Are there Real Effects of Licensing on Academic Research? A Life Cycle View

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A prominent issue in the debates over faculty involvement in university licensing is whether financial incentives associated with licensing have diverted faculty from basic toward applied research (Stephan and Levin 1996). Available evidence is limited and provides mixed results. Lach and Schankerman (2003) provide empirical support for the view that invention activity, as measured by invention disclosures, is positively related to the share of license income accruing to faculty. Thursby and Thursby (2002, 2004) provide support for the view 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.

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In this paper, we present a life cycle model of faculty research that allows us to examine this and related issues. 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 income since publications are rewarded in salary. Thus, as in Levin and Stephan (1991), 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 motive for applied research, which does not decline over the life cycle. Applied work that is licensed provides a future income stream that continues regardless of work effort.

1 Prior Art

This research is related to prior work in the economics of science, life cycle behavior, and university-industry technology transfer. 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, and 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 Ph.D. 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, and Stephan and Levin 1996).

The study most relevant to ours is that of Levin and Stephan (1991). In their model, scientists engage in research for two reasons: their love of puzzle solving and as 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 which 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.[1]

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 era (Cohen *et al.* 1994, 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 (1998) 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. By contrast, Mansfield (1995), Zucker *et al.* (1994, 1998), Stephan *et al.* (2002), and Murray (2002) find a complementary relationship between research productivity and commercial activity. Mansfield's (1995) 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

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

start new enterprises while continuing research in their academic appointments. In the case of tissue engineering, Stephan *et al.* (2002) 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 (2002) find a positive relationship between invention disclosures and the share of license revenue 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 (2004) which examines the research profiles of 3,241 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* (2003) 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. By 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.

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 (1991), 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, which 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 that 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,and n_t to maximize

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

where $\rho > 0$, $U(\cdot)$ and $V(\cdot)$ are assumed to be twice differentiable and strictly concave in their arguments.

In it's 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 it is also 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 embryonic inventions require further development for commercial success (Thursby *et al.* 2002, and 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 in 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 revenue. We assume that capital markets are perfect so that the faculty member's license income can be cashed in at t.

3 Simulations

The system is sufficiently complex that we resort to simulations to characterize the time paths of research efforts and productivity. To simplify, we follow Ryder *et al.* (1976) in assuming $\rho = i = 0$ so that life cycle earnings are spread evenly over the life cycle. 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:

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

where $\gamma_i \geq 0$ $(i = 1, 2, 3)$ and φ is either 0 and 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. (1994)). 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 (where $n_t = 100 - a_t - b_t$) 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 licensing 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 $t = 1, 2, ..., 30$. 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 $\delta = (0.2, 0.4)$, $\gamma_3 = (0.2, 0.3)$, $\gamma_1 = (0.0, 0.15, 0.2, 0.3, 0.4, 0.5)$, and $\gamma_2 = (0.25, 0.3, 0.4, 0.5, 0.75)$ where $\gamma_1 \leq \gamma_2$. 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 $\theta_3 = 0.5$).[2] In the non-licensing regime all $\alpha_i = 0$ and $s = 0$. In the licensing regime we use parameter combinations from the sets $s = (0.25, 0.5)$, $\alpha_1 = (0.4, 0.6)$, $\alpha_2 = (0.0, 0.3, 0.5)$ where $\alpha_1 \geq \alpha_2$ and $\alpha_3 = (0.25, 0.4)$. 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 3.1−3.2, 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.

[2] 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.

3.1 Development Case

In this section, we consider the behavior of a faculty member who chooses basic and applied effort to 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. For this reason 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. But in this case applied work only provides license income while basic effort provides utility and income, so the extent to which licensing increases applied effort is not clear.

