THE NONLINEAR EFFECTS OF TEACHING AND CONSULTING ON ACADEMIC RESEARCH PRODUCTIVITY[1]

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Abstract

This study tests the proposition that moderate amounts of faculty time spent in the "non-research" roles of teaching and consulting are, in fact, facilitative of research productivity; and establishes values for the point at which such activities cease to have a facilitating effect. This was done by fitting continuous piecewise-linear regression models to 1980 data pertaining to a national sample of 5605 faculty. The study illustrates the effectiveness of piecewise-linear methods relative to polynomial techniques for problems of this kind and suggests that the former approach should be much more prevalent. The results indicate that up to four hours per week of consulting and up to eight hours per week of teaching are indeed facilitative of research productivity. Policy implications are discussed.

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Abstract

This study tests the proposition that moderate amounts of faculty time spent in the "non-research" roles of teaching and consulting are, in fact, facilitative of research productivity; and establishes values for the point at which such activities cease to have a facilitating effect. This was done by fitting continuous piecewise-linear regression models to 1980 data pertaining to a national sample of 5605 faculty. The study illustrates the effectiveness of piecewise-linear methods relative to polynomial techniques for problems of this kind and suggests that the former approach should be much more prevalent. The results indicate that up to four hours per week of consulting and up to eight hours per week of teaching are indeed facilitative of research productivity. Policy implications are discussed.

Introduction

Both in the U.S. and abroad, higher education administrators attempt to enhance faculty and institutional performance through influence on the time academicians spend in various roles (e.g., teaching, research). In the Netherlands, for example, the proportion of time that a public university faculty member should spend on each role is explicitly prescribed. In U.S. institutions, different prescriptions are accepted in popular wisdom and clear regulations are often associated with activities such as consulting.

Administrators in higher education generally view faculty consulting activity as a form of simple income augmentation (e.g, Louis, et.al., [21]). Time spent consulting is generally assumed to detract from productivity in the primary roles of teaching and research; a position which is manifest in policies placing upper limits on consulting time without encouraging such activity. Recent exploratory research by Rebne [26] indicates that "moderate" amounts of consulting generally facilitate research productivity. Rebne argues that there is a need for a policy shift in this area; away from simple restriction and towards an effort to determine optimal levels of academic consulting. However, this could not be undertaken without more precise information about the apparently nonlinear relationship between consulting time and research productivity.

The study has three purposes. Two pertain to the immediate question of research productivity. Specifically, we (1) test the proposition that moderate amounts of consulting are facilitative of research productivity and (2) establish explicit values for the point at which consulting time ceases to have a facilitating effect on productivity. In addition, we also supply explicit optimal values for time spent in the teaching role as a predictor of research productivity, thus refining policy-oriented research pertaining to this dimension of academic work (see [24]).

Our third concern is methodological and pertains to the use of piecewise-linear regression techniques in the context of problems of this kind. This method of spline regression is usually limited to natural science research (see [28] for examples). For the most part, social scientists and management researchers use polynomial regression techniques to improve the fit of covariates or to assess the explanatory value of a given predictor. Such a method imposes a symmetry requirement to which many problems do not lend themselves (the present topic being merely illustrative in this regard). One method which does not impose a symmetry requirement involves comparing the coefficients of neighboring intervals (e.g., [25]). The intervals are first selected and a linear model is fitted to each interval. There are two problems with this. The first is that some phenomena cannot be measured in such a way that a meaningful slope can be fitted to each interval. For example, very often survey research respondents cannot be expected to provide continuous data (again, the present topic being illustrative of this sort of research problem). The second is that this method does not produce a continuous model; that is, the point at which the adjacent interval lines meet does not coincide with the measurement interval boundaries. This leads to methodologically induced mis-estimation of the optimal or “tipping” points. Therefore, in piecewise-linear regression, it is important to fit a continuous model, as is done in the present study.

There has been other quantitative work on the subject of the use of a professor’s time. For example, the paper by McClure and Wells [23] describes a method for choosing among several different teaching schedules in order to simultaneously meet faculty wishes while also meeting institutional needs. The present problem appears to require a comparable level of methodological rigor; in particular, the use of nonlinear statistical techniques. Our review of the literature indicates that piecewise-linear regression models have yet to be applied to policy problems of this kind.

Academic Roles and Research Productivity: Alternative Hypotheses

In general, sociologists define a "role" in terms of behaviors exhibited in specific situations. While our data do not permit us to examine activities in detail, we can consider the performance effects of time spent in the various roles comprising the fairly universal functions of teaching, research and service. The strong, positive relationship between research/writing time and productivity is well-established in the literature — see [9] and [24]. Of greater interest are the effects of time spent in such alternative roles as teaching and consulting. Here, two theories are germane. The first, complementary role theory, suggests nonlinear relationships between time spent in various academic roles and individual performance. The second, time-scarcity theory, suggests linear relationships.

