# Scientists' salaries and the implicit contracts theory of labour markets

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**Abstract:** Government intervention in labour markets is often justified by citing phenomena in actual labour markets which deviate from the predictions of neoclassical theory. The case for such intervention will be considerably weakened if the anomalous phenomena can be explained by implicit labour market theories that are extensions of the neoclassical theory. The purpose of the current research is to test two well-defined alternative implicit labour markets models of the labour market for scientists. The test makes use of a longitudinal data set compiled by the author that contains data for scientists on number of citations per year and on annual salaries. The evidence, although somewhat mixed, tends to support the 'learning model' over the 'incentives model'. The most dramatic evidence is that the effect of citations on salaries declines as the scientist gains experience. More evidence will be required before we can reach sound general conclusions on the empirical success of the theories.

**Keywords:** Learning; incentives; scientists' salaries; implicit labour markets; compensation; scientific reward structure.

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**Biographical notes:** Arthur M. Diamond, Jr. is the Noddle Professor of Business Administration at the University of Nebraska, Omaha. His research focuses mainly on the economics of science and technology, and has appeared in journals such as *Science; Economic Inquiry; The Journal of Human Resources;* and *Science Technology and Human Values*. Recently 29 leading scholars in several fields commented on his essay 'The Economics of Science' in a special issue of *Knowledge and Policy: The International Journal of Knowledge Transfer and Utilization*.

## 1 Introduction

The conventional neo-classical theory of labour economics leads us to expect that workers in every period will be paid the value of their marginal product in that period. In the past two decades, however, labour economists have paid increasing attention to evidence inconsistent with the standard theory. Some of the evidence consists of repeated empirical studies showing that years of experience remain an important determinant of earnings even after experience-related differences in productivity have been taken into account. Other evidence consists of the stability of wages over the business cycle and over demand-related shifts in firm profitability. Yet other evidence consists of the common observation for many occupations (e.g., research scholars) that the variance in measures of productivity (e.g., the number and quality of published articles) is much greater than the variance in salaries.

Partly in response to such evidence, an active literature (sometimes called the 'implicit contracts literature') has arisen attempting to account theoretically for the stylized facts. The literature is generally related to the concerns of labour economists, but frequently is also of interest to macroeconomists (especially those concerned with unemployment) and to specialists in industrial organization and finance. So far, the literature is overwhelmingly dominated by purely theoretical work, but a few papers have begun to bring systematic empirical analysis to bear on evaluating the theories. One main reason for the lack of empirical tests is that most of the divergent predictions of the competing models involve the relation of productivity to compensation. Since data sets with good measures of productivity are rare, tests of competing models have likewise been rare. The current research makes use of a data set compiled by the author that contains data for research scientists, economists and mathematicians (collectively referred to as 'scientists' in the rest of the paper) on: number of publications per year (quantity of output), number of citations per year (quality of output) and annual salaries (compensation). The data set is 'longitudinal' which means that it includes multi-year data for each scientist in the sample.

The purpose of the research is to test two well-defined alternative models of the labour market for scientists.

## 2 Alternative models

For a discussion of earlier research on the determinants of scientists' salaries see Diamond [1]. The basic ideas in implicit contracts theory have been well-summarized in Rosen's 1985 survey article [2] which also provides references to many of the important papers in this literature [3,4]. Another useful survey article is Parson's 1986 paper in the *Handbook of Labor Economics*. In the last paragraph of his conclusion, Parsons [5] notes:

> "The empirical analysis of employment contracting has only begun. I suspect that much more empirical work is now necessary if progress in this area is not to degenerate into the relatively uninsightful enumeration of the theoretical possibilities." [5,p. 843]

Raisian [6] and Brown [7] are among the few works to test implicit contracts models. Brown finds that when tenure with the firm is correctly measured, the tenure variable along with other standard variables such as the education and experience variables explain most of the variation in earnings over the life-cycle. He concludes that there is not much left for implicit contracts models to explain.

