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THE IMPACT OF SCHOOLING ON WAGES:
A THEORETICAL ANALYSIS

by

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Abstract

This paper examines the theoretical effect of schooling time on wage rates at various points in time. Although there is an intuitive presumption that the effect should equal the interest rate there is no theoretical justification for this if post schooling investment is permitted. However, optimality does require that the interest rate equal a weighted average of the effects of schooling on log wages at different points in the time path of wages. A constant effect is shown to be inconsistent with a concave human capital technology. It is also demonstrated that the effect of schooling on log wages at a point in time is a non-increasing function of the length of the elapsed post schooling investment period. The effect of schooling on absolute wages follows the opposite pattern.

The Impact of Schooling on Wages: A Theoretical Analysis

1. INTRODUCTION

Two conclusions emerge from the voluminous empirical literature on the wage-schooling relationship. First, by virtually any criterion employed, the semi-log form of the wage-schooling relationship dominates all other simple functional forms. Second, in the semi-log equation, the coefficient on years of schooling lies in the range .08 to .15.

Despite Rosen's [16, p. 8] comment that "though the dimensions of the schooling regression coefficient are the same as those of a rate of return, it has no causally significant interpretation," there is a pervasive intuitive presumption that the schooling coefficient ought to equal the rate of interest. Consequently, the size of the estimated coefficient has focussed the econometric discussion of bias on upward bias.¹ Further, advocates of competing theories of the wage-schooling relationship have gone to some trouble to demonstrate that the theory being advanced predicts either a rate of return or schooling coefficient in excess of the rate of interest.² Moreover, within the theoretical human capital literature there has been a great deal of discussion on why the rate of return to schooling ought to be larger than the rate of interest.³

The first question addressed herein is a very simple one. Irrespective of problems with the data, lack of identification of underlying structural parameters and shortcomings of the simple theory, when does the theoretical effect of schooling on log wages equal the interest rate in the simplest efficiency units model? Under reasonable assumptions about the production function for human capital, the derivative of log wages with respect to

schooling equals the interest rate if there is no post schooling investment.⁴

The second problem to be addressed is more complex. While illuminating in many other respects, the optimal accumulation models pioneered by Ben Porath [2, 3] have not shed much light on the semi-log wage equation.⁵ The relationship between the time at which one stops specializing in the production of human capital (the end of the schooling period) and the level of wages at various points in the life cycle is complex. Accordingly, it may be suggested that one should not have strong priors on either the performance of any simple approximation to the wage-schooling relationship, or the size of any particular coefficient.

The second problem is thus to show, again irrespective of econometric considerations, that a model including post-schooling investment has a good deal to say about log wages and schooling. If one focusses on the choice of schooling time and on-the-job training time, as opposed to the level of the capital stock, it may be shown that

- i) a weighted average of the effect of schooling on log wages at various points in the life cycle equals the interest rate;
 - ii) a constant effect of schooling on log wages is not consistent with a concave technology for the production of human capital;
 - iii) the effect of schooling on log wages at any point in time is a non-increasing function of the duration of time since schooling;
- and iv) the effect of schooling on the level of wages at any point in time is a non-decreasing function of the duration of time since schooling.

2. THE RATE OF INTEREST AND THE EFFECT OF SCHOOLING ON LOG WAGES

Consider the pure schooling model of capital accumulation [16]. In this model, infinite-lived individuals, facing a perfect capital market, choose the length of the period of full-time investment to maximize the present value of wage income. Foregone wages are the only cost of investment. Let

J^0 = length of the investment period,⁶

r = rate of interest,

$K^0 = K^0(J^0)$ = monotone increasing, strictly concave human capital production function,⁷

and R = flow rental rate per efficiency unit of human capital.

The individual problem is

$$\max_{K^0, J^0} W = \int_{J^0}^{\infty} RK^0 e^{-r\tau} d\tau$$

$$\text{S.T. } K^0 = K^0(J^0),$$

which may be rewritten

$$\max_{J^0} W = RK^0 \frac{e^{-rJ^0}}{r}.$$

Letting $w^1 = RK^0$, the necessary condition may be rearranged to yield

$$\frac{\partial \log w^1}{\partial J^0} = r$$

The derivative of the log of post-schooling wages with respect to schooling must equal the interest rate.

