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EXPERIENCE, VINTAGE AND TIME EFFECTS IN THE GROWTH OF EARNINGS: AMERICAN SCIENTISTS, 1960-70

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Introduction

This paper is concerned with the growth of individual earnigns over time. Four aspects of time are distinguished: experience, age, vintage and calendar year. The first and most widely studied is accumulated work experience, i.e. time spent earning and learning on the job. The second is the process of aging, which occurs even if the worker is out of the labor force. Vintage represents the time in history during which the individual was being educated. The general advance in knowledge implies that more recent cohorts (especially Ph.D. scientists) may enter the labor force with greater earning capacity and/or greater learning ability. The final aspect is the point in time in which the individual's earnings are observed. The passage of time brings changes in market conditions which may represent trends in supply or demand, business cycles and special circumstances relevant only to a particular year. Each of these aspects has different implications for individual earnings growth, which shall be explored in this study.

The first section of the paper provides a brief outline of a theory of planned growth in earnings. As in the works of Becker (1964), Mincer (1962, 1974), Ben Porath (1967) and Rosen (1972, 1973), the emphasis of the model is on investment in on-the-job training. Ours is a generalization in which the roles of age, time and vintage are discussed separately from experience.

The second and main section of the paper is devoted to an empirical attempt to estimate the role of experience, vintage and age on the growth in earnings and to separate these effects from exogenous changes in market conditions. A fundamental problem arises in the identification of the separate effects on earnings of each of the various aspects of time. The source of the difficulty is that causal factors which vary with time and experience, such as market conditions and the individual's allocation of human capital to the market, are not measured directly. When the various dimensions of nominal time itself are used as explanatory variables, some obvious identities emerge. For instance, over time the change in time equals the change in experience and age of fully employed scientists for each cohort. Similarly, at a point of time an additional year of experience implies a year older vintage for continuously employed scientists. We present a detailed specification of the earnings function which accounts for the inherent multicollinearity between variables such as time, vintage and experience. One of our main objectives is to point out the implications of this identification problem for the analysis of earnings data. Though we cannot completely eliminate this difficulty, longitudinal data, which follows the same individuals over a period of time, allows us to identify more aspects of time than one could obtain from a single cross section.

Our data source is the Longitudinal File from the National Register of Scientific and Technical Personnel. Most of our results relate to scientists with a Ph.D. who reported continuously at two-year intervals during the decade 1960-1970. The real earnings of these scientists grew by an average of 4.7 percent per annum. We estimate that at most two percentage points of this rather substantial annual growth rate in earnings is due to exogenous time effects. At least 2.7 percentage points can be attributed to the accumulation of experience. The contribution of experience is shown to depend negatively on age and positively on vintage. These results are in the direction predicted by our theory. There is also a positive effect of being male, of graduating from a top-ten-ranked school and of being employed in academics.

A special emphasis is given to the rather novel finding of a positive vintage effect on the growth of earnings. (This should be distinguished from the vintage effects on the level of earnings which were first discussed by Welch [1973].) It is shown that this effect leads to a systematic divergence between cross-section and actual lifetime earnings profiles. Specifically, previous estimates, based upon cross-section data, tend to underestimate the true effect of experience and schooling on earnings.

We provide a descriptive analysis of the exogenous changes in market conditions occurring during the period. No attempt is made to relate them to causal changes, such as past and expected future enrollment and government research grants. We find two basic tendencies: (1) Over the decade as a whole, scientists in academic institutions enjoyed better market conditions and thus a higher growth rate than those employed in private industry. (2) Toward the end of the decade, there is a marked reduction in the market's contribution to the growth rate. In some fields, such as physics, we note an actual reduction in the real earnings of new entrants.

We conclude with a brief discussion of the changes in relative earnings over the decade by field and type of employer. These results summarize the combined effects of experience and time. Both worsening market conditions and lower experience-related growth caused the difference in earnigns between private industry and academics to fall from 32 percent in 1960 (for the 1958 cohort) to 12 percent in 1970 (for the same cohort). We also find that strong experience effects helped in some cases to mitigate the reduction in earnings in fields which suffered a relative decline in demand. For instance, while real starting salaries in physics grew at a considerably lower rate than those for scientists in general during the decade, the relative earnings of cohorts which entered prior to 1960 were only slightly affected by the changing market conditions.

I. A Model of Earnings Growth

In this section we present a simple model of investment in human capital from which we derive an optimal rule for the growth in earnings. Analytically, the novel aspect of the model is that the rate of growth in earnings is independent of initial conditions, so that the analysis of factors determining the level of earnings can be separated from those affecting its growth. This feature is convenient for an empirical analysis which focuses on differences in earnings growth. We specify the channels through which vintage and age may affect the growth in earnings.

Consider an individual who enters the labor force at time μ. He is endowed with an initial level of human capital $K_\mu(0)$ (i.e., earning capacity) and a production function for new human capital which depends on his vintage and age. The production function is most conveniently defined in terms of "time," i.e., the proportion of earning capacity which is sacrificed to obtain a given rate of growth in his capital stock. Analytically,

$$(1) \qquad y = G_\mu \left(\frac{dK}{d\tau}\frac{1}{K}, \tau\right)$$

where $0 \leq y \leq 1$ is the proportion of earnings capacity retained, $\frac{dK}{d\tau}\frac{1}{K}$ is the rate of accumulation of human capital, K, and τ is age. We assume that both partial derivatives of G_μ are negative. Thus at each age a larger sacrifice of current earning is necessary to acquire a higher rate of accumulation. This is a restriction imposed by equilibrium wage structure. As the individual becomes older, it is increasingly difficult to obtain additional knowledge for a given investment of time. Notice that the production function is assumed to be independent of time.

The individual forms expectations on future prices which will obtain at time $t = \mu + \tau$. On basis of these expectations he chooses an investment plan which maximizes the expected present value of his real lifetime earnings. We assume that on average his lifetime expectations are correct so that no revision of the optimal plan is necessary. We can thus view the development of earnings as consisting of a permanent part which reflects the optimal plan which the individual chooses upon entering the labor force and a transistory part which reflects unexpected changes in prices, or technology.

Earnings can thus be written as

$$(2) \qquad Y = K^*(\mu,\tau)\ y^*(\mu,\tau)R^e(t)D(t)$$

where $R(t) = R^e(t)D(t)$ is the rental rate of human capital,[1] $R^e(t)$ is the expected rental rate and $D(t)$ denotes unexpected deviations which reflect unforeseen changes in demand or supply. $K^*(\mu,\tau)$ denoted the optimal level of capital which is controlled by the individual through his choice of $y^*(\mu,\tau)$.

A specific solution of the individual optimization problem requires the specification of the trade-off functions $G(\cdot)$. In general there will be different production functions associated with school and on-the-job training.[2] For the sake of brevity, we shall consider only post-school investment. We assume that the trade-off function for such an investment is:

$$(3) \qquad G_\mu\left(\frac{dK}{d\tau}\frac{1}{K}, \tau\right) = \left[1 - \frac{1}{\beta(\tau)}\left(\frac{dK}{d\tau}\frac{1}{K} + \delta(\tau)\right)\right]^\alpha \qquad 0 \leq \alpha \leq 1$$

where $\beta(\tau)$ is an efficiency parameter which depends on age, and $\delta(\tau)$ is the rate of depreciation of K, which also depends on age. The fixed parameter

α governs the concavity of the trade-off function. Concavity is assumed to avoid jumps in the level of investment. The specification (3) is in the spirit of Blinder and Weiss [1976] and Rosen [1975]. It assumes a different type of neutrality from the one first suggested by Ben Porath [1967]. In this model $\frac{\dot{K}}{K}$ is independent of K_0 along the optimal path while $\dot{K}$ is independent of K_0 in the Ben Porath formulation. The multiplicative model (2) and (3) leads naturally to log earning as a dependent variable. In this sense it is more consistent with empirical practice.

