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Are there real effects of licensing on academic research? A life cycle view

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Abstract

Do financial returns to licensing divert faculty from basic research? In a life cycle model in which faculty can conduct basic and/or applied research (the latter can be licensed) licensing increases applied relative to basic effort. However, leisure falls so basic research need not suffer. If applied effort also leads to publishable output, then research output and stock of knowledge are higher with licensing than without. In a tenure system licensing has a positive effect on research output unless license incentives are high. Overall results suggest a positive impact of tenure on research output over the life cycle.
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The dramatic growth of entrepreneurial activity associated with university licensing in the last few decades has prompted much debate. While universities tout this as evidence of the increasing role of universities in economic growth, others question whether such activity compromises the basic research mission of universities. For example, a provocative *Atlantic Monthly* cover story on the "kept" university suggests the increasing trend of university industry deals (such as the Novartis–Berkeley research agreement in the late 1990s) could seriously compromise research agendas, diverting faculty toward research in corporate interests. The increasing trend of faculty to hold positions in startup and corporate boards further suggests faculty may increasingly face conflicts with the primary responsibilities in research (Boyd et al., 2003; Zerhouni, 2004).

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Scholarly analysis of these issues is limited and provides mixed results. Lach and Schankerman (2003) provide empirical support for the view that university research responds to financial incentives, showing that invention disclosures are positively related to the share of license income accruing to inventors.[1] However, Thursby and Thursby (2002, in press) suggest that increased disclosure activity is more reflective of an increased willingness of faculty to engage in commercial activity than a change in research profile. Their study of faculty in six major research universities shows that over the last two decades, the probability a faculty member will disclose an invention has increased tenfold, while research productivity has remained roughly constant. In essence, despite the importance of the issue, we know little about the effect of faculty involvement in licensing on the nature of research.

In this paper, we construct several life cycle models of faculty behavior that allow us to examine this and related issues. In the models we consider, the faculty member faces a fixed teaching load and chooses the amount of time to devote to research (which can be either basic or applied) and the amount of time to take as leisure. We model both the puzzle solving and financial motives for the faculty member to conduct research, and we consider her behavior with and without the possibility of licensing. This allows us to examine the effect of licensing on the research mix, as well as the total amount of time working, throughout the life cycle. We also examine the effect of the tenure decision on the type of research conducted with and without the possibility of licensing.

We show that, with or without licensing, and with or without a tenure system, the faculty member devotes more time to research early in her career, so that leisure rises over time. In that sense, licensing does not alter the life cycle pattern. We show that there are, nonetheless, real effects of licensing since it yields a higher ratio of applied to basic effort and lower leisure throughout the life cycle. Thus, as suggested by Lach and Schankerman, faculty respond to economic incentives. Importantly, however, this diversion does not mean that research is compromised. In our models, leisure is the activity most compromised, so that total research effort rises, and in most of the models we consider, basic effort rises with the introduction of licensing.

The implications of licensing for research output and the stock of knowledge depend not only on the effect on applied and basic effort, but also on whether applied effort contributes to the stock of knowledge. We show that in the worst case scenario, the applied effort involved with licensing is pure development and adds nothing to the stock of knowledge. If, however, the applied effort involved in licensing leads to publishable output as well as licenses, then the outlook is more favorable. In this case, we show that research output and the stock of knowledge are generally higher with licensing than without. The exception to this is when a tenure system is coupled with very high incentives to license.

In Section 1, we discuss prior work in this area and how this paper contributes. Section 2 presents the basic model. Section 3 presents life cycle behavior for three different scenarios: a development model in which only basic effort contributes to the stock of knowledge, a complements model in which basic and applied efforts are complements in the production of both research and licenses, and a model in which basic and applied effort are substitutes in research production. Section 4 presents results when tenure is introduced to the model, and Section 5 concludes.

[1] When a faculty member believes she has an invention with commercial potential, she files a formal disclosure of the invention to her university's technology transfer office. This disclosure is the first step in licensing.

1. Prior art

This research is related to prior work in the economics of science, life cycle behavior, and university-industry technology transfer, as well as the role of academic tenure. While several studies in these areas examine faculty research, their relevance to the current debates is limited since all but a few abstract from licensing.

1.1. The economics of science

Recent work in the economics of science focuses on the economic implications of scientific reward systems. In her recent survey, Stephan (1996) points out that this work owes much to sociologists and historians of science for demonstrating the importance scientists attach to solving puzzles and to being the "first" to solve them (Hagstrom, 1965; Kuhn, 1970; Merton, 1957). Levin and Stephan (1991) incorporate the love of puzzle-solving into a life-cycle model in which scientists choose how to split work effort between research and other income-earning activities. A "taste" for science also plays a major role in Stern's (2004) empirical analysis of wages offered to PhD biologists. Dasgupta and David (1987, 1994) focus on the efficiency aspects of a "priority-based" system in which all rewards go to the first to discover a result. While this system results in duplication of research and multiple discoveries (Dasgupta and Maskin, 1987; Merton, 1973), it also creates incentives for scientists to share information freely and quickly. This is in contrast to the industrial world where there are strong incentives to restrict the flow of knowledge. As scientists become more entrepreneurial, it is natural to wonder if science will suffer (Dasgupta and David, 1987; Nelson, 1992; Stephan and Levin, 1996).

The study most relevant to ours is that of Levin and Stephan. In their model, scientists engage in research for two reasons: their love of puzzle solving and an investment in future earnings. While the investment motive declines over the life cycle, the utility or joy from solving puzzles does not. In their model, research productivity at any stage is higher the greater a scientist's "taste" for research, and while research productivity declines over the life cycle, the profile is flatter the greater the taste for science.

We construct a life cycle model that is similar in that faculty derive utility from research but differs in the types of research that can be done and the financial rewards to research. In Levin and Stephan, faculty earn a university salary that at any point in time is positively related to the portion of time spent teaching and the stock of publications. Thus, time spent on research reduces current earnings but increases future earnings as in other investment models of human capital. By contrast, we allow research to increase both current and future earnings as in "experience" models of human capital in which individuals accumulate knowledge in their time spent working. Moreover, faculty can do either (or both) basic and applied research, and when research has an applied component, faculty earn license income.[2]

1.2. University-Industry technology transfer

Empirical evidence on university-industry interaction and faculty research is mixed both in focus and results. Some studies suggest that applied research increased in the post Bayh-Dole

[2] See Killingsworth (1982) for a theoretical review and synthesis of the investment in training and learning by doing (experience) models of human capital accumulation.

era (Cohen et al., 1998; Morgan et al., 1997; Rahm, 1994), while others point to a long history of such research (Mowery and Ziedonis, 2002; Mowery et al., 1999; Rosenberg and Nelson, 1994). Cohen et al.'s survey of university-industry research centers (UIRCs) provides evidence of countervailing effects of industry collaboration on faculty productivity, with so-called commercial outputs of research increasing and publications decreasing (except in biotechnology). Given the importance of publications for industrial productivity (Adams, 1990), these results are cause for concern.

In contrast, Rosenberg and Nelson point to a rich history of complementary relationships in industrial and university research, including the emergence of many of the strong engineering disciplines. More recently, Murray's (2002) interviews with leading academic scientists in tissue engineering reveal a co-evolution of basic scientific and technical solutions in industry. Empirical studies by Mansfield (1995), Zucker et al. (1994, 1998), Stephan et al. (in press), and Murray (2002) find a complementary relationship between research productivity and commercial activity. Mansfield's study of 321 academic researchers found that faculty frequently worked on basic problems suggested by their industrial consulting. Similarly, Zucker et al. (1994, 1998) found that the most productive scientists in biotechnology often start new enterprises while continuing research in their academic appointments. Stephan et al. (in press) and Murray (2002) examine patent and publication data showing that research results are both patented and published.

The bulk of this literature abstracts from the relationship between licensing and faculty research. Not surprisingly, however, the few studies that focus on licensing also provide mixed results. Lach and Schankerman find a positive relationship between invention disclosures and the share of license income accruing to inventors. While they interpret this as showing the responsiveness of research to financial incentives associated with licensing, we argue that disclosures show the faculty's willingness to engage in licensing and may or may not reflect changes in research agendas. Thursby and Thursby (2002) examine whether the growth in university licensing is driven by an unobservable change in the propensity of faculty and administrators to engage in license activity. They find that changes in the direction of research are relatively less important than increases in the propensity of administrators to license inventions and in business reliance on external R&D. However, these data are not at the level of the individual scientist, but rather research outputs at the university level.

The study most closely related is Thursby and Thursby (in press), which examines the research profiles of 3241 faculty from six major US universities from 1983 through 1999. They find that while the probability a faculty member will disclose an invention increased tenfold over this period, the portion of research that is published in "basic" journals remained constant. They also find that both publications and disclosure activity rise and then fall with age (with publications peaking before disclosure). These results suggest that understanding the relationship between faculty research and licensing requires an understanding not only of financial incentives, but also life cycle behavior.