Murphy [8] was the first economist to attempt to empirically distinguish between competing contract models. His analysis uses a longitudinal data set he constructed based on the *Forbes* Executive Compensation Surveys for 1974-1984. The surveys contain salary, bonus and biographical data on Chief Executive Officers (CEOs) for 1,191 corporations. Executive productivity is measured by the firm's rate of return which was obtained from a variety of publicly available stock market databases. Murphy tested two models. The key feature of the 'incentives' model is that 'productivity depends on unobservable effort' while the key feature of the 'learning' model is that 'ability is unknown and is revealed over time'.

Murphy notes, in agreement with Parsons' earlier comments, that in current research on contract theory, "surprisingly little direct empirical research has been undertaken or reported, ..., and attempts to reconcile competing hypotheses are rare" [8,p.59]. The current research increases by one the number of those rare attempts.

We follow Murphy in considering one version of an 'Incentives Model' and two versions of a 'Learning Model'.

1 Incentives model

A scientist's productivity in the first model depends on two components: effort and luck. Productivity that is higher than that expected, will increase the scientist's earnings; lower productivity will lower earnings. If scientists are risk-averse, then it is assumed to be efficient for universities to offer contracts that spread the increase or decrease over the remaining periods. As retirement approaches, increases or decreases will be spread over fewer periods, with the result that the variance in a given scientist's earnings will increase with experience. For the same reason, the variance of salaries among a cohort of scientists will increase as the scientists gain experience.

2 Learning model (expected marginal product version)

A scientist's productivity in the first version of the second model depends on two components: ability and luck. Initially, the scientist's ability is unknown both to him and to the university. Actual ability is learned by repeated observations of actual productivity. In each period, the scientist receives the value of his expected productivity based on the best estimate of his ability. When the actual productivity is lower than expected, the estimate of ability will be revised downward; conversely, when actual productivity is higher. Differences between actual and expected productivity will result in larger revisions earlier in the scientist's career than later (when the scientist has already established a lengthy track record). As a result, the variance in a given scientist's earnings will decrease with experience. The cross-sectional variance of salaries among a given cohort of scientists, however, will increase as the variance in salaries gradually increases to reflect the distribution of actual abilities among the scientists.

If the luck component is a random variable that is symmetrically distributed around its mean, then approximately half of the scientists in a given year will receive a salary increase and half will receive a salary decrease.

Under this version of the learning model, the salaries of scientists are expected to increase at a decreasing rate. As the university obtains better information about the abilities of professors, they more efficiently assign capital to the more able scientists. The result is that on average the value of the expected marginal product will increase with experience, but at a decreasing rate. The decreasing rate is because additional realizations of productivity increase the precision of the estimate of ability by smaller and smaller amounts with each realization.

3 Learning model (insurance version)

A scientist's productivity in the second version of the second model depends on the same two components as in the first version: ability and luck. Initially, the scientist's ability is unknown both to him and to the university. Actual ability is learned by repeated observations of actual productivity. In each period, the scientist receives the value of his expected productivity based on the best estimate of his ability. When the actual productivity is lower than expected, the estimate of ability will be revised downward; conversely, when actual productivity is higher. Differences between actual and expected productivity will result in larger revisions earlier in the scientist's career than later (when the scientist has already established a lengthy track record). As a result, the variance in a given scientist's earnings will decrease with experience.

The insurance version differs from the expected marginal product version in that the insurance version assumes that universities will be the most efficient providers of income insurance for risk-averse scientists. (The expected marginal product model assumes either that scientists are risk neutral or, more plausibly, that some other institution is more efficient than the university at providing scientists insurance to smooth fluctuations in income). In the insurance version of the model, even when the luck component of productivity is symmetrically distributed, scientists will in effect be insured by universities against declines in salary. Another implication of this model that distinguishes it from the first version of the learning model is that a scientist who has a good year following a series of years with below average productivity will not always receive an increase in salary. The reason is that because of the insurance aspect of the contract, the scientist is already being overpaid relative to the value of his productivity.