The model leads to the following differential equation for planned earnings (see the Appendix for a proof):

$$(4) \qquad \frac{dY}{d\tau}\frac{1}{Y} = \frac{1}{1-\alpha}\left[\beta_\mu(\tau) + \alpha\frac{d\beta}{d\tau}\frac{1}{\beta} - \delta(\tau) + g_{\mu+\tau} - \alpha r_{\mu+\tau}\right]$$

whenever $0 < y < 1$. (We denote by $g_{\mu+\tau}$ and $r_{\mu+\tau}$ the expected rate of change in the rental rate and the expected interest rate at time $t = \mu + \tau$). When no investment is undertaken, $y = 1$,

$$(5) \qquad \frac{dY}{d\tau}\frac{1}{Y} = -\delta(\tau).$$

A complete solution of the model requires the determination of the length of the schooling period (which may be interpreted as a phase in which $y = 0$) and the no-investment period $y = 1$. (For a complete solution, assuming no age effects, wee Weiss [1975]. To simplify, we shall assume that the level of schooling is predetermined and that equation (4) is valid throughout the observable age range.

Equation (4) shows quite clearly the effects of the various exogenous factors on the planned growth in earnings. A permanent increase in the interest rate or the depreciation rate will lead to a lower growth rate. A permanent increase in the expected rate of change of the rental rate g leads to a steeper earnings profile. For example, a 1 percent increase in g produces a more than 1 percent increase in the growth of observed earnings. This reflects the increased profitability of investment in human capital when the rate of growth in productivity is higher. When the rate growth or interest is expected to vary, an individual will shift his investment so that higher growth in earnings will be observed when the real interest rate is low or when the growth in the real rental rate, g, is high. Diferences in β, the efficiency parameter, may arise from differences in individual ability. A person with greater learning ability will have a steeper log earnings profile.

The effects of age are reflected in the dependence of productivity and depreciation on age. Generally speaking, they tend to introduce concavity in the log earning profile. In the special case in which learning efficiency β is independent of age while the depreciation rate δ increases linearly with age or experience, the log earning profile will be quadratic in experience. This is the form popularized by Mincer [1974].

The effect of vintage on the rate of growth in earnings is through its effect on the efficiency parameter β. This effect should be distinguished from the possible effects of vintage on the level of earnings through increases in the initial earning capacity $K_{\mu}(0)$. A potential systematic source of vintage effects is a process of learning by doing. In the simplest case each generation can be viewed as starting with a higher initial level of human capital, thus embodying the knowledge accumulated by past generations.[3]

Within our model such an increase will not affect investment behavior and later vintages will have uniformly a higher level of human capital throughout their life. If the initial human capital stock of each vintage grows at a constant rate, so will the aggregate over all age groups. The model then becomes identical ot one in which a population grows at a constant exogenous rate.

It seems clear that past knowledge is not transmitted in such a costless, one-shot fashion. In fact, schools and firms serve as a vehicle for the intergenerational transfer of knowledge. The embodiment of past knowledge requires the investment of time on the part of the individual and is, therefore, spread over a considerable part of his life. As general knowledge accumulates, recent vintages benefit more from the investment of their time in school. It seems plausible that they also become more "efficient" in terms of their learning on the job. Put differently, the rate of transmission depends jointly on the stock of existing knowledge as well as on the amount of time (and other resources) that each individual spends learning, and on the amount of resources which are spent teaching him. It is obvious that such a trend of increasing learning efficiency is not neutral with respect to its effect on the shape of the investment plan. Other things being equal, new vintages will tend to invest more in human capital. They will spend more time in school and their earning profiles will be steeper.[4]

For the purpose of empirical implementation, it is important to distinguish between two alternative specifications of the increase in individual learning efficiency. We may assume that the parameter β depends simply on the chronological time of investment. Thus, independently of the date of entry into the labor force all investors at time t have equal learning efficiency. Under such circumstances there will be a motivation to postpone the investment in human capital. It is possible, for instance, that individuals will decide to enter or re-enter school at later stages of their life. An alternative view which is perhaps more plausible is that at each point of time the general advance knowledge affects individuals differentially depending upon how recently their human capital was acquired. The reason is that new knowledge is often different from past knowledge. For example, a different technique, a different theory, and occasionally a different language may be used to present it. Therefore, recent vintages will find the general advance of knowledge to be more complementary to their human capital and will be relatively more efficient in producing new human capital than older vintages at any given point in time. An extreme version of this view, one that allows us to retain the simple structure of the individual maximization problem, is that each successive vintage is endowed with a superior production function (i.e., higher β as well as higher K_0) for new knowledge which remains fixed throughout life.[5]

II. Empirical Implementation

A. Specification

In order to apply the model to data, we need to specify the exogenous variables which appear in equation (4). The basic simplifying assumption is that the effects of age, vintage, and other causal factors, such as sex, level and quality of schooling and type of employer, are linear. We further assume that the rental rate is expected to grow at some constant rate, while the interest rate is expected to remain constant. Planned earnings then satisfy the equation:

(6) $$\frac{dY}{d\tau}\frac{1}{Y} = a_0 + a_1\tau + a_2\mu + \sum_{j=3}^{J} a_j x_j$$

where τ is age, μ is vintage and x_j, j=3, J, are other factors which affect growth.

Rather than estimating equation (6) directly, using first differences in the log of individual earnings, we shall estimate its coefficients from a corresponding level equation. The reason is that we want to estimate the exogenous time effects on the level which would allow us to separate unexpected changes in demand from more systematic causes of the growth in earnings.

Using equation (2) and integrating equation (6) for every individual from μ to t, we obtain the earnings level equation:

(7) $$\ln Y(t,\mu) = \ln Y_\mu + a_0(t-\mu) + a_1[\tau^2(t) - \tau^2(\mu)] + a_2\mu(t-\mu) + \sum_{j=3}^{n} a_j x_j (t-\mu) + \ln D(t).$$

The function D(t) is specified by a dummy variable for each year of observation. The initial level of earnings is given by

(8) $$\ln Y_\mu = \tilde{g}\mu + \beta_0 + \beta_2\tau(\mu) + \sum_{j=3}^{J} \beta_j x_j$$

where $\tilde{g}$ is the rate of growth in starting salaries, $\tau(\mu)$ is age at highest degree, and the x_j, j=3,$\cdots$, J, are again other factors which affect starting salaries. Finally, rewrite[6]

(9) $$a_1[\tau^2(t) - \tau^2(\mu)] = \beta_1[\tau(t)-\tau(\mu)]^2 + \beta_2\tau(\mu)[\tau(t)-\tau(\mu)]$$
$$= \beta_1\cdot(t-\mu)^2 + \beta_2\tau(\mu)\cdot[t-\mu].$$

Substituting from equations (8) and (9) into (7), we obtain the basic functional form which we shall estimate.

One important aspect of this final specification needs to be considered further. The following identity is satisfied for every observation on each individual:

(10) Year of highest degree + Experience = Year of observation, or

$$\mu + t - \mu = t.$$

This identity implies an exact collinearity which forces one of the three variables - vintage, experience or time - to be dropped from the regression. The coefficient of the two remaining variables will then incorporate its effect. We omit the effect of vintage on starting salaries, μ. Therefore, the coefficient of experience will be $(a_0 - \tilde{g})$, while the year dummies will include the effect of $\tilde{g}$.

Notice that no information is lost by estimating the model in a level form. In particular, $\hat{a}_0$, the cohort average rate of growth over a given period (with all other variables being zero), can be estimated by adding the coefficient of the appropriate year dummy, divided by the length of the period, to the experience coefficient.