There is little theoretical research on the financial incentives facing faculty and the allocation of effort across types of research. Beath et al. (2003) and Jensen and Thursby (2004) both examine faculty research incentives in a principal agent context where the university is the principal and the faculty member the agent. Beath et al.'s analysis is static and examines the potential for the university to ease its budget constraint by allowing faculty to conduct applied research on a consulting basis. In contrast, Jensen and Thursby's (2004) model is dynamic and provides an analysis of the effect of patent licensing on research and the quality of education, where the latter effect is a function of research choices (and hence future stocks of knowledge) as well as the portion of patentable knowledge that can be used in education. Given their emphasis on the education problem, they abstract from life cycle patterns. Their work is similar to ours since the faculty they model derive utility simply from the time spent doing the research as well as the prestige associated with successful research. They show that with these effects in the researcher's choice problem, the opportunity to earn license income may well not change his/her research agenda, which of course provides one explanation for why we might observe little change in the pattern of basic relative to applied publications.

1.3. Academic tenure

There is an extensive literature on the economic benefits and costs of academic tenure. On the benefit side, McPherson and Winston (1983) posit the need to provide income insurance to induce risk-averse faculty to specialize in research in the face of increasing obsolescence as they specialize. Carmichael (1988) highlights the role of tenure in creating a system in which senior faculty are willing to hire the best junior faculty, while Siow (1998) explores the "up or out" deadline for tenure decisions in preventing senior faculty from postponing tenure decisions for their junior colleagues suboptimally. On the cost side, much of the literature predicts lower research output after tenure (Alchian, 1953; Lazear, 2004). Not surprisingly, empirical studies provide conflicting results. Moreover, these studies examine, not pre- and post-tenure performance per se, but research productivity with age (Levin and Stephan, 1991; Li and Ou-Yang, 2003, and Oster and Hammermesh, 1998).

None of this work considers pre- and post-tenure research incentives in conjunction with the incentives for applied and basic research. In this paper, we consider these issues together since one might expect licensing to reinforce further a diversion of research post tenure. Indeed, Thursby and Thursby (in press) find that, controlling for age, publications, and the portion of research that is basic, the likelihood that faculty disclose is higher after tenure. Accordingly, we model tenure as a disincentive for risk averse faculty to conduct applied research prior to tenure. In our simulations, tenure provides a strong incentive for faculty to conduct basic research prior to tenure, and after tenure research declines according to the life cycle hypothesis. It is important to note, however, that the level of research at any point in the life cycle, even after the tenure date, is likely to be higher with a tenure system. This is because the boost in basic research early in the career increases the stock of knowledge, which is a complement to both applied and basic research at any point in the career.

2. Basic model

In this section, we consider the research profile of an individual faculty member over the life cycle. In our model, the faculty member can engage in applied and/or basic research and can earn income both as current salary and license income. Both types of research have consumption value and both contribute to current and future income since research, as well as teaching, is rewarded in salary. Thus, as in Levin and Stephan, there is a consumption motive for research that does not decline over the life cycle and a financial motive that does. In our case, however, there is an additional financial motive for applied research that does not decline over the life cycle. Applied work that is licensed provides a future income stream that continues regardless of work effort.

In general, we think of a faculty member choosing across four activities at any time t: teaching, h_t, basic research, b_t, applied research, a_t, and leisure, n_t. We assume the hours devoted to teaching are determined by a fixed teaching load, so we consider the effective time constraint as $100 = b_t + a_t + n_t$. The faculty member's objective is to maximize utility over her career, which begins at time 0 (receipt of PhD) and ends at retirement, T. Utility, U_t, is a function of research output, R_t (this is the love of problem solving), market goods, X_t, leisure, n_t, and the net present value of assets at retirement, $V(A_T)$. The faculty member's problem is to choose b_t, a_t, X_t, n_t, and A_T to maximize:

$$J = \int_0^T \mathrm{e}^{-\rho t} U(R_t, X_t, n_t)\,\mathrm{d}t + V(A_T), \tag{1}$$

where the rate of time preference, $\rho \geqslant 0$, $U(\cdot)$ and $V(\cdot)$ are assumed to be twice differentiable and strictly concave in their arguments. In the basic model, we abstract from risk aversion and tenure.

In its most general form, research output is a function of time spent on basic and/or applied research, as well as the individual's knowledge stock K_t:

$$R_t = f(b_t, a_t, K_t). \tag{2}$$

The knowledge base, K_t, increases with R_t, and, while knowledge doesn't diminish with time, its relevance for current research does, so that changes in the stock of relevant knowledge is given by

$$\dot{K}_t = R_t - \delta K_t, \tag{3}$$

where δ is the depreciation rate.

Salary is, in part, remuneration for teaching (assumed equal for all individuals and all t). Faculty members are also compensated for research (all of which we assume is publishable). Here we assume that salary is not determined simply by current research, but also the output from past research that is still useful in research. Her current salary is then given by

$$S_t = rK_t + H_t, \tag{4}$$

where H_t represents income from teaching and r is the rental rate on the stock of knowledge (that is, relevant publications). Under Bayh–Dole, research can also lead to license income.

The faculty member can also earn license income, which is a function of licenses generated by her work and her share of the university's income from these licenses. While, in general, licenses can be based on either basic or applied research, recent survey evidence suggests that most inventions are embryonic and require further development for commercial success (Thursby et al., 2002; Jensen and Thursby, 2001). For the moment, we abstract from development effort (which would not be publishable) and assume that, in general, licensable output, L_t, is a function of time spent on applied and basic research, as well as the stock of knowledge:

$$L_t = g(a_t, b_t, K_t). \tag{5}$$

The change in financial assets over time is given by

$$\dot{A}_t = -pX_t + S_t + sV_t(L_t) + iA_t \tag{6}$$

where p is the (constant) price of market goods and i is the interest rate, and $V_t(L_t)$ is the net present value of licensable output at time t. There is no uncertainty in the model so the net present value of licensable output, V_t, is known and s is the inventor's share of license income. We assume that capital markets are perfect so that the faculty member's license income can be cashed in at t.

3. Licensing versus No licensing simulations

The system is sufficiently complex that we resort to simulations to characterize the time paths of research efforts and productivity. We follow much of the life cycle literature in assuming $\rho = i = 0$ so that life cycle consumption is spread evenly over the life cycle (see Ryder et al., 1976; Levin and Stephan, 1991). We set current consumption $X_t = 100$ and the initial value of $K_0 = 1$. The utility function is one commonly used in life cycle models:

$$U = \ln(R_t^{\theta_1} X_t^{\theta_2} n_t^{\theta_3}), \tag{7}$$

where $\theta_i > 0$ ($i = 1, 2, 3$)

For the research production function, we pick a form that allows us to incorporate the notion that applied work may indeed improve the productivity of basic research effort:

$$R_t = \varphi[a_t^{\gamma_1} b_t^{\gamma_2} K_t^{\gamma_3}] + (1 - \varphi)[(a_t^{\gamma_1} + b_t^{\gamma_2}) K_t^{\gamma_3}], \tag{8}$$

where $\gamma_i \geq 0$ ($i = 1,2, 3$) and φ is either 0 or 1. When $\varphi = 1$, the production function is purely multiplicative and allows for the complementarity of applied and basic work observed by Mansfield (1995) and Zucker et al. (1994, 1998). When $\varphi = 0$, it is additive so that applied and basic research are substitutes (as implied by Cohen et al. (1998)). The additive form allows the faculty member to specialize in either type of research, but precludes complementarity.

In the most general case, we also allow basic and applied effort to directly lead to licenses as well as publications:

$$L_t = a_t^{\alpha_1} (1 + b_t)^{\alpha_2} K_t^{\alpha_3}, \tag{9}$$

where $\alpha_i \geq 0$ ($i = 1, 2, 3$). This form loosely captures the notion that inventions licensed require further development since some applied effort is always necessary in order to produce licenses. While basic effort in period t is not necessary for period t license output, for $\alpha_2 > 0$ it will have a direct effect on license output in addition to the indirect effect through the stock of knowledge. By allowing complementarity of basic and applied effort in both research and licensing, we allow for the much discussed case of research in Pasteur's Quadrant where curiosity driven research has immediate commercial applications.

We solve the system for R_t, A_t, L_t, K_t, a_t, b_t, and n_t for given values of the utility and production function parameters φ, θ_i ($i = 1, 2, 3$), γ_i ($i = 1, 2, 3$), α_i ($i = 1, 2, 3$), the rate of depreciation of the knowledge base, δ, and the share of license income that accrues to the researcher, s. All parameters are non-negative. Without loss of generality we set $T = 30$. For each combination of parameters we solve the system and record the values of the variables R_t, L_t, K_t, a_t, b_t, and n_t at periods $t = 1, 2, \ldots, 30$. Thus, while the system is continuous, we only examine it at 30 points over the life-cycle beginning with the first period (one period after the start of employment as a faculty member) and ending with the final period (the beginning of retirement).