## 3 Data

The data set to be analysed in the proposed research has previously been used to answer three questions. The first [9] was how the order of authorship on an academic paper affects the compensation that a scientist receives. The second [1] was whether the academic labour market rewards the number of citations that other scientists make to a scientist's published work. The third [10] was whether a scientist's research productivity declines with age. In what follows in this section, I discuss some of the unique features of the data.

Since the purpose of the study was to investigate the productivity of research scientists, a population with a high concentration of research scientists was chosen: full and *emeriti* professors in highly ranked departments. The departments selected were located either at the University of California at Berkeley or at the University of Illinois at Urbana because, as state supported schools, they make faculty salary data publicly available. In order to insure the robustness of the results and to allow inter-departmental comparisons, three departments at each school were chosen for study. The departments chosen were: Urbana chemistry, Berkeley economics, Berkeley mathematics, Urbana mathematics, Berkeley physics, and Urbana physics.

The basic samples were obtained from faculty listings in catalogues from the late 1970s. Since these listings underrepresented those who were nearing the end of their careers in the early years of the *Science Citation Index* (i.e., the 1960s) the samples were augmented by all those full and *emeriti* professors listed in a catalogue from the middle 1960s who were not also listed in the catalogue from the late 1970s. From these samples, any scientist was dropped for whom biographical information was not available.

Occasionally a scientist was also omitted from the sample if his name was identical to another scientist as listed in *the Science Citation Index* (SCI) since it would have been too costly to distinguish citations to his work from those to the like-named scientist's work.

At the time of collection of the data, annual volumes of the SCI had been published from 1961 through 1979, but since the coverage of mathematics journals in the first four years was very limited, only the years 1965–1979 were used to obtain mathematics citation counts. In construction of the data set, the main measure of citations consisted simply of the total number of citations made in a year to all of a scientist's earlier work. For example, if a scientist was cited 40 times in 1979 according to the 1979 SCI, the scientist's 1979 citation count would be 40.

**Table 1** Sample means*

| | *All* | *Chemistry* | *Economics* | *Mathematics* | *Physics* |
|---|---|---|---|---|---|
| No. of Scientists | 263 | 28 | 22 | 106 | 108 |
| Year of Birth | 1925.8 | 1925.4 | 1922.0 | 1927.4 | 1924.9 |
| | (9.0) | (8.4) | (11.7) | (9.4) | (8.3) |
| | [3350] | [343] | [148] | [1295] | [1573] |
| Year of PhD | 1952.7 | 1951.3 | 1951.3 | 1954.2 | 1952.0 |
| | (8.9) | (8.2) | (11.9) | (9.6) | (8.1) |
| | [3350] | [343] | [148] | [1295] | [1573] |
| Year of Assoc. Professorship | 1958.0 | 1953.6 | 1957.8 | 1962.0 | 1957.6 |
| | (9.4) | (8.9) | (10.2) | (9.3) | (8.9) |
| | [2360] | [343] | [113] | [531] | [1382] |
| Year of Full Professorship | 1964.7 | 1962.5 | 1962.5 | 1966.3 | 1964.0 |
| | (8.0) | (8.0) | (10.2) | (7.5) | (7.9) |
| | [3295] | [343] | [148] | [1240] | [1573] |
| Year of Observation*** | 1971.2 | 1969.8 | 1975.4 | 1971.9 | 1970.5 |
| | (4.9) | (5.6) | (2.3) | (4.2) | (5.2) |
| | [3350] | [343] | [148] | [1295] | [1573] |
| Potential Experience*** | 18.5 | 18.5 | 24.1 | 17.7 | 18.5 |
| | (9.2) | (8.8) | (11.1) | (9.6) | (8.4) |
| | [3350] | [343] | [148] | [1295] | [1573] |
| Salary (in 1967 $) | 17377.8 | 17897.4 | 20129.3 | 16781.7 | 17472.2 |
| | (4707.3) | (4987.5) | (5167.5) | (4574.7) | (4596.7) |
| | [3350] | [343] | [148] | [1295] | [1573] |
| Annual citations received to all previous work | 34.3 | 74.9 | 25.9 | 17.9 | 39.5 |
| | (57.1) | (81.2) | (30.3) | (24.5) | (65.8) |
| | [3349] | [343] | [148] | [1294] | [1573] |