By using data on the level and not merely the growth in earnings, we can, to some extent, break the total cohort growth into experience, time and vintage effects. The level equation also measures the growth in earnings between any pair of years net of the effect of experience. The crucial issue is whether this growth is due to the difference in time or is due to the difference in vintage between the observations for which experience is the same. One extreme possibility is that all growth is in starting salaries and is thus vintage specific. There are no changes in the rental rate for human capital and thus no further exogenous effects on the cohorts' earnings. Hence, all further growth is attributed to additional experience acquired by the cohort. The true experience effect (evaluated at zero level of experience) is in this case a_0. The other extreme possibility is that the growth in starting salaries reflects the general growth in the economy which, at a given point of time, benefits identical members of the labor force equally, irrespective of experience. In this case the true experience effect (evaluated at zero level of experience) is $a_0 - \tilde{g}$. Since in general $\tilde{g}$ will include some presumably positive element which is vintage specific, we shall identify a_0 as the upper bound on the experience effect and $a_0 - \tilde{g}$ as the lower bound.

In order to complete the empirical specification, we must consider the error term in the log earning equation. We may distinguish two components of the error term: pure chance elements which are independent across observations, and unobserved persistent level effects. Individual differences in the initial level of human capital, K_0, and the initial investment in on-the-job training, y_0, are among the unobserved level effects. Under the present model, K_0 is unrelated to the investment pattern of the individual, and its omission causes no bias. On the other hand, if we assume that more recent vintages start their working life investing a larger proportion of their earnings capacity, the omission of y_0 will cause an overestimate of the experience effect and an underestimate of the growth effect. We use a generalized least square estimation method which incorporates the individual level component of the error structure as a random variance component. By using repeated observations for each scientist, efficiency is enhanced, and this source of heteroscedasticity is eliminated. (For more details, see Lillard and Weiss [1976].)

B. The Data

Our source of data is the National Science Foundation's Register of Technical and Scientific Personnel. We use a longitudinal sample of Ph.D.'s in which each scientist reported continuously at two-year intervals over the decade 1960-1970. The sample is composed of six fields: biology, chemistry, earth sciences, mathematics, physics and psychology.[8] Separate G.L.S. regressions were estimated for each field and for the aggregate of all fields and are reported in the Appendix.

The dependent variable is the log of basic earnings[9] in real 1970 dollars (observations with zero basic earnings were eliminated). Scientists who were employed in academic institutions could report tehir annual income on a 9 to 10 or 11 to 12 months' basis. All observations were transformed to a full-year basis.[10] In order to separate investment in on-the-job training from investment in schooling, we eliminated all students from the data. Scientists who were not fully employed were also eliminated.[11]

The independent variables are:

1. Age. Age is broken into three parts: age at highest degree (measured from age 22), work experience, and break. Break is defined as the difference between years since degree and the reported years of work experience. All three components of age and their interaction with experience are used. Since the longitudinal data indicated reporting error in the experience variable, the experience measure is calculated by year from the average reported during the decade.

When data on both experience (i.e., years of professional work experience) and years since highest degree are available, total experience is broken into predegree and postdegree experience along the lines suggested by Johnson and Stafford [1974].[12] In the fairly large number of cases (a maximum of

15 percent, in 1970) in which experience is not reported, (1) postdegree experience was set equal to years since degree and (2) predegree experience was set at the mean of the corresponding group with complete information on both experience and years since degree.

2. Time and Vintage. Year dummy variables are used to indicate the year of observation. This allows year to affect only the level of earnings. Reported year of highest degree is used as a measure of vintage. It is allowed to enter regressions only as an interaction with experience. These restrictions are imposed to avoid the identification problem which follows from equation (10).

3. Sex. In subsamples with a sufficient number of females (at least a hundred[13]), a dummy for sex was included and allowed to interact with experience.

4. Type of Employer. For scientists who were employed continuously by the same employer, we use dummies for the following types of employment: academic institutions, private industry, government. Those who changed employer during the decade are classified as unstable. The type-of-employer dummies are allowed to interact with experience and with the year of observation.

5. Quality of School. Data on the ranking of the school from which the scientist obtained his highest degree allowed use of a dummy variable to indicate whether the school is ranked in the top ten.[14]

The sample means for the independent variables are presented in Table 1. There is considerable variation in some of these across fields. The proportion continuously employed in private industry varies from 1% in psychology to 57% in chemistry. The proportion of scientists with unstable type of employment is fairly high and reaches 36% in physics. This, however,

Table 1. NSF Longitudinal Sample Characteristics

	Field						
	Aggregate	Chemistry	Physics	Biology	Math	Psych	Earth Sci.
Sample Size	11295	4330	1614	2160	758	1636	647
Type of Employer (%)							
Academic	.382	.208	.372	.552	.679	.446	.451
Government	.102	.053	.064	.138	.032	.185	.236
Industry	.274	.564	.205	.072	.074	.014	.130
Unstable	.237	.175	.358	.236	.215	.322	.182
% Female in Sample*	.026	.014	0	.047	0	.081	0
Ph.D. at Top Ten Grad. School	.302	.244	.354	.333	.352	.290	.487
Year of Ph.D.							
Mean (1900's)	50.4	49.6	51.3	49.6	51.0	52.1	51.1
Std. Dev.	7.3	7.3	7.1	7.6	8.0	6.6	7.4
Age of Ph.D.							
Mean	29.3	28.1	28.8	29.3	29.6	31.5	30.9
Std. Dev.	4.2	3.3	3.6	4.2	4.7	5.4	4.4
Experience in 1960							
Mean	9.5	10.2	8.6	10.0	9.8	7.8	8.9
Std. Dev.	7.2	7.3	7.0	7.4	7.8	6.4	7.3
Pre-Degree Exp.							
Mean	2.6	1.9	2.6	2.2	3.5	3.7	4.2
Std. Dev.	3.5	2.8	3.3	3.4	4.3	4.3	4.0
Break in Exp.							
Mean	.17	.12	.08	.40	.16	.10	.07
Std. Dev.	.78	.67	.56	1.1	.72	.77	.49

*Females were omitted from fields with less than one hundred females in the sample.

is an overestimate of mobility, since those persons not reporting type of employer in any year are also included in this category. The proportion of female scientists who are continuously employed is quite small. The highest proportion was 8% in psychology. The proportion of scientists with a Ph.D. from a top ranked school varies from 24% in chemistry to almost 50% in earth sciences. There is an inverse relation with the size of the field, suggesting that a more standardized measure of quality is necessary.

There is considerable variation in the age at degree within fields. The standard deviation is about 4 years, which is more than half the standard deviation in the chronological year at which the degree was obtained. The average age at attainment of Ph.D. is 30 years and almost 3 years of predegree work experience is reported. Partially due to our procedure in choosing the data, the mean break in experience (which is admitted only if it occurred prior to 1960) is very low. The mean post-degree experience is about 10 years, reflecting the relatively large proportion of young scientists in the sample.

III

Vintage, Experience and Time Effects: Some Empirical Results

This section begins with an analysis of sources of differences in earnings growth among scientists over the 1960-70 decade. These sources include field, type of employment, quality of Ph.D. granting institution, and sex as well as vintage, experience, and time. The results are based on the parameter estimates reported in the appendix. Due to the large number of interactions it is more revealing to describe the results in terms of predicted growth patterns rather than in terms of the basic coefficients. The predicted growth rates are based on the average time trend, i.e. the 1970 year effect (relative to 1960) divided by ten. Unless otherwise stated the individual year effects are ignored.[15]

1. Experience, Age, and Vintage

Observing each cohort over a period of 10 years allows a separation, to some extent, of the effects of vintage from the effects of experience on the growth of earnings. Total mean annual growth rates by level of experience and vintage for all scientists in academic employment are presented in Table 2. The rate of growth in earnings declines with increased experience for a given cohort. A ten year difference leads to a rather large 1.2 percentage points reduction in the annual real growth rate. It is important to distinguish this finding on the concavity of the log earning experience profile from previous cross section findings. Concavity of actual cohort earning profiles neither implies nor is implied by concavity of cross section profiles. In fact, if individual earnings profiles are linear (i.e. the absence of age effects) but vintage effects operate linearly on the slope of the earning function, the cross-sectional log earnings function is a concave quadratic function in experience, such as estimated by Mincer (1974) and his students. This, however, would be a

Table 2. Annual Growth Rates in Earnings by Vintage and Experience for all Academics

VINTAGE	YEARS OF EXPERIENCE				
	2	12	22	32	42
1958	7.5	6.3	5.0	3.8	2.5
1948	7.1	5.9	4.6	3.4	2.1
1938	6.8	5.6	4.3	3.1	1.8
1928	6.4	5.2	3.9	2.7	1.4

Note: The ranges indicated by arrows are those observed in the data for the decade 1960-70.

purely cross-section phenomenon reflecting vintage rather than experience effects.

