying the constant instead of one of the other variables.[12]

No studies, as far as I know, have used a human capital variable as an alternative to the labor-augmenting quality index in estimating production functions. While at the national accounting level it need not make any difference which variable is used, the two approaches used in a Cobb-Douglas framework would imply different elasticities of substitution between different types or components of labor. Consider two alternative aggregate production function models

$$Y = AK^{\alpha}L^{\beta} = AK^{\alpha}N^{\beta}E^{\beta}$$

where $E = \sum_i r_i N_i / N$ and the r_i's are some base period rentals (wages) for the different categories of labor, and

$$Y = BK^{a}N^{b}H^{c}$$

where H is a measure of "human capital." To be consistent with the E measure it would have to be based on a capitalization of the wage differentials over and above the returns to "raw," unskilled, or uneducated labor (r_0).[13] Thus, approximately

$$H = \delta \sum_i (r_i - r_0)N_i$$

where δ is a capitalization ratio on the order of one over the discount rate. Note, that given our definitions we can rewrite H as

$$H = \delta(EN - r_0N) = \delta N(E - r_0)$$

[12] Data from the 1964 Census of Agriculture may allow a test of the Nelson-Phelps hypothesis. These data provide separate information on the education of the farm *operator* as distinct from that of the rest of the farm labor force. The Nelson-Phelps hypothesis implies that the education of entrepreneurs is a more crucial, in some sense, determinant of productivity than the education of the rest of the labor force.

[13] An H index based on costs (income forgone and the direct costs of schooling) would be similar to the one described in the text only if all rates of return to different levels of education were equal to each other and to the rate used in the construction of the human capital estimate.

TABLE 5

Various Education Measures in an Aggregate Agricultural Production Function (Sixty-Eight Regions, U.S. 1949)

Education Variable	Coefficients of X_6 (man-years)	Coefficients of Education Variable	R^2
S	.539	.0165 (.0065)	.9789
log S	.536	.297 (.119)	.9789
E	.524	.431 (.181)	.9787
E_2	.520	.455 (.203)	.9785

S—Mean school years completed of the rural farm population (25 years old and over). E—Logarithm of the school years completed distribution of the rural farm population weighted by mean income of all U.S. males, 25 years and over in 1949. Mean incomes from H. Houthakker [34]. E_2—Same as E except that the weights are mean wage and salary income of native white males (over 25) in 1939. Mean incomes by school years completed computed from the 1940 *Census of Population, Education*, Washington, 1947, pp. 147 and 190. Other variables are the same as in row 1 of Table 4.

SOURCE: Unpublished mimeographed appendix to Griliches [23].

and substituting it into the human capital version of the production function we get

$$Y = CK^aN^{b+c}E^c\left(1 - \frac{r_0}{E}\right)^c.$$

Thus, the *H* version implies that the production function written in terms of *E* is not homothetic with respect to *E*. Moreover, it implies that the elasticity of substitution between *H* and *N* is unity, while the *E* version assumes (for fixed *r*'s) that the elasticity of substitution between different types of labor (the N_i) is infinite, at least in the neighborhood of the observed price ratios.

While such different assumptions are not operationally equivalent, it is probably impossible to discriminate between them on the basis of the type and amounts of data currently available to us. Consider the last equation; it differs from the straight E version by having a different coefficient on E than on N. If we estimate the E equation in an H world, we shall be leaving out the variable $\log(1 - r_0/E)$ with a c coefficient in front of it. But $\log(1 - r_0/E)$ is approximately equal to $-r_0/E$, since $r_0/E < 1$, and the regression coefficient of the left out variable, in the form of $1/E$ on the included variable $\log E$, will be on the order of one, for not too large variations in E. Hence, the estimated coefficient of E in an H world will be on the order of $2c$, which is not likely to be too different from the coefficient of N^{b+c}.

More generally, it is probably impossible to distinguish between various different but similar hypotheses about how the index E should be measured, at least on the basis of the kind of data I have had access to. Whether one uses "specific" or national income weights, or just simply the average number of school years completed, one has variables that are very highly correlated with each other. This is illustrated by the results reported in Table 5, based on an unpublished appendix to my 1963 study. Our data are just not good enough to discriminate between "fine" hypotheses about the form (curvature) of the relationship or the way in which such a variable is to be measured.

IV AGGREGATION

OBVIOUSLY, in constructing such indexes of "quality" (or human capital) we are engaged in a great deal of aggregation. There are many different types and qualities of "education" and much of the richness and the mystery of the world is lost when all are lumped into one index or number. Nevertheless, as long as we are dealing with aggregate data and asking over-all questions, the relevant consideration is not whether the underlying world is really more complex than we are depicting it, but rather whether that matters for the purpose of our analysis. And even if we

TABLE 6

Ratios of Mean Incomes for U.S. Males by Schooling Categories

Year	High School Graduates to Elementary School Grads		College Graduates to High School Graduates	
1939	1.40[a]		1.57[c]	
1949	1.41	1.34[b]	1.63	
1958		1.48	1.65	
1959		1.30		1.51[d]
1963		1.49		1.45
1966		1.56		1.52

[a]Elementary 7–8 years

[b]Elementary 8 years

[c]College 4 + years

[d]College 4 years

SOURCE: From Table 3

decide that one index of E hides more than it reveals, our response will surely not be "therefore let's look at 23 or 119 separate labor or education categories," but rather what kind of two-, three-, or four-way disaggregation of E will give us the most insight into the problem.

From a formal point of view, we can appeal either to the Hicks composite-good or to the Leontief separability theorems to guide us in the quest for correct aggregation. If relative prices (rentals or wages) of labor with different schooling or skill levels have remained constant, then we lose little in aggregating them into one composite input measure. A glance at the "relative prices" for different educational classes reported for the United States in Table 3 does not reveal any drastic changes in them. Thus, it is unlikely that at this level of aggregation much violence is done to the data by putting them further together into one L or E index. Similar results can be gleaned from a variety of occupational and skill differential data (see Tables 6 and 7). In general, they have remained remarkably stable in the face of very large changes in relative

TABLE 7

Ratios of Mean Incomes of U.S. Employed and Salaried Males: Professional and Technical Workers to Operatives and Kindred

Year	
1947	1.67
1950	1.58
1953	1.55
1959	1.67
1964	1.63

SOURCE: From U.S. Bureau of Census, *Trends in Income of Families and Persons in the U.S.: 1947 – 1964*, Technical Paper No. 17, Washington, 1967, Table 38.

numbers and other aspects of the economy.[14] In fact, the apparent constancy of such numbers constitutes a major economic puzzle to which I shall come back later.

When we abandon the notion of one aggregate labor input and are faced with a list of eight major occupations, eight schooling classes, several regions, two sexes, at least two races, and an even longer list of detailed occupations, there doesn't seem to be much point in trying to distinguish all these aspects of the labor force simultaneously. The next small step is obviously not in the direction of a very large number of types of labor but rather toward the question of whether there are a few underlying relevant "dimensions" of "labor" which could explain, satisfactorily, the observed diversity in the wages paid to different "kinds" of labor. The obvious analogy here is to the hedonic or characteristics approach to the analysis of quality change in consumer goods, where an attempt is made to reduce the observed diversity of "models" to a smaller set of relevant characteristics such as size, power, durability, and so forth.[15] One can identify the "human capital" approach as a one-dimen-

[14] The constancy of relative differentials implies a rise in absolute differential and a rise in the incentive to individuals to invest more in their education.

[15] See Griliches [26] and Lancaster [41] for a recent survey and exposition of such an approach.

sional version of such an approach.[16] Each person is thought of as consisting of one unit of raw labor and some particular level of embodied human capital. Hence, the wage received by such a person can be viewed as the combination of the market price of "bodies" and the rental value of units of human capital attached to (embodied in) that body:

$$w_i = w_o + rH_i + u_i$$

where u_i stands for all other relevant characteristics (either included explicitly as variables, controlled by selecting an appropriate sub-class, or assumed to be random and hence uncorrelated with H_i). If direct estimates of H are available, this type of framework can be used to estimate r. If proxy variables are used for H, such as years of schooling, age, or "experience," one can proceed to the estimation of income-generating functions as did Hanoch [31] and Thurow [59] which, in turn, can be interpreted as "hedonic" regressions for people. Alternatively, if one is willing to assume that the implicit prices (w_0 and r) are constant, and one has repeated observations for a given i, one can use such a framework to estimate the unobserved "latent" H_i variable. Consider, for example, a sample of wages by occupation for different industries: If one assumes that occupations differ only by the amount of human capital embodied per capita, and that the price of "bodies" and of "skill" is equalized across industries, then this is just a one-factor analysis model, and it can be used to estimate the implied relative levels of H_i for different occupations. Of course, having gone so far one need not stop at one factor, or only one underlying skill dimension. The question can be pushed further to how many latent factors or dimensions are necessary or adequate for an explanation of the observed differences in wages across occupations and schooling classes?

This is, in fact, the approach pursued by Mitchell [44] in analyzing the variation of the average wage in manufacturing industries by states. He concludes that one "quality" dimension is enough for his purposes. He does, however, make the very stringent assumption that the implied

[16] Actually, it could be thought of as a two-dimensional or factors model, body and skill, but since each person is taken to have only one unit of body (even a Marilyn Monroe), the *B* dimension becomes a numeraire and for practical purposes this reduces itself to a one-factor model.

relative price ratio of bodies to human capital, or of skilled and unskilled wages (w_0/r), is constant across states and countries. This is a very strong assumption, one that is unlikely to be true for data cross-classified by schooling. Studies of U. S. data (see, e.g., Welch, [62] and Schwartz [51] have in general found significantly more regional variation in the price of unskilled or uneducated labor than in the price of skilled or highly educated labor, implying the nonconstancy of skill differentials across regions (and presumably also countries).