Now suppose there is a job that has a training component requiring a fraction s_1 of working time. Denote time spent on this job by J^1 and the human capital production function for on-the-job training be $K^1 = K^1(s_1 J^1, K^0)$.

J^0 and J^1 are chosen to maximize

$$W = \frac{R}{r} \{ (1-s_1)K^0 [e^{-rJ^0} - e^{-r(J^0+J^1)}] + (K^0+K^1) e^{-r(J^0+J^1)} \}.$$

The necessary condition may be written

$$\frac{\partial \log w^1}{\partial J^0} = \frac{r \{ (1-s_1)(1-e^{-rJ^1}) + (1 + \frac{K^1}{K^0})e^{-rJ^1} \}}{(1-s_1)(1-e^{-rJ^1}) + (1 + \frac{\partial K^1}{\partial K^0})e^{-rJ^1}} \equiv r^*.$$

A sufficient condition for r^* to exceed r is

$$\frac{K^1}{K^0} > \frac{\partial K^1}{\partial K^0}.$$

That is, the output elasticity of accumulated capital in the on-the-job training production function must be less than 1. This holds if $K^1(\cdot)$ is concave.

The condition determining J^0 will always equate the increments to current and future wages, holding their time path constant, to the cost of forestalling receipt of the stream of wages. If increments to post-schooling wages are used to proxy the former and r times the level of post-schooling wages proxy's the latter, both marginal costs and returns are under-estimated; costs moreso than returns if the technology is concave. As a consequence it will appear as if either r is large or the necessary condition is not fulfilled. Only if there is no post-schooling investment period should the effect of schooling on log wages equal the interest rate.

3. LIFETIME VARIATION IN THE EFFECT OF SCHOOLING ON LOG WAGES

This section makes use of the condition determining the optimal length of the schooling period to place restrictions on the effect of schooling on log wages at different points in time.

To generalize the simple model of Section 2, let

J^i = time spent on job i ($i=0, \dots, n+1$).

$$\bar{J}^i = \sum_{j=0}^{i-1} J^j, \quad \bar{J}^{n+2} \equiv \sum_{j=0}^{n+1} J^j = \infty.$$

s_i = fraction of J^i spent investing ($i=0, \dots, n+1$).

$$s_0 = 1 \text{ and } s_{n+1} = 0 \text{ are assumed. } 0 \leq s_i \leq 1 \quad \forall i.$$

$I^i = s_i J^i$ = investment time on job i .

K^i = human capital produced on job i ($K^{n+1} = 0$).

$$\bar{K}^i = \sum_{j=0}^{i-1} K^j = \text{capital accumulated prior to job } i.$$

$$\bar{K}^0 = 0.$$

$K^i = K^i(I^i, \bar{K}^i)$ = human capital production function for job i , $i > 0$.

$$K^0 = K^0(s_0 I^0) = K^0(J^0).$$

$$w^i = R(1-s_i) \bar{K}^i.$$

$$\eta^i = \frac{\bar{K}^i}{K^i} \frac{\partial K^i}{\partial \bar{K}^i}$$

$$J = (J^0, \dots, J^n)$$

and $K = (K^0, \dots, K^n).$

With this notation, life wealth is

$$W = \sum_{j=1}^{n+1} \int_{\bar{J}^j}^{\bar{J}^{j+1}} R(1-s_j) \bar{K}^j e^{-r\tau} d\tau$$

$$= \sum_{j=1}^{n+1} \frac{R}{r} (1-s_j) \bar{K}^j e^{-r\bar{J}^j} (1 - e^{-rJ^j})$$

The individual problem is then⁸

$$\max_{K, J} W = \sum_{j=1}^{n+1} \frac{R}{r} (1-s_j) \bar{K}^j e^{-rJ^j} (1-e^{-rJ^j})$$

$$\text{S.T. } K^j = K^j(I^j, \bar{K}^j).$$

A traditional approach would be to solve the constraints for $J^i = J^i(s_i, K^i, \bar{K}^i)$ and choose K to

$$\max_K W = \text{S.T. } J^i = J^i(s_i, \bar{K}^i, K^i).$$

However, for the purpose of examining the relationship between wages and schooling time, it is preferable to use the constraints to eliminate the K^i . The two approaches obviously yield the same solution.⁹