We interpret the concavity of the earning function as reflecting the role of age in reducing the productivity of producing human capital. There is, however, an identification problem which arises from the fact that holding age at highest degree constant, experience and age move collinearly. It is quite possible that the mere accumulation of experience (or more generally human capital) is the cause of the observed reduction in growth rates. Fortunately, the N.S.F. data which we use allow us to separate age and experience effects on the growth in earnings. The effect of age, given experience, is represented by the age of highest-degree experience interactions. This is a significant and fairly large effect. For instance, a scientist who obtained his Ph.D. at age 30 rather than age 26 will for every level of experience have a rate of growth in earnings which is lower by .4 percentage points. This result supports the notion discussed in the theoretical analysis, that age per se increases the depreciation of earning capacity or alternatively reduces the capacity to acquire new human capital.

Our results indicate that differences in vintage have a significant effect on the rate of growth in earnings. Table 2 illustrates that more recent vintages have, for the same level of experience, a greater rate of growth in earnings. The effect is, however, smaller than that of the concavity of the log earning profile. For example, a ten-year difference in vintage leads to a difference of .4 percentage points in growth.

Before we proceed, however, an alternative interpretation of the patterns in Table 2 must be noted. The interaction between experience and the year of observation was omitted from the regression because of the identification problem discussed earlier. Thus a scientist of 1958 vintage with 12 years of experience is observed in 1970 while a 1948 vintage scientist with 12 years of experience is observed in 1960. Shifts in the relative earnings of all scientists, by the same percentage irrespective of their experience, are accounted for; but the possibility that changing market conditions affect scientists of different levels of experience differently is not considered. More specifically one may expect that newly hired scientists will suffer more during a downturn and gain more in the upswing. If this were the case we would expect to find individual year effects on the slope which would be significantly different from a pure trend. This possibility was tested for physics which underwent the sharpest changes in market conditions during the decade. We found no significant departure from trend. This provides weak support for the vintage interpretation of the positive interaction between year of degree and experience, and for the concavity interpretation of the negative experience squared effect.

An important implication of finding greater experience related earnings growth for more recent vintages is that cross-section data systematically underestimates the true contribution of experience. For instance, for the 1958 cohort with 12 years of experience in 1970 the cross section estimate is 3.2 percent while the true effect is at least 3.6 percent. This basic finding is brought out more clearly in diagram 1 where the predicted earnings profiles of selected cohorts and two predicted cross-section profiles are graphed. A cross-section prediction is obtained by varying experience with vintage while holding year of observation constant. Since scientists with less than 10 years of experience in 1970 are not present in the sample, that part of the profile is a pure extrapolation for this sample. It is worth noting, however, that this prediction is very close to the actual 1970 cross-section profile from inde-

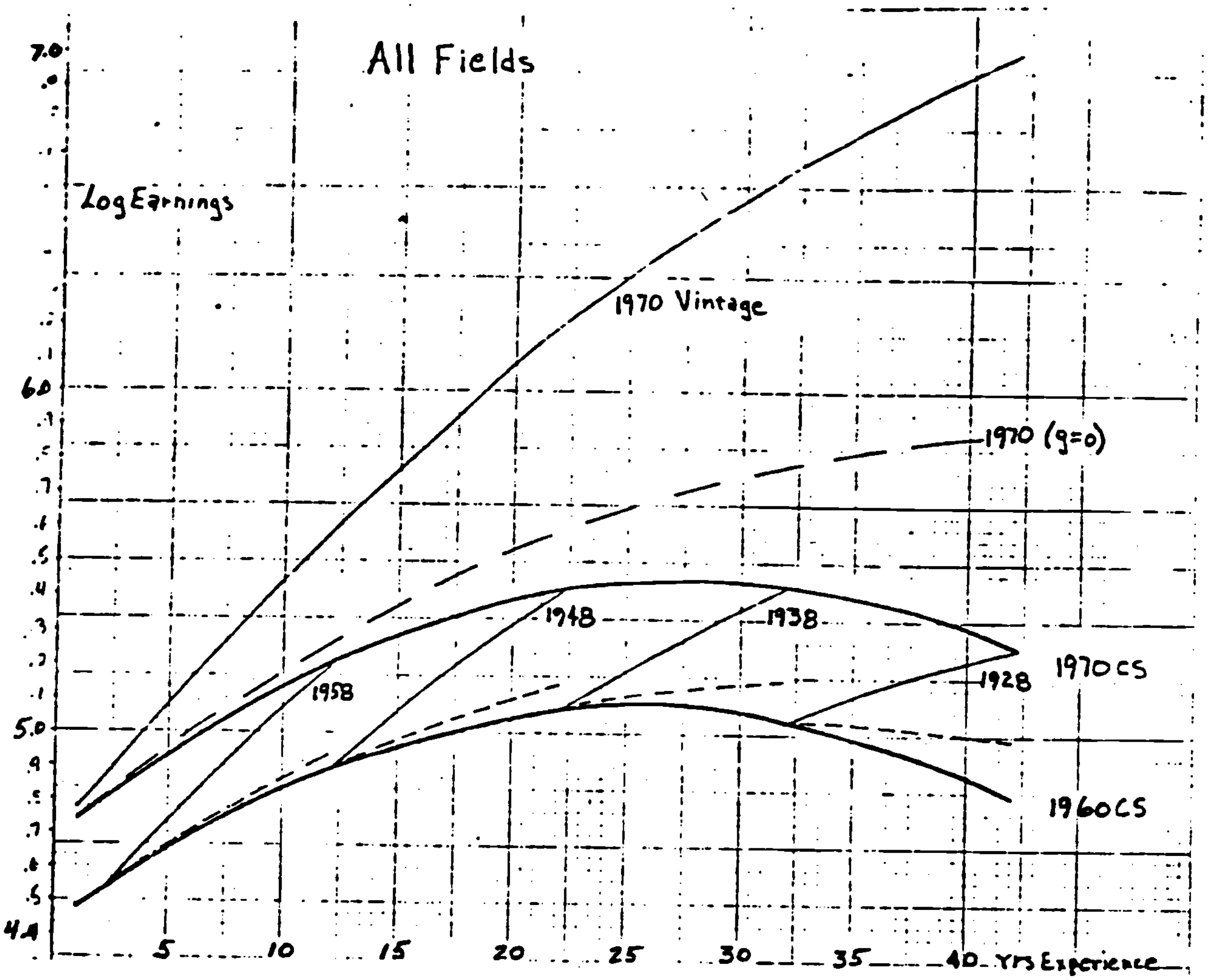

Figure 1. Log Earnings Profiles for the Aggregate of All Fields - Academics

Assumes Male = 1, Break in Experience = 0, Pre-Degree Experience = 0, Top Ten School = 0, Age at Highest Degree = 26.

pendent data which include scientists of all experience levels (see Lillard and Weiss [1976]). Notice that the 1960 and 1970 cross sections tend to diverge slightly at high experience levels. This reflects the positive interaction between experience and year of highest degree and may be interpreted as follows: either younger cohorts are more productive at on-the-job training investments or older cohorts experience greater productivity shifts during the decade.