In a recent paper, Welch [63] outlines a several dimensions model of the general form

$$w_{ij} = w_{0j} + r_{1j}S_{1i} + r_{2j}S_{2i}$$

where i is the index for the level of school years completed, j is the index for states, S_1 and S_2 are two unobserved underlying skill components associated with different educational levels. This is not strictly a factor-analysis model any longer, both because the r's are assumed to vary across states and because no orthogonality assumptions are made about the two latent skill levels. With a few additional assumptions, Welch shows that if the model is correct one should be able to explain the wage of a particular educational or skill level by a linear combination of wages for other skill levels and by no more than three such wages (since there are only three prices here: two "skills" and one "body"). The linearity arises from the implicit assumption that at given prices any unit of S_1 or S_2 (and "body") is a perfect substitute for another. Thus, even though different types of labor are made up of a smaller number of different qualities which may not be perfectly substitutable for each other, because the whole bundle is defined linearly, one can find linear combinations of several types of labor which will be perfectly substitutable for another type of labor. For example, while college and high school graduates may not be perfect substitutes, one college graduate plus one elementary school graduate may be perfect substitutes for two high school graduates. Welch analyzes incomes by education by states and concludes that in general one doesn't need more than three underlying dimensions to explain eight observed wage levels, and that often two are enough. It is not clear whether Welch is using the best possible and most parsimonious normalization, or whether a generalization of the factor-analytic approach with oblique factors could not be adapted to this problem, but clearly this is a very interesting and promising line of analysis.

The approximate constancy of relative labor prices by type, the implicit linearity of the Welch model, and some scattered estimates of rather high elasticities of substitution between different kinds of labor or education levels (e.g., Bowles [8]), all imply that we will lose little by aggregating all the different types of labor into one over-all index as long as our interest is not primarily in the behavior of these components and their relative prices.

V ABILITY

THIS is a very difficult topic with a large literature and very little data. What little relevant data there are have been recently surveyed by Becker [2] and Denison [17]. It has been widely suggested that the usual income-by-education figures overestimate the "pure" contribution of education because of the observed correlation between measured ability and years of school completed. On the basis of scattered evidence both Becker and Denison decide to adjust downward the observed income-by-education differentials, Denison suggesting that all differentials should be reduced by about one-third.

It is useful, at this point, to set up a little model to help clarify the issues. Assume that the true relation in cross-sectional data is

$$Y_i = \beta_0 + \beta_1 S_i + \beta_2 A_i + u$$

where Y is income, S is schooling and A is ability, however measured. The usual calculation of an income-schooling relation alone leads to an estimate of a schooling coefficient (b_{ys}) whose expected value is higher than the true "net" coefficient of schooling (β_1), as long as the correlation between schooling and the left out ability variable is positive. The exact bias is given by the following formula:

$$Eb_{ys} = \beta_1 + \beta_2 b_{AS}$$

where b_{AS} is the regression coefficient in the (auxiliary) regression of the left out variable A on S, the included one. Moving to time series now, and still assuming that the underlying parameters (β_1 and β_2) do not change, we have the relationship

$$\bar{Y} = \beta_0 + \beta_1\bar{S} + \beta_2\bar{A} + u$$

where the bars stand for averages in a particular year. Now if b_{YS} is derived from cross-sectional data and is used in conjunction with the change in the average schooling level to predict (or explain) changes in $\bar{Y}$ over time, it will overpredict them (give too high a weight to $\bar{S}$) unless $\bar{A}$ changes pari passu. But it is assumed that the distribution of A, innate ability, is fixed over time and hence, its mean ($\bar{A}$) does not change. This, therefore, is the rationale for considering the cross-sectional income-education weights with some suspicion and for adjusting them downward for the bias caused by the correlation of schooling with ability.

I should like to question these downward adjustments on three related grounds: 1. Much of measured ability is the product of "learning," even if it is not all a product of "schooling." Often what passes for "ability" is actually some measure of "achievement," and the argument could be made that it in turn is determined by a relation of the form

$$A = \alpha_0 + \alpha_1 S + \alpha_2 QS + \alpha_3 LH + \alpha_4 G + v$$

where S is the level of schooling, QS is the quality of schooling, LH are the learning inputs at "home," and G is the original genetic endowment. If one were to substitute this equation into the original relation for Y one would find that the "total" coefficient of the schooling variables is given by

$$\beta_1 + \beta_2\alpha_1 + \beta_2\alpha_2 b_{QS \cdot S}$$

where $b_{QS \cdot S}$ is the relation between the quality and quantity of schooling in the cross-sectional data, and the "total" coefficient associated with changes in total "reproducible" human capital (including that produced at home) by

$$\beta_1 + \beta_2 \,|\, \alpha_1 + \alpha_2 b_{QS \cdot S} + \alpha_3 b_{LH \cdot S} \,|$$

where $b_{LH \cdot S}$ summarizes the relation between learning at home and at school in cross-section. Now while the simple coefficient of income and schooling b_{YS} may overestimate the partial effect of schooling (β_1) holding achievement constant, it may not overestimate that much, if at all, the "total" effect of schooling. 2. The estimated downward adjustments for ability may be overdone particularly in the light of strong interaction of "ability" and schooling as they affect earnings. That is, since the relation between A and Y holding S constant is strong only at higher S levels, b_{AS} may be quite low, and the bias in the estimated b_{YS} may not be all that large. 3. Moreover, the whole issue hinges on whether or not $\bar{A}$ as measured has really remained constant over time. To the extent that proxies such as father's education are used in lieu of "ability," it can be shown that at least their levels did not remain constant.

It is probably best, at this point, to confess ignorance. "Ability," "intelligence," and "learning" are all very slippery concepts. Nor do we know much about the technology of schooling or education. What are the important inputs and outputs, what is the production function of education, how do the various inputs interact? Some work on this is in progress (see Bowles [9]) and perhaps we will know more about it in the future. We do know, however, the following things: 1. Intelligence is not a fixed datum independent of schooling and other environmental influences. 2. It can be affected by schooling.[17] 3. It in turn affects the amount of learning achieved in a given schooling situation. 4. Because the scale in which it is measured is arbitrary, it is not clear whether the relative distribution of "intelligence" or "learning abilities" has remained constant over time.

> The doctrine that intelligence is a unitary something that is established for each person by heredity and that stays fixed through life should be summarily banished. There is abundant proof that greater intelligence is associated with increased education. . . . On the basis of present information it would be best to regard each intellectual ability of a person as a somewhat generalized skill that has developed through the circumstances of experience, within a certain culture, and that can be further developed by means of the right kind of exercise. There may be limits to ability set by heredity, but it is probably safe to say that very rarely does an individual really test such limits.[18]

[17] See e.g., the studies of separated identical twins summarized in Bloom [7].
[18] Guilford [28], p. 619.

Actually, IQ and achievement tests are so intimately intertwined with education that we may never be successful in disentangling all their separate contributions. IQ tests were originally designed to determine which children could not learn at "normal" rates. Consequently, children with above average IQ are expected to learn at above normal rates. The effect of intelligence on learning is presumably twofold (or are these two sides of the same coin?): Higher IQ children know more to start with and this "knowing more" makes it easier to learn a given new subject (since knowing more implies that it is less "new" than it would otherwise be), and higher IQ children are "quicker." They absorb more for a similar length of exposure, and hence know more at the end of a given period. Since schools try, in a sense, to maximize the students' "achievement," and since achievement and IQ tests are highly enough correlated for us to treat them interchangeably, one might venture to define the gross output of the schooling system as ability. That is, schools use the time of teachers and students and their respective abilities to increase the abilities of the students. From this point of view, the student's ability is both the raw material that he brings to the schooling process, which will determine how much he will get out of it, and the final output that he takes away from it. Hence, at least part of the apparent returns to "ability" should be imputed to the schooling system.[19] How much depends on what is the bottleneck in the production of educated people—the educational system or the limited number of "able" people that can benefit from it. If, as I believe may be the case, ability constraints have not been really binding, very little, if any, of the gross return to education should be imputed to the not very scarce resource of innate ability.

[19] Consider two extreme worlds. In one, the only product of the school systems is "ability" or "achievement." In this world, school years completed are just a poor measure of the product of schools. If correct measures of "ability" were available, they would dominate any earnings-education-ability regressions and imply zero coefficients of the school years completed variable. Nevertheless, almost all of the observed "ability" differential would be the product of "education." A second world is one in which the educational system does nothing more than select people for "ability," by putting them through finer and finer sieves, without adding anything to their innate ability in the process. Again, an earnings-education-ability correlation would come out with zero coefficients to education net of ability. Still, in an uncertain world with significant costs of information, there is a significant social product even in the operation of grading and sorting schemes. Even in such a world there is a net value added produced by the educational system, though it may be very hard to measure it. See Zusman [66] for the beginning of an economic analysis of sorting phenomena.

Actually, the little data we have shows a surprisingly poor relation between earnings and "ability" measures when formal schooling is held constant. Wolfle summarized the conclusions of such studies as of 1960:

> High school grades, intelligence-test scores, and father's occupation were all correlated with the salaries being earned fifteen to twenty years after graduation from high school, but the amount of education beyond high school was more clearly, more distinctly related to the salaries being earned.
>
> There is another conclusion from the data, one of perhaps greater importance. It is this: the differences in income were greatest for those of highest ability. It is of some financial advantage for a mediocre student to attend college, but it is of greater financial advantage for a highly superior student to do so.[20]

Examining the tables from Wolfle's studies reproduced in Becker and Denison, one is struck both by the importance of interaction, and by the very limited effect of IQ on earnings except for those within the upper tail of the educational distribution.[21] In fact, the IQ adjustment constitutes only a very small portion of Denison's total "ability" adjustment. One of his major adjustments is based on a cross classification of earnings-by-education by father's occupation. It is not clear at all why this is an "ability" dimension.[22] Higher-income and -status fathers will provide both more schooling at home and *buy* better quality schooling in the market. To the extent that these differences reflect the latter rather than the former, it does not seem reasonable to adjust for them at all.