To answer the basic question of how licensing affects faculty choices and resulting outputs, we compare life cycle behavior when licensing is not rewarded ($s = 0$) with the pattern when $s > 0$. We do this for a large set of parameter values and for different variations of the production functions. Results are presented for parameter combinations from the sets $\delta = (0.2, 0.4)$, $\gamma_3 = (0.2, 0.3)$, $\gamma_1 = (0.0, 0.2, 0.3, 0.4, 0.5)$, and $\gamma_2 = (0.25, 0.4, 0.5, 0.75)$ where $\gamma_1 < \gamma_2$. Early runs indicated that qualitative results on life-cycle behavior varied little over the parameters of the utility function;

thus we use only single values for the θ_i ($\theta_1 = \theta_2 = 0.25$ and $\theta_3 = 0.5$).[3] In the non-licensing regime all $\alpha_i = 0$ and $s = 0$. In the licensing regime we use parameter combinations from the sets $s = (0.25, 0.5, 0.7)$, $\alpha_1 = (0.4, 0.6, 0.8)$, $\alpha_2 = (0.0, 0.3, 0.4, 0.5)$ where $\alpha_1 > \alpha_2$ and $\alpha_3 = (0.25, 0.4, 0.6)$. While the system does not converge for all parameter combinations, it does for a large number. Since behavior clearly depends on parameter values, we present results based on averages across parameter combinations.

In Sections 3.1 and 3.2, we present results for three production functions of interest. As a benchmark, Section 3.1 considers results for a model that, without licensing, is similar to Levin and Stephan's life cycle model. In this model, there is a single type of research that is publishable (i.e, $\varphi = 1$, and $\gamma_1 = 0$), and when licensing is possible, license output only requires applied effort (which is not publishable) but yields license income (i.e., $\alpha_2 = 0$ and $s > 0$). Section 3.2 presents results for the case where applied and basic research are complements in both the research and licensing production functions ($\phi = 1$ and all α_i and γ_i are positive). Section 3.3 presents the case where applied and basic effort are substitutes in the production of research.

3.1. Development model

In this section, we consider the behavior of a faculty member who maximizes life cycle utility given by (7) when research and licensing production are given by

$$R_t = b_t^{\gamma_2} K_t^{\gamma_3}, \tag{10}$$

and

$$L_t = a_t^{\alpha_1} K_t^{\alpha_3}. \tag{11}$$

Intuitively, we would expect this model to provide the bleakest view of the effect of licensing since the applied effort necessary for licensing does not contribute to the knowledge base. We refer to this as the "development model." To the extent that the financial return to licensing diverts faculty from basic to applied work, the stream of research suffers. It is not clear how much work effort will be diverted, however, because applied work provides only license income while basic effort provides utility and income.

Fig. 1 plots the average values of applied and basic effort across parameter combinations when licensing is not rewarded ($s = 0$) and when it is ($s > 0$). Since basic effort is the only research input and applied the only license input, this model relies on the least number of possible parameter combinations. Also recall that the system does not converge for all combinations. To ensure meaningful comparisons, the figure is based on averages across a matched set of combinations for which the system converged. In this case, the results are based on 154 parameter combinations.

Clearly, when there are no returns to licensing (pecuniary or nonpecuniary) applied effort is zero in every period. The results for this case are analogous to those of Levin and Stephan. On the other hand, when licensing is rewarded, some effort is diverted to applied work in every period, and this effort increases throughout the life cycle. This, of course, follows from the fact that returns to research output end at period T while license output gives returns beyond T.

Also of note, basic effort with licensing exceeds that without early and late in the life cycle, though the effect is quite small on average. In the middle of the career, however, basic effort

[3] Note that increases in the parameters of the research production function increase research output and affect utility. Hence, an increase in θ_3 is tantamount to increasing the production parameters.

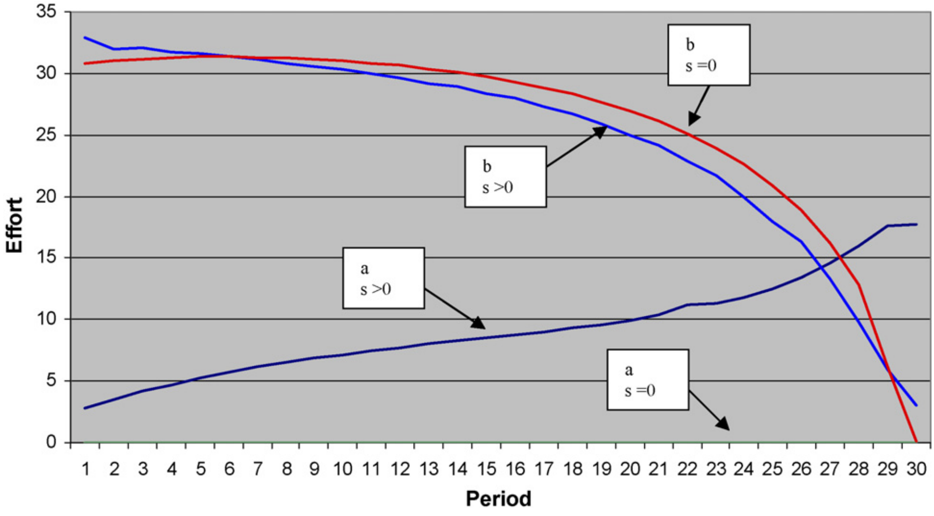

Fig. 1. Applied and basic effort in the development model.

with licensing falls below that without licensing. By the end of the career, basic effort (and hence research output) falls toward zero in the absence of licensing, while with licensing, basic effort decreases but remains positive throughout the life cycle. This occurs because of the indirect effect of basic effort on license output through the stock of knowledge. Thus the financial return to license output increases basic as well as applied effort toward the end of the life cycle (relative to a regime without licensing).

Leisure can be inferred from the combined plots for a_t and b_t and is given in Fig. 2. In non-licensing regime, leisure activity increases over the life-cycle; with licensing, it increases with age except for a few periods at the beginning. Since the ability to license increases applied effort and

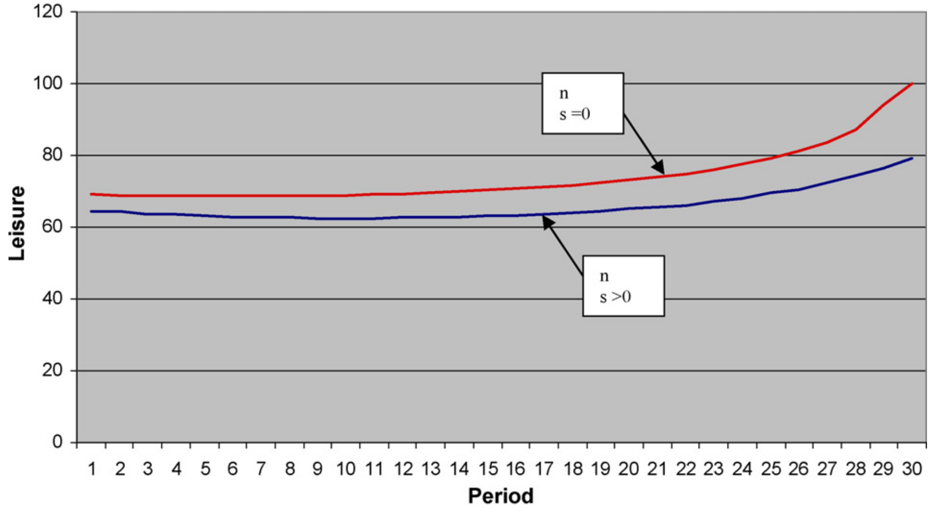

Fig. 2. Leisure in the development model.