Figure 1 plots the average values of applied and basic effort across parameter combinations when licensing is not rewarded ($s = 0$) and when it is ($s > 0$). In the first case we average life-cycle effects over 20 parameter combinations and in the second we consider 157 combinations. When $s = 0$ there are no returns to licensing (pecuniary or nonpecuniary) so a_t is zero in every period, so the plot is not shown. Results of note are:

1. When licensing is rewarded, some effort is diverted to applied work in every period and this effort increases toward the end of the life cycle. This, of course, follows from the fact that returns to research output end at period T while licensing output gives returns beyond that point.

2. Licensing lowers basic effort early in the life cycle, though the effect is quite small on average. Note also that by the end of the career, the presence of licensing actually increases basic effort relative to the nolicensing regime. This occurs because, although basic effort has no direct effect on license output, it has an indirect effect through the stock of knowledge. Thus the increase in the financial rewards for license output relative to research output toward the end of the life cycle increases basic as well as applied effort.

3. Leisure can be inferred from the combined plots for a_t and b_t, and is plotted in Figure 2. In both the licensing and non-licensing regimes, leisure activity increases over the life-cycle. Since the ability to license increases applied effort and reduces

basic effort early in the life cycle, 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 initially negligible. Toward the end of the life cycle, the presence of licensing decreases leisure (relative to the non licensing case) since both applied and basic effort increase.

4. As in Levin and Stephan (1991) research output and the stock of knowledge initially increase but eventually they decline as a result of the decline in basic effort. As shown in Figure 3, research output is lower with than without licensing until the very end of the life cycle. The latter effect follows from the fact that basic research effort with licensing is higher toward the end of the life cycle. 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.[3]

To summarize, in this model licensing does indeed divert faculty from research, but the effect for the parameter values we consider is remarkably small. Moreover the negative impact on research is early in the life cycle since basic effort increases toward the end of the career. Thus while research output and the stock of knowledge rise and then fall with licensing, the plots are flatter than without licensing. Toward the very 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 Case

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 it 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:

[3] 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.

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

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, or $\gamma_1 > \gamma_2$. In the licensing function we assume the opposite in that the exponent of applied is larger than that of basic ($\alpha_1 > \alpha_2$). For the case without licensing we consider 14 sets of parameters, and for the case with licensing we consider 114 sets. Figure 5 gives life-cycle results for applied and basic effort in both the case of no licensing ($s = 0$) and licensing ($s > 0$). Results of note with this specification are:

1) Faculty spend more time on basic than applied effort regardless of the licensing regime. In the regime without licensing this clearly follows from our assumption on the relative values of $\gamma_1$and γ_2

2) As in the development case, leisure increases at an increasing rate throughout the life cycle. As shown in Figure 6, this pattern occurs regardless of the licensing regime.

3) With or without licensing, basic and applied research decrease toward the end of the career. Without licensing, they converge to values near zero by the end of the career, which of course follows from the short time horizon for the financial returns from research. In the case of licensing, however, there is an extra financial incentive for research late in the career. Thus while both applied and basic research decline, they converge toward higher values with licensing than without licensing.

4) As expected, licensing induces more applied effort throughout the life cycle. Licensing also increases the amount of basic effort in this specification, although the amount is negligible until late in the life cycle. Thus total research effort in each period is actually higher with licensing than without. This, of course, implies that the real diversion of effort induced by licensing is away from leisure. Over the life cycle, the extra financial incentive leads faculty to work more.

5) The effect of licensing on total research output depends, not only on the change in optimal effort, but also on the productivity of effort. As shown in Figure 7, on average there is little difference in total research output or the stock of knowledge with and without licensing until late in the life cycle. This is a result of the fact that research, which has a higher marginal effect on research output in the cases we consider, changes little until late in the career.

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, the stock of knowledge suffered from licensing since applied effort did not contribute to the stock of knowledge. While it may be a function of the range of parameter values chosen, it is interesting to note that in both cases the effects of licensing early in the life cycle are negligible.

While not shown in the figures, 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.[4]

3.3 Substitutes

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.* 1998). To examine this, we consider life cycle behavior when the production function is given by

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

So that the only change in the model is in the research production function, we continue to assume the licensing production function is 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 Pastuer's Quadrant.