In most studies that use IQ or achievement tests, these tests are taken at the end of the secondary school period. As we have noted, such test scores are to some unknown degree themselves the product of the

[20] Wolfle [65], p. 178.

[21] This is also supported by the greater role of "ability" at the lower end of the educational distribution found by Hansen, Weisbrod, and Scanlon [32]. IQ tests, however, are not very good discriminators at the very extremes of the distribution. For a sample of Woodrow Wilson Fellowship holders, Ashenfelt and Mooney [1] found that: "The inclusion of an ability variable affected the estimate of the other education-related variables only in a very marginal fashion. . . . The misspecifications caused by the absence of an ability variable seem to be quite small indeed" (for samples of highly educated people).

[22] ". . . it is what the parents *do* in the home rather than their *status* characteristics which are the powerful determinants of home environment." Bloom [7], p. 124.

TABLE 8

Taxed Income at Thirty-Five by Number of Years of Formal Schooling and I.Q. at age Ten, Males, Malmo, Sweden

I.Q. at Age 10	*Number of Years of Formal Schooling*											
	Less than 8 yrs.			8–10 yrs.			11–14 yrs.			14 yrs. and more		
	M	S.D.	n	M	S.D.	n	M	S.D.	n	M	S.D.	n
115+	17,450	4260	20	21,943	7363	35	33,750	35238	32	43,158	19219	19
108–114	16,625	5165	32	19,538	7793	26	19,429	12893	14	41,000	18267	13
93–107	15,266	5270	109	18,176	8118	68	21,735	7477	34	31,400	26567	5
86–92	17,744	10306	39	17,462	5955	13	20,500	7527	10	–	–	–
–85	14,548	4041	73	14,929	4611	28	17,750	4763	4	35,533	6182	3

SOURCE: From Husén (35), Table 16.
NOTE: M = mean income in kroner; S.D. = standard deviation; n = number of cases.

educational system (at the high school and elementary level). To separate the "value added" component of schools one would like to have such scores at a much younger age, upon entry into the schooling system. I have come across only one set of data, for the city of Malmo in Sweden (from Husen, [35]), which provides a distribution of earnings at age thirty-five by formal schooling and by IQ at age *ten*.[23] They are reproduced in Table 8. One of the important aspects of this particular sample is that it does cover the whole range of both the schooling and IQ distribution. We can use these data to investigate how much change there is in the income-education coefficient when IQ is introduced as an explicit variable.

After some experimentation with scaling and the algebraic form of the relationship, the following weighted regressions were computed for these data (nineteen observations) with $n/(S.D.)^2$ as weights:[24]

$$\log Y = 9.317 + \underset{(.011)}{.053S} \qquad R^2 = .589$$

and

$$\log Y = 8.938 + \underset{(.007)}{.051S} + \underset{(.0009)}{.0042A} \qquad R^2 = .836$$

where Y is income, S is years of school completed and A is the IQ score. In these data "original" IQ is an important variable, "explaining" an additional 30 per cent of the variance in the logarithm of incomes, but its introduction does almost nothing to change the coefficient of schooling. There would have been little bias from ignoring it.[25]

Similar results, but based on much more tenuous evidence, can also be had for the United States. For the United States we do not have yet any data on earnings by education and ability on a large scale, but we do have a large body of income-by-education data from the 1960 census of population, and a distribution of "ability" (Armed Forces Qualifica-

[23] I am indebted to C. A. Anderson for drawing my attention to these data.

[24] The scaling chosen was 6, 9, 13, and 17 and 73, 89, 100, 111, 127 for the schooling and IQ categories respectively.

[25] The results were essentially the same for the linear and log-log forms. The semilog forms reported in the text fit the data best on the "standard error in comparable units" criterion. The results are also similar for unweighted regressions, except that the coefficient of schooling is significantly higher.

TABLE 9

Regression Coefficients of the Logarithm of Income on Schooling and of "Ability" on Schooling by Regions

	$b_{(\log Y)S}$	b_{AS}
Northwest, total	.0663	.426
Northcentral, total	.0702	.470
South, total	.1011	.424
South, nonwhite	.0726	.343
West, total	.0760	.475

SOURCE: *Income by schooling,* data from 1960 Census of Population, median income for males age 35–44; schooling extimated as the midpoint of the class intervals and 18 for 5 + years of college category. *"Ability" by schooling,* based on the estimated distribution of the Army Forces Qualification Test for youths aged 19–21 in 1960; from Karpinos [38]. AFQT percentiles scaled by the approximate average score (probit) associated with the particular percentile range (–5, –2, 0, 2, 5 for less than 9, 10–35, 36–64, 65–92, and 93–100, respectively).

On the basis of the above numbers, the implied β and γ in the equation $\log Y_{ij} = \partial_j + \beta S_{ij} + \gamma A_{ij}$ are .112 and –.07, respectively.

tion Test) by school years completed based on tabulation of army induction tests of youths in 1964–65 (Karpinos, [38]).[26] Since the two bodies of data are not for the same population or time periods, what follows is very much an approximation, prompted by the desire to see whether these data could be of some use after all. Consider the equation

$$\log Y_{ij} = \alpha_j + \beta S_{ij} + \gamma A_{ij}$$

where the index i goes over schooling classes and j over regions. We cannot compute this relationship directly, since we do not have the covari-

[26] The AFQT is primarily an achievement rather than an innate ability test: "The examinee's score on the tests depends on several factors: on the level of his educational attainment; on the quality of his education (quality of the school facilities); and other knowledge he gained from his educational training or otherwise, in and outside of the school. These are interrelated factors, which obviously vary with the youth's socio-economic and cultural environment, in addition to his innate ability to learn—commonly understood as IQ, nor are they to be translated in terms of IQ." From Karpinos, [38]. Thus, it is probably inappropriate to use these data to get at a pure "net" schooling effect.

ances of A with log Y, but we do have information on the relationship of A to S. If we ignore A and estimate a truncated relationship of log Y on S for each region separately, we would get as our coefficient of S in each region (using the left-out-variable formula):

$$Eb_j = \beta + \gamma \cdot b_{ASj}$$

where the term b_{AS} is the regression coefficient in the auxiliary regression connecting the left-out variable A with the included variable S. Since we have such b_j's and b_{ASj} for several regions, we can compute the implied β and γ by another round of least squares. Table 9 summarizes such a computation based on data for five regions of the United States. Note that implicit in this computation is the assumption that regional differences in the observed slope of the income-education relationship must be due to regional differences in the association between schooling and ability.

The figures reported in Table 9 actually imply a negative γ. That is, if an adjustment were made for ability, it would *increase* the estimated influence of schooling on income. This is largely the result of the fact that the only major difference in the income-schooling slope is observed for the South (total, white and nonwhite), while the observed increase in ability with education in the South is only average or even lower.[27] Given the quality of these data, the inherent arbitrariness in the scaling of A, and the many tenuous assumptions required, these results should not be taken seriously. But they too do not come up with any strong evidence for the overwhelming importance of "ability" as distinct from "schooling."[28]

There are two more points to be made. First, to the extent that measured ability is an important determinant of earnings *only* at the higher education levels, it is not correct to "reduce" the education coefficient, or the weights attached to the higher education classes in the con-

[27] A more detailed analysis using the AFQT-schooling distribution for ten rather than five regions and mean income by schooling data for males aged forty-five–fifty-four, yielded very similar results and will not be reported here. I am indebted to F. Welch for providing me with the adjusted state data on mean income by schooling.

[28] The Carroll and Ihnnen [15] study of a group of North Carolina technical school graduates can also be interpreted to support this view.

struction of quality indexes, unless there is evidence that the observed increases in educational attainment have been associated with a lowering in the average ability of the educated. I know of no evidence which points in this direction. There is no evidence that the growth in educational attainment has been restricted by the drawing down of the "pool of ability."[29] There is a large body of evidence pointing to the existence of many high-ability lower-class children who do not go on to college or finish high school for a variety of economic and social reasons.[30] In spite of the tremendous increase in the number of college graduates in this country, the distribution of college students by social origin (father's occupation) has not changed significantly or adversely in the last thirty years.[31] Also, if ability were a major constraint one might have expected that the observed income differentials would narrow, as poorer-quality

[29] See Halsey [30] for a discussion and criticism of this metaphor.

[30] See, e.g., Telser [58], and Folger and Nam [21].

[31] The following table adapted from the U.S. Bureau of the Census (*Current Population Reports*, Census P-20, No. 132, 1964, "Educational Changes in a Generation," Table 1) sheds some light on this question:

DISTRIBUTION OF MALES BY YEARS OF SCHOOL COMPLETED, BY AGE, AND BY FATHER'S OCCUPATION AND EDUCATION, U.S., MARCH, 1962
(in per cent)

Age and Cohort	College Graduates		Some College	
	Father White Collar	Father White Collar, Some College Education	Father White Collar	Father White Collar, Some College Education
20–24 1938–42	—	—	88	31
25–34 1928–37	64	27	60	23
35–44 1918–27	62	26	55	19
45–54 1908–17	62	25	55	19
55–64 1898–1907	60	14	56	15

Similar implications can also be read into the British data reported by Floud and Halsey [20].

people were getting more education.[32] This does not appear to have happened, however. One might even conjecture that as education spread, the selection processes were actually improved, and hence that there may be a higher correlation of ability with education today than was true thirty years ago.[33] It is also possible that our children being taller and healthier than the previous generations may also be more intelligent.[34]

The second point to be made is that much of what is used as a proxy for "ability" is not really an innate ability and need not and has not remained constant over time. Denison in examining the Wolfle-Smith data concludes that about 6 per cent of the observed college-high school income differential can be attributed to the "rank in high school" and about 3 per cent to IQ. These, of course, are not independent, but in any case, at most 10 per cent of the differential can be ascribed on the basis of the internal evidence of the Wolfle-Smith data to something that could be a reflection of innate ability. An additional 7 per cent of the differential is ascribed to differences in father's occupation. The rest, about *half*

[32] Unless, of course, the quality of high school graduates deteriorated more than that of college graduates. Given the relative size of the two groups and the observed minor effect of "ability" on earnings for high school graduates, this is an unlikely event, at least as measured by conventional IQ scores. But the widening of the differential between elementary and high school graduates may indicate that those who do not get past elementary education may today be much more affected by ability constraints and other handicaps than used to be the case in the past.