* The top number is the mean. The second number (in parentheses) is the standard deviation. The third number [in brackets] is the number of observations for which the mean and standard deviation were calculated.

** Since the data set is longitudinal, there are multiple observations for each scientist. The number of observations per scientist varies, depending mainly on the availability of salary information.

*** Potential experience is equal to the year of the observation minus the year of receipt of PhD.

Descriptive statistics for the main sample used in the earnings functions, as well as sub-samples for the four academic disciplines, appear in Table 1. The economics and chemistry disciplines are represented in the sub-samples by one department each, while the mathematics and physics disciplines are represented by two departments each.

## 4 Estimation and results

I examine the robustness of Murphy's results by applying the tests he performed on the executive labour market, to the labour market for scientists. I use standard ordinary-least-squares regressions to estimate earnings functions for the scientists. The regressions estimated take the form:

$$(\ln salary_t)-(\ln salary_{t-1})=\beta_0+\beta_1(\text{potential experience})+\beta_2 \text{ citations}_t - \text{citations}_{t-1})+\varepsilon$$

where the error term, ε, is assumed to be independently and identically distributed (i.i.d.) across scientists, universities, academic disciplines and years. Since salary structures and citation practices often differ by discipline (and sometime by university), the i.i.d. assumption would be obviously false if the regression were in levels of the relevant variables. In the regressions estimated here, the assumption that the error term is i.i.d. is made somewhat more plausible by the use of first differences in salaries and in citations.

The dependent variable is the first difference of the natural log of salaries. My measure of performance is the first difference in the annual citations received to all of the scientist's previous work [11]. The level of potential experience is also included in the regressions. In Table 2, I report earnings functions for all scientists and for scientists grouped into three roughly equal-sized groups ordered on the basis of level of experience.

**Table 2** Regressions of change in log salary on observations grouped by experience*

| | | *Years of potential experience* | | |
|---|---|---|---|---|
| *Variable* | *All* | *0-13* | *14-21* | *22 or more* |
| Level of potential experience** | 0.00031 | 0.00279 | -0.00204 | 0.00046 |
| | (1.637) | (2.432) | (1.776) | (0.979) |
| Change in annual citations | 0.00060 | 0.00146 | 0.00035 | 0.00018 |
| | (8.472) | (8.764) | (3.845) | (1.627) |
| Constant | -0.00107 | -0.02471 | 0.04328 | -0.00780 |
| | (0.271) | (2.291) | (2.160) | (0.563) |
| Number of persons | 263 | 168 | 189 | 162 |
| Number of observations*** | 3347 | 1115 | 1080 | 1167 |
| $R^2$ | .022 | .072 | .016 | .003 |
| Mean of dependent variable | 0.0050 | 0.0014 | 0.0081 | 0.0055 |
| Variance of dependent variable | 0.0105 | 0.0162 | 0.0074 | 0.0080 |

* The absolute value of the t-statistics are reported in parentheses.

** Potential experience is equal to the year of the observation minus the year of receipt of Ph.D.

*** Since the data set is longitudinal, there are multiple observations for each academic. The number of observations per academic varies, depending mainly on the availability of salary information.

Citations appear to be an important determinant of the salaries of scientists in the sample. In the regression for all scientists in the sample, the coefficient of citations is statistically significant at customary significance levels. The estimate of 0.0060 implies that at the sample mean salary of $17,377.80 (in 1967 dollars), an additional citation adds about $10 (in 1967 dollars) to a scientist's salary. This value is in the range of earlier estimates of the marginal value of a citation (for a survey of these estimates [1]).