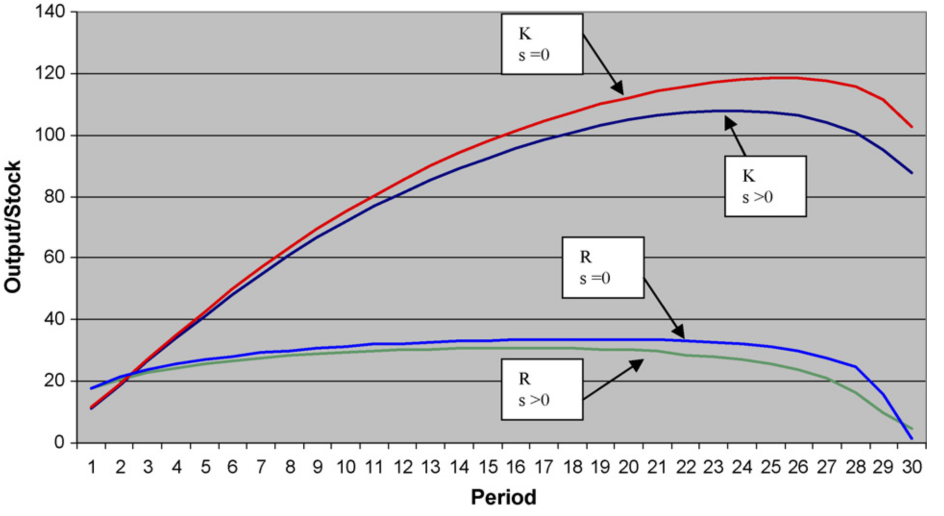

Fig. 3. Research and stock of knowledge in the development model.

reduces basic effort over some periods, whether licensing increases or decreases, leisure depends on the relative effects. For the parameter values we consider, the net effect of the second source of income on leisure is always negative; faculty always work more in a licensing regime though the split of effort between basic and applied is affected. This result is robust to all of the scenarios we consider (i.e., all production functions, with and without tenure).

As in Levin and Stephan, research output and the stock of knowledge initially increase but eventually decrease as a result of the decrease in basic effort over time. As shown in Fig. 3, research output is generally lower with than without licensing. Only at the very beginning and very end of a career does the presence of licensing increase research output R. This, of course, follows from the fact that basic effort (which is the only effort that adds to the stock of knowledge in this case) early and late in a career is higher with than without licensing. It is important to note, however, that comparisons of the levels of research output and the stock of knowledge (as opposed to the shape of the plots) are dependent on the parameter values considered, and we present only averages over a number of parameter combinations.[4]

In Fig. 4 we plot the level of license output when $s > 0$ (license output is, of course, always zero when $s = 0$). Interestingly, L rises throughout a career until the very last periods. Recall that basic effort in this model does not directly enter the licensing production function, though it does enter through its effect on the stock of knowledge K. Thus, the fall in L at the end of the career comes from the fall in basic research and the resulting effect on K. In Thursby and Thursby (in press) we consider the disclosure activity of a sample of 3342 faculty over as many as 17 years. For those faculty we find that disclosure activity (and hence, most likely licensing) rises early in a career only to fall in the final stages of the life cycle. Thus our empirical results support the theoretical results presented here.

[4] Since we are presenting average behavior for a highly nonlinear process it can be misleading to consider, say, average behavior for basic and applied effort and use that to infer, say, research output. It is not the case that average research behavior across a number of parameter combinations is the same as research computed from average basic and applied effort for those same parameter combinations.

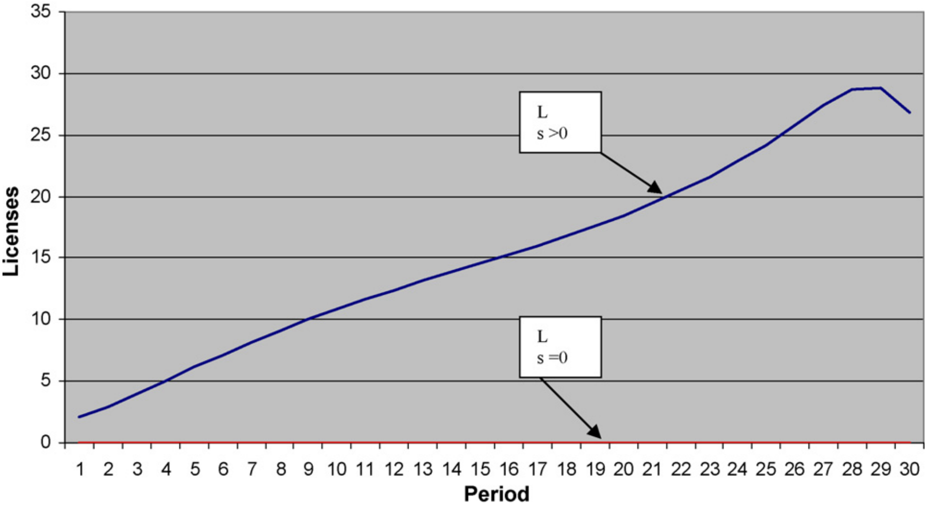

Fig. 4. Licensing income in the development model.

To summarize, in this model licensing does indeed divert faculty from research over most of the career, and the stock of knowledge K is generally lower with licensing. This detrimental effect follows from our narrow definition of research in which only basic effort adds to research output and the stock of knowledge. Note, however, that licensing leads faculty to work more over the career. Also, while research output and the stock of knowledge rise and then fall with licensing, the plots are flatter than without licensing. Toward the end of the career, research output with licensing is higher than without. Because this effect is late, however, the stock of knowledge suffers in the licensing regime (as compared to no licensing).

3.2. Complements model

We now consider the case that one would expect to provide the most favorable view of licensing. In this case, the applied effort that is necessary for licensing also produces publishable research output so that it adds to the stock of knowledge, and enters the faculty member's utility function. Basic and applied effort are complements in both the research and license production functions in the sense that an increase in either type of effort increases the marginal product of the other. The production functions are given by

$$R_t = a_t^{\gamma_1} b_t^{\gamma_2} K_t^{\gamma_3}, \tag{12}$$

and

$$L_t = a_t^{\alpha_1} (1 + b_t)^{\alpha_2} K_t^{\alpha_3}. \tag{13}$$

In the research function, we restrict the analysis to cases where, for the same amount of effort, basic has a higher marginal product than applied effort, or $\gamma_1 < \gamma_2$. In the license output function we assume the opposite in that the exponent of applied is larger than that of basic effort ($\alpha_1 > \alpha_2$). With these production functions, the maximum number of parameter combinations is 384. Fig. 5 gives applied and basic effort for the 242 combinations for which the system converged.

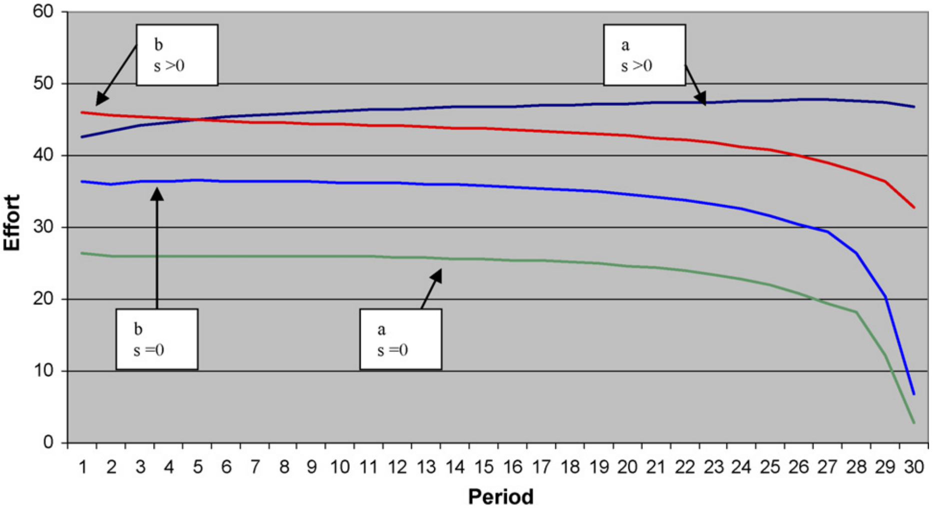

Fig. 5. Applied and basic effort in the complements model.

Without licensing, basic effort is always greater than applied, and both converge to values close to zero by the end of the career. The result that basic effort exceeds applied comes from the assumption that $\gamma_1 < \gamma_2$. With licensing, however, basic effort exceeds applied only in the early part of the career. It is important to note that even though the ratio of applied to basic effort increases (and exceeds one after period 5), basic effort throughout the career exceeds basic effort in the absence of licensing. This most likely occurs because basic and applied effort are complements in licensing as well as research. Also, and unlike the no licensing regime, applied and basic effort late in the life cycle converge to positive levels rather than zero at the end of the life-cycle. This is a result of the extra financial incentive associated with licensing.

The results for leisure, research output, and the stock of knowledge can be inferred from Fig. 5 and so are not graphed. That is because total research effort is higher in the licensing regime throughout the life cycle; leisure is decreased while research output and the stock of knowledge are increased by licensing. The results on license output are similar to those in the development case with the exception that license output does not dip late in the career. Also not shown in the figure, an increase in the rate of depreciation δ of the knowledge base decreases the amount of basic and applied research in each period, and, as well, it decreases research output and the stock of knowledge. This result is consistent with earlier work on the obsolescence of knowledge and life cycle behavior and is independent of the licensing regime.[5]

To summarize, the complements case presents a more favorable view of licensing than the development case. While the nature of research changes toward more applied effort, this effort is useful in both research and licensing and adds to the stock of knowledge. In the development case, research and the stock of knowledge suffered from licensing since applied effort did not contribute to the stock of knowledge. Also, there is less of a reduction in license output late in the career for the complements model than for the development model. Finally, to the extent that there is diversion away from basic effort, it is only a relative effect. In levels there is more of both

[5] See McDowell (1982) and Stephan and Levin (1992).

basic and applied effort. To the extent that there is a meaningful diversion of faculty effort, it is a diversion away from leisure.