[33] Something like this is implied in the slightly higher regression and correlation coefficient for the relationship of ability to schooling in the North Central States than in the South, reported in Table 8. This is also supported by the following table taken from a recent article by Turnbull [60], p. 1426; the data are derived from Wolfle's study and from the Project TALENT survey:

PERCENTAGES OF HIGH SCHOOL GRADUATES GOING ON TO COLLEGE, BY ABILITY GROUP

Ability group	Wolfle 1953	TALENT 1960
Lowest (fourth) quarter	20	19
Third quarter	32	32
Second quarter	38	54
Top (first) quarter	48	80

[34] The Educational Testing Service recently notified a large number of students who took the Graduate Record Examination that instead of having scored in the, say, ninety-eighth percentile, as previously announced, upon restandardization for the more recent experience, their scores were more accurately described as being in the ninety-fourth percentile. The mean score of men in the 1964–67 norm group was 5.5 per cent higher on the verbal ability test and 10.7 per cent higher on the quantitative ability test than that of the 1952 basic reference group. (See Educational Testing Service, [19].)

of the one-third adjustment, is based on the difference between the size of the over-all differential as reported in these data (for Illinois, Minnesota, and Rochester men) and the national average differential. At best, therefore, this is not an adjustment for "ability" but for *regional* differences in income and the regional correlation between average incomes and levels of education.[35] Thus, less than one-third of the "one-third" adjustment is related conceptually to ability per se.

Even if one allows that the underlying IQ distribution has not changed over time, the other proxy variables, such as father's occupation and regional distribution have changed. Consider, for example, the simple model where father's education is used as a control variable. Then in cross section we have

$$Y_s = \beta_0 + \beta_1 S_s + \beta_2 S_F$$

where the subscripts s and F stand for sons and fathers respectively. If one ignored the education of fathers variable, one would estimate

$$Eb_{YS} = \beta_1 + \beta_2 b_{S_F S_s}$$

where $b_{S_F S_s}$ is probably less than one (the slope of the relationship between the schooling of fathers and sons). In time series, however, we would have

$$\overline{Y}_s = \beta_0 + \beta_1 \overline{S}_s + \beta_2 \overline{S}_F.$$

But the average schooling of fathers has been growing at approximately the same rate as that of sons! Hence, the total effect of schooling should be measured by $\beta_1 + \beta_2$, and the unadjusted b_{YS} is closer to that than the "net" β_1!

Similarly, the average level of education in the North grew at about the same rate as that in the South. Since the North had more education to start with and a higher average wage associated with it, this would lead to a growth in the *share* of the North in "total" labor quality. Hence, if one holds region constant in deriving the educational weights, one should, on the other hand, also adjust the labor input upward for the

[35] This adjustment is also probably overdone, since we know that education differentials in the North Central States were lower than in most of the rest of the U.S. In that sense, the Wolfle-Smith figures are not representative.

fact that the share of the higher quality regions grew at the same time. Thus, the one-third downward adjustment suggested by Denison may be a serious overadjustment if what we are interested in is an estimate of the rate of growth in the *total* quality of the labor force. One should recognize, however, that not all of the growth attributed to changing educational attainment is the *net* product of the education system per se.

VI THE PUZZLE OF THE CONSTANCY OF DIFFERENTIALS

THE main evidence on the relative constancy of educational and skill differentials in the post-World War II period in the U. S. is summarized in Tables 3, 6, and 7 and has been alluded to before. Becker [2] (Table 14, p. 128) reaches similar conclusions about the behavior of rates of return to higher education over time. The puzzling thing is that these differentials and rates of return should change so little in the face of very large shifts in the relative numbers of educated workers. Between 1952 and 1966 the ratio of males between the ages of eighteen and sixty-four in the U. S. civilian labor force with high school education and more to those with elementary education and less changed from about 1 to 1 to about 2.5 to 1, and still their relative incomes did not change greatly.

There appear to be four possible explanations of the phenomenon, three on the demand side and one on the supply side.[36] On the demand side we can conceive three sources of increased demand for skilled workers which could have counterbalanced the depressing effect of the increase in their supply: 1. It may just happen that goods that have an income elasticity higher than one have on average a higher skill content embedded in them than do goods whose income elasticity is less than one. 2. It may be that for some reason not yet clear technical change has been on the average "skill using" and "unskilled labor saving." 3. It is possible, and plausible, that physical capital is more complementary with skilled than with unskilled labor. Since physical capital has been growing

[36] This section and also parts of Section 4 have been inspired and owe a great deal to my reading of Welch's [64] unpublished paper on this topic.

at a higher rate than the labor force, this would imply also a growth in the relative demand for educated labor. 4. Finally, it may be that all of this is essentially a reflection of the nature of the supply of skills. The most important factor in the production of skill is the labor of students and teachers. If the production function (time requirements) of skills does not change much over time, the prices of skilled and unskilled labor must move roughly in proportion to each other, since skilled labor can be "manufactured" from unskilled labor in a roughly unchanging way, using resources whose price is proportional both to the input and output price of this process. The existence of such a relation does not, of course, contradict the various demand hypotheses, but makes it very much harder to distinguish among them.

There is very little empirical evidence on any of these points. Nor is it obvious that a priori they are all plausible. It is easy, for example, to think of some commodities such as "food away from home" that have a high income elasticity and a rather low skill content. A crude check on the over-all demand hypothesis can be made by investigating whether changes in employment between 1950 and 1960 by industries have any association with the average educational attainment of the labor force in each of the industries. Using data from the 1960 Census of Population for 149 industries we get a correlation coefficient of about .33 for the relationship between the percentage change in the employment of males between 1950 and 1960 and the logarithm of mean school years completed by industry in 1960.[37] This is a statistically significant but not very strong relationship. A similar calculation for females yields no relationship at all ($r^2 = -.07$). While such a relation could be due to several causes, there does appear to be something in the demand hypothesis which may warrant further exploration.

Since we do not know how to measure neutral technical change very well, the probability of measuring the "skill-bias" of technical change in a nontautological fashion is even lower, and I shall not pursue this further here. There remains yet the possibility of capital-skill complementarity which will be explored in the next section.

[37] The figures were taken from the 1960 Census of Population, Vol. I, Part 1, Table 211 and Vol. II, Part 7F, "Industrial Characteristics," Table 21. The results of using median years of school completed, a weighted E index, and the logarithm of the E index were almost identical.

VII ARE PHYSICAL AND HUMAN CAPITAL COMPLEMENTS?

TO investigate this question we have to start with a three-input production-function output depending on capital and two types of labor (or "bodies" and "skill"). We shall write it in the form

$$Y = F(K, L, S)$$

with the hypothesis to be investigated being that (in the Allen sense):

$$0 < \sigma_{LK} > \sigma_{SK} \lesseqgtr 0$$

where the σ_{ij}'s are the respective partial elasticities of substitution. It is not clear where one could get some evidence on this. At the aggregate level things are much too collinear to be of much help (moreover, we can't really measure anything more than the trends in K, L, and S with any degree of accuracy). At the micro level, one usually does not have data on S and K at the same time or place, and what is even worse, one rarely has any relevant input price data and the price data one has (such as wages) are subject to significant biases precisely because of the existence of the third variable S, significant differences in the quality of the labor force. The following model may, however, give some hope of success:[38] If one starts with inputs defined per unit of output (assuming for this purpose constant returns to scale), and measures everything in logarithms of the variables, one can write (as an approximation), the demand functions for inputs as

$$x_i = a_i + \Sigma \eta_{ij} p_j = a_i + \Sigma v_j \sigma_{ij} p_j$$

where x_i is the logarithm of the ith input per unit of output, p_j is the logarithm of the "real" price of the jth input, η_{ij}'s are the respective price elasticities $(\Sigma_i \eta_{ij} = 0)$, v_j is the share of the jth factor in total cost, and the σ_{ij}'s are the Allen-Uzawa partial elasticities of substitution ($\sigma_{ij} = \sigma_{ji}$, and $\sigma_{ii} < 0$). Consider now the special case of three inputs: L–labor, K–capital, and S–skill or schooling, with the corresponding (rental) prices W, R, and Z. Then, using the homogeneity condition, we can write (using lower case letters to denote the logarithms of the corresponding variables)

[38] This model is based on unpublished notes by H. G. Lewis. See also Mundlak [45].

$$l = \eta_{ll}(w - z) + \eta_{lk}(r - z) + a_l$$
$$k = \eta_{kl}(w - z) + \eta_{kk}(r - z) + a_k$$
$$s = \eta_{sl}(w - z) + \eta_{sk}(r - z) + a_s$$

and subtracting the first two equations from the third

$$s - l = (\eta_{sl} - \eta_{ll})(w - z) + (\eta_{sk} - \eta_{lk})(r - z) + (a_s - a_l)$$
$$s - k = (\eta_{sl} - \eta_{kl})(w - z) + (\eta_{sk} - \eta_{kk})(r - z) + (a_s - a_k)$$

or

$$(s - l) = v_l(\sigma_{sl} - \sigma_{ll})(w - z) + v_k(\sigma_{sk} - \sigma_{lk})(r - z) + c_1$$
$$(s - k) = v_l(\sigma_{sl} - \sigma_{kl})(w - z) + v_k(\sigma_{sk} - \sigma_{kk})(r - z) + c_2$$

The hypothesis that skill or education is more complementary with physical capital than is physical (or unskilled, or unschooled) labor would imply that the coefficient of $(r - z)$ in the first equation is negative $(\sigma_{lk} > \sigma_{sk})$ and that the coefficient of $(w - z)$ in the second equation is also negative $(\sigma_{kl} > \sigma_{sl})$. At the same time, one would expect the other two coefficients to be positive.[39]

If data were available on the relevant prices, one could estimate either version, in one case assuming that the approximation is better when one assumes the demand elasticities to be constant over the observed range, or alternatively, making the same assumption about the elasticities of substitution.