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, or $\gamma_1 > \gamma_2$. In the licensing function we assume the opposite in that the exponent of applied is larger than that of basic ($\alpha_1 > \alpha_2$). For the case without licensing we consider 14 sets of parameters, and for the case with licensing we consider 114 sets.

As shown in Figures 9 to 12, we find the same qualitative results in this case as we do for complements. Research effort increases and then decreases over the life cycle regardless of licensing. With licensing, the portion of research effort that is spent on basic work declines, but as long as applied research leads to the stock

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

of knowledge as well as licensing, neither total research output nor the stock of knowledge suffer. In fact, late in the life cycle, both total research output and the stock of knowledge increase in a licensing regime.

3.4 Tenure

So 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 be counted toward tenure, while applied work may not be counted toward it, and leisure surely is not. 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 which can assume two values over her career: a non-zero positive value before the tenure decision at time d, $t \leqslant d$, and zero on tenure, i.e, $t > d$. 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 $b_t, a_t, X_t,$and n_t to maximize the utility function given by:

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

where the disutility associated with risk is modeled as

$$\Phi_t = -\eta_t \frac{a_t . n_t}{b_t}. \tag{16}$$

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.

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.[5] 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.

Figures 13, 14, and 15 present results for the development case and figures 16, 17, and 18 present results for the complements case. For each case we present the life-cycle patterns of applied, basic and leisure effort and research output with and without a tenure system ($\eta > 0$ and $\eta = 0$, respectively). With a tenure system, we consider a simple time-varying coefficient of risk-aversion of the faculty member, assuming values of $\eta_t \in (0.25, 0.50)$ 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 $d = 7$. The absence of a tenure system implies that neither type of research nor leisure is associated with risk at any point in the life-cycle.

The results are similar for both the development and complements cases:

1) Tenure raises basic effort in the first six periods of the life cycle and reduces the amount of time taken as leisure. After the tenure decision, basic effort and leisure follow patterns close to those without a tenure system.

2) The major difference between the development and complements cases is in the effect of tenure on applied effort. In the development case, applied effort is higher with tenure than without, while in the complements case applied effort is lower in the initial periods with tenure. We interpret the former effect as a result of the fact that the stock of knowledge in the initial periods is higher with tenure (because basic effort is higher) and knowledge and applied effort are complements in the licensing production function.

3) Research output and the stock of knowledge are higher over the life cycle with a tenure system but notice the differences are quite small. Thus, while the ratio of applied to basic research is much lower in case of an impending tenure decision, total research output is barely different than in a regime without tenure.

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

4 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 of licensing on the research mix, as well as the total amount of time working, throughout the life cycle.

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. We also find that, as suggested by Lach and Schankerman (2003), faculty respond to economic incentives. In our models, research responds to the financial incentive provided by licensing, but the activity compromised is not basic research, but leisure.

The implications of licensing for research output and the stock of knowledge depend on the model specification. The worst case scenario considered is the model in which the applied effort necessary for licensing adds nothing to the stock of knowledge. In this case research output suffers from the introduction 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 these cases, basic research is affected little by the introduction of licensing, and since applied effort rises, research output improves. Interestingly, this result is not dependent on the assumption that basic and applied effort are complements in production; they depend only on the fact that applied effort contributes to the stock of knowledge.

Several limitations of the analysis should be noted. First, our production functions represent output in terms of numbers of publications and licenses. Another limitation is that the analysis relies on simulations with particular functional forms and parameter values. Further, it is important to note that the results presented are based on averages across parameter values.