3.3. Substitutes model

A natural question to ask is how dependent these results are on the form of the production function. In particular, the suggestion from the empirical literature is that if basic and applied effort are substitutes rather than complements, licensing might negatively affect the profile of research output and the stock of knowledge (Cohen et al.). To examine this, we consider life cycle behavior when the production function is given by

$$R_t = [(a_t^{\gamma_1} + \beta_t^{\gamma_2})K_t^{\gamma_3}]. \tag{14}$$

Since the only change in the model is in the research production function, license output continues to be given by (13). Thus, while applied work does not improve the productivity of basic effort, basic effort can still be thought of as lying in the so-called Pasteur's Quadrant. We continue to restrict the analysis to cases where $\gamma_1 < \gamma_2$ and $\alpha_1 > \alpha_2$.

There are only two meaningful differences in life-cycle behavior between the substitutes and complements models. First, basic effort is always higher than applied in the substitutes model regardless of the licensing regime.[6] Thus applied and basic effort need not be complements in the production of research in order for basic research to benefit from licensing. Second, as in the development model, there is a clear downturn in license output at the end of the career. Of greater importance are the similarities between the two models. Note that life-cycle behavior is essentially the same for the complements and substitutes models and that neither total research output nor the stock of knowledge suffer with licensing.

4. Models with tenure

Thus far we have abstracted from the incentives created by a system in which faculty obtain tenure seven years into the career cycle. In this section, we explore how a tenure system might affect research effort with licensing. The tenure system we envision is one in which the faculty member knows that basic research will increase the likelihood of tenure, while diverting time into applied work and leisure decreases the likelihood. In the periods before the university makes the tenure decision, we assume that spending time on applied research and leisure increases the risk of not getting tenure, while engaging in basic research decreases the risk.

We model risk as the disutility associated with applied research and leisure before tenure. We use a simple time-varying coefficient of risk-aversion, η_t, of the faculty member that can assume two values over her career: a positive value before the tenure decision at time d, $t \leqslant d$, and zero on tenure, $t > d$. Utility, U_t, is a function of research output, R_t, consumption of market goods, X_t, leisure, n_t, (dis)utility from risk-aversion, Φ_t, and the net present value of assets at retirement, $V(A_T)$. The faculty member's problem is to choose b_t, a_t, X_t, n_t, and A_T to maximize the utility function given by

$$J = \int_0^T e^{-\rho t} U(R_t, X_t, n_t, \Phi_t)\,dt + V(A_T), \tag{15}$$

[6] This would occur in the complements model only with sufficiently low values of s.

where the disutility associated with risk is modeled as

$$\Phi_t = -\eta_t \frac{(1 + a_t)(1 + n_t)}{b_t}. \tag{16}$$

Thus, the disutilty from risk-aversion is an increasing function of the researcher's coefficient of risk-aversion, η_t, applied research, a_t, leisure, n_t, and a decreasing function of basic research, b_t. A more risk-averse faculty member has a higher positive value of the coefficient of risk-aversion, and as a consequence, has a higher disutility from engaging in applied research and leisure before tenure. The coefficient of risk-aversion can vary across faculty members and varies over the life-cycle, depending on whether a faculty member is tenured or not. This functional form also allows us to interpret the coefficient of risk aversion as representing different tenure standards across universities (where higher values of η_t signify more stringent standards).

Thus, in our simplified model, we consider the effect of risk associated with the nature of research before tenure and not the risk associated with low research output since we continue to assume that all research output is publishable. Alternatively, we could attach a higher probability of publication to different types of research effort, or we could introduce a threshold of publications necessary to obtain tenure.[7] The second alternative would necessitate a more complicated production structure and should yield similar results since it would increase expected utility from basic research effort. The last alternative might well produce different results since the tenure decision would not distinguish between the types of research effort in awarding tenure.

To operationalize tenure in our simulations, we consider a simple time-varying coefficient of risk-aversion of the faculty member, assuming values of $\eta_t = (0.25, 0.50)$ before tenure decision ($t \leqslant d$), and $\eta_t = 0$ for all periods after tenure ($t > d$), where the tenure decision is made at period $d = 7$.

4.1. Tenure in the development model

Consider again the model in which applied effort produces only license output and basic effort affects licensing only though the stock of knowledge. In Fig. 6, we assume a tenure system is in effect and examine how the introduction of a licensing regime affects life-cycle behavior.[8] With the addition of the parameters for the coefficient of risk aversion, the number of possible parameter combinations in the development model increases to 432. The figures are based on results for the 306 that converged.

Not surprisingly, there is a sharp change in behavior pre-tenure versus post-tenure. With or without licensing, basic effort is much higher before than after tenure, and leisure (not shown in the figure) is much lower before tenure than after. The introduction of licensing has a positive effect on the level of basic effort throughout the life cycle, although this effect is more dramatic before the tenure year than after. As in the development model without tenure (See Fig. 1), licensing increases applied effort, but in a tenure system the increase in applied effort is greater after the tenure year. Also as before, leisure is lower throughout the life cycle with licensing.

As shown in Fig. 7, the relatively large increase in basic effort early in the career leads to higher research output and a higher stock of knowledge with licensing than without. This is in contrast

[7] See Siow (1984) for a model of occupational choice under uncertainty.

[8] The "odd" behavior of the system in periods 8 and 9 is most likely due to difficulties in the optimization program with the discontinuity in η after period 7.

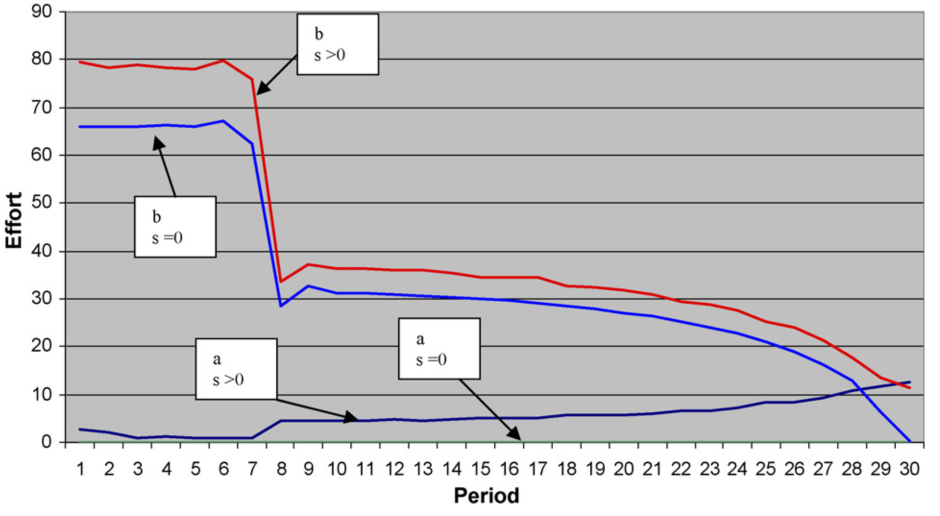

Fig. 6. Applied and basic effort in the development model in a tenure system: no licensing vs. licensing.

to our results in the absence of tenure where the introduction of licensing reduced basic effort, research output, and the stock of knowledge over much of the life cycle. The difference comes from the substantial boost that tenure gives to basic effort early on. This, in turn, leads to a higher stock of knowledge that carries forward through the remainder of the career.

Thus, while research effort over time reflects the pattern predicted by much of the literature on academic tenure (i.e., less research after than before tenure), these results suggest that research at any point in time might be higher in our tenure model than the base model. Fig. 8 compares applied and basic effort with licensing in the base and the tenure models. As expected, basic

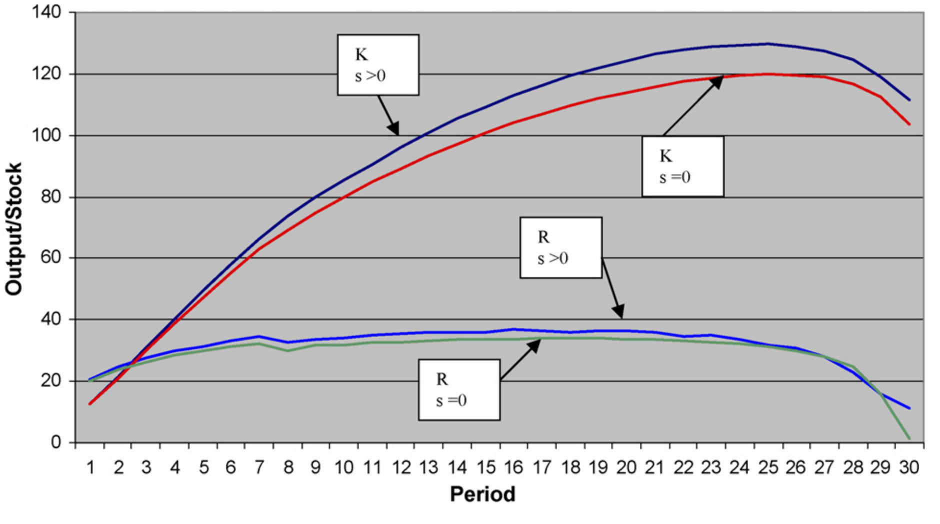

Fig. 7. Research and stock of knowledge in the development model in a tenure system: no licensing vs. licensing.