A cohort prediction is obtained by varying experience with the year of observation while holding year of Ph.D. constant. We shall first consider such predictions within the sample period. The solid lines connecting the 1960 and 1970 cross sections show the average development of the cohort's earnings over the decade. They reflect both experience and time effects and can be viewed as the upper bound estimate of the experience effect during the decade. The dashed line represents the lower bound of experience effect, i.e. the growth in earnings which the cohort would experience in the absence of any exogenous growth in earnings. This line is above the cross section due to significant interaction between experience and vintage mentioned previously. There are thus these two extreme alternative interpretations for the development of cohort earnings over the decade. (1) The profile represents the true experience earnings relationship for the corresponding cohort resulting from accumulation of human capital. The cohort profiles differ due to initial endowment differences. And (2) the cohort profile represents the movement of individuals along experience earnings profiles which are being continuously shifted over time by changes in productivity, and more generally, market conditions. Under this interpretation, there are no vintage effects on the initial level of earnings. Rather than attributing all growth to experience, as we would do under the first interpretation, the share attributed to experience is now given by the dashed lower bound estimates, while the remainder (i.e. the difference between the solid and dashed lines) is attributed to exogenous time effects.

To further dramatize the difference between cross-section and cohort estimates, consider prediction out of the sample for the 1970 Ph.D. vintage. One prediction, of course, can be extrapolated from the 1970 cross section in Figure 1. This prediction is valid only in a perfectly static economy. The dashed and solid profiles represent the lower and upper bound estimates for the future development of earnings in a growing economy. The lower bound estimate is based upon the assumption that in the decade 1960-70 all exogenous growth reflected changes in market conditions common to all vintages and that from 1970 on no further growth in the real rental rate for human capital is expected. The upper bound estimates assume that all past growth is due to vintage effects which continue at the same rate for the 1970 cohort or, alternatively, that the average trend in the rental rate for human capital which existed during the period 1960-1970 will continue in the future.

A striking aspect of these predictions is that even under conservative assumptions we still predict that older scientists will enjoy an increase in their real earnings. This is in contrast to the observed downturn in cross-section profiles which tend to peak after 26 or 27 years of experience and are considerably flatter than the projected profile of any given vintage. More generally, due to effects of vintage on the growth in earnings, the cross-section data will tend to overestimate the concavity of true lifetime profiles.

The effects of vintage on the growth in earnings are not uniform across field or level of schooling. The interaction between year of highest degree and experience tends to be strong in physics, mathematics and biology and weak in psychology. The vintage effect also appears to decrease with the level of schooling. Estimates of the same earnings function for scientists with only a B.A. or M.A. degree from pooled cross sections of the years 1960, 1966, and 1970 showed no significant interaction between year of highest degree and experience. This difference in the interaction effect by levels of schooling means that the cross-section earnings profile underestimates the cohort experience effect to a greater degree for scientists with Ph.D.'s than for scientists with only a B.A. or M.A. degree. Therefore, cross-section comparisons by level of degree will underestimate the true contribution of schooling to lifetime earnings.

Given the rather strong implications of our finding a positive interaction between vintage and experience-related growth in earnings, it is important to note that this interaction is quite stable under several alternative specifications of the earnings function and in different data, i.e., independent pooled cross sections - 1960, 1966, 1970 (for details see Lillard and Weiss [1976] and Weiss [1975]). This leads us to conclude that, at least for the population under study, the vintage-experience interaction is robust. Needless to say, further tests based upon a longer time period and more direct measures of the causal factors which are captured by the year of highest degree are necessary before accepting the hypothesis of nonneutrality in vintage effects.

2. Quality of Schooling, Sex, Type of Employer and Field

Scientists who obtain their Ph.D's from a top-ranked institution were found to have a lsightly, but significantly, higher rate of growth in their earnings. This may indicate greater learning efficiency, probably due to self-selection, and thus more on-the-job investment. This result seems to be consistent with the finding of higher experience-related growth at higher levels of schooling. We found that for the 1958 cohort evaluated at 12 yaers of experience the lower bound on the experience-related growth in private industry was 4.2 percent for Ph.D.'s, 3.2 percent for M.A.'s and 3.1 percent for B.A.'s.

In psychology (where a large number of females are concentrated) there is a significant difference in the growth of earnings between females and males. The earnings profile of a woman has both a lower level and a flatter slope. Similar results, based on cross-seciton data, were reported by Johnson and Stafford [1974]. It is interesting to note that this difference persists for women who participated continuously over the decade, controlling for past breaks in experience. Of course it is still possible that the risk of future breaks diminishes the profitability of investment and leads to flatter profiles.

The discussion of experience effects is concluded with a description of the cohort rates of growth by type of employer and field. Since we allow year effects to differ by type of employer and field, it is more difficult to determine whether differences in the rate of growth reflect differences in investment behavior or in market conditions. Estimated average growth rates in starting salaries (vintage or time level effects) as well as total cohort growth rates are therefore presented separately. The estimated (lower bound) experience effect is then given by the difference between the cohort growth rate (Table 3) and the appropriate growth rate in starting salaries (Table 4).

Generally speaking, the experience effect appears to be weaker in private industry than in academic institutions, possibly indicating less investment on the job. Except for biology, however, the interaction between experience and private industry was not significant in the separate fields. (See Appendix Table) The effect of experience tends to be large in biology, physics, and chemistry and relatively small in psychology. Psychology provides a clear examply of the trade-off between future and current earnings in that high starting salaries are associated with low experience effects. It appears that fields differ in the trade-offs between current and future earnings which they offer. In fields with considerable amount of joint research, where highly experienced scientists and new entrants can combine their research effort, there is more opportunity for young scientists to invest in job training. This is reflected in the relatively large numbers of young scientists who report research as their primary work activity in fields like chemistry, physics, and biology.[16] Such fields are likely to have a larger experience effect.

Though we cannot specify their source, we nevertheless point to some of the patterns in estimated growth rates in starting salaries (Table 4). As

Table 3. Average Annual Growth Rates 1960-70 by Field, Type of Employer and Cohort

SOURCE	FIELD						
	All Fields	Biology	Chemistry	Earth Sciences	Math	Physics	Psychology
Academics							
Vintage							
1958	6.8	7.4	6.5	6.3	7.1	6.7	7.0
1948	5.2	5.6	4.9	4.9	5.6	5.0	5.4
1938	3.6	3.9	3.4	3.4	4.0	3.4	3.8
1928	2.0	2.2	1.8	2.0	2.5	1.7	2.2
Private Industry							
Vintage							
1958	4.8	6.0	4.7	4.4	5.2	5.0	5.7
1948	3.2	4.3	3.1	3.0	3.7	3.3	4.1
1938	1.6	2.6	1.5	1.6	2.2	1.6	2.5
1928	0.0	0.8	0.0	0.1	0.6	0.0	0.9
Government							
Vintage							
1958	6.7	7.7	6.3	6.5	6.8	6.7	6.4
1948	5.1	6.0	4.7	5.0	5.3	5.1	4.8
1938	3.5	4.3	3.2	3.6	3.8	3.4	3.2
1928	1.9	2.5	1.6	2.1	2.2	1.7	1.6

Table 4. Average Annual Growth in Starting Salaries 1960-70 by Field, and Type of Employer

SOURCE	All Fields	Biology	Chemistry	Earth Sciences	Math	Physics	Psychology
Academics	2.7	2.5	2.5	3.0	2.2	1.6	3.4
Private Industry	1.1	2.0	0.9	0.8	1.3	0.0	1.8
Government	2.7	2.7	2.9	3.4	1.9	1.8	3.0

already indicated, they include both vintage effects specific only to the entering cohort and general shifts in market conditions common to all cohorts. It is most likely that some of the differences in these rates (as distinguished from levels) reflect differences in demand (and/or supply) conditions. This source of growth was generally greatest in psychology and least in physics. It was low for those employed in private industry, as illustrated by the marked 1.6 percentage point difference in growth rate (1.1 vs. 2.7) between scientists employed in private industry and those employed in academic institutions. It appears that for the decade under discussion, demand conditions shifted in favor of academics. Most of the shift, however, occurred during the early part of the decade. (This can be seen from the individual year effects in the Appendix.)