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Figure 1. Applied & Basic in the Development Model

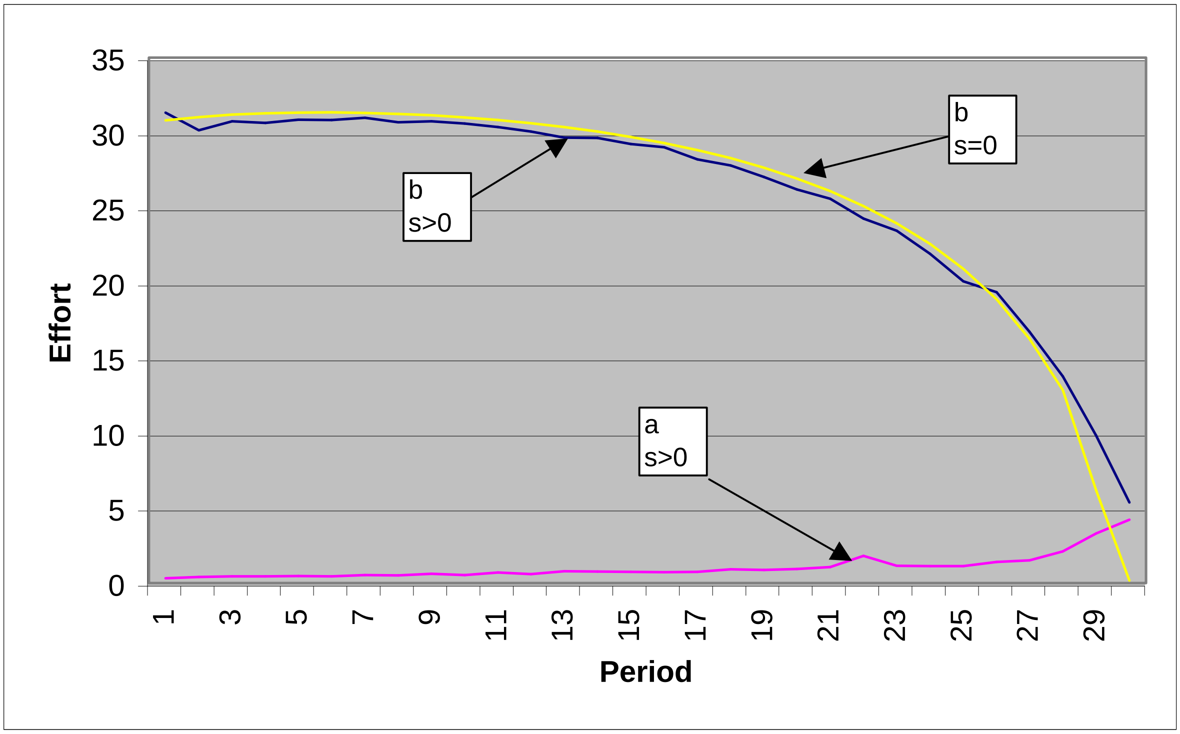