The problem to be solved is therefore

$$\max_J W = \sum_{j=1}^{n+1} \frac{R}{r} (1-s_j) \bar{K}^j e^{-rJ^j} (1-e^{-rJ^j})$$

Since $w^i = RK^i(1-s_i)$, the present value of wages earned on job i is

$$(1) \quad PV^i = \int_{J^i}^{J^i+1} w^i e^{-r\tau} d\tau = \frac{w^i}{r} e^{-rJ^i} (1-e^{-rJ^i})$$

and

$$(2) \quad W = \sum_{j=1}^{n+1} PV^j.$$

For future reference, let

$$(3) \quad \alpha^j = PV^j/W.$$

Then

$$\alpha^j \geq 0 \text{ and } \sum_{j=1}^{n+1} \alpha^j = 1.$$

Further, for fixed values of J

$$(4) \quad \frac{\partial \bar{K}^{\ell}}{\partial K^h} = \begin{cases} 1 & \text{if } 0 \leq h = \ell-1 \leq n-1 \\ \prod_{j=h+1}^{\ell-1} \left(1 + \frac{\partial \bar{K}^j}{\partial \bar{K}^j}\right) & \text{if } 0 \leq h < \ell-1 \leq n. \end{cases}$$

J^0 is the length of the schooling period. Attention is therefore restricted to the choice of J^0 . J^0 is chosen to satisfy

$$(5) \quad \sum_{j=1}^{n+1} \left\{ \frac{R}{r} (1-s_j) \frac{\partial \bar{K}^j}{\partial K^0} \frac{\partial K^0}{\partial J^0} e^{-rJ^j} (1-e^{-rJ^j}) \right\} = r \sum_{j=1}^{n+1} \left\{ \frac{R}{r} (1-s_j) \bar{K}^j e^{-rJ^j} (1-e^{-rJ^j}) \right\}$$

Using (1) and (2), the left-hand side equals rW . That is, the marginal cost of schooling time (as of $t=0$) is the value of delaying the life income stream for dJ^0 , the "Hicksian Income" rW .¹⁰

Recall that $RK^i(1-s_i) = w^i$. Then (5) may be rewritten

$$(6) \quad \sum_{j=1}^{n+1} \left\{ \frac{1}{w^j} \frac{\partial w^j}{\partial J^0} - r \right\} w^j e^{-rJ^j} (1-e^{-rJ^j}) = 0.$$

Using (1), (2) and (3) we obtain

Proposition 1

$$\sum_{j=1}^{n+1} \alpha^j \frac{\partial \log w^j}{\partial J^0} = r.$$

Proposition 1 states that J^0 should be chosen so that a weighted average of the effect of schooling on wages on the various jobs equals the interest rate. This is just another way of saying that the rate of return on opportunity cost must equal the interest rate.¹¹

Proposition 1 does not preclude the possibility that schooling might have the same effect on log wages at each point in time. Proposition 2 states that constancy of the effect of J^0 on log wages is not consistent with a concave technology for the production of human capital.

Proposition 2

Let J be such that (5) holds. Then

$$\frac{\partial \log w^j}{\partial J^0} = r \quad \forall j=1, \dots, n+1 \Leftrightarrow \eta^j = 1 \quad \forall j=1, \dots, n+1$$

Proof

i) Necessity.¹²

Consider $j = l \geq 2$

$$(7) \quad \frac{1}{w^l} \frac{\partial w^l}{\partial J^0} = r \Rightarrow \frac{\partial \bar{K}^l}{\partial K^0} \frac{\partial K^0}{\partial J^0} = r \bar{K}^l$$

For $j = l + 1$

$$(8) \quad \frac{1}{w^{l+1}} \frac{\partial w^{l+1}}{\partial J^0} = r \Rightarrow \frac{\partial \bar{K}^{l+1}}{\partial K^0} \frac{\partial K^0}{\partial J^0} = r \bar{K}^{l+1}$$

Using (4) and the definition of \bar{K}^{l+1} , (8) may be rewritten

$$(9) \quad \frac{\partial \bar{K}^l}{\partial K^0} \left(1 + \frac{\partial K^l}{\partial \bar{K}^l}\right) \frac{\partial K^0}{\partial J^0} = r (\bar{K}^l + K^l).$$

Using (7), (9) becomes

$$r \bar{K}^l \left(1 + \frac{\partial K^l}{\partial \bar{K}^l}\right) = r (\bar{K}^l + K^l)$$

or

$$\eta^l = 1$$

ii) Sufficiency.