There is an additional set of assumptions that may allow us to estimate these questions almost without any price data. If one has data by state and industry for the two-digit manufacturing industries in the United States (and assumes that σ's are approximately the same for all these industries, though not the v's), one may hypothesize (a) that the true rental price of capital r does not differ among states but may differ as between industries (because of different depreciation, obsolescence, and risk rates), (b) that the real price of skilled labor has been effectively equalized by migration and the unions, and hence that z is a constant at a point of time, and (c) that the price of pure physical labor does differ between states (not having been equalized by migration) but

[39] This model could be "simplified" further by noting the relationship between input and output prices and using it to solve one of the input prices, substituting the output price throughout. But unless one has good data on output prices by states and industries, or is willing to assume that they are constant, there is little to be gained from such a substitution.

is essentially the same for all industries within the same state. The coefficients of $(w - z)$ could then be effectively estimated by state dummy variables (or more correctly cross-dummies, if we allow also the v's to vary, which we'll have to, to achieve identification) and the coefficients of $(r - z)$ by industry dummies. The expected sign relations could then be checked by computing the ratio of the respective coefficients in the two equations (e.g., $\widehat{v_l(\sigma_{sl} - \sigma_{kl})(w - z)}/\widehat{v_l(\sigma_{sl} - \sigma_{ll})(w - z)}$ should be negative).

Alternatively, at a more aggregate time-series level, one may assume that factor prices are changing in the same way for all industries. Then, using an alternative but equivalent set of two equations, we have

$$(s - l) = v_l(\sigma_{sl} - \sigma_{ll})(w - z) + v_k(\sigma_{sk} - \sigma_{lk})(r - z)$$
$$(k - l) = v_l(\sigma_{kl} - \sigma_{ll})(w - z) + v_k(\sigma_{kk} - \sigma_{lk})(r - z)$$

In time series we expect that the rate growth of $r - z$ will be negative, that the rate of growth of $(w - z)$ may be positive (due to the larger increase in S over time) but close to zero, which should lead to a positive correlation between the change in $(s - l)$ and $(k - l)$ under our hypotheses, with the regression coefficient of $(s - l)$ on $(k - l)$ being less than one. This is implied by our hunch that $\sigma_{sl} < \sigma_{kl} > 0$ and $\sigma_{kk} < \sigma_{sk} < \sigma_{lk} > 0$.

A preliminary and crude foray into data for twenty-eight "two-digit" industries in the United States in 1949 and 1963 yielded some not very strong support for the hypothesis outlined here.[40] There is a positive

[40] The limits of this set of data are based on the availability of time series on gross capital stocks in constant prices at the two-digit level. These are derived from a forthcoming book by M. Gort. (I am indebted to Michael Gort for making these yet unpublished data available to me.) The list of industries runs through ten manufacturing industries from "food" to "other transportation equipment," and nine other large industries: mining, railroads, electric utilities, gas utilities, telephone, contract construction, wholesale trade, and retail trade. The capital stocks are as of beginning of 1949 and 1963. Total employment for these industries for 1948 and 1963 is taken from BLS Bulletin 1312-5; the percentage of the male labor force that consists of professional and technical workers is taken from the "Occupation by Industry" volumes of the 1950 and 1960 Census of Population; and the wage of unskilled labor is identified with the median earnings of laborers who worked 50–52 weeks in these industries and is taken from the respective 1950 and 1960 Census volumes on occupational characteristics. Denoting total employment by N and professionals as a fraction of the labor force by P, S is given by $N \cdot P$ and L, the level of the "unskilled" labor force by $N(1-P)$. All the regressions and correlations were computed using total employment in 1963 as weights.

relation between *capital* per unskilled worker and *skilled worker* per unskilled worker across these industries. The simple weighted correlation coefficient between the logarithms of these variables is .48 in 1949, .50 in 1963, and .47 for the change in these variables between these two years.[41] Assuming that the omission of the capital-rental variable does not significantly bias the other results (this is equivalent to assuming that it is uncorrelated with the unskilled labor wage rate across industries), we get the "right" signs in the regressions $s - l$ and $s - k$ on w. The estimated coefficients in the two equations are respectively 4.4(.9) and −2.0(1.8) for 1949 and 2.6(.5) and −.8(.8) for 1963. The second of the four coefficients is the one we are most interested in, as it is proportional to $\sigma_{sl} - \sigma_{kl}$ and is negative, as expected, but this finding, however, is not statistically "significant" at conventional levels. Similarly, the regression coefficient of $\Delta(s - l)$ on $\Delta(k - l)$ is positive and less than one (.47 with an estimated standard error of .17), but again this result should not be taken too seriously. It could be due to common errors in the measurement of l and the spuriousness arising out of the appearance of L in the denominator of both variables. Better and more extensive data for testing such hypotheses is being assembled, but their analysis is only in its earliest stages.

VIII TENTATIVE SUMMARY

THERE are a large number of important topics which have not been even touched upon in this survey. I have neglected the very important one of the interaction of on-the-job training, schooling, experience, obsolescence, and aging. I have also said nothing about different types of education

[41] While such correlation coefficients are "significant" at conventional levels, the over-all fit is quite poor and there are a number of notable outliers. The chemical industry has a high capital-labor and a high skill ratio, but the electric machinery industry has a high skill ratio and a relatively low capital-labor ratio, while the utility industries have very high capital-labor ratios but only average skill ratios. Similarly, the highest rates of growth in capital-per-man occurred in this period in mining and construction. Mining had also probably the highest rate of growth in the relative number of highly skilled workers, while construction had one of the lowest. There are no easy answers.

and the measurement of the quality of education. Nor have I discussed models of optimal investment in human capital or the correct treatment of the educational sector and the investment in human capital in a more comprehensive set of national accounts. Hopefully, many of these topics will be dealt with by other participants in this conference.[42]

It would seem to me that the over-all state of the measurement of the contribution of education is in reasonably good shape and has been validated by econometric studies. What needs more work is the elucidation of the processes of production of human capital and the determinants of the rates of return to different types of educational investment.

REFERENCES

[Note: This list includes several important works not referred to explicitly in the text.]

1. Ashenfelter, O., and J. D. Mooney, "Graduate Education, Ability, and Earnings," *Review of Economics and Statistics,* XLX (1), 1968, 78–86.
2. Becker, G. S., *Human Capital,* New York, NBER, 1964.
3. ————, *Human Capital and the Personal Distribution of Income,* Woytinsky Lecture No. 1, University of Michigan, 1967.
4. Ben-Porath, Y., "The Production of Human Capital and the Life Cycle of Earnings," *Journal of Political Economy,* 75 (4), 1967, 352–65.
5. Besen, S. M., "Education and Productivity in U. S. Manufacturing: Some Cross-Section Evidence," *Journal of Political Economy,* 76 (3), 1968.
6. Blaug, M., *Economics of Education,* A Selected Annotated Bibliography, Oxford, 1966.
7. Bloom, B. S., *Stability and Change in Human Characteristics,* New York, 1964.

[42] On the issue of training and experience see Mincer [43] and Thurow [59] among others; see Denison [16], Welch [62], and the Coleman report [14] for very different ways of estimating the relative quality of schooling; see Ben-Porath [4] for a model of human capital investment and Bowman [12] and Kendrick [40] for discussions of the treatment of education in national accounts.

8. Bowles, S., "Aggregation of Labor Inputs in Economics of Growth and Planning," *Journal of Political Economy*, January–February, 1970.
9. ————, "Towards an Educational Production Function," this volume.
10. Bowman, M. J., "Schultz, Denison, and the Contribution of 'Eds' to National Income Growth," *Journal of Political Economy*, 72 (5), 1964, 450–64.
11. Bowman, M. J., and C. A. Anderson, "Distributed Effects of Educational Programs," in *Income Distribution Analysis*, North Carolina State University, 1966.
12. Bowman, M. J., "Principles in the Valuation of Human Capital," *Review of Income and Wealth*, 14 (3), 1964, 217–46.
13. Brown, M., and A. Conrad, "The Influence of Research and Education on CES Production Relations," in M. Brown, ed., *The Theory and Empirical Analysis of Production*, New York, NBER, 1967, 341–71.
14. Coleman, J. S., *et al.*, *Equality of Educational Opportunity*, U. S. Dept. of Health, Education and Welfare, Washington, D. C., 1966.
15. Carroll, A. B., and L. A. Ihnnen, "Costs and Returns for Two Years of Post Secondary Technical Schooling: A Pilot Study," *Journal of Political Economy*, 75 (6), 1967, 862–73.
16. Denison, E. F., *The Sources of Economic Growth in the United States and the Alternatives Before Us*, Supplementary Paper No. 13, New York, Committee for Economic Development, 1962.
17. ————, "Measuring the Contribution of Education," in *The Residual Factor and Economic Growth*, OECD, 1964, 13–55, 77–102.
18. ————, *Why Growth Rates Differ*, Brookings Institution, 1967.
19. Educational Testing Service, *Handbook for the Interpretation of GRE Scores, 1967–68*, Princeton, 1967.
20. Floud, J., and A. H. Halsey, "Social Class, Intelligence Tests, and Selection for Secondary Schools," in Halsey, Floud, and Anderson, eds., *Education, Economy and Society*, Glencoe, Ill., 1961, 209–15.
21. Folger, J. K., and C. B. Nam, *Education of the American Population*, A 1960 Census Monograph, Washington, D. C., 1967.
22. Griliches, Z., "Measuring Inputs in Agriculture: A Critical Survey," *Journal of Farm Economics*, XLII (5), 1960, 1411–27.