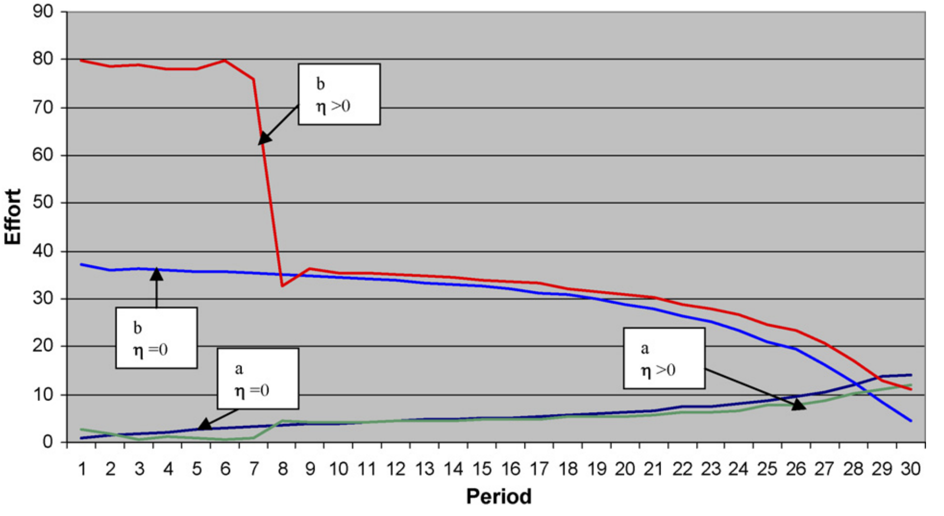

Fig. 8. Applied and basic effort in the development model with licensing: tenure vs. base model.

research is higher over the entire life cycle in the tenure model as compared to the base model. While not shown, the stock of knowledge and research output are also necessarily higher.

In interpreting this comparison, it is important to understand that the base model is not one in which the faculty member is at risk of being fired in any period. The best way to think of our comparison is in terms of employment with and without a probationary period. Our tenure model has a 6-year probationary period, and the base model has none. The result that research is higher in the tenure model shows that tenure has a benefit beyond screening since it induces faculty to produce more basic research early with continued benefits post tenure. In a more general context, one could think of the comparable benefit of probation as inducing employees to acquire more skills during their probationary period than they otherwise would.

4.2. Tenure in the complements model

Figs. 9 and 10 present the results for the complements model with a tenure system. For this model there are 816 possible parameter combinations and we report results for the 498 for which the model converged. As with the development model, we observe a sharp change in behavior pre-tenure versus post tenure. However, as is evident in Fig. 9, the boost that a tenure system gives to basic effort (and hence the stock of knowledge) early in the career is greatest in the absence of licensing. Post tenure, both applied and basic effort are higher in a licensing regime, but the early effect on the stock of knowledge leads to higher research in a non-licensing regime.

Interpreting these results is difficult because of the offsetting effects involved. There is an increased incentive for basic effort in the first 6 years with a tenure system. Because of the complementarity of basic and applied effort in both production and licensing, the introduction of licensing increases the incentive for both types of effort (hence the reduction in leisure), but the impact depends on the exponents in the production functions as well as the share of revenue accruing to the faculty member.

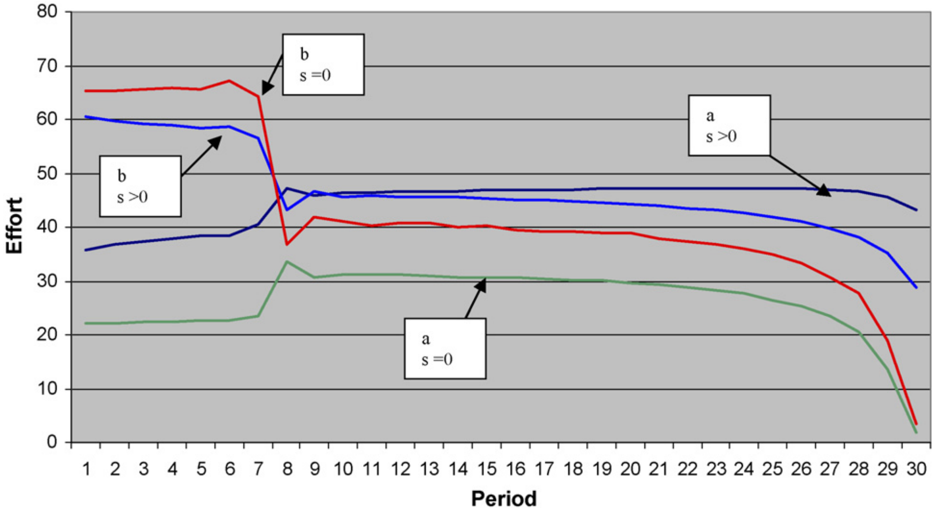

Fig. 9. Applied and basic effort in the complements model in a tenure system: licensing vs. no licensing.

To understand these effects better, we separated our results into those with low and high incentives to license. Fig. 11 plots applied effort for three cases: (i) no licensing, (ii) low incentives to license $s < 0.5$, $\alpha_1 \leq 0.4$, and $\alpha_2 < 0.5$, and (iii) high incentives to license $s \geq 0.5$, $\alpha_1 \geq 0.6$, and $\alpha_2 \geq 0.5$. As expected, applied effort is highest in the last regime where the inventor's share of revenue and productivity of effort are highest. However, as shown in Fig. 12, the impact of licensing on basic effort is nonlinear. Prior to the tenure year, basic effort is highest without licensing and lowest with high license incentives. In the middle of her career (i.e., after tenure until late in the career), basic effort is highest for positive but relatively low shares and license productivity and lowest without licensing. Late in the career, basic effort is highest for the high license incentives.

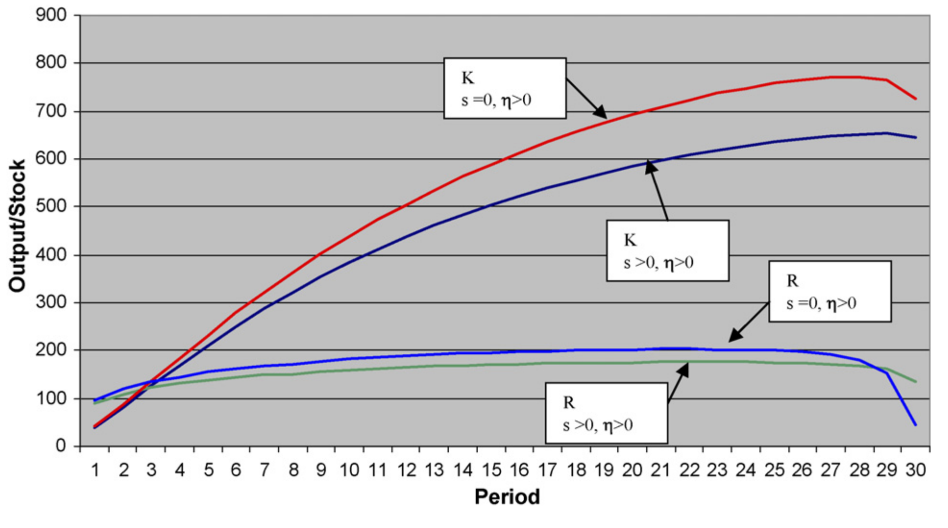

Fig. 10. Research and stock of knowledge in the complements model in a tenure system: licensing vs. no licensing.

