
Capital-Skill Complementarity
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NOTES

CAPITAL-SKILL COMPLEMENTARITY

Zvi Griliches *

In a previous paper [3] I suggested the following three-input demand model for testing the possibility that "skill" or "education" is more complementary with physical capital than unskilled or "raw" labor:

$$\ln S/N = a_1 + (\eta_{sn} - \eta_{nn}) \ln W/Z + (\eta_{sk} - \eta_{nk}) \ln R/Z \quad (1)$$

$$\ln S/K = a_2 + (\eta_{sn} - \eta_{kn}) \ln W/Z + (\eta_{sk} - \eta_{kk}) \ln R/Z \quad (2)$$

where N is "raw" labor, K is capital, S is skill or schooling with the corresponding (rental) prices W, R, and Z. In getting to this set of equations we have assumed constant returns to scale and used the condition $\sum_i \eta_{ij} = 0$. Note also that $\eta_{ij} = v_j \sigma_{ij}$, where v_j is the share of the j^{th} factor in total costs and the σ_{ij}'s are the Allen-Uzawa partial elasticities of substitution ($\sigma_{ij} = \sigma_{ji}$ and $\sigma_{ii} < 0$). Thus, the hypothesis can be restated as

$$0 < \sigma_{nk} > \sigma_{sk} \text{ and } \sigma_{kn} > \sigma_{sn},$$

and implies a negative coefficient for ln R/Z in the first equation and for ln W/Z in the second.

The basic difficulty in testing such a hypothesis is the lack of good price series for either K or S.[1] The strategy of this note is to use cross-sectional data for the United States and assume, which is not too implausible, that the price of "skill" or skilled labor (Z) has been largely equalized by the mobility of educated labor, and hence can be treated as approximately constant across states and industries. Of the two remaining prices, the quality of the data on wages of unskilled labor is much superior to that on the cost of physical capital. Hence, we shall concentrate on the coefficient of the "better" variable, ln W, in the second equation and endeavor to show that the use of a "poor" variable for R cannot account by itself for the observed negative coefficient (of ln W in equation (2)).

We have two sets of data. The first is more extensive, using observation on two-digit manufacturing industries in individual states in 1954, but is restricted by the availability of only crude occupational distribution data for the construction of skill variables. The second body of data is based on the 1960 Census of Population data on the education of workers by industry and on the 1964 Annual Survey of Manufactures for data on capital per worker. These data are available for 60 three-digit manufacturing industries for the United States as a whole. There is no geographical breakdown, except for the differential average location of an industry, to provide us with significant variance in the real price of labor.

The results of fitting these two equations to the first set of data (two-digit Manufacturing Industries, by States, $N = 261$) are summarized in table 1. Two measures of "skill" are used: the first, O, is an all inclusive measure of "quality per man," using the observed occupational and sex distribution within an industry and state and national average earnings by occupation and sex to "predict" the earnings ("earning power") of the average worker in the particular industry and state (see previous paper [3], for additional discussion of such "quality" indexes). The second measure, S/US, is just a ratio of the number of skilled to unskilled workers, where "skilled" is defined as all workers who are not laborers, operatives, or service workers. The capital measure used, B, is an estimate of the gross book number value of fixed assets at the beginning of 1954; the average wage per hour of production workers, W, is assumed to be proportional to the relevant price of unskilled or "raw" labor; and the cost of capital is approximated by the "gross rate of return," GRR, which is computed as value added minus payrolls divided by the book-value of fixed assets. In addition, state and industry dummy variables are included in some of the regressions. The industry dummies are expected to adjust for general industry-wide errors in such ex post cost of capital measures.

To summarize briefly, the results presented in table 1 have all the expected signs. The coefficient of ln GRR in the first set of equations is always

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[1] Even if one had the relevant data, the alternative of attacking the problem directly by estimating a general three-input production function, $Y = F(N, S, K)$, is not really promising, since questions about the relative size of elasticities of substitution are questions about the curvature of the $F(\ )$ function which are usually very hard to answer on the basis of ordinary economic data. As far as the production function is concerned the σ's are second order parameters and hence almost impossible to estimate. They are, however, first order parameters in the derived demand equations.