23. ———, "Estimates of the Aggregate Agricultural Production Function from Cross-Sectional Data," *Journal of Farm Economics*, XLV (2), 1963.
24. ———, "Research Expenditures, Education, and the Aggregate Agricultural Production Function," *The American Economic Review*, LIV (6), 1964, 961–74.
25. ———, "Production Functions in Manufacturing: Some Preliminary Results," in M. Brown, ed., *The Theory and Empirical Analysis of Production*, Studies in Income and Wealth, Vol. 31, New York, NBER, 1967.
26. ———, "Hedonic Price Indexes Revisited: Some Notes on the State of the Art," in Amer. Stat. Assoc., *1967 Proceedings of the Business and Economics Section*, 1967b.
27. ———, "Production Functions in Manufacturing: Some Additional Results," *Southern Economic Journal*, 35 (2), 1968, 151–56.
28. Guilford, J. P., "Intelligence Has Three Facets," *Science*, 160 (3828), 1968, 615–20.
29. Hall, R. E., "Technical Change and Capital from the Point of View of the Dual," *Review of Economic Studies*, 1968.
30. Halsey, A. H. (ed.), *Ability and Educational Opportunity*, OECD, 1961.
31. Hanoch, G., "An Economic Analysis of Earnings and Schooling," *Journal of Human Resources*, II (3), 1967, 310–29. Also, unpublished Ph.D. dissertation, "Personal Earnings and Investment in Schooling," Chicago, 1965.
32. Hansen, W. L., B. A. Weisbrod and W. J. Scanlon, "Schooling and Earnings of Low Achievers, *American Economic Review*, vol. 60, no. 3, (June 1970).
33. Hildebrand, G. H., and T. C. Liu, *Manufacturing Production Functions in the U. S., 1957*, Cornell University Studies in Industrial and Labor Relations, Vol. XV, 1965.
34. Houthakker, H. S., "Education and Income," *Review of Economics and Statistics*, 41 (1), February 1959, 24–28.
35. Husen, T., "Talent, Opportunity, and Career: A 26 Year Follow-up," *School Review*, 76 (4), December, 1968, University of Chicago.
36. Johnson, H. G., "Comment," in *The Residual Factor and Economic Growth*, OECD, 1964, 219–27.

37. Jorgenson, D. W., and Z. Griliches, "The Explanation of Productivity Change," *Review of Economic Studies,* XXXIV (3), No. 99, 1967.

38. Karpinos, B. D., "The Mental Qualifications of American Youths for Military Service and Its Relationship to Educational Attainment," *1966 Proceedings of the Social Statistics Section of the American Statistical Association*, 1966, 92–111.

39. Kendrick, J. W., *Productivity Trends in the United States*, Princeton, 1961.

40. ————, "Investment Expenditure and Imputed Income in Gross National Product," in *47th Annual Report of the NBER*, New York, 1967.

41. Lancaster, K., "A New Approach to Consumer Theory," *Journal of Political Economy,* 74 (2), 1966, 132–57.

42. Miller, H. P., "Annual and Lifetime Income in Relation to Education," *The American Economic Review,* (5), December, 1960, 962–86.

43. Mincer, J., "On-the-Job Training: Costs, Returns, and Some Implications," *Journal of Political Economy,* 70 (5), 1962, Part 2, Supplement: *Investment in Human Beings.*

44. Mitchell, E. J., "Explaining the International Pattern of Labor Productivity and Wages: A Production Model with Two Labor Inputs," *Review of Economics and Statistics,* L (4), 1968, 461–69.

45. Mundlak, Y., "Elasticities of Substitution and the Theory of Derived Demand," *Review of Economic Studies,* 1968.

46. Nelson, R. R., and E. S. Phelps, "Investment in Humans, Technological Diffusion, and Economic Growth," *The American Economic Review,* LVI (2), 1966.

47. Nerlove, M., "Embodiment and All That: A Note," unpublished mimeographed paper, 1965.

48. Richter, M. K., "Invariance Axioms and Economic Indexes," *Econometrica,* October 1966.

49. Rosen, S., "Short-Run Employment Variation on Class-I Railroads in the U. S., 1947–1963," *Econometrica,* 36 (3–4), 1968, 511–29.

50. Schmookler, J., "The Changing Efficiency of the American Economy, 1869–1938," *Review of Economics and Statistics,* 34 (3), August 1952, 214–31.

51. Schwartz, A., "Migraticn and Life Span Earnings in the U. S.," unpublished Ph.D. dissertation, University of Chicago, 1968.
52. Selowsky, M., "Education and Economic Growth: Some International Comparisons," unpublished Ph.D. dissertation, University of Chicago, 1967.
53. Schultz, T. W., "Capital Formation by Education," *Journal of Political Economy,* 1960, 571–83.
54. ————, "Education and Economic Growth," in N. B. Henry, ed., *Social Forces Influencing American Education*, Chicago, 1961.
55. ————, *The Economic Value of Education*, New York, 1963.
56. Solow, R. M., "Technical Change and the Aggregate Production Function," *Review of Economics and Statistics,* 39 (3), August 1957, 312–20.
57. Strumlin, S. G., "The Economic Significance of National Education," 1925, translated from Russian and reprinted in Robinson and Vaizey (eds.), *The Economics of Education*, New York, 1966, 276–323.
58. Telser, L. G., "Some Economic Aspects of College Education," Economics of Education Research Paper No. 59–5, University of Chicago, unpublished dittoed paper, 1959.
59. Thurow, L. C., *Poverty and Discrimination,* Brookings Institution, Washington, D. C., 1969, Chapter V.
60. Turnbull, W. W., "Relevance in Testing," *Science,* 160, 1968, 1424–29.
61. U. S. Bureau of the Census, *Trends in the Income of Families and Persons in the U. S.: 1947–1964,* Technical Paper No. 17, Washington, D. C., 1967.
62. Welch, F., "The Measurement of the Quality of Schooling," *The American Economic Review,* XLVI (2), 1966, 379–92.
63. ————, "Linear Synthesis of Skill Distributions," *Journal of Human Resources,* IV (3), Summer 1969, 311–27.
64. ————, "Education in Production," *Journal of Political Economy,* January-February, 1970
65. Wolfle, D., "Economies and Educational Values," in S. E. Harris (ed.), *Higher Education in the U. S.: The Economic Problems,* Cambridge, Mass., 1960.

66. Zusman, P., "A Theoretical Basis for Determination of Grading and Sorting Schemes," *Journal of Farm Economics,* 49 (1), 1967, 89–106.
67. Griliches, Z., "Capital-Skill Complementarity," *Review of Economics and Statistics,* 51 (40), November 1969, 465–68.
68. Jensen, Arthur R., "How Much Can We Boost IQ and Scholastic Achievement?" *Harvard Educational Review,* 39 (1), Winter 1969, 1–123.
69. Schrader, W. B., "Test Data as Social Indicators," Educational Testing Service, SR-68-77, Princeton, N. J., September 1968.
70. Taubman, P., and Wales, T. J., "Mental Ability and Higher Educational Attainment Since 1910," University of Pennsylvania Discussion Paper No. 139, October 1969.

COMMENTS

JOHN CONLISK
UNIVERSITY OF CALIFORNIA, SAN DIEGO

Most of this comment concerns the role of education in aggregate production functions and in growth analysis. Some brief remarks on the income-education-ability interrelation conclude the comment.

I. THE ROLE OF EDUCATION IN AGGREGATE PRODUCTION FUNCTIONS AND IN GROWTH ANALYSIS

For a long time, a major puzzle in the growth literature was that the total measured growth in inputs did not add up to measured growth in output. Consider this puzzle in the context of an aggregate production function $Y = F(X_1, \ldots, X_m)$ which gives output Y as a constant returns function F of m inputs $X_1, \ldots, X_m$. Taking the growth rate of both sides:

$$\dot{Y}/Y = v_1\dot{X}_1/X_1 + \ldots + v_m\dot{X}_m/X_m \tag{1}$$

where v_i is the relative marginal product share of X_i [$v_i = (\partial F/\partial X_i)X_i/Y$].

The puzzle in the literature was that, when observed values of the magnitudes on the right were plugged in, they did not add up to the observed value of $\dot{Y}/Y$. The difference, or residual, was often vaguely referred to as "technical change." It was not (to my knowledge) until the important paper by Griliches and Jorgensen [4] that the terms on the right of (1) were measured carefully and completely enough to add up to $\dot{Y}/Y$. They accomplished this full "explanation" of growth in substantial part by their quality correction to observed labor growth (reviewed in Section II of the current Griliches paper).

However, this "explanation" of growth of output in terms of growth of inputs may be viewed as only the first of two prinicipal levels of growth explanation. At the second level, one may ask why the inputs grew as they did, particularly inputs like physical and human capital, which are endogenous to the economic system. In an aggregate modeling context, the first level of explanation requires only the specification of an aggregate production relation; the second level of explanation requires enough additional relations to form a complete growth system. There is a large neoclassical growth literature devoted to such complete aggregate growth systems; but, unfortunately, this literature has not come to grips with the problem of how to treat education. While under the influence of Griliches' stimulating paper, I have had some thoughts on this problem which I would like to relate here.

Griliches suggests two ways in which an aggregate production function might include education (defined in a broad sense):

$$Y = F(K,H,N) \qquad \text{and} \qquad Y = F(K,EN) \tag{2}$$

In the first case, output Y is given as a constant returns function of physical capital K, human capital H, and the number of workers N. In the second case, output is given as a constant returns function of physical capital K and quality-corrected labor EN, where N is the number of workers and E is a labor-augmenting quality multiplier. The two hypotheses are not observationally equivalent (nor exclusive for that matter); but, as Griliches points out, it is doubtful that available data can distinguish them by ordinary production-function estimation methods. However, if the two versions of (2) are built into complete growth models in what appear to be "natural" ways, they yield quite different implications about long-run growth behavior. Perhaps these implications can be used to distinguish the two functions empirically.