Figure 2. Leisure the Development Model

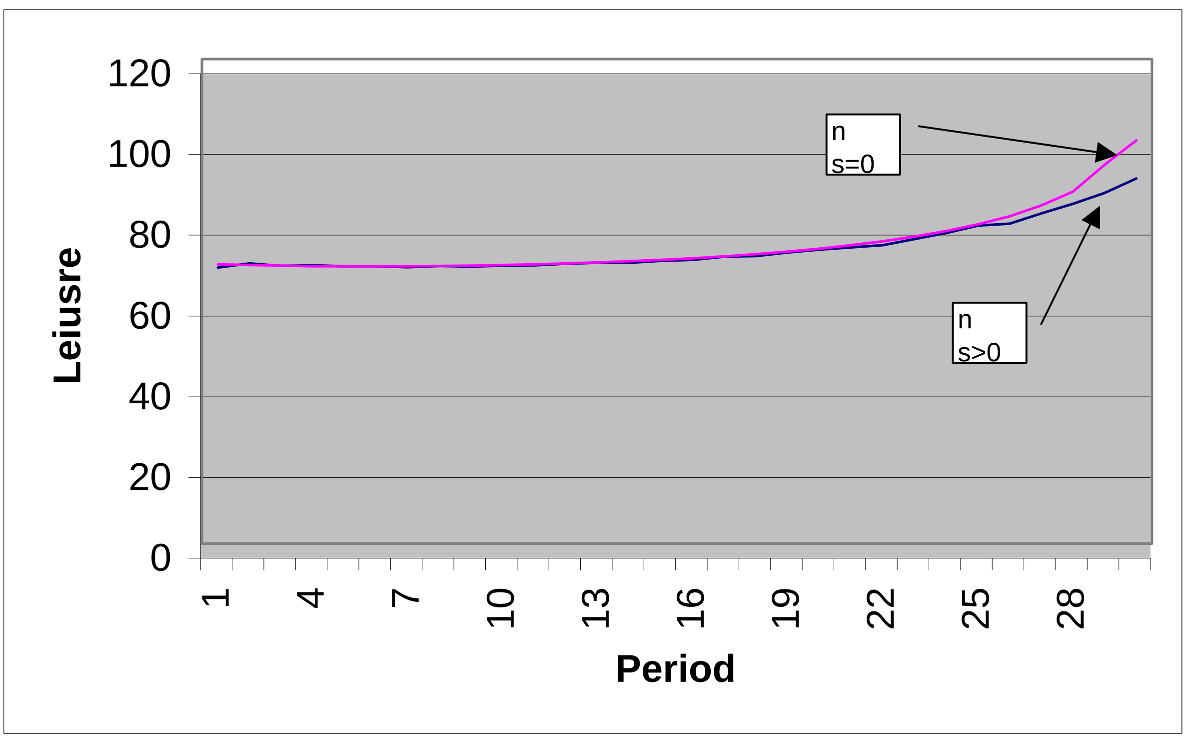

Figure 3. Research (R) and Stock of Knowledge (K) in the Development Model

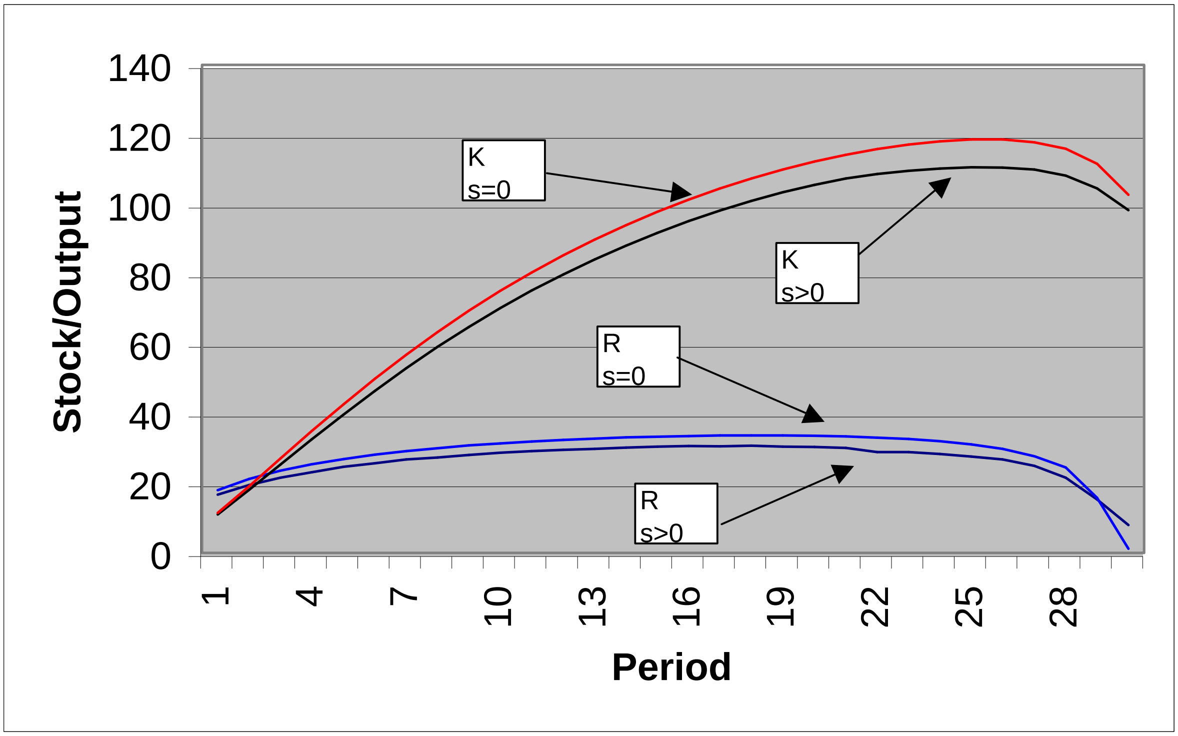