Complementary Roles. Complementary role theory suggests that time spent on a given academic role would be predictive of success in that role as well as other occupational roles associated with it. For example, time spent preparing for classes could have a beneficial effect on research practice through the development of complementary knowledge and skills. Complementary role theorists such as Marks [22] and Faia [7] have gone on to suggest that a balanced commitment to various roles is likely to have an "energizing impact" on all activities. This position suggests nonlinear relationships between time spent on alternative roles and research productivity, with moderate activity in alternative roles being associated with the highest levels of performance.

Time-Scarcity. An alternative hypothesis rests on the assumption that commitment of time and energy to one role must come at the expense of success in another. This, the scarcity theory of role behavior, is exemplified by the work of Goode [11] as well as Coser and Coser [4], and may be used to account for perceptions of debilitating "role strain" as individuals attempt to fulfill multiple obligations. This position would seem to be taken by the many young scholars who seek work situations involving minimal teaching responsibilities in the expectation that this will facilitate research success. Under this theory, time spent in any role except research would be negatively and linearly related to research performance.

Previous Findings. Most empirical research in this area has been concerned with the relationship between teaching effectiveness and research performance. As time spent in teaching roles is, in itself, predictive of teaching effectiveness, the results of such studies are relevant to the present work. Faia's review [7] of such research is somewhat inconclusive but offers no support for the negative effect hypothesized by scarcity theorists. Research by Hayes [12], Hicks [14] and Hoyt & Spangler [17] found a positive relationship between teaching proficiency and research productivity. While other studies have found no relationship, there is no indication of a negative association (see [1], [6], [9], [19]). A review of the literature indicates only two studies which have extended the complementary role thesis to non-teaching roles – Pelz and Andrews [24] and Rebne [26]. Pelz and Andrews' results indicate that, in general, moderate levels of nonresearch activity (including administration as well as teaching) are facilitative of research performance. It is expected, then, that moderate levels of activity in an alternative role would be associated with highest levels of research performance, while indications of imbalance (very low or very high alternative activity) would be associated with lower research productivity. Rebne [26] also found support for the complementary role thesis in examining the relationship between consulting time and productivity, with moderate levels of consulting being positively correlated with research achievements.

While previous research generally supports the complementary role thesis and the prediction of non-linear relationships for time spent in non-research roles, the specific mechanisms governing these relationships are likely to vary. As outlined above, light-to-moderate teaching duties (as well as time spent in preparation) might be expected to enhance research performance insofar as keeping abreast of developments in the field would serve both roles. However, a heavy emphasis on teaching should have a negative effect as faculty find themselves without sufficient time to devote to research.

Positive effects from consulting activity might have purely serendipitous origins, with new research problems being found through the applied problem-solving process. Alternatively, as suggested in [26], positive effects could stem from a calculated effort towards synergy. Examples of the latter would include undertakings of action research likely to be of interest to the disciplinary community (such as certain managerial consulting activity that is expected to have research implications) or the negotiation of access to an industrial research setting in the context of an otherwise unrelated consulting project.

Again, however, high levels of activity in this role should detract from research performance. In part, this would again be the result of unavoidable time scarcity (as would be true for any alternative role). In addition, though, it seems likely that the effects of a degree of isolation from other scholars and developments in the field would take hold – a problem not inherent in teaching-related roles. Expectations of a facilitative effect for low-to-moderate time spent on administration and university committee work are more difficult to posit. However, the results of Pelz and Andrews [24] specifically indicate effects in keeping with the complementary role thesis and such expectations are extended to the present study.

To summarize, the prescription for balanced effort suggested by complementary role theory assumes that at high levels of activity time scarcity inevitably becomes a negative factor. Of special interest, then, are the effects of low-to-moderate alternative activities and identification of the point at which further effort becomes dysfunctional in terms of the outcome of interest.

The Sample, Data and Preliminary Analysis

The data set used in this study was collected in 1980 by the UCLA Higher Education Research Institute. The survey instrument consisted of closed-ended questions concerning personal characteristics, work roles, publishing activity, types of research conducted, as well as attitudes, values and goals concerning education and academic work. The primary purpose of this survey was to facilitate research on human resource issues in higher education. Initial sampling units were institutions, with respondents being drawn from a nationally representative sample of 98 colleges and universities. The sample is representative of academic organizations in terms of size, control (public vs. private), region, and student selectivity (see [2]). While now more than ten years old, this data set remains the most comprehensive of its kind.

All academic personnel at these institutions were asked to complete the questionnaire and approximately 30% did so. The sample was restricted to include only those respondents whose institutional settings, professional preparation and work roles were unlikely to preclude research production. Only faculty who satisfied the following four conditions were retained: (1) employed at degree-granting institutions (excludes two-year colleges), (2) holder of a graduate degree (master's or Ph.D.), (3) having academic responsibilities which were not primarily administrative (less than 17 hours a week in this function), and (4) provided complete self-report data on time spent in various academic roles. A total of 5605 responses were used in the present study.