In private industry a relatively low experience effect combined with the low growth in starting salaries produced a large two percentage-point difference in the total growth rate relative to academics (from Table 3). Comparison across fields, on the other hand, frequently indicates that a large experience effect is compensated by a low growth rate in starting salaries. This reduces variation in cohort total growth rates across fields. The growth of academic starting salaries is 1.6 percent in physics, for instance, vs. the 2.7 percent for all academics. The total cohort growth rate in phsycis is, however, only slightly less than average. These results clearly indicate that movements in starting salaries may be misleading estimates of the actual development of earning differentials.

In summary, the following patterns in the cohort total growth rates during the decade were noted:

(1) A high growth rate for scientists of recent vintage: growth rates for the 1958 vintage in academics range from 6.3 percent in earth sciences to 7.4 percent in biology.

(2) Considerably lower growth rates for scientists of older vintages: for the 1928 vintage in academics, these range from 1.7 in physics to 2.2 percent in mathematics. Note that due to differences in the vintage effects and the concavity of the earning profiles across fields, there is a change in the ranking of the fields as we move across cohorts.

(3) In private industry there are considerably lower growth rates. The youngest cohort (1958) in private industry grew by only 4.8 on the average, and the older vintage (1928) experienced virtually no real growth.

The differences by field are somewhat larger in private industry than in academics. For the youngest vintage (1958), there is a range from 4.4 percent in earth sciences to 6.0 percent in biology. This range narrows for older cohorts.

(4) Scientists in the government enjoyed real growth rates which are similar to those in academics. The noticeable exceptions are psychology and biology. Psychologists employed in the government experienced less growth than scientists in academics. The opposite is true for biologists. These differences, however, are much smaller than the differences between private industry and academics.

3. Some Implications for Changes in Relative Earnings Over Time

To obtain further insight into the implications of the size and pattern of real growth rates just discussed, let us conclude with a brief description of changes in the level of real earnings and the distribution of these changes by field and type of employer. These changes, presented in Tables 5 and 6, summarize the combined effects of the various vintage, time, and experience effects.

Table 5. Relative Earning Differences by Field (Academic Ph.D.'s)

	Annual Earnings All Fields* (dollars)	FIELD EARNINGS RELATIVE TO ALL FIELDS (PERCENT)					
		Biology	Chemistry	Earth Sciences	Math	Physics	Psychology
1960 Experience							
2	9183.7	-2.8	-6.4	0.6	-1.2	2.6	5.3
12	13271.7	2.5	-7.8	-0.6	1.7	7.2	4.6
22	15799.8	4.3	-8.8	4.6	1.1	6.7	7.0
32	15495.0	2.7	-9.3	16.2	-3.1	1.0	12.7
1970 Experience							
12	18110.4	2.9	-9.6	-4.0	1.7	1.4	7.3
22	22334.0	6.7	-10.8	-3.8	5.1	5.3	6.3
32	22689.2	7.1	-11.5	2.8	5.0	4.0	8.5
42	18988.5	4.0	-11.7	15.9	1.4	-2.4	13.9

*Geometric means

Table 6. Annual Earning in Private Industry and Government Relative to Academics by Field (percent)

	All Fields	Biology	Chemistry	Earth Sciences	Math	Physics	Psychology
Private Industry:							
1960 Experience							
2	32.5	31.3	36.3	26.7	56.0	40.9	32.6
12	28.8	23.1	34.7	29.7	46.5	39.0	35.9
22	25.0	15.0	33.1	32.7	37.0	37.2	39.2
32	21.2	6.8	31.4	35.6	27.5	35.4	42.5
1970 Experience							
12	12.4	18.0	18.1	7.8	37.3	23.7	20.0
22	8.6	9.8	16.5	10.8	27.8	21.9	23.3
32	4.9	1.6	14.9	13.7	18.3	20.1	26.6
42	1.1	-6.6	13.3	16.6	8.9	18.3	29.9
Government:							
1960 Experience							
2	9.0	3.0	22.1	8.4	29.9	18.5	3.0
12	8.0	5.1	17.0	5.2	30.5	16.4	0.7
22	7.9	7.1	11.9	2.0	31.1	14.3	-1.7
32	7.3	9.1	6.8	-1.2	31.7	12.3	-4.1
1970 Experience							
12	8.1	6.8	20.2	9.8	27.2	18.8	-2.6
22	7.5	8.8	15.1	6.6	27.8	16.8	-5.0
32	7.0	10.9	10.0	3.4	28.4	14.7	-7.3
42	6.4	13.0	4.9	0.2	29.0	12.7	-9.7

First, the annual rate of growth of 6.8 percent for the recent (1958 vintage) cohort implies that their real level of earnings almost doubled over the decade. In fact, it increased (for all scientists in adademics) from a mean of about $9,200 (in 1970 dollars) in 1960 to $18,100 in 1970. The oldest (1928) vintage had a much lower, but still substantial, gain from $15,500 (1970 dollars) in 1960 to $19,000 in 1970, an increase of 23 percent.

There were some noticeable changes in the relative earnings of the various cohorts by field. Biology, mathematics, and psychology improved their position relative to all fields while chemistry, physics, and earth sciences lost ground. There also was an increase in the range in earnings differentials between the lowest extreme, chemistry, and the highest extreme, psychology. Depending upon the cohort, the difference in earnings rose from 12 to 20 percent in 1960 up to 17 to 25 percent in 1970. The tendency for the difference between these two fields to be lower for the more recent cohorts reflects the stronger vintage effects on the growth in earnings in chemistry.

As one would expect from our discussion of the growth rate by type of employer, there are marked changes in earnings differences by employer. For the 1958 vintage, for instance, the monetary advantage of private industry relative to academics reduced from 32 percent in 1960 to 12 percent in 1970. This pattern is uniform across fields. In contrast we do not find a systematic reduction in the differences between the earnings of scientists in government and in academics. Again it is interesting to note that the difference between earnings in academics and in private industry is larger for the younger cohort. This is a reflection of differences in the experience effects which were already mentioned. Lifetime profiles in private industry tend to be flatter, and consequently, earnings differences among experienced scientists are lower than earnings differences among those with less experience.

Conclusion

The main conclusion which emerges from our study is that growth in earnings is not uniform or neutral. There is, therefore, no simple mechanical method by which individual actual life-time profiles can be inferred from a single cross section of data. Though much of the variance in growth is due to changing market conditions which were specific to the period under discussion there still remain systematic, and to some extent predictable, differences in growth due to levels of experience, schooling and vintage. An attempt was made to relate such differences in growth to differences in investment behavior which are to some extent voluntary.

The emphasis on investment behavior is helpful in focusing attention on some apparently systematic aspects of the earnings profile. In particular, the positive interaction between the date at which the degree is obtained (i.e., vintage) and the slope of the earnings profile admits a natural interpretation within the investment model. The same is true of the negative effect of age on the contribution of experience to earnings. Whether these phenomena can also be explained by an alternative or more general model is an important unresolved issue.

It should be noted that differences in planned earning profiles were explained within the limits of a rather narrowly specified model. It was assumed that individual earnings capacity, though not directly observable to the researcher, is known to employer and employee, that markets are sufficiently competitive to make general training a feasible alternative, that individuals can borrow freely on account of their future earnings, and that the effects of uncertainty and nonmonetary differentials are negligible. Most likely the relaxation of some of those assumptions would lead to better understanding of the role of individual characteristics in earnings growth.