First, consider very briefly the standard neoclassical growth model without education; we will call it Model A:

$$Y = F(K,N)$$
$$\dot{K} = sY - \delta K$$
$$\dot{N}/N = n$$

Here $\dot{K} \equiv dK/dt$; s is a constant gross savings rate; δ is a constant depreciation rate; and n is a constant population growth rate. F, like all production functions used here, is assumed to exhibit constant returns to scale. Given some very weak additional restrictions of F and the parameters, Model A has a unique, stable, equilibrium growth path on which $\dot{Y}/Y = \dot{K}/K = n$. (For a reference to a derivation of this standard result, see footnote 1.) Heuristically, the reason K, and thus Y, are limited to growth rate n in equilibrium is that diminishing average returns to K as K/N rises prevent K/N from rising indefinitely. Put another way, K cannot grow indefinitely faster than N because N will ultimately become scarce enough relative to K to bottleneck further growth in K/N. The observed output growth rate in real life is of course larger than the population growth rate n. So there is here an unexplained difference, or residual, between the observed output growth rate and the rate $\dot{Y}/Y = n$ predicted by Model A. Thus, at both the first level of growth explanation of equation 1 and at the second level of growth explanation of Model A, the literature has been puzzled by an unexplained residual. (To invoke an exogenously given rate of Harrod neutral factor augmentation in Model A is of course no more of a real explanation of the second level residual than invoking the catch phrase "technical change" is an explanation of the first level residual.)

Now introduce education into Model A via the first of functions (2) and we have Model B:

$$Y = F(K,H,N)$$
$$\dot{K} = sY - \delta K$$
$$\dot{H} = s'Y - \delta' H$$
$$\dot{N}/N = n$$

where s' and δ' are savings and depreciation parameters for human capital. If human capital is treated in parallel to physical capital, then these equations seem a natural extension of Model A. Under some weak restrictions on F and the parameters, Model B has a unique, stable, equilibrium path on which $\dot{Y}/Y = \dot{K}/K = \dot{H}/H = n$.[1] This is the same result as for Model A, and for the same reason. K and H cannot grow indefinitely faster than N because N will ultimately become scarce enough relative to K and H to bottleneck growth to rate n. Thus, the residual between the observed level of $\dot{Y}/Y$ in real life and the predicted rate $\dot{Y}/Y = n$ is the same in Model B as in Model A, despite the inclusion of human capital in Model B.

Now introduce education into Model A via the second of function (2) and we get Model C:

$$
\begin{aligned}
Y &= F(K,EN) \\
\dot{K} &= sY - \delta K \\
\dot{E} &= s'Y/N - \delta' E \\
\dot{N}/N &= n
\end{aligned}
$$

where s' and δ' are a savings and a depreciation parameter regulating growth in E. Since E is a productivity multiplier with an implicit "per worker" dimension (in contrast to H which does not have a per worker dimension), it is appropriate that the first term on the right of the $\dot{E}$ equation is in per worker units (that is, divided by N). Let $L = EN =$ the quality-corrected labor force. Then Model C may be written more compactly:

$$
\begin{aligned}
Y &= F(K,L) \\
\dot{K} &= sY - \delta K \\
\dot{L} &= s'Y - (\delta' - n)L
\end{aligned}
\tag{3}
$$

Displayed in this form, Model C shows a symmetric treatment of the two inputs K and L. That is, neither input grows at an exogenously given rate, as the labor input does in both Models A and B. Hence the equilibrium behavior of Model C is different. Under some weak restrictions on F and the parameters, Model C has a unique, stable, equilibrium path on which:

[1] References to derivations are needed for Models A, B, and C. For Model A, the path-breaking article by Solow [5] will still do as well as any. For Model B, I do not know of a reference which is right to the point, but the results will be grasped immediately by anyone who understands Model A. For Model C, see Conlisk [2].

$$\dot{Y}/Y = \dot{K}/K = \dot{L}/L = \underset{(+,+,-,-,+)}{g(s,s',\delta,\delta',n)} > n \tag{4}$$

where g is a function which is related to F and which has partials of the indicated signs. (For reference to derivations, see footnote 1.) Note especially that $\dot{Y}/Y > n$ in equilibrium. That is, in strong contrast to Models A and B, Model C *can* explain the difference, or residual, between the observed level of $\dot{Y}/Y$ in real life and the population growth rate n. The sensitivity of $\dot{Y}/Y$ to all the parameters of Model C is another strong contrast with Models A and B (where $\dot{Y}/Y = n$, regardless of other parameters).

These results suggest that Model C, which centers around Griliches' function $Y = F(K,EN)$, is more relevant to real life than Model B, which centers around Griliches' function $Y = F(K,H,N)$. The victory of the $Y = F(K,EN)$ function over the $Y = F(K,H,N)$ function, of course, depends on the other relations in Models B and C also. However, I think I have rounded out Models B and C in a "natural" fashion, given the conventional ways of doing things in the growth literature.

If we now make the distinction between equilibrium and disequilibrium behavior in Models B and C, we can go considerably further in discussing their contrasting relevance to real life. Start with the question of whether it is Model B's equilibrium or disequilibrium behavior which should be tested against real economies. As discussed above, equilibrium is reached in Model B when the ratios K/N and H/N get so large that the relative scarcity of N bottlenecks further growth in K/N and H/N. It would seem that even a rich country like the United States is nowhere near this situation. Surely the amounts of physical and human capital per worker in the United States are not so large that workers cannot sustain any further increases. (In part, this is what Griliches is saying when he argues in Section V of his current paper that further educational attainment is not restricted by past "drawing down of the 'pool of ability'.") This suggests that the relevant part of Model B's behavior is its disequilibrium behavior when K/N and H/N are far below their equilibrium levels.

If the last paragraph is correct, it might be asked why numerical studies of the speed of adjustment of neoclassical growth models do not show more clearly that such models cannot reach equilibrium in anything like relevant time periods. There is a simple answer. Suppose a speed of adjustment study uses a Cobb-Douglas function of the form $Y = AK^{1-\alpha}N^{\alpha}$ (as several studies have). It would be conventional to use an α-value of about $\alpha = .7$, on the grounds that .7 is about labor's relative share of output. However, labor's relative share is in large part due to the human capital embodied in labor. So, in the expanded function $Y = AK^{1-\alpha-\beta}H^{\beta}N^{\alpha}$, an appropriate value for α is probably very much less than .7. But it can be shown (see Conlisk [1], for example) that the speed of adjustment of a model like Model B is very much faster for larger values of α than for smaller values of α. (α is the crucial exponent because N is the bottlenecking input.) Thus, the available numerical studies tend to underestimate the time it takes for neoclassical models to approach equilibrium, because these studies give much too high a value to α (or the corresponding magnitude in non-Cobb-Douglas models).

Once a case is made that real life growth corresponds to the disequilibrium behavior of Model B, economists are likely to look for a new model which describes real life growth as equilibrium behavior. Equilibrium analysis is easier to work with than disequilibrium analysis. (A good example of this is unemployment theory. Unemployment is a disequilibrium state with respect to the classical macro-model; so economists have naturally gravitated to Keynesian models which describe unemployment as an equilibrium state.) Starting from Model B in search of a model with a shorter run equilibrium, an obvious question is—will Model C do?

In Model C, equilibrium is reached when K/L reaches its equilibrium value. But equilibrium constancy of $K/L = (K/N)/E$ is possible both for very high values of K/N and E (such as for a rich country) and for very low values of K/N and E (such as for a poor country). Thus, Model C's equilibrium behavior applies to both rich and poor countries. This indicates that the equilibrium behavior of Model C is much shorter run in nature than that of Model B (which applies only to economies so rich that they can sustain no more physical and human capital per worker). Putting this argument another way: there is no mechanism in Model C by which increases in K/N and E can result in a bottlenecking scarcity of N. Workers are able to handle effectively unlimited amounts of capital and education per worker. That is the situation that real economies are now in—able to handle more capital and education per worker.

The discussion thus far may be summarized in the following points:

1. Growth explanation may be viewed from two levels—a first level, centering on an aggregate production function, in which growth in output is explained in terms of growth of inputs; and a second level, requiring a complete system of equations, in which the growth of both output and inputs is explained.

2. At both levels of explanation, the literature reflects puzzlement at the difference, or residual, between the amount of output growth observed in real life and the amount of output growth explained by the economic models.

3. Griliches suggests two ways of including education in an aggregate production function—the $Y = F(K,H,N)$ form and the $Y = F(K,EN)$ form. If one uses the measurement techniques of the Griliches-Jorgensen work, the puzzle of the residual at the first level of explanation can apparently be solved with either production function form (though they in fact concentrate on the $Y = F(K,EN)$ form).

4. If one straightforwardly expands Griliches' two production functions to complete models, and if one sticks to equilibrium analysis, the puzzle of the residual at the second level of growth explanation can apparently be solved only with the $Y = F(K,EN)$ function.

5. More specifically, the equilibrium state of Model B, which is built around the $Y = F(K,H,N)$ function, is a state in which the amount of physical and human capital per worker are so great that a relative scarcity of workers bottlenecks further growth in K/N and H/N. The real world seems nowhere near such a state, though it seems impossible to rule out the possibility of such a state in the distant future. Thus, if Model B is currently relevant at all, it would seem that its disequilibrium behavior is what is relevant.

6. On the other hand, the equilibrium state of Model C, which is built around the $Y = F(K,EN)$ function, appears to be much shorter run in nature. As in real life, the workers in Model C are always ready to handle effectively greater amounts of physical capital and education per worker.

7. All this adds up to a tentative preference for Griliches' $Y = F(K,EN)$ function over his $Y = F(K,H,N)$ function, at least in currently popular growth modelling contexts.