It is sufficient to show that

$$(10) \quad \eta^j = 1 \Rightarrow \frac{K^0}{K^j} \frac{\partial \bar{K}^j}{\partial K^0} = 1.$$

For in that case, (5) reduces to

$$(11) \quad \frac{\partial K^0}{\partial J^0} = r K^0.$$

Under (11) and the hypothesis $\eta^j = 1$

$$\begin{aligned} \frac{\partial \bar{K}^j}{\partial K^0} \frac{\partial K^0}{\partial J^0} &= \frac{\bar{K}^j}{K^0} \cdot r K^0 \\ &= r \bar{K}^j. \end{aligned}$$

Equivalently,

$$\frac{1}{w^j} \frac{\partial w^j}{\partial J^0} = r.$$

To show that (10) holds, start at $j=2$. From (4)

$$\begin{aligned} \frac{\partial \bar{K}^2}{\partial K^0} &= 1 + \frac{\partial K^1}{\partial K^0} \\ &= 1 + \frac{K^1}{K^0} \quad \text{since } \eta^1 = 1 \\ &= \frac{\bar{K}^2}{K^0} \quad \text{by definition of } \bar{K}^2. \end{aligned}$$

The result holds for $j=2$. Now assume that for some $j = l \geq 3$

$$(12) \quad \frac{K^0}{\bar{K}^{l-1}} \frac{\partial \bar{K}^{l-1}}{\partial K^0} = 1.$$

For $j = l$, (4) implies

$$\begin{aligned} \frac{\partial \bar{K}^l}{\partial K^0} &= \frac{\partial \bar{K}^{l-1}}{\partial K^0} \left(1 + \frac{\partial K^{l-1}}{\partial \bar{K}^{l-1}} \right) \\ &= \frac{\partial \bar{K}^{l-1}}{\partial K^0} \left(1 + \frac{K^{l-1}}{\bar{K}^{l-1}} \right) \quad \eta^{l-1} = 1 \\ &= \frac{\bar{K}^{l-1}}{K^0} \left(1 + \frac{K^{l-1}}{\bar{K}^{l-1}} \right) \quad \text{from (12)} \\ &= \frac{\bar{K}^l}{K^0}. \end{aligned}$$

Therefore, for all j

$$\eta^j = 1 \Rightarrow \frac{K^0}{K^j} \frac{\partial \bar{K}^j}{\partial K^0} = 1$$

Q.E.D.

Thus, at the optimum, the effect of schooling on log wages is a constant, equal to the rate of interest if and only if the human capital production function is locally linear in accumulated stocks of capital. The sum of the output elasticities of time, I^j , and accumulated stocks must exceed 1. Note that even if $\frac{\partial \log w^j}{\partial J^0} = r$ for all j , this does not imply that w^j is the opportunity cost of schooling time for any j , and that the marginal returns to schooling can be measured by the effect on w^j . It does imply that both the opportunity cost and the marginal returns are estimated with the same proportional error.

While Proposition 1 ties the effect of schooling on log wages to the interest rate, Proposition 2 states that the relationship will not, under reasonable conditions, be well approximated by a constant. For any given individual, the effect of schooling on wages depends on the point in the investment path at which the wages are observed.

Knowing that the effect of schooling on wages is not a constant is only useful if one has some idea about how the effect varies.

Proposition 3

Let $\eta^j < 1 \forall j=1, \dots, n$.