TABLE 1. — CAPITAL-SKILL COMPLEMENTARITY REGRESSIONS U.S. MANUFACTURING INDUSTRIES (2-DIGIT), 1954, BY STATES, N = 261

Dependent Variable				Coefficients of					
				ln W	ln GRR	Dummies		R^2	σ^2_u
						States	Industries		
I)									
	a)	O/L	1.	.302 (.023)	−.023 (.009)			.445	.081
			2.	.354 (.028)	−.020 (.008)	√		.534	.077
			3.	.054 (.022)	−.009 (.005)	√	√	.920	.033
	b)	S/US		.113 (.155)	−.020 (.034)	√	√	.909	.229
II)									
	a)	O/B	1.	−1.055 (.111)	.996 (.041)			.763	.384
			2.	−.615 (.138)	.715 (.049)		√	.859	.308
			3.	−1.351 (.157)	.697 (.038)	√	√	.939	.231
	b)	S/B		−.615 (.137)	.715 (.049)		√	.859	.308

O/L — Logarithm of "Skill" per man (and female) based on *1950 Census of Population* data on occupations by industry, weighted by 1949 mean incomes by occupations and sex from *Census Technical Paper 17*, table 38. Basic form of index is similar to the one constructed from 1960 data and described in Griliches [1].

S/US — Logarithm of "Skilled" to "Unskilled" workers ratio in 1950. "Unskilled" defined as operatives, laborers, and service workers, from *1950 Census of Population*. "Skilled" — all others.

B — Bookvalue of Fixed Assets in 1954. Based on *Census of Manufacturers* book value data for 1957 and investment expenditures in 1954–1957. Construction of variable described in Griliches [2].

S/B — Logarithm of "skilled workers" per unit of capital computed by multiplying the number of man-hours in 1954 by the fraction "skilled" in 1950 and dividing by B. Similarly O/B = ln O/L − ln B/L, where L are total man-hours in 1954.

W — Average wage rate per hour of production workers, 1954.

GRR — Gross rate of return = (Value added − Total Payrolls)/Bookvalue of fixed assets, 1954.

negative, though often not significantly so. Nevertheless, this is an interesting finding in light of the rather poor quality of this variable (which would tend to bias its coefficient toward zero) and the fact that there is no spurious relation between it and the dependent variable; they are computed from entirely separate sets of data. More interesting is the very "significant" negative sign of the coefficient of the "better" ln W variable in the second set of equations. If the model is accepted, it definitely implies a higher elasticity of substitution of "raw" labor for capital than for skilled labor. The positive coefficient for ln GRR is consistent with the model but could be in part spurious, since GRR is computed by dividing nonlabor payments by the capital measure used on the left-hand side of the same equation. The likely presence of errors in the capital measure would tend to bias the coefficient of ln GRR towards unity. Accepting the probability of such a bias we shall endeavor to show below that it cannot, by itself, explain the negative coefficient of ln W.

The results for the second set of data (60 United States Manufacturing Industries) are summarized in table 2. Here a similar all-inclusive quality index, Q, is constructed using the educational and sex distribution of workers in 1960 and mean United States earnings by these categories in 1959. The second measure of "schooling," H, measures it above a minimum unskilled level which is attributed to "raw" labor. Ignoring the fact that these indexes are first constructed separately for males and females and then aggregated, the relation between them is very simple:

$$Q_j = \sum_i w_i N_{ij}/N_j, \qquad H_j = \sum (w_i - w_o) N_{ij}/N_j$$

and hence

$$N_j Q_j = N_j H_j + w_o N_j = N_j(H_j + w_o)$$

where the summation is over the various schooling classes, N_{ij} is the number of workers with i^{th} level of schooling in industry j, $N_j = \sum_i N_{ij}$ is the total number of workers in industry j, w_i are national earnings by schooling weights, and w_o is the average income of the lowest (less than five years) schooling class. Here the wage of unskilled labor, WUS, is based on independent data on the median earnings of full-time laborers by industry (from the 1960 Census of Population); the cost of capital, GRR, is computed as before (except that bookvalue is averaged for the beginning and end of the year and inventories are included in the definition of capital); and the measure of capital services, *SK*, is a more complicated concept, allowing for rentals of equipment and a role for inventories. (A more detailed definition of *SK* is given in the notes to table 2.)

Here again the estimated coefficients have the expected signs: negative but not "too strong" for the relatively poor *GRR* variable in the schooling per worker equations, and negative and significant for the better *WUS* variable in the schooling per capital equations.