Scientific productivity was measured by reports of publishing activity. Specifically, respondents were asked to report total number of works (refereed articles, books and monographs) published or accepted for publication in the past two years (1978-80). This basic productivity index (output/input ratio) used the following response categories and codes: 1= no publications in the past two years, 2= 1-2, 3= 3-4, 4= 5-10, and 5= more than 10 articles, books or monographs. The response codes were converted to mid-point values in order to approximate actual output. Midpoint values for the open-ended category (more than 10) were assigned by estimating Pareto distributions for each category and using the mid-point of this distribution in the analysis.

As is true of productivity measurement among research and development professionals in industry, the measurement of scientific productivity in universities is difficult. While the issue cannot be taken up here, it is important to note that purely quantitative measures such as the present one have been found to correlate well with qualitative measures such as citation counts and assessments of journal quality (see [3], [13], [20]). Ideally, types of journals and articles (for example, theoretical versus applied) would be considered in the analysis; as would a distinction between textbooks and more scholarly works. Conceivably, time spent consulting, for example, would tend to bias scholars towards publishing in more applied journals. However, effective use of such information would depend on knowledge about the relative status of journal types across disciplines included in the study [27].

Activity in various academic roles was measured by reports of average weekly hours spent during the current academic term. Response categories consisted of four-hour intervals for values below 21. Again, these are self-report measures and are subject to unknown bias. However, a preliminary analysis of responses gave no indication of inconsistency with what is known about overall faculty activity levels (see [24], [7]).

Table One shows the general forms of relationships between time spent on academic roles and research productivity. For this table, activity levels were collapsed to form categories of (1) no activity in the role, (2) low activity (1-8 hours weekly), (3) medium activity (9-20 hours) and (4) high activity (20-45+ hours). The number of refereed articles, books, and monographs published between 1978 and 1980 is de-

		PUBLICATIONS 1978–80[3] *TWOPUB*			
TIME SPENT IN ROLES:[4]		None 0	Low 1–8	Medium 9–20	High 20–45+
1. Scheduled Teaching	Mean	4.01	4.41	2.14	1.66
	n	279	2628	2575	123
2. Teaching Preparation	Mean	3.89	4.04	2.84	1.70
	n	270	2200	2770	365
3. Advising Students	Mean	3.45	3.30	3.22	1.22
	n	340	4579	661	25
4. All Teaching	Mean	3.16	5.13	4.31	2.46
(1–3 above) *TIMETTPA*	n	58	388	1940	3219
5. Consulting	Mean	3.17	3.63	3.83	2.93
TIMECONS	n	4089	1152	268	96
6. Administration	Mean	2.64	3.54	3.45[5]	—[6]
	n	1480	3311	814	0
7. Committee Work	Mean	3.11	3.30	3.48	—
	n	547	4808	248	2
8. Research and Writing	Mean	0.77	2.06	4.27	6.36
TIMERES	n	612	2229	2011	753

Table 1: Productivity by Time Spent in Academic Roles (Source: 1980 UCLA HERI Faculty Survey, compiled by the authors)

Footnotes:

3. Refereed articles, books, and monographs

4. Average weekly hours for the previous term

5. Includes only 9–16 hours

6. $>$ 16 hours excluded from sample

noted by $TWOPUB$. Cell means for the index of two-year publishing $TWOPUB$ were then computed for each level of activity in these roles. The number of hours per week spent on research, consulting, and teaching (including time in the classroom, time spent preparing for class, and time spent advising students) are denoted by $TIMERES$, $TIMECONS$, and $TIMETTPA$ respectively. One limitation of this analysis is the necessity of assuming that levels of activity have remained fairly consistent for the years preceding the survey. Given the often lengthy period between the time research is initiated and the time it reaches print, the effect being sought is more properly that of a lagged variable reflecting activity in the mid-1970's.

While our cross-sectional data do not permit such an analysis, Fulton and Trow [10] have shown that individual patterns of research activity remain quite constant over time, with slightly greater activity found among researchers in their early to mid thirties.

As expected, the highest level of productivity was achieved by those spending the most time on research and writing (20-45+ hours weekly). The relationship between time spent and performance is positive, linear and in keeping with previous research ([9], [24]). Those faculty who were spending no time on research (11% of the sample) still managed to publish. However, members of this group on average publish only once in almost three years (or at about a quarter of the average rate); if we assume that a quarter of them publish at the average rate, this would account for all publishing in the group.