Murphy finds some mixed evidence [8, pp.70&72, Tables 3&4] that the coefficients of the experience variables are negative, indicating that the experience-earnings profile is concave. The concavity of the experience-earnings profile is predicted by the expected marginal product version of the learning model. The incentives model and the insurance version of the learning model yield no implications on the curvature of the profile. In contrast with Murphy's findings for executives, I find mixed evidence indicating no statistically significant relationship between the level of potential experience and the change in log salary [12]. The most plausible interpretation is that for my sample, the experience-earning profile is linear. If sound, this interpretation would be inconsistent with the expected marginal product version of the learning model.

According to the incentives model, because universities smooth income for risk-averse scientists, changes in annual citations will be reflected in the salaries in all remaining periods. Thus, a one period change in citations will have a greater one period effect on salaries later in the scientist's career when there are fewer remaining periods. Conversely, according to the learning models, a one period change in citations will have smaller effects on salaries later in the scientist's career, because as time passes the information gained about actual ability from observing a change in citations will be small relative to the scientist's accumulated track record. An examination of Table 2 reveals that the coefficients of the citations variables fall with increasing potential experience [13]. This result is consistent with what Murphy found for executives [8.pp.70&72, Tables 3&4] and supports the learning models.

The incentive model predicts that a given scientist will have increasing variance in salary as he progresses through his career. The learning models have the opposite implication. In Table 2, I have estimated the variance in the difference in log earnings over three ranges of values of potential experience. The variance drops by more than half from the first range to the second, and rises slightly from the second to the third. The evidence is thus mixed, but to the extent that it indicates that the variance of salaries declines with experience, it would support the learning models over the incentive model. Murphy's evidence for executives [8,pp.70&72, Tables 3&4] was also mixed, but perhaps also slightly favoured the learning models.

The evidence cited so far tends to support the learning models in preference to the incentive model. We have encountered some limited evidence in favour of the insurance version of the learning model, in the form of a failure to find the concave earnings-experience profile that is predicted by the first version.

Some additional evidence can be brought to bear in order to distinguish between the two versions of the learning model. Of the 3550 observations for which we observe salary differences, a substantial 1479 (44.1%) are negative, indicating that in my sample, declines in real earnings are not at all rare. Murphy had found for the executives [8,p.73] that 34% of salary differences are negative. The high percentage of negative salary differences is strong evidence against models that predict that scientists are fully insured against declines in salary (*viz*. the insurance version of the learning model).

A further test between the two versions of the learning model is possible. The expected marginal product version implies that whenever productivity increases, salary will also increase. The insurance version, however, implies that after several periods of low productivity, a salary increase may not follow. The reason is that, at that point, the scientist may already be earning more, due to the insurance aspect of the labour contract, than the scientist's value of marginal product. As a rough test of the two versions, I divide the sample into observations where the level of citations has been below the median for each of the past two years on the one hand, as opposed to those where the citations in at least one of the past two years have been above the median. 'Median' here was operationally defined as the median number of annual citations for all observations in the scientist's discipline. I estimate OLS regressions on the difference in log salaries for each sub-group of observations. These regressions are reported in Table 3. Since the coefficient is much higher for the group that is below the median citations in each of the past two years, this evidence strongly favours the expected marginal product version of the learning model.

This finding is similar to that reported by Murphy for executives [8,p.74, Table 5].

**Table 3** Regressions of change in log salary on observations grouped by citations received in previous two years*

| *Variable* | *Below median citations in each of the past two years* | *Above median citation in at least one of the past two years* |
|---|---|---|
| Level of potential experience** | 0.00037 | 0.00270 |
| | (1.350) | (1.012) |
| Change in annual citations | 0.00233 | 0.00058 |
| | (4.164) | (7.794) |
| Constant | -0.00311 | 0.00033 |
| | (0.575) | (0.059) |
| Number of persons | 173 | 212 |
| Number of observations*** | 1348 | 1998 |
| $R^2$ | .014 | .030 |

* The absolute value of the t-statistics are reported in parentheses.