Then

$$\frac{1}{w^j} \frac{\partial w^j}{\partial J^0} > \frac{1}{w^{j+1}} \frac{\partial w^{j+1}}{\partial J^0} \quad \forall j=1, \dots, n.$$

Proof

Define

$$\delta_p^l = \frac{\frac{1}{w^{l+1}} \frac{\partial w^{l+1}}{\partial J^0}}{\frac{1}{w^l} \frac{\partial w^l}{\partial J^0}}.$$

Now

$$\frac{1}{w^j} \frac{\partial w^j}{\partial J^0} = \frac{1}{K^j} \frac{\partial K^j}{\partial K^0} \frac{\partial K^0}{\partial J^0}.$$

Therefore

$$\delta_P^{\ell} = \frac{\frac{1}{K^{\ell+1}} \frac{\partial K^{\ell+1}}{\partial K^0}}{\frac{1}{K^{\ell}} \frac{\partial K^{\ell}}{\partial K^0}}.$$

Using (4)

$$\delta_P^{\ell} = \frac{K^{\ell}}{K^{\ell+1}} \frac{\prod_{i=1}^{\ell} \left(1 + \frac{\partial K^i}{\partial K^i}\right)}{\prod_{i=1}^{\ell-1} \left(1 + \frac{\partial K^i}{\partial K^i}\right)} = \frac{K^{\ell}}{K^{\ell+1}} \cdot \left(1 + \frac{\partial K^{\ell}}{\partial K^{\ell}}\right).$$

Now

$$\delta_P^{\ell} < 1 \text{ if } \frac{\partial K^{\ell}}{\partial K^{\ell}} < \frac{K^{\ell+1}}{K^{\ell}} - 1 = \frac{K^{\ell}}{K^{\ell}}$$

or $\eta^{\ell} < 1$ as assumed.

Q.E.D.

A further result is

Proposition 4

Assume $s_{i+1} < s_i \forall i=0, \dots, n$. Then¹³

$$\frac{\partial w^j}{\partial J^0} < \frac{\partial w^{j+1}}{\partial J^0}.$$

Proof

$$\frac{\partial w^j}{\partial J^0} < \frac{\partial w^{j+1}}{\partial J^0} \quad \forall j=1, \dots, n.$$

Define δ_A^{ℓ} by

$$\begin{aligned}
\delta_A^l &= \frac{\frac{\partial w^{l+1}}{\partial J^0}}{\frac{\partial w^l}{\partial J^0}} \\
&= \frac{\frac{\partial \bar{K}^{l+1}}{\partial K^0} (1-s_{l+1})}{\frac{\partial \bar{K}^l}{\partial K^0} (1-s_l)} \\
&= \left(1 + \frac{\partial \bar{K}^l}{\partial K^0}\right) \left(\frac{1-s_{l+1}}{1-s_l}\right) \quad \text{from (4)} \\
&> 1
\end{aligned}$$

Q.E.D.

From Proposition 1, even if we had the ideal data set wherein everyone choosing a given level of schooling revealed their current value of $\partial \log w^j / \partial J^0$, the average effect would be unlikely to equal the interest rate unless the average was calculated using the weights α^j . Using Proposition 3, if the average assigns greater weight to younger workers, the estimated average effect will exceed the rate of interest.

Proposition 3 states that the effect of schooling on log wages should be a non-increasing function of time elapsed since schooling. Proposition 4 states that so long as individuals choose jobs with successively smaller time requirements for investment, the absolute effect of schooling on the level of earnings should be a non-declining function of time elapsed since schooling.¹⁴ Propositions 3 and 4 together imply that if the interaction between schooling and total duration of time spent in on-the-job training is not effectively captured, the empirical choice of functional form will be biased towards those functions that assign

that interaction small weight. Heckman and Polachek [10] find, using the Box-Cox [4] transformation, that the best fitting functional form is somewhere between semi-log and linear.¹⁵ This is approximately what one would expect given Propositions 3 and 4. When they included schooling-experience interactions, the best fitting form more closely approximates a semi-log. However, the change is small, indicating that the specified interaction does not capture the effect well.

4. SUMMARY

This paper has examined the theoretical relationship between schooling and log wages at the individual level. When post-schooling investment is allowed for, the costs and returns to schooling are not properly measured using the post-schooling wage. Consequently there is no presumption that the effect of schooling on log wages should equal the rate of interest.

However, a weighted average of the effects of schooling on log wages (the j^{th} weight being the fraction of the present value of lifetime wages that is earned on the j^{th} job) must equal the rate of interest. It was also shown that a constant effect of schooling on log wages is equivalent to an on-the-job training technology that is locally linear in accumulated capital. Further, the effect of schooling on log wages is non-increasing as the post-schooling investment period gets longer, while the absolute wage effect follows the opposite pattern under reasonable assumptions.