As Table One indicates, the relationship with Scheduled Teaching Hours is non-linear, with some teaching being facilitative relative to either no activity, on the one hand, or medium-to-high activity, on the other. The bivariate relationships with Teaching Preparation Time, Committee Work, Administrative Work and Consulting Time have similar forms. In general then, the relationships are non-linear and in keeping with the complementary role argument that balanced activities will enhance research productivity.

Interestingly, faculty appear to be able to sustain substantial amounts of time on both administrative and committee work without a negative effect on research productivity. Low and Medium cell means are roughly equal in both functions and higher than those of faculty who report no activity in these areas. Surprisingly, even large amounts of time spent consulting have little negative impact. Inasmuch as faculty routinely claim work weeks of 60-65 hours [7] the data suggest that, for most alternative roles, time scarcity becomes a factor only at extremely high values. In the present sample, the average working week is lower (the mean is approximately 44 hours) and just 10% of the faculty report working at least 60 hours per week. This perhaps indicates that the present sample is more representative of the academic community as a whole.

Methodology and Results

Among various alternative faculty work roles, preliminary analysis indicated that the three best predictors of research productivity are time spent on research ($TIMERES$), time spent consulting ($TIMECONS$), and time spent teaching ($TIMETTPA$) (including time in the classroom, time spent preparing for class, and time spent advising students). We restricted attention to these variables, fitting a model in which these were the independent variables and the number of papers published in the last two years ($TWOPUB$) was the dependent variable.

As mentioned above, the exact time that a faculty member spends on each role was not known; instead, it was known that the faculty member spent an amount that fell into four-hour intervals, for example, between one and four hours teaching each week. In order to fit the model, intervals were replaced by their midpoints, so a faculty member spending between one and four hours teaching was regarded as spending $2\frac{1}{2}$ hours teaching; five to eight hours was assumed to reflect $6\frac{1}{2}$ hours teaching. These values, of course, closely approximate typical classroom time for one- and two- course "loads", respectively.

Before finding $TWOPUB$ as a function of the three independent variables $TIMERES$, $TIMETTPA$, and $TIMECONS$, we investigated the relationships among these variables. Because teaching time is the least discretionary activity and affects time available for the other roles, we first fitted a simple linear regression of $TIMERES$ against $TIMETTPA$ of the form

$$TIMERES = a + b\,TIMETTPA + \epsilon. \tag{1a}$$

(Throughout, ϵ represents the error.) The best least squares model has

$$a = 19.3, \quad b = -0.34. \tag{1b}$$

This model gives an F-ratio of 901, which is significant at the .0001 level. This accounts for almost 14% of the variance of $TIMERES$, that is, $R^2 = .14$. In order to determine how the time available for consulting is affected by the time spent on teaching and research, we found the best least squares multilinear regression of $TIMECONS$ against $TIMETTPA$ and $TIMERES$ of the form:

$$TIMECONS = a + b\,TIMETTPA + c\,TIMERES + \epsilon. \tag{2a}$$

The best model has

$$a = 6.1, \quad b = -0.12, \quad c = -0.11. \tag{2b}$$

This model gives an F-ratio of 219, which is significant at the .0001 level. Here, R^2 is only .07. As expected, time scarcity did affect the relationship among these three roles, but not to the extent that one role directly replaced another. Note that these values of R^2 are small, so it is reasonable to use a multiple stage regression, where the variables are fit to the residuals of earlier stages; that is, we will first develop a model using $TIMERES$, then we add $TIMETTPA$ to the model, and finally we add $TIMECONS$.

Before formulating a multiple stage nonlinear regression model, we consider a multilinear model. Recall that we want to model $TWOPUB$ using the three time variables. The multilinear model for the data is:

$$\begin{aligned} TWOPUB &= a + b\,TIMECONS + c\,TIMERES \\ &\quad + d\,TIMETTPA + \epsilon. \end{aligned} \tag{3a}$$

and the best fit has

$$a = 2.31, \quad b = 0.04, \quad c = 0.15, \quad d = -0.03. \tag{3b}$$

The F-ratio for this model is 652, with the tail having probability $< .0001$. The regression reduces the sum of squares by 17690 to 50635, so the total $R^2 = 0.259$.

The multilinear model describes the relationship of $TWOPUB$ to the independent variable $TIMERES$ well, but it is inadequate for capturing the nonlinear relationship between $TWOPUB$ and the other two independent variables. Therefore, we fitted a simple linear regression of $TWOPUB$ against $TIMERES$. Since $TIMECONS$ is more discretionary than $TIMETTPA$, we fitted that last. Therefore, after fitting $TIMERES$, we fitted $TIMETTPA$ and then $TIMECONS$ in nonlinear models.

The nonlinear model we chose to fit was a piecewise-linear one. Piecewise-linear models are suitable when the data can be divided into two parts, a linear model fits the data well on each part, and there is a fairly abrupt change between the two parts. This method is an alternative to fitting a quadratic model and has the advantage that no symmetry requirement is imposed. It was clear from a preliminary examination of the data (substantiated below) that an assumption of symmetry would be unrealistic.