Our empirical work did not incorporate market information, and therefore left unanswered the question, "What are the true underlying causes which operate under the heading of time and vintage?". Identifying the causal forces underlying these significant nominal differences would be a natural and important next step.

Footnotes

[1]An implicit assumption in this formulation is that individual with different levels of skills are <u>perfect</u> substitutes in production. There is thus a single rental rate.

[2]This will in general lead to a discontinuity in investment just upon leaving school. See Weiss [1975].

[3]If the state of knowledge is a function of past investment of all generations, then this process implies a discrepancy between the private and social returns for investment in human capital (see Arrow [1962] and Levhari[1966]). Thus, even if one may express doubts as to the importance of educational externalities within a generation, they are probably important with an intergenerational context.

[4]It is, however, not clear whether other things can in fact remain constant. For instance, if a larger initial segment of life is spent investing in human capital, the demand for borrowing by the young vintages will increase, and older vintages will be induced to provide the necessary transfer only at increasingly higher interest rates. The increase in the interest rate will provide a check to the tendency for increased investment. Note also that we ignored in the analysis the direct costs of the training process. If all costs are the opportunity costs of the individual (e.g., a new worker in the firm observes the others work without affecting their productivity), then changes in the rental rate of human capital will <u>not</u> affect investment decisions. In the more realistic case with direct costs the reduction in the rental rate will also put a check on the tendency for increased investment. The probable increases in the marginal cost of teaching will provide a further check.

[5]It should be pointed out that vintage or cohort effects may arise in a number of additional ways. Some may be specific exogenous factors, such as a war; others may reflect trends other than the general advance in knowledge. Specifically, we would expect the average ability (or productivity) of scientists who obtained their degrees during World War II to be lower than that of vintages of more normal times. More to the point, if there is in fact a trend of decreasing school admission standards, then such a trend would mitigate (or possibly offset) the effects of the advance in knowledge on the level and slope of the earnings profiles.

[6]If $\delta(\tau)$ and $\beta(\tau)$ in equation (4) depend only on age, then a restricted form is implied such that $a_1 = \beta_1 = \frac{\beta_2}{2}$. But we shall not incorporate this restriction allowing for the possibility, for instance, that the rate of depreciation depends on the number of years since degree rather than on age.

[7]This identity is not strictly correct due to possible breaks in the accumulation of experience. In the empirical analysis we shall control for such breaks.

[8]Scientists were allocated into fields on the basis of highest specialty. Only those with stable highest specialty were included in the sample; i.e., it was required that the highest specialty in each year equaled their Ph.D. major. The percent of reported years in which highest specialty was not equal to specialty of major degree is: 17.6 in Biology, 11.4 in Chemistry, 9.2 in Earth Science, 6.1 in Mathematics, 9.6 in Physics, 8.1 in Psychology.

This number is an upper bound on the proportion of scientists eliminated on the basis of occupational mobility, since some probably changed specialty more than once.

[9] The data also contained information on gross earnings, which include consulting fees, honoraria, and the like. Though conceptually superior, this measure of income has not been used by most researchers using the N.S.F. data. A reason is the probable errors of measurement which arise when the reporting scientist estimates his gross earnings. To allow comparability to other studies, we present earnings functions only in terms of basic earnings.

[10] The adjustment factor in each field is based upon a previous estimation from independent 1966 and 1970 cross section data in which a dummy variable for a 9 months salary was put on the right hand side of the regression equation (see Weiss [1975]). These correction factors are 1.086 for Chemistry, 1.149 for Physics, 1.178 for Biology, 1.142 for Psychology, 1.193 for Earth Sciences, and 1.099 for Mathematics.

[11] In order to be included in the sample, all individuals had to report their year of highest degree, year of birth, major of highest degree, first specialty, basic earnings and employment status.

Individuals were eliminated from the sample if they did not report a basic salary for all six years, if they had not received a Ph.D., and if their Ph.D. major differed from their reported first specialty in all six years.

[12] Predegree experience is defined to be experience minus years since degree if the difference is positive. It is defined to be zero otherwise. It should be pointed out that in the cases in which the difference is positive but there is a break in career _after_ the acquisition of the degree, then we in fact obtain true predegree experience minus break rather than predegree experience alone. We _cannot_ discover the existence of such breaks from the data. The only case in which a break is revealed is when reported experience is less than years since degree.

[13]More precisely, at least one hundred women had to be present prior to elimination on the basis of other criteria.

[14]For each scientist we had information on the name of the institute which awarded the degree. The rank of the institution is based upon the rankings provided by Cartter for 1964 and 1969, Keniston for 1957, and Hughes for 1925. See Johnson and Stafford [1974].

[15]Unless otherwise specified, the reported growth rates assume: males with no breaks in experience, no predegree experience, not from a top school, and age at highest degree equal to twenty-six.

[16]The proportion of scientists with less than 10 years of experience, who in 1970 reported their primary work activity as research are (by field): .485 for Biology, .494 for Chemistry, .235 for Earth Sciences, .244 for Mathematics, .581 for Physics, .290 for Psychology.

Appendix

The purpose of this appendix is to prove equation (4) in the text which describes the optimal planned growth in earnings.

The maximization problem faced by a person of vintage μ can be written as

$$\text{A.1} \qquad \max_{\{K\}} \int_0^T e^{-\int_0^\tau r(\mu+x)dx} R^e(\mu+\tau)KG(\frac{dK}{d\tau}\frac{1}{K}, \tau)d\tau .$$

such that $K(0) = K_\mu$; where T is the exogenously given length of working life. We shall consider here only the phase in which an iterior solution with respect to $\frac{\dot{K}}{K}$ occurs. We shall thus ignore the constraints which are implied by $0 \leq y \leq 1$ and by nonfeasibility of negative gross investment in human capital, i.e., $\frac{K'}{K} + \delta \geq 0$. (For a more detailed solution see Weiss [1975]).

The Euler first order condition is

$$\text{A.2} \qquad \frac{\dot{K}}{K} = \frac{G}{G_1} - \frac{\dot{G}_1}{G_1} + r - g$$

where G_1 is the partial derivative of G with respect to $\frac{\dot{K}}{K}$, $g = \frac{\dot{R}^e}{R^e}$ and we use the 'dot' notation to denote total derivative with respect to age.

Let us use the notation:

$$x = [\frac{\dot{K}}{K} + \delta(\tau)] \frac{1}{\beta(\tau)} \qquad \text{and} \qquad f(x) = (1-x)^\alpha$$

Then, under the functional form (3) assumed in the text for the trade-off function $G(\ )$, condition (A.2) may be rewritten as

A.3 $$\dot{x} = \frac{f'(x)}{f''(x)} [r + \delta + \frac{\dot{\beta}}{\beta} - g] + \beta \frac{f(x) - xf'(x)}{f''(x)}$$

The rate of increase in earning is given by

A.4 $$\frac{\dot{Y}}{Y} = g + \frac{\dot{K}}{K} + \frac{f'(x)}{f(x)} \dot{x} = g + \beta x - \delta + \frac{f'(x)}{f(x)} \dot{x}$$

and substituting for $\dot{x}$ we obtain

A.5 $$\frac{\dot{Y}}{Y} = g + \beta x - \delta + \frac{[f'(x)]^2}{f(x)\ f''(x)} [r + \delta + \frac{\dot{\beta}}{\beta} - g] + \beta \frac{[f'(x)]^2}{f(x)\ f''(x)} [\frac{f(x) - xf'(x)}{f'(x)}]$$

But, under our specification, $f(x) = (1-x)^{\alpha}$ and

A.6 $$\frac{[f'(x)]^2}{f'(x)\ f''(x)} = \frac{\alpha}{\alpha-1} \quad \text{and} \quad \frac{f(x) - xf'(x)}{f'(x)} = x\,\frac{1-\alpha}{\alpha} - \frac{1}{\alpha}$$

Hence

A.7 $$\frac{\dot{Y}}{Y} = g - \delta - \frac{\alpha}{1-\alpha} (r + \delta + \frac{\beta}{\beta} - g) + \frac{\beta}{1-\alpha} = \frac{1}{1-\alpha} [\beta + g - \delta - \alpha r - \alpha \frac{\dot{\beta}}{\beta}]$$

which is equation (4) in the text.