TABLE 2. — CAPITAL-EDUCATION COMPLEMENTARITY: 60 UNITED STATES MANUFACTURING INDUSTRIES, 1963 (1960)

	Coefficients of			
Dependent Variable	ln *WUS*	ln *GRR*	R^2	σ^2_u
I)				
ln *Q/N*	.913	−.114	.706	.109
	(.084)	(.039)		
ln *H/N*	1.220	−.050	.729	.131
	(.100)	(.046)		
II)				
ln *Q/SK*	−1.136	.595	.352	.430
	(.330)	(.152)		
ln *H/SK*	−.830	.659	.314	.446
	(.343)	(.158)		

The data on characteristics of workers are from the 1960 Census of Population, "Industrial Characteristics," PC(2)7F, table 21, and "Occupational Characteristics," PC(2)7A, table 28. The data on capital and rates of return are from the 1963 Census of Manufacturers and the 1964 Annual Survey of Manufactures, 1965 (AS)–6. The list of industries is the same as in table 21 of PC(2)–7F, starting with "Logging" and ending with "Leather products, except footwear."

GRR — gross rate of return = (Value Added — Total Payrolls — Total Rentals)/ (.51 Average Bookvalue of fixed assets + Average Inventories) where the bookvalue of fixed assets and the value of inventories at the end of 1962 and 1963 are averaged and .51 is an approximate translation of "gross" into "net" bookvalue based on data in the 1958 Census of Manufactures.

SK — capital services = .12 Average Gross Bookvalue + Total Rentals + .07 Average Inventories. This is consistent with a 7 per cent rate of interest and about 15 per cent net depreciation rate, which in turn is consistent with aggregate figures for 1957 given in the 1958 Census of Manufactures.

WUS — Median wage and salary income of male laborers who worked 50–52 weeks in 1959. From table 20 in PC(2)–7A.

Q — Education per man index, constructed from table 21 in PC(2)–7F for males *and* females using 1959 mean earnings by education (for males) and 1959 median incomes of females who worked 50–52 weeks as weights. For additional discussion of such indexes see Griliches [2].

H — Human capital per person (up to a constant of proportionality) = $(Q_M - 2035)\ (1 - FF) + (Q_F - 1026)FF$ where *FF* is the fraction of female workers and 2935 and 1026 are the weights of the lowest educational class ("less than five years of schooling") for males and females respectively. This attributes to *H* all of the (average) earning power above the wage of the least educated class. To convert it into actual human capital units, it would need also to be divided by some discount factor which would capitalize these estimated flows.

H/SK and *Q/SK* are obtained by dividing the two education per man measures by capital services per total number of employees (in 1963, from Census of Manufactures).

Thus, in both sets of data, there is evidence for the hypothesis that "skill" or "schooling" is more complementary with capital than unskilled or unschooled labor. It remains to be shown that these results are not a spurious consequence of the use of relatively poor cost of capital measures. To show this we shall concentrate on the second equation. Let small letters stand for the logarithms of the variables and let "true" unobserved versions of these variables be identified by asterisks (we'll be interested in this distinction only for k and r), then we can write the second equation as

$$s - k^* = aw + \beta r^* + u \tag{3}$$

let $k = k^* + v$ and $r^* = \pi - k^*$, then $r = \pi - k = r^* - v$, which in turn can be rewritten in terms of the observed variables as

$$(s - k) = aw + \beta r - (1-\beta)v + u. \tag{4}$$

Thus, running the regression in the observed variables is equivalent to leaving out a relevant variable v with the coefficient $-(1-\beta)$ that is negatively correlated with the included variable r (since $r = r^* - v$).[2]

It can be shown (see appendix), if one makes all the standard assumptions and in addition assumes that v is a random error uncorrelated with w and r^*, that the estimated coefficient of *GRR* is biased towards one [3]

$$E(\beta'-\beta) = (1-\beta)\lambda_v/(1-r^2_{rw}) \tag{6}$$

where

$$\lambda_v = \sigma^2_v/\sigma^2_r = \sigma^2_v/(\sigma^2_{r*} + \sigma^2_v)$$

is the fraction of the observed variance in r due to "error" and r^2_{rw} is the square of the simple correlation coefficient *in the sample* between the observed r and w. On the other hand, the bias in the coefficient of w, the one we are interested in, can be written as

$$\begin{aligned} E(a'-a) &= -\text{ bias } \beta' \cdot b_{rw} \\ &= -(1-\beta)\ \lambda_v\ b_{rw}/(1-r^2_{rw}) \end{aligned} \tag{7}$$

where b_{rw} is the regression coefficient, in the sample, of r on w. Since it is assumed that $\beta > 0$, and since all of our estimated β's are less than one, we expect the true β to be less than β'. Hence $1 >$ bias $\beta' > 0$, and therefore the magnitude of the absolute bias in a' is bounded by the observable b_{rw}. To make a long story short, the observed b_{rw}'s are negative, − .6 for the first sample and − .3 for the second sample, and hence this type of bias would make the estimated (negative) a''s appear to be less negative than they really are. Even if one accepted the possibility that all the error in r is due