The best simple linear regression for $TWOPUB$ in terms of $TIMERES$ of the form

$$TWOPUB = a + b\,TIMERES + \epsilon. \tag{4a}$$

is to take

$$a = 1.44, \quad b = 0.166. \tag{4b}$$

The F-ratio for this model is 1800, with the tail having probability $< .0001$. The regression reduces the sum of squares by 16619 to 51706, that is, the total $R^2 = 0.243$. Therefore, we chose a model of the form

$$\begin{aligned} TWOPUB &= 1.44 + .166 TIMERES + \\ &\qquad f_1(TIMETTPA) + f_2(TIMECONS) + \epsilon, \end{aligned} \tag{5}$$

where $f_1(TIMETTPA)$ is a function of $TIMETTPA$ and $f_2(TIMECONS)$ is a function of $TIMECONS$.

Because teaching time is less discretionary than consulting time, we fitted $TIMETTPA$ before fitting $TIMECONS$. Thus, we used a multistage approach, fitting the linear term first ($TIMERES$) and then fitting the nonlinear terms in order ($TIMETTPA$ and then $TIMECONS$). The data indicated a nonlinear dependence of $TWOPUB$ upon $TIMETTPA$. A quadratic model could have been fitted, but that would have implied that research productivity is symmetric about some optimal level. Therefore, it was decided to use a piecewise-linear model of the form

$$TWOPUB = \begin{cases} .166 TIMERES + b_{10} \\ \qquad + b_{11} TIMETTPA + \epsilon, \quad TIMETTPA \le a, \\ .166 TIMERES + b_{20} \\ \qquad + b_{21} TIMETTPA + \epsilon, \quad TIMETTPA > a. \end{cases} \tag{6a}$$

The model should be continuous, so the additional requirement

$$b_{10} + b_{11} a = b_{20} + b_{21} a \tag{6b}$$

was imposed. The value of a which gives the best fit will then be an estimate of the optimal number of hours per week that the faculty member should spend teaching. This is the "optimal value" for that role, ie, the number of hours at which increasing the amount of time spent teaching has a negative effect on research productivity. Thus, the model gives a linear fit to the left of the optimal value a and to the right of a, but the lines may have different slopes. This model has five parameters (a, b_{10}, b_{11}, b_{20} and b_{21}), but, because of the continuity requirement (6b), only four degrees of freedom.

Models of this type have been analyzed in the statistical literature. For a discussion of their theoretical properties, see Feder [8]. Under standard assumptions on the error distribution, Feder proved that the maximum likelihood estimators for the parameters in equation (6) are consistent, and that they are asymptotically normal and unbiased. For consideration of algorithms, see Hudson [18] and Hinckley [15, 16]. The algorithms exploit the fact that for a fixed value of a, the model is linear in the parameters b_{ij}. In fact, the slopes b_{11} and b_{21} can be found by fitting simple linear regressions to the data to the left of a and to the data to the right of a. The intercepts found using these simple linear regressions may have to be modified slightly to produce b_{10} and b_{20} in order to ensure that the lines meet at a. Thus, the maximum likelihood estimate can be found by varying a and finding the appropriate values of the remaining parameters.

The values of a and b which give the fit with smallest residual sum of squares are

$$\begin{array}{cr} a & 7.5 \\ b_{10} & -0.21 \\ b_{11} & 0.33 \\ b_{20} & 2.62 \\ b_{21} & -0.04 \end{array} \tag{6c}$$

For comparison, it is possible to fit a linear model in $TIMETTPA$ of the form

$$TIMERES = .166TIMERES + c + d\,TIMETTPA + \epsilon \tag{7a}$$

The best model of this form has

$$c = -0.03, \quad d = 2.23 \tag{7b}$$

The model in equation (7) reduces the residual sum of squares by an additional 774 to 50932 over the simple linear regression for $TWOPUB$ on $TIMERES$ given in equation (4). The nonlinear regression given in equation (6) reduces the sum of squares by a further 707 to 50225. Testing the hypothesis that $b_{11} \neq b_{21}$ has an F ratio of 39.4, indicating that the slopes are significantly different at the level .00001. The linear fit in $TIMETTPA$ of equation (7) gives a total $R^2 = 0.255$, while the nonlinear fit of equation (6) gives a total $R^2 = 0.265$.