Appendix Table 1: Regression Estimates by Field and Estimation Technique

INDEP. VAR.	DEPENDENT VARIABLE IS LOG EARNINGS															
	GLS CHEMISTRY		GLS PSYCHOLOGY		GLS BIOLOGY		GLS PHYSICS		GLS EARTH SCI		GLS MATH		GLS ALL FIELDS		OLS ALL FIELDS	
	COEF	|t|	COEF	|t|	COEF	|t|	COEF	|t|	COEF	|t|	COEF	|t|	COEF	|t|	COEF	|t|
CONST	4.343		4.466		4.351		4.434		4.433		4.378		4.418		4.054	290.0
YR62	.0881	12.1	.0846	9.6	.0722	9.6	.0627	6.9	.0739	6.2	.0852	8.0	.0813	22.8		
YR64	.1590	16.5	.1700	12.5	.1509	13.1	.1312	10.1	.1859	10.8	.1573	9.3	.1621	31.4		
YR66	.2271	17.4	.2530	12.7	.2021	12.0	.1745	9.4	.2546	10.5	.2189	8.7	.2270	30.8	.209	28.8
YR68	.2767	16.1	.3360	12.3	.2625	11.3	.2083	8.3	.3214	9.8	.2575	7.4	.2865	28.7		
YR70	.2536	11.6	.3373	9.5	.2488	8.2	.1572	4.8	.2961	6.9	.2198	4.9	.2685	20.8	.245	42.9
PRE EXP=(P)	.0116	5.8	.0129	6.0	.0094	3.5	.0187	7.1	.0202	5.9	.0082	2.3	.0160	15.3	.0128	9.3
PxE	.0002	2.0	-.0002	1.6	-.00008	.6	-.0005	3.4	-.0004	2.1	-.0001	.8	-.0002	3.2	-.00038	3.7
EXP=(E)	.0533	33.4	.0519	20.8	.0631	28.9	.0613	26.3	.0478	15.0	.0589	18.1	.0539	57.9	.0644	47.7
BRK=	-.0095	1.5	-.0163	1.4	.0511	8.0	.0334	2.0	-.0179	.7	-.0124	.6	.0064	1.7	.0440	10.2
BRKxE	.0001	.3	-.0001	.2	-.0008	2.4	-.0019	3.0	-.0007	.7	.0004	.5	.0001	.7	-.0021	7.9
AGEHD	.0049	2.8	.0039	2.2	.0072	3.2	-.00007	.03	.0017	.5	.0056	1.7	.0012	1.3	.0088	7.5
AGEHDxE	-.0013	14.6	-.0011	11.3	-.0015	13.1	-.0011	8.0	-.0007	4.0	-.0012	6.8	-.0010	21.5	-.0013	14.6
E^2	-.0006	10.3	-.0008	7.5	-.0006	6.7	-.0004	4.6	-.0008	6.1	-.0004	3.0	-.0006	16.5	-.0008	11.2
TOPSC	-.0117	1.1	.0037	.2	-.0196	1.4	.0150	1.1	-.0249	1.3	.0033	.2	.0056	.9	.012	.9
TOPSCxE	.0018	3.6	.0013	1.7	-.0002	.3	.0016	2.3	.0015	1.5	.0010	1.0	.0012	4.1	.0015	1.7
YHDxE	.00033	3.2	.000005	.03	.00055	3.5	.00079	4.9	-.00015	.7	.00076	3.3	.00035	5.4	.00027	3.7
FEMALE	-.1590	4.1	-.0956	3.7	-.1983	6.3	0	0	0	0	0	0	-.1853	10.8	-.124	5.3
FEMxE	-.0015	.8	-.0048	3.6	-.0013	.8	0	0	0	0	0	0	-.0012	1.5	-.006	3.9
PRIV=(PI)	.3662	26.7	.3198	4.3	.3294	10.3	.4122	19.2	.2614	7.2	.5785	11.9	.3326	39.6	.393	26.0
GOVT=(G)	.2114	8.4	.0347	1.5	.0259	1.0	.1886	5.9	.0903	3.1	.2976	3.8	.0912	7.9	.068	4.2
UNSTAB=(U)	.2298	14.0	.0234	1.2	.0232	1.3	.2837	15.9	.1512	5.0	.2003	6.9	.1566	19.2		
PIxE	-.0016	1.6	.0033	.5	-.0082	3.2	-.0018	.9	.0030	.9	-.0095	1.8	-.0038	5.9	-.006	7.1
GxE	-.0051	2.8	-.0024	1.0	.0020	1.1	-.0021	.9	-.0032	1.6	.0006	.1	-.0006	.6	.0022	2.5
UxE	.0001	.1	-.0004	.2	.0022	1.5	-.0034	2.3	-.0022	.7	-.0027	1.1	-.0007	1.0		
PIx62	-.0384	4.9	.1072	2.5	.0101	.6	-.0088	.7	-.0463	2.1	.0054	.2	-.0249	5.2		
PIx64	-.0742	8.8	-.0381	.8	-.0150	.7	-.0512	3.4	-.1395	5.6	.0003	.01	-.0676	12.9		
PIx66	-.1296	13.5	-.1244	2.1	-.0316	1.4	-.0982	5.7	-.1983	7.0	-.0597	1.5	-.1169	19.6	-.097	6.2
PIx68	-.1729	15.8	-.1276	1.8	-.0679	2.6	-.1510	7.5	-.2359	7.2	-.0943	1.9	-.1668	24.3		
PIx70	-.1654	13.3	-.1587	1.9	-.0515	1.7	-.1528	6.5	-.2188	5.8	-.0917	1.6	-.1636	20.8	-.110	7.1
Gx62	-.0407	2.8	-.0232	1.7	-.0231	1.7	-.0400	2.0	-.0324	1.8	-.0501	1.3	-.0350	5.2		
Gx64	-.0045	.3	-.0191	1.2	.0180	1.2	-.0075	.3	-.0307	1.6	-.0122	.3	-.0123	1.7		
Gx66	-.0147	.8	-.0582	3.0	-.0001	.01	-.0030	.1	-.0326	1.5	-.0303	.6	-.0333	4.0	-.026	1.5
Gx68	-.0469	2.3	-.0629	2.8	-.0369	1.9	-.0389	1.4	-.0483	2.0	-.0707	1.3	-.0593	6.3		
Gx70	.0314	1.4	-.0326	1.2	.0175	.8	.0244	.8	.0463	1.7	-.0333	.5	-.0038	.4	-.001	.1
Ux62	-.0291	3.0	.0114	1.0	.0261	2.4	.0048	.4	-.0154	.8	.0389	2.3	.0013	.3		
Ux64	-.0736	6.8	.0038	.3	.0260	2.1	-.0318	2.6	-.0552	2.5	.0170	.9	-.0249	4.5		
Ux66	-.1323	10.9	-.0080	.5	.0247	1.8	-.0844	6.0	-.0714	2.7	-.0077	.4	-.0573	9.2		
Ux68	-.1657	12.0	-.0098	.6	.0076	.5	-.1288	8.0	-.0980	3.2	-.0583	2.3	-.0861	12.0		
Ux70	-.1805	11.4	-.0028	.1	.0111	.6	-.1301	7.0	-.0641	1.8	-.0656	2.2	-.0896	10.8		
R^2	.533*		.671*		.668*		.624*		.676*		.701*		.608*		.634	

*Equations estimated in deviation form with constant calculated separately. R^2 values are weighted but exclude the contribution of the constant.

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