In my opinion, the growth model literature is far too little concerned with questions of interpretation and practical relevance; so I am grateful to Griliches for stimulating a helpful viewpoint on the Model B versus Model C issue. One can hope that Griliches and other education experts will in the future delve further into what I have here called the second level of growth explanation. Growth model theorists and education experts would seem to be more natural allies than their past cooperation indicates.

II. THE INCOME-EDUCATION-ABILITY INTERRELATION

Four brief remarks on the ability issue will conclude my comment.

1. The determination of a person's income involves a number of jointly dependent variables and a number of independent variables. Variables like wealth and debt would ordinarily be included along with income in the dependent variable list, while variables like parents' education and age would be included in the independent variable list. Variables like education and ability might fall in either list, depending on the time period involved and the exact way the variables are defined. In any case, a simultaneous-equations model seems needed to handle the situation. Yet individual income determination analysis more often than not centers on a single equation with income the dependent variable. In studying macroeconomic income determination, economists would typically reject this single-equation approach outright, even though the macro problem is probably a conceptually easier one (since an economy does not have a life cycle in any sense relevant here, and since the law of large numbers operates strongly to simplify aggregate behavior). Thus, I think Griliches is taking a useful line when (in the third paragraph of his Section V) he starts taking a simultaneous-equations view of things.

2. I sometimes worry that economists will no sooner get the ability issue apparently nailed down than the whole bias problem will arise again with respect to another type of excluded variable, which I shall call motivation. Consider two men of junior college education who are apparently similar in every way except that one has a very high IQ (measured at age ten, say) and the other a very low IQ. The usual hypothesis in the literature is that the high-IQ man may be expected to earn more. However, one might ask why the high-IQ man never finished college and how the low-IQ man got that far. A plausible suggestion is that the high-IQ

man has considerably less motivation. If this suggestion is correct and applies across human beings in general, then we have another explanatory variable, collinear with education and ability, which needs to be included if the quantitative effects of various determinants of income are to be sorted out.

3. The matched data on income, education, and age ten IQ which Griliches presents for Malmo, Sweden, are of great interest, since they are just the sort of data which are often asked for. However, I'm not sure the data show what Griliches says they show. In Griliches' regression of income on education and IQ, using this data, education and IQ are both highly significant and quantitatively important. Nonetheless, excluding the IQ variable from the regression has virtually no effect on the estimated coefficient of education. This must mean that education and IQ are not very collinear. If such is the case, then this data set cannot contain much information on excluded-variable bias for data sets where education and IQ are considerably more collinear.

4. Finally, I might review here some small bits of evidence I have recently collected on the income-education-ability interrelation. In Conlisk [3] I suggested two approaches for getting around the lack of matched data on a person's earnings, education, and ability. The first approach was to substitute occupation as a proxy for earnings, and then to use data from psychologists' and educators' studies of intelligence (in which matched data on occupation, education, and other variables are routinely recorded). This approach was illustrated with a human development sample of about seventy men. Occupation at age thirty was used to construct a proxy for income; education was measured as years of schooling; IQ measures were available for a number of age levels from infancy to eighteen years; and various background variables were also available. In a series of regressions with the earnings proxy the dependent variable, education was highly significant and IQ highly insignificant in every regression run. The second approach for getting around the lack of matched income-education-ability data involves aggregate observational units. Data from separate samples, which are unmatched on individuals, may be matched on the aggregate units. Two illustrations of this approach were presented—the first a cross-state analysis using World War I army intelligence test data and income-education data from other

sources, and the second a cross-occupation analysis using World War II army intelligence test data and census income-education data. In the cross-state analysis, the education variable dominated the ability variable. In the cross-occupation analysis, however, the ability variable displaced about half of education's explanatory importance.

REFERENCES

1. John Conlisk, "Unemployment in a Neoclassical Growth Model—the Effect on Speed of Adjustment," *Economic Journal*, September 1966, 550–66.
2. ————, "A Modified Neoclassical Growth Model with Endogenous Technical Change," *Southern Economic Journal*, October 1967, 199–208.
3. ————, "A Bit of Evidence on the Income-Education-Ability Interrelation," 1968, unpublished.
4. Zvi Griliches, and D. W. Jorgensen, "The Explanation of Productivity Change," *Review of Economic Studies*, July 1967, 249–83.
5. Robert Solow, "A Contribution to the Theory of Economic Growth," *Quarterly Journal of Economics*, February 1956, 65–94.

RICHARD R. NELSON

YALE UNIVERSITY AND THE RAND CORPORATION

One of the characteristics of a superb craftsman, like Zvi Griliches, is that he leaves a discussant very little room for examining problems of commission. Even were this not so, I still would feel compelled to focus my remarks on a set of issues with which Griliches dealt hardly at all; namely, the conceptual problems of education as an input to a production function.

I am quite uneasy about the way we economists, theorists, and econometricians are thinking about our dynamic production functions these days. I am concerned that somehow we think the "production function" of growth economics is the same as the "production function" in the old theory of the firm. I think they are quite different animals.

Not so many years ago, before the focus of interest turned to growth and related topics, the production function, in its setting of the neoclassical theory of the firm, was a reasonably clear and solid concept. To produce a given quantity of output certain minimal (alternative sets of) inputs were required. Some of these inputs were needed because they went into the product, like the eggs and milk that go into cake. Others were required because certain operations needed to be performed on the former; an egg beater, a stove, electricity to power both, and man time to operate and control. This notion of a production function one can almost "feel." While, of course, the kinds of production functions we played with in the theory of the firm were much more aggregate than this, beneath the aggregate we could think of a set of more solid production functions.

Underlying (or related to) this concept of the production function there are a *number of related notions*. Behind the scenes is the notion of a well-defined production set, with certain possibilities known, and others unknown, and nothing blurry about the distinction between the two. With all possibilities perfectly known, there really is no problem of technological efficiency. Neither are there problems with making optimizing choices of factor mix.

As we economists have broadened our concerns beyond the relatively uninteresting questions of the comparative statics of a very statical firm, our concept of a production function has also broadened and, I maintain, become very different, although we often write and crank turn as if they were the same. Surely, variables like accumulated research and development expenditure, or investment in extension, have no place in the earlier concept of the production function. Common use is evolving a new definition of the production function, which includes anything and everything that explains output differences (including overtime). Pragmatically this may be convenient. But certainly the older, more solid, concept has fallen by the wayside and there is no reason why concepts associated with it, such as perfect knowledge and optimal choice, should be associated with the new. But sometimes we seem to carry them over mechanically.

Which brings me to education and the production function. In the old concept of the production function, labor simply operated (cooperatively with machines) on the used-up inputs. With this concept it certainly makes sense to think of some minimal body of experience that the worker has to have in order to make a cake. (Some investment is needed in order to obtain the relevant knowledge.) And beyond that level it is easy to think of how, at least up to a point, more experience could make the worker more effective. At the simplest level, less time might be spent looking at the recipe, the set-up operations (getting out all the ingredients) might take less time, etc. In this case experience would be "labor augmenting." It also is possible that a more experienced worker would use less materials per cake (no wastage) and by working faster would require less reserved machine time. In this case experience would be "total-factor-productivity" increasing. And there are other forms one can think of. If one associates education (a chefs' school?) with experience, one can, within this concept of the production function, think meaningfully about how education enters.

However, I maintain that more experienced chefs making a constant cake is not what the observed high returns to education are all about. It is well known that the educated élite do not have dirty (or doughy) hands. I have not taken the trouble to look up what our college-educated members of the work force do, as compared to those with less education. I am confident that most of them are in positions requiring them to make decisions of one kind or another on the basis of information, which it would be difficult or impossible for them to interpret without their educational background, or a lot of special training or experience. And the decisions are real ones, it is not a matter of simply following a static decision rule, or recipe, more efficiently. This certainly is a reasonable characterization for doctors, scientists, lawyers, business executives, and government officials. Generally they are in an environment of considerable flux so that the decision problems they face do not follow a regular routine, not because someone neglected to draw one up but because such problems cannot be made fully formal and routine. Periodically or continuously persons in these professions face the problem of having to learn about something new.

The notion that our better educated people are more adequately equipped to make, or learn to make, decisions, is at once obvious, and very difficult to fit into our traditional production function concept. The reason, of course, is that in our theory of the firm—the unit that operates the production function—no one makes decisions. There is no process of decision making. Decisions (or actions) simply occur and are optimal. And there is nothing to "learn." Everything relevant to decision making simply is known.

I think these are serious problems in the theory of the firm and in the concept of the production function in the theory of the firm, but that is not my concern here. For certainly within the concept of a production function that is evolving for analysis of economic growth we are not stuck with the traditional formulation. How should we proceed to model?

Edmund Phelps and I made a left-handed try, a few years ago, to build a simple model in the spirit of my discussion here. Making decisions regarding new technological options certainly is an archetype of the kind of situation where, I argued here, education should have payoff. Thus, we developed a little model of education as a variable influencing the rate of diffusion. One predictive implication is that the returns to education would be greater, the faster the pace of technological change. Finis Welch, in a recent paper, appears to have found just that. One policy implication is that the returns to an R & D project should be lower the lower the educational attainments of the people who could use the results. If right, this has some significance.

Another model, in this spirit, that I have recently developed, relates education to a head start on learning a specific set of tasks. Education on the part of the new worker is a substitute for experience. One implication of this is that the cost level of an industry will be related to its pace of expansion, but that the penalties of rapid growth will be less when the young work force is well educated than when it is not. This model seems to explain the high costs of rapidly expanding industries in certain less developed countries, and also why countries like Taiwan seem to have less trouble with the worker inexperience problem. The model has some implications for both educational and manufacturing policy in the less developed countries.

I give these examples not to push my own work but rather to suggest that there may be real payoffs from modeling education in quite different ways than those on which Griliches focuses and which seem to have drawn the lion's share of the attention up to now. Predictive and policy implications are not insensitive to specification. Clearly a lot more thinking needs to be done about education in dynamic production functions.