FOOTNOTES

¹A notable exception is the paper by Griliches [7]. Griliches demonstrates that the bias may in fact be negative if schooling is viewed as subject to errors of measurement.

²For example Riley [14], presenting the screenist argument, provides an example wherein the screening model generates a log wage equation with a schooling coefficient equal to a constant (> 1) times the rate of interest. Lazear [11], examining the consumption aspects of schooling, shows that a schooling coefficient in excess of the rate of interest is consistent with several hypotheses. For example, if schooling is productive but generates disutility, a high rate of return is just compensation. If schooling is not productive, but is a normal (but not superior) good, the schooling coefficient has approximate expectation $.083/\phi$ (at 12 years of education) where ϕ , $0 < \phi < 1$, is the income elasticity of demand for schooling.

³The econometric discussion has focussed on the treatment of ability ([5], [6], [7], [1, pp. 79-88]). On the theoretical level, it is argued that the simple analysis ignores: a) the effect of risk ([13], [1, p. 55]); b) capital market imperfections [1, pp. 56-61]; and c) the effect of higher wages on hours supplied and the value of leisure [12].

⁴That the marginal effect of schooling on log wages is not generally equal to the rate of interest is not a new result. See, for example, Griliches [7, p. 4]. Being specific about why this is the case is more novel.

⁵The optimum accumulation models have contributed to understanding the life cycle path of investment. In such a framework, the schooling period is primarily an annoying initial phase in which the control is on a boundary. The questions addressed herein do not flow naturally from the optimum accumulation approach.

⁶Following Rosen [16], activities with a different investment component may be thought of as different "jobs". Accordingly, schooling is job 0.

⁷For notational simplicity, an initial stock of capital is ignored.

⁸The order of the s_i ($i=0, \dots, n+1$) could be viewed as a matter of choice. However, as the results (with the exception of Proposition 4) do not depend on the order of the s_i , except for the requirements $s_0 = 1$ and $s_{n+1} = 0$, the choice of order is ignored.

⁹This is, of course, subject to the qualification that the Jacobian of the system of constraints be non-singular. The "neutrality hypothesis" [2] is a simple device for the equivalent of eliminating the J^i in an optimal control version of this problem.

¹⁰That is, the opportunity cost of schooling time must take account of the fact that increasing schooling time delays the returns from on-the-job training as well as the receipt of the first post-schooling wage. As all of life earnings occur after schooling, the cost is equal to the interest foregone by delaying the entire stream of earnings with present value W , rW .

¹¹The necessary condition for the choice of J^l ($l=0, \dots, n$) may be written

$$(*) \quad \sum_{j=l+1}^{n+1} \alpha^j \left[\frac{1}{w^j} \frac{\partial w^j}{\partial J^l} - r \right] = - \frac{w^l}{W} e^{-r} J^{l+1}.$$

For $l=0, \dots, n$, (*) defines a system of $n+1$ equations. The equations are linear in the α^j and may be solved recursively starting at $l=n$. Without further restrictions, the pattern of the α^j as j increases is not determinate.

¹²For $j=1$, $w^1 = RK^0(J^0)(1-s_1)$ which does not depend on any accumulated stocks, although it may depend on an initial endowment. The endowment, however, would not depend on J^0 .

¹³If the ordering of the s_i is allowed to be a choice variable, $s_{i+1} < s_i$ does not necessarily follow. It is simple to show that $s_{i+1} < s_i$ if the J^i are nearly the same length. In an optimal control framework, one may think of the model as restricting the J^i to be the same (very short) for all i , whence $s_{i+1} < s_i$ follows. See, for example, [2, 3].

¹⁴The effect of J^0 on accumulated capital \bar{K}^i is always rising with i . However, as w^i depends on s^i , the effect of J^0 on w^i as i varies, depends on the s^i . $s_{i+1} < s_i$ is simply a sufficient condition for w^i to follow the same pattern as \bar{K}^i .

¹⁵These results are, of course, sensitive to the basic assumption that there is a transformation of wages of the form $\tilde{w}(\lambda) = (w^\lambda - 1)/\lambda$, which is i.i.d. normally distributed. There is some evidence that this is not the case [18].

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