When $TIMERES$ is 10 hours per week, this model looks as in figure 1 for various values of $TIMETTPA$. The only thing which changes as $TIMERES$ changes is the

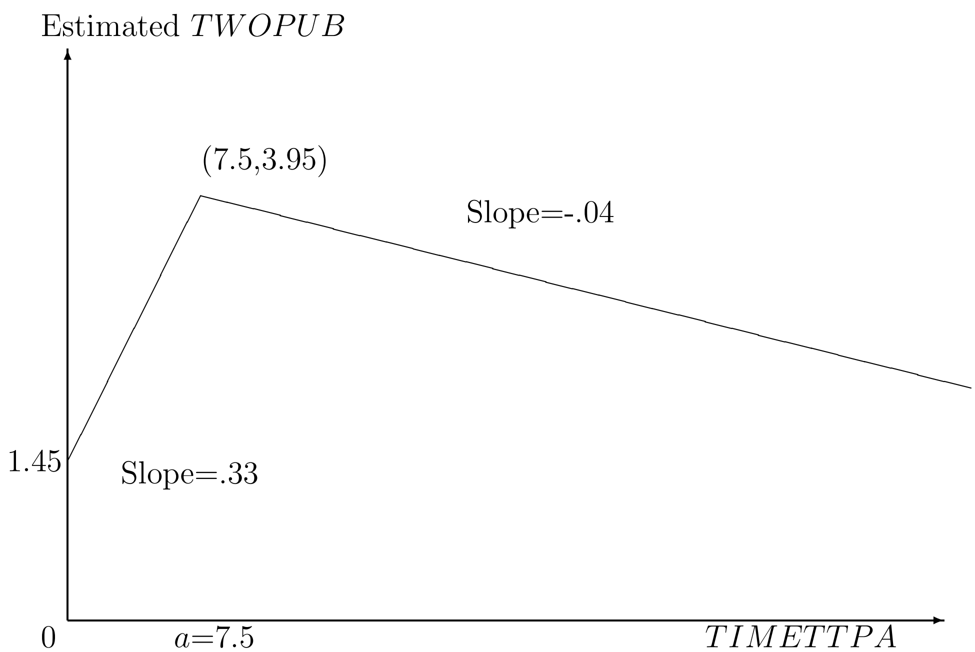

Figure 1: Estimated $TWOPUB$ vs $TIMETTPA$, when $TIMERES$=10

intercept; the slopes of the two lines and the optimal value remain unchanged. As can be seen, the optimal value a is at 7.5 hours. Because our original data were expressed in intervals, which we represented by their midpoints, this optimal value corresponds to spending between 6 and 9 hours teaching each week. In terms of teaching load, this can be regarded as approximately one course per semester (allowing for preparation and advising). Thus, all things being equal, teaching more than one course per semester has a detrimental effect on research productivity, but the first course has a beneficial effect on research.

Following Seber and Wild [28], we can set up a confidence interval for the optimal value of a. This requires looking at the parameter $F(a)$ given by

$$F(a) := \frac{S(a) - S(7.5)}{S(7.5)/(n-P)},$$

where $S(a)$ is the sum of squares when the optimal value is assumed to be a and the best parameters are then chosen for b_{ij}, $n = 5605$ is the number of observations, and $P = 4$ is the number of free parameters. The 95% confidence interval on the value of a is then

$$\{a : F(a) \leq F^{.05}_{1,n-P} = 3.85\}.$$

This gives an interval of $5.9 \leq a \leq 8.3$, which is a smaller interval than the 6 to 9 hour interval estimated above. The interval is nonsymmetric about the optimal value $a = 7.5$ because the model is nonlinear.

One of the reasons that we attempted to fit a piecewise-linear model rather than a quadratic model was that the data appeared to lack symmetry. To check this assumption, we fitted a linear model for the dependent variable $TWOPUB$ in the independent variables $TIMERES$, $TIMETTPA$ and $TIMETTPA^2$, so

$$TWOPUB = a_0 + .166\, TIMERES + a_1 TIMETTPA + a_2 TIMETTPA^2 + \epsilon \quad (8)$$

The best such model has a sum of squares of 50804, that is, $R^2 = .256$. Recall that the linear model with independent variables $TIMERES$ and $TIMETTPA$ has $R^2 = .255$, and the piecewise-linear model has $R^2 = .265$. Thus, the piecewise-linear model provides a considerably better fit than the quadratic model, in that it results in an increase in R^2 which is ten times larger than that supplied by the quadratic model, while requiring just one extra parameter. Again, the piecewise linear model also offers superior estimation of tipping points in decision variables of this kind.