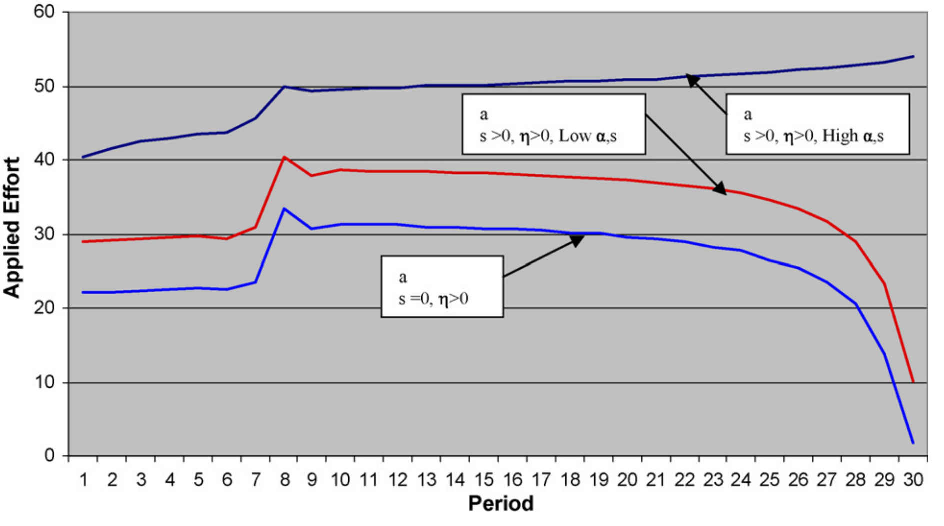

Fig. 11. Applied effort in the complements model in a tenure system: high, low licensing vs. no licensing.

Fig. 13 plots research output for the three cases. Until very late in the career, research output is highest in the licensing regime with low values of s and α_i, and it is lowest in the licensing regime with high values of s and α_i. This means that licensing improves research output when the returns are positive but relatively low, but it compromises research output over much of the life cycle when the returns are very high. The reason for this is that tenure boosts basic effort prior to the tenure year much more when s and α_i are low or equal to zero than when s and α_i are high. The relative high levels of basic effort early in the career with low or zero s and α_i yield relatively higher stocks of knowledge so that basic and applied efforts are more productive in those cases after tenure.

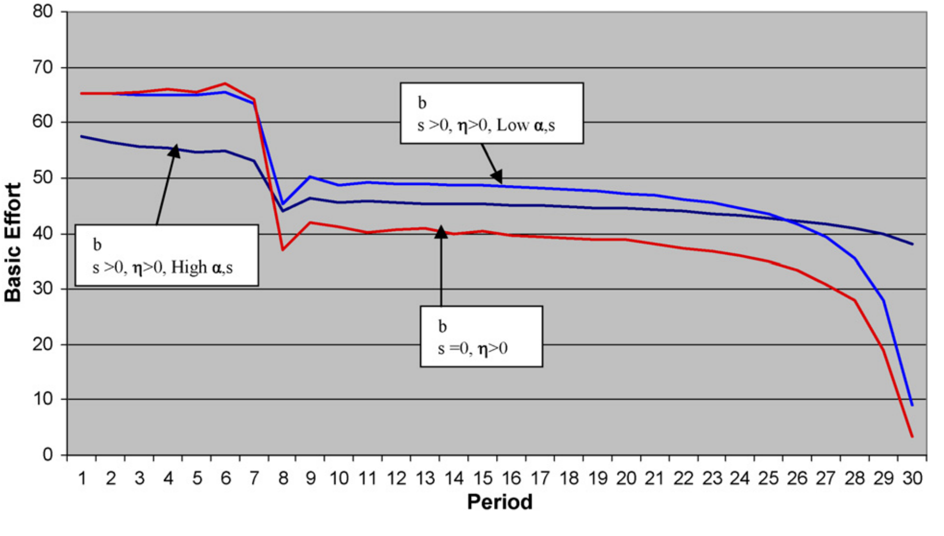

Fig. 12. Basic effort in the complements model in a tenure system: high, low licensing vs. no licensing.

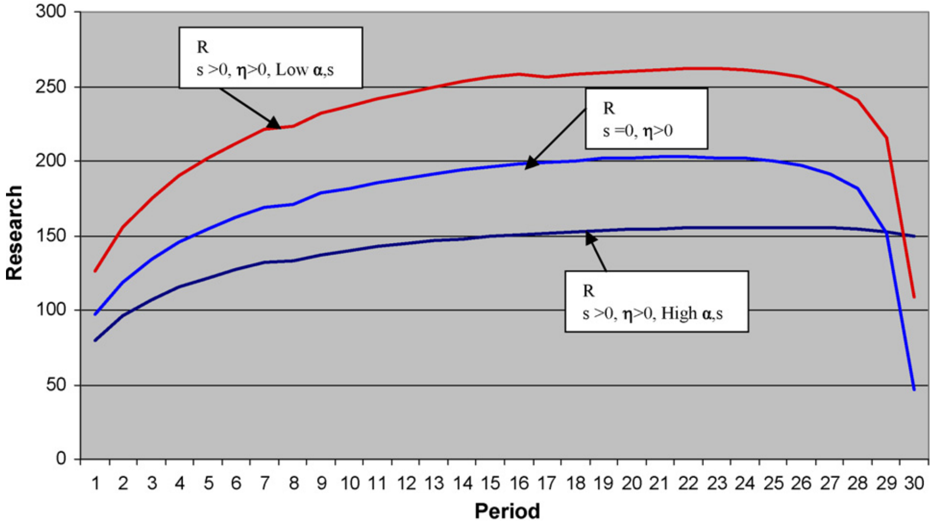

Fig. 13. Research output in the complements model in a tenure system: high, low licensing vs. no licensing.

Thus licensing in a tenure world increases basic effort for much of the career as long as the financial incentives are not too high. This result is interesting in light of Jensen et al.'s (2003) finding that faculty shares of royalty income are indeed lower in US universities with higher quality faculty (as measured by the National Research Council rankings of PhD granting departments). In their work, administrators set the shares of license income accruing to faculty and the technology transfer office (TTO) in a principal agent model with the administrator as the principal and the TTO and faculty as agents. Utility in their model is a function only of revenue, so diversion of faculty from research is not an issue to administrators. Our results suggest a new implication of their empirical result: perhaps administrators in top universities (as defined by the NRC) have been wise in their choices.

5. Concluding remarks

An important issue in the debates over university licensing is whether the associated financial incentives compromise the research mission of the university by diverting faculty from basic research. In this paper, we argue that understanding the effects of licensing on research requires an understanding of faculty motives in conducting research and how they vary over the life cycle. We construct several life cycle models of faculty behavior that take into account both the puzzle solving and financial motives for faculty to conduct research. In the models we consider, the faculty member faces a fixed teaching load and chooses the amount of time to devote to research (which can be either basic or applied) and the amount of time to take as leisure. We consider her behavior with and without the possibility of licensing. This allows us to examine the effect throughout the life cycle of licensing on the research mix as well as the total amount of time working.

We show that, with or without licensing and regardless of the research production functions considered, faculty devote more time to research early in their career, so that leisure rises over time. In that sense, licensing does not alter life cycle patterns. There are, nonetheless, real effects of licensing since it yields a higher ratio of applied to basic effort and lower leisure throughout the life cycle. Thus, as suggested by Lach and Schankerman, faculty respond to economic incentives. This is not to say, however, that licensing compromises research effort. In our models, leisure is the activity most compromised, so total research effort rises, and in most of the models we consider, basic effort rises with the introduction of licensing.

The implications of licensing for research output and the stock of knowledge depend on the model specification. The worst case scenario is of course the development model without tenure because in this case applied effort adds nothing to the stock of knowledge. In this case, research output suffers from the introduction of licensing. If, however, the applied effort involved in licensing leads to publishable output as well as licenses, then the outlook is more favorable. In these cases, research output and the stock of knowledge are generally higher with licensing than without. Interestingly, this result is not dependent on the assumption that basic and applied effort are complements in production. It stems, rather, from the fact that applied effort contributes to the stock of knowledge and the complementarity of basic and applied effort with the stock of knowledge in the license production function. The complementarity between research effort and the stock of knowledge also explains the positive view of tenure in our models. Finally, the only negative effect of licensing in these cases is with a tenure system when the incentives to license are extremely high.

Several limitations of the analysis should be noted because they present opportunities for future research. First, we focus on a subset of issues related to the "kept" university. Another important issue is how commercial involvement by faculty affects the dissemination of research. There is increasing empirical evidence that sponsored research and/or licensing may lead to delays in publication and/or research that is kept secret, particularly with exclusive licensing (Murray and Stern, 2005; Thursby and Thursby, 2002, 2003). We abstract from this since we examine a single faculty member's research. In a more general setting with many researchers, restricted knowledge flows might well alter our conclusions regarding cumulative knowledge for the complements case.

Second, we do not examine welfare implications of faculty choices. A welfare analysis is well beyond our scope and would require consideration of many other aspects, such as dissemination patterns as in Mukherjee and Stern (2005), the optimal stage for research to be transferred to industry as in Aghion et al. (2005), and other educational issues (see Stephan and Levin, 1996). Note, as well, in modeling tenure we assume that the faculty member has the freedom to choose research topics so that issues of academic freedom are ignored.