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[2] We could have complicated the model some more by adding also an error to the "profit variable" $\pi = \pi^* + e$, which would have led to $r = r^* + e - v$. This would have only attenuated the effects we are looking for, since e and v would operate in opposite directions, and would have only strengthened the argument.

[3] This, and the following statement require also the assumption $\lambda < 1 - r^2_{rw}$ which is likely to hold for our samples since the observed r^2_{rw} is quite small (about .04 in the first set of data).

to the randomness of profits, rather than to errors in the measurements of K, which would imply a negative bias in β', this too could not explain away the observed negative α''s, since again one would expect bias β' in this case too, to be less than one in absolute value. Thus, the observed negative α''s cannot be explained as the consequence of using a bad cost of capital variable and therefore can be taken as an indication of greater capital-schooling (skill) complementarity.[4]

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[4] The statement in the text does not distinguish adequately between two related but different hypotheses: $\sigma_{nk} > \sigma_{sk}$ and $\sigma_{nk} > \sigma_{ns}$. The evidence presented above supports the second one better than the first, though it does support both.

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APPENDIX

Derivation of formulae (6) and (7):

Start with the general case of the left out variable v which is correlated with only one of the included variables (r). Then the "true" equation is

$$y = aw + \beta r + \gamma v + u$$

while we estimate, by least squares,

$$y = aw + bv + u'.$$

Then, given the usual assumptions

$$Ea = \alpha + \gamma b_{vw \cdot r}$$
$$Eb = \beta + \gamma b_{vr \cdot w}$$

where the $b_{vi \cdot j}$ is the regression coefficient of the i^{th} variable in the "auxiliary" regression of the left out variable v on the included variables i and j. Moreover, we know that we have the following identities

$$b_{vw} = b_{vw \cdot r} + b_{vr \cdot w} b_{rw}$$
$$b_{vr} = b_{vr \cdot w} + b_{vw \cdot r} b_{wr}.$$

Now, by assumption, $b_{vw} = 0$. Hence

$$b_{vw \cdot r} = - b_{vr \cdot w} b_{rw}$$

which leads immediately to the general version of (7):

$$\text{Bias } \alpha' = -\text{Bias } \beta' \cdot b_{rw}.$$

Also, substituting the previous expression for $b_{vw \cdot r}$ in the b_{vr} relation leads to

$$b_{vr \cdot w} = b_{vr}/(1-r^2_{rw})$$

since $b_{rw}\, b_{wr} = r^2_{rw}$. Therefore the general version of (6) is given as

$$\text{Bias } \beta' = E(b-\beta) = \gamma b_{vr}/(1-r^2_{rw}).$$

The versions of (6) and (7) given in the text follow immediately upon noting that $\gamma = -(1-\beta)$, and that $b_{vr} = -\lambda_v$, given the assumption that v is a random error uncorrelated with r^* and $r = r^* - v$.

FACTOR INTENSITY REVERSALS AND THE CES PRODUCTION FUNCTION

Thomas L. Hutcheson [*]

The proof of the factor-price equalization theorem in a two-factor, multi-good model requires the assumption of the impossibility of factor-intensity reversals between at least two traded goods [8, p. 6] [4, p. 332].[1] While other assumptions of the theorem were sometimes challenged, the factor-intensity assumption was generally considered plausible until Minhas argued that between different industries, one should expect to find "different degrees of sensitivity to changes in those data which influence the choice of factor combinations [6, p. 2].[2] Applying a CES production function to the

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[1] The strong form of the factor-intensity assumption is that the production functions of the two industries are such that one industry will have a higher capital/labor ratio regardless of the ratio of the factor prices which the industries face. The weak form is that while reversals may occur, they are unlikely within the range of factor-price ratios observed internationally.

[2] Minhas used a first degree homogeneous CES production function, which for the "i^{th}" industry, can be written:

$$V_i = \left[A_i K_i^{-\beta_i} + a_i L_i^{-\beta_i}\right]^{1/1-\beta_i}$$

where V_i = value added; K_i = capital; L_i = labor; A_i and