Having fitted $TIMERES$ and $TIMETTPA$, we then fitted $TIMECONS$ in the same manner as $TIMETTPA$. Thus, we set up a model of the form

$$TWOPUB = \begin{cases} .166TIMERES - 0.21 + .33TIMETTPA \\ \quad +d_{10} + d_{11}TIMECONS + \epsilon, \\ \quad \text{when } TIMETTPA \leq 7.5 \text{ and } TIMECONS \leq c, \\ .166TIMERES + 2.62 - .04TIMETTPA \\ \quad +d_{10} + d_{11}TIMECONS + \epsilon, \\ \quad \text{when } TIMETTPA \geq 7.5 \text{ and } TIMECONS \leq c, \\ .166TIMERES - 0.21 + .33TIMETTPA \\ \quad +d_{20} + d_{21}TIMECONS + \epsilon, \\ \quad \text{when } TIMETTPA \leq 7.5 \text{ and } TIMECONS \geq c, \\ .166TIMERES + 2.62 - .04TIMETTPA \\ \quad +d_{20} + d_{21}TIMECONS + \epsilon, \\ \quad \text{when } TIMETTPA \geq 7.5 \text{ and } TIMECONS \geq c. \end{cases} \tag{9a}$$

The model should be continuous, so the additional requirement

$$d_{10} + d_{11}c = d_{20} + d_{21}c \tag{9b}$$

was imposed. The value of c which gives the best fit will then be an estimate of the point at which the slope of the best fit changes from d_{11} to d_{21}. Depending upon whether the consulting level is below c or above c, research productivity per hour per week of consulting will differ. The values of c and d which give the fit with smallest residual sum of squares are

$$\begin{array}{lr} c & 3.5 \\ d_{10} & -0.19 \\ d_{11} & 0.23 \\ d_{20} & 0.59 \\ d_{21} & 0.01 \end{array} \tag{9c}$$

For comparison, it is possible to fit a linear model in $TIMECONS$ of the form

$$TWOPUB = \begin{cases} .166TIMERES - 0.21 + .33TIMETTPA \\ \quad +e + f\,TIMECONS + \epsilon, \\ \quad \text{when } TIMETTPA \leq 7.5 \\ .166TIMERES + 2.62 - .04TIMETTPA \\ \quad +e + f\,TIMECONS + \epsilon, \\ \quad \text{when } TIMETTPA \geq 7.5 \end{cases} \tag{10a}$$

The best model of this form has

$$e = -0.09, \quad f = 0.05. \tag{10b}$$

The model in equation (10) reduces the residual sum of squares to 49897, an additional reduction of 328 over the model of equation (6). The nonlinear regression of equation (9) reduces the sum of squares by a further 263 to 49634. Testing the hypothesis that $d_{11} \neq d_{21}$ has an F ratio of 14.8, indicating that the slopes are significantly different at the level .00001. With a linear fit in $TIMECONS$ (model (10)), we obtain a total $R^2 = 0.270$; with a nonlinear fit (model (9)), the total $R^2 = 0.274$. Notice that we obtain an optimal value $c = 3.5$. This falls between the midpoints of the intervals corresponding to 1–4 and 5–8 hours per week spent consulting. Thus, the first half-day per week spent consulting is beneficial to research, but any further consulting is harmful.

As for TIMETTPA, we can fit a confidence interval for the optimal value of $TIMECONS$. The 95% confidence interval for c is $0 \leq c \leq 4.5$. Once again, the confidence interval is not symmetric about the optimal value $c = 3.5$ because of the nonlinearity of the model.

Thus, our final model is

$$TWOPUB = \begin{cases} -0.40 + .166TIMERES + .33TIMETTPA \\ \quad +0.23TIMECONS + \epsilon, \\ \quad \text{when } TIMETTPA \leq 7.5 \text{ and } TIMECONS \leq 3.5, \\ 2.43 + .166TIMERES - .04TIMETTPA \\ \quad +0.23TIMECONS + \epsilon, \\ \quad \text{when } TIMETTPA \geq 7.5 \text{ and } TIMECONS \leq 3.5, \\ 0.38 + .166TIMERES + .33TIMETTPA \\ \quad +0.01TIMECONS + \epsilon, \\ \quad \text{when } TIMETTPA \leq 7.5 \text{ and } TIMECONS \geq 3.5, \\ 3.21 + .166TIMERES - .04TIMETTPA \\ \quad +0.01TIMECONS + \epsilon, \\ \quad \text{when } TIMETTPA \geq 7.5 \text{ and } TIMECONS \geq 3.5. \end{cases} \tag{11}$$

For this model, we have $R^2 = 0.274$, whereas for the linear model, $R^2 = 0.259$. We summarize the results of our analysis in Table 2.

		R^2	I1	S1	I2	S2	TP	n_1, n_2	P(Tail)
Linear Model (3)		.259	—	—	—	—	—	—	—
Nonlinear Model (11)		.274	—	—	—	—	—	—	—
$TIMERES$ (4)		.243	1.44	0.166	—	—	—	—	—
$TIMETTPA$	Linear (7)	.011	2.23	-0.03	—	—	—	—	—
	Nonlinear (6)	.010	-0.21	0.33	2.62	-0.04	7.5	446, 5159	$< 10^{-5}$
$TIMECONS$	Linear (10)	.005	-0.09	0.05	—	—	—	—	—
	Nonlinear (9)	.004	-0.19	0.23	0.59	0.01	3.5	4907, 698	$< 10^{-5}$

Table 2: Summary of results

Key:

- The table shows the results for the linear model and the nonlinear model. The nonlinear model is subdivided into terms for $TIMERES$, $TIMETTPA$, and $TIMECONS$. The numbers is parathenses refer to equation numbers in the text.