Finally, by focusing on the transfer of knowledge through either publication or licensing, we have abstracted from other ways that university researchers interact with industry. For example, we do not differentiate between income from licensing to an established firm and income from a license to a start-up company where the faculty member might take a leave from the university. We have also not discussed faculty consulting, which is common with both start-ups and established firms (Murray, 2002; Mansfield, 1995). While the model we construct says nothing about the case of the faculty member taking a leave, the results could easily be reinterpreted in terms of consulting. That is, the income the faculty member earns from applied research could be interpreted as consulting income in any of the models we present without loss of generality. If one believes that consulting contributes to the faculty member's income but not to research output, then the appropriate model would be the development model. Alternatively, the complements model is consistent with Mansfield's survey results, showing that consulting often leads to basic research ideas. We believe further analysis of this case is important, since in other work (Thursby et al., 2007; Jensen et al., 2006) we have found substantial involvement of university faculty in industrial patenting (both in start-up and established firms) while they remain employed in the university.

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References

Adams, J., 1990. Fundamental stocks of knowledge and productivity growth. Journal of Political Economy 98, 673–702.

Aghion, P., Dewatripont, M., Stein, J., 2005. Academic freedom, private-sector focus, and the process of innovation. NBER Working Paper 11542.

Alchian, A., 1953. In: Bradley, P.D. (Ed.), Private Property and the Relative Cost of Tenure. In the Public Stake in Union Power. University of Virginia Press, Charlottesville, pp. 350–371.

Beath, J., Owen, R., Poyago-Theotoky, J., Ulph, D., 2003. Optimal incentives for income-generation within universities. International Journal of Industrial Organization 21, 1301–1322.

Boyd, E., Cho, M., Bero, L., 2003. Financial conflict of interest policies in clinical research: issues for clinical investigators. Academic Medicine 78, 769–774.

Carmichael, H.L., 1988. Inventives in academics: why is there tenure? Journal of Political Economy 96, 453–472.

Cohen, W., Florida, R., Randazzese, L., Walsh, J., 1998. Industry and the academy: uneasy partners in the cause of technological advance. In: Noll, R. (Ed.), Challenges to Research Universities. The Brookings Institution, Washington, pp. 171–199.

Dasgupta, P., David, P., 1987. Information disclosure and the economics of science and technology. In: Feiwel, G.R. (Ed.), Arrow and the Ascent of Modern Economic Theory. New York University Press, New York.

Dasgupta, P., David, P., 1994. Toward a new economics of science. Research Policy 23, 487–521.

Dasgupta, P., Maskin, E., 1987. The simple economics of research portfolios. The Economic Journal 97, 581–595.

Hagstrom, W., 1965. The Scientific Community. Basic Books, New York.

Jensen, R., Thursby, M., 2001. Proofs and prototypes for sale: the licensing of university inventions. American Economic Review 91, 240–259.

Jensen, R., Thursby, M., 2004. The academic effects of patentable research. NBER Working Paper 10758.

Jensen, R., Thursby, J., Thursby, M., 2003. The disclosure and licensing of inventions in US universities. International Journal of International Organization 21, 1271–1300.

Jensen, R., Thursby, J., Thursby, M., 2006. In or out: University research and faculty consulting. Working paper.

Killingsworth, M., 1982. Learning by doing and investment in training: a synthesis of two rival models of the life cycle. Review of Economic Studies 49, 263–271.

Kuhn, T., 1970. The Structure of Scientific Revolutions. University of Chicago Press, Chicago.

Lach, S., Schankerman, M., 2003. Incentives and inventive activity in universities. CEPR Discussion Paper 3916.

Lazear, E.P., 2004. The Peter Principle: a theory of decline. Journal of Political Economy 112, 141–163.

Levin, S., Stephan, P., 1991. Research productivity over the life cycle: evidence for American scientists. American Economic Review 81, 114–132.

Li, S., Ou-Yang, H., 2003. Incentives, Performance, and Academic Tenure. Duke University, Mimeo.

Mansfield, E., 1995. Academic research underlying industrial innovations: sources, characteristics, and financing. Review of Economics and Statistics 77, 55–65.

McDowell, J., 1982. Obsolescence of knowledge and career publication profiles: some evidence of differences among fields in costs of interrupted careers. American Economic Review 72, 752–768.

McPherson, M., Winston, G., 1983. The economics of academic tenure: a relational perspective. Journal of Economic Behavior and Organization 4, 163–184.

Merton, R., 1957. Priorities in scientific discovery: a chapter in the sociology of science. American Sociological Review 22, 635–659.

Merton, R., 1973. In: Storer, N.W. (Ed.), The Sociology of Science: Theoretical and Empirical Investigations. University of Chicago Press, Chicago.

Morgan, R., Kannankutty, N., Strickland, D., 1997. Future directions for university-based engineering research. ASEE PRISM 6, 33–36.

Mowery, D., Nelson, R., Sampat, B., Ziedonis, A., 1999. The effects of the Bayh-Dole Act on U.S. University Research and Technology Transfer: an analysis of data from Columbia University, the University of California, and Stanford University. In: Branscomb, L.M, Kodama, F., Florida, R. (Eds.), Industrializing Knowledge: University-Industry Linkages in Japan and the United States. MIT Press, Cambridge, MA.

Mowery, D., Ziedonis, A., 2002. Academic patent quality and quantity before and after the Bayh-Dole Act in the United States, Research Policy 31, 399–418.

Mukherjee, A., Stern, S., 2005. Disclosure or Secrecy? The Economics of Open Science. Northwestern University, Mimeo.

Murray, F., 2002. Innovation as coevolution of science and technology: exploring tissue engineering. Research Policy 31, 1389–1403.

Murray, F., Stern, S., 2005. Do formal intellectual property rights hinder the free flow of scientific knowledge? An empirical test of the Anti-Commons hypothesis. NBER Working Paper 11465.

Nelson, R., 1992. What is 'commercial' and what is 'public'. In: Rosenberg, N., Landau, R., Mowery, D. (Eds.), Technology and the Wealth of Nations. Stanford University Press, Stanford.

Oster, S., Hammermesh, D., 1998. Aging and productivity. Review of Economics and Statistics, 154–156.

Rahm, D., 1994. U.S. universities and technology transfer: perspectives of academic administrators and researchers. Industry and Higher Education 8, 72–78.

Rosenberg, N., Nelson, R., 1994. American universities and technical advance in industry. Research Policy 23, 323–348.

Ryder, H., Stafford, F., Stephan, P., 1976. Labor, leisure and training over the life cycle. International Economic Review 17, 651–674.

Siow, A., 1984. Occupational choice under uncertainty. Econometrica 52, 631–645.

Siow, A., 1998. Tenure and other unusual personnel practices in academia. Journal of Law, Economics, and Organization 14, 152–173.

Stephan, P., 1996. The economics of science. Journal of Economic Literature 34, 1199–1235.

Stephan, P., Levin, S., 1992. Striking the Mother Lode in Science: The Importance of Age, Place, and Time. Oxford University Press, New York.

Stephan, P., Levin, S., 1996. Property rights and entrepreneurship in science. Small Business Economics 8, 177–188.

Stephan, P., Gurmu, S., Sumell, A.J., Black, G., in press. Who's patenting in the university? Evidence from the survey of earned doctorates. Economics of Innovation and New Technology.

Stern, S., 2004. Do scientists pay to be scientists? Management Science 50, 835–853.

Thursby, J., Jensen, R., Thursby, M., 2002. Objectives, characteristics and outcomes of university licensing: a survey of major U.S. Universities. Journal of Technology Transfer 26, 59–72.

Thursby, J., Thursby, M., 2002. Who is selling the ivory tower? Sources of growth in university licensing. Management Science 48, 90–104.

Thursby, J., Thursby, M., 2003. University licensing and the Bayh-Dole Act. Science 301, 1052.

Thursby, J., Thursby, M., in press. Patterns of research and licensing activity of science and engineering faculty. In: Ehrenberg, R., Stephan, P. (Eds.), Science and the University. University of Wisconsin Press, Madison.

Thursby, J., Fuller, A., Thursby, M., 2007. U.S. faculty patenting: Inside and outside the university. Working paper, January 2007.

Zerhouni, E. W., 2004. NIH ethics concerns: consulting arrangement and outside awards. In: Testimony Before the Oversight and Investigations Subcommittee, Committee on Energy and Commerce. US House of Representatives.

Zucker, L., Darby, M., Armstrong, J., 1994. Geographically localized knowledge: spillovers or markets. Economic Inquiry 36, 65–86.

Zucker, L., Darby, M., Brewer, M., 1998. Intellectual capital and the birth of U.S. Biotechnology Enterprises. American Economic Review 88, 290–306.