** Potential experience is equal to the year of the observation minus the year of receipt of PhD.

*** Since the data set is longitudinal, there are multiple observations for each scientist. The number of observations per scientist varies, depending mainly on the availability of salary information.

## 5 Conclusions and future work

The 'learning' implicit contracts models seem somewhat more consistent with the data on scientists than the 'incentives' implicit contracts model. The clearest evidence is that the effect of citations on salaries declines with experience – a finding that is consistent with the learning models, but not with the incentives model. Although less clear-cut, the variance of the difference in log salaries does seem to decline with experience, again a finding that is consistent with the learning models, but not with the incentives model.

The data on scientists does not seem to strongly support one version of the learning model over the other. Evidence for the expected marginal product version consists of the finding that the return to high citations is not lower when preceded by two years of citations below the median level. Additional evidence for the expected marginal product version is the finding that close to 50% of the observations (specifically 44%) indicate a decline in real salary.

On the other hand, evidence for the insurance version consists of the failure to find concavity in the experience-earnings profile. (This finding could also be interpreted as evidence for the incentives model, since both the incentives mode and the insurance version of the learning model are silent on the shape of the profile). One avenue for further research will be to devise additional tests to more sharply distinguish the two versions of the learning model.

Government intervention in labour markets is often justified by citing phenomena in actual labour markets that deviate from the predictions of neoclassical theory. The case for such intervention will be considerably weakened if the anomalous phenomena can be explained by implicit labour market theories that are extensions of the neoclassical theory. In the current work I have added to the small literature that attempts to test the empirical soundness of two versions of the implicit labour market theories. More evidence will be required before we can reach sound conclusions on the empirical success of the theories.

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1 Diamond, A.M., Jr. (1986) 'What is a citation worth?', *The Journal of Human Resources*, Vol. 21, No. 2, Spring, pp.200–215.

2 Rosen, S. (1985) 'Implicit contracts', *Journal of Economic Literature*, Vol. 23, September, pp.1144–1175.

3 Malcomson's [4] more recent survey of a portion of the implicit contracts literature, still cites Rosen's paper as a useful general survey of implicit contracts.

4 Malcomson, J.M. (1997) 'Contracts, hold-up and labor markets', *Journal of Economic Literature*, Vol. 35, No. 4, December, pp.1916–1957.

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10 Diamond, A.M., Jr. (1986) 'The life-cycle research productivity of mathematicians and scientists', *The Journal of Gerontology*, Vol. 41, No. 4, July, pp.520–525.

11 Murphy uses the level of performance (in his case, the company's rate of return) rather than a first difference. Level of performance should have no systematic relationship to changes in salary. If workers were always paid their value of marginal product, for instance, and if the VMP was known with certainty, then *changes* in salary would depend on *changes* in productivity, not on the *level* of productivity. Even in the more complicated cases considered by Murphy, changes in salary depend on changes in effort (first model) or on changes in estimates of ability (second model). In either case, the evidence for changes in effort or for changes in estimates of ability are observed changes in productivity, not observed levels of productivity.

12 One referee suggests that the reason experience is concave in Murphy's study and linear in mine, may be that 'learning-by-doing' is more important for Murphy's CEOs, than for my academics.

13 In order to gauge the robustness of the results, I re-estimated the regressions with the addition of dummy variables for academic department (controlling for university and academic field). The coefficients on citations still declined with experience. I also estimated the regressions with period dummy variables (controlling for year) in addition to the department dummies. Again, the coefficients still declined with experience. These results indicate that the assumption that the error terms are i.i.d. may be acceptable.

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