- The column headed R^2 gives the error accounted for by the various parts of the model. The total R^2 for the nonlinear model (.274) is the sum (to within rounding error) of the linear term for $TIMERES$, the linear and nonlinear terms for $TIMETTPA$, and the linear and nonlinear terms for $TIMECONS$.

- The columns headed I1 and S1: For the nonlinear terms, these give the intercept and the slope, respectively, for the part of the model to the left of the tipping point. For the linear parts of the model, these give the intercept and the slope for the model.

- The columns headed I2 and S2: These give the intercept and the slope, respectively, for the part of the model to the right of the tipping point.

- The column headed TP: This gives the tipping points.

- The column headed n_1, n_2: n_1 is the number of cases to the left of the tipping point, and n_2 is the number of cases to the right of the tipping point.

- The column headed P(Tail): This gives the probability of the tail for the F-test that the data to the two sides of the tipping point are significantly different.

- Entries labeled —: These cells in the table are not applicable.

While these values are modest, it is perhaps noteworthy that even the most general models have never explained more than 60% of research productivity variance. See Creswell [5], page 55.

Thus, a researcher can typically expect to produce about one additional paper every two years for each additional six hours of research per week. For small amounts of teaching (less than eight hours per week or one course per semester) the increase in productivity from an hour of teaching is greater than that from an hour of research, with one extra paper per two years resulting for each three hours of teaching per week. Teaching more than eight hours per week has a slightly detrimental effect on research productivity. For small amounts of consulting (less than half a day per week) the increase in productivity from an hour of consulting is greater than that from an hour of research, resulting in one extra paper every two years for each four hours of consulting per week. Additional consulting does not hurt research productivity, but the positive effect is very marginal, and the increase in productivity is far less than would be obtained if the extra time was devoted to research.

Discussion

In this study, a piecewise multilinear regression model has been used to examine relationships between research productivity and time spent in a range of academic roles. The analysis supports the view that it is inappropriate to regard academic job content in zero-sum terms when research productivity is the outcome of interest. Time spent on the (ostensibly) non-research roles of teaching and consulting is not negatively related to productivity at all levels of activity. Rather, the roles are complementary, albeit at modest levels of non-research activity. Specifically, we found that the first 8 hours of weekly activity devoted to teaching activities actually has a positive effect on research performance. A half-day devoted to consulting activity also contributes to research.

These findings are at odds, of course, with the common assumption that teaching simply detracts from research performance, as well as the view that consulting by faculty amounts to nothing more than moonlighting. These are job analysis and design decision variables which should be considered by all academicians and most certainly by anyone in a position to exercise policy over faculty job content. While we do not necessarily favor overt "management" of academic roles, the results of this study suggest the efficacy of closer attention to such roles in relation to important outcomes such as research productivity.

Future research, perhaps of a qualitative nature, should be undertaken to explain these relationships. One possible explanation for the serendipitous relationships includes the possibility that both teaching and consulting generate ideas for research, help refine propositions and concepts and so on. In addition, the basic precept of modern work design that meaningful task variety in itself enhances performance seems plausible.

In addition to such work, a replication of the present study is advisable since activity patterns have probably changed since 1980. Applied fields such as management and four-year "teaching" colleges have increasingly sought to enhance their prestige through heightened research standards. There has also been renewed interest in instructional quality. While we would not expect such changes to alter, substantially, the functional relationships produced by our analysis, we would anticipate discernible administrative and behavioral responses to the time-scarcity thesis our results challenge. Thus, in the teaching area, attention should be paid to rationale and trends in policies and practices concerning the use of internal or external funding to "buy-out" teaching time. With respect to consulting, further and potentially dysfunctional restrictions might be advanced by administrators. If so, faculty with a high commitment to consulting could be expected to manage their practices so as to increase perceived linkages with teaching and/or research, as institutional job content and performance norms might dictate.

Methodologically, the study demonstrates the value of applying piecewise linear regression techniques to certain socio-economic research problems. In the area of measurement, a wide range of social science survey research involves interval level data which cannot readily be improved upon. In the present instance, we expect that respondents are typically incapable of reporting the precise number of hours spent on any of these roles. Therefore, the interval measures used in such studies are entirely appropriate, even if they do not lend themselves to nonlinear analysis with more conventional nonlinear regression techniques. Conventional methods also impose a symmetry requirement on the data. Most important, piecewise linear regression techniques offer the most precise point estimates or tipping points for decision variables of this kind. For these reasons, we expect that a wide range of policy oriented research problems would lend themselves to application of this method.

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