Figure 4. License Output in the Development Model

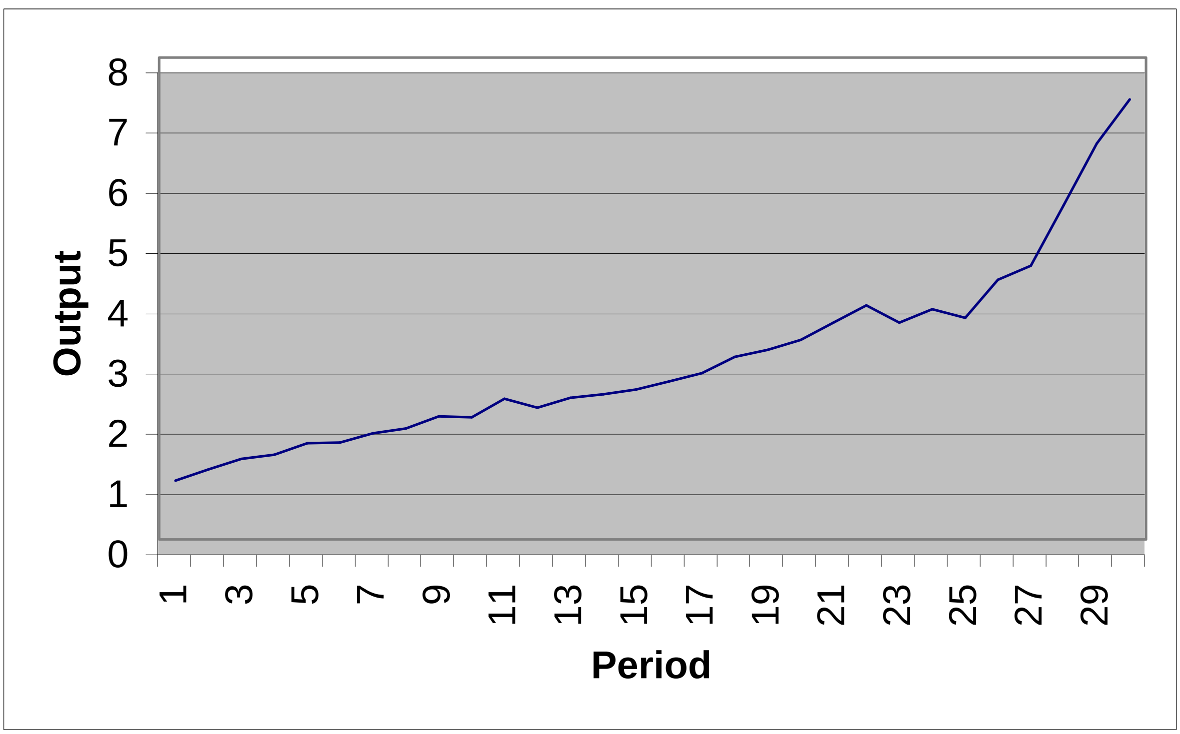

Figure 5. Basic and Applied in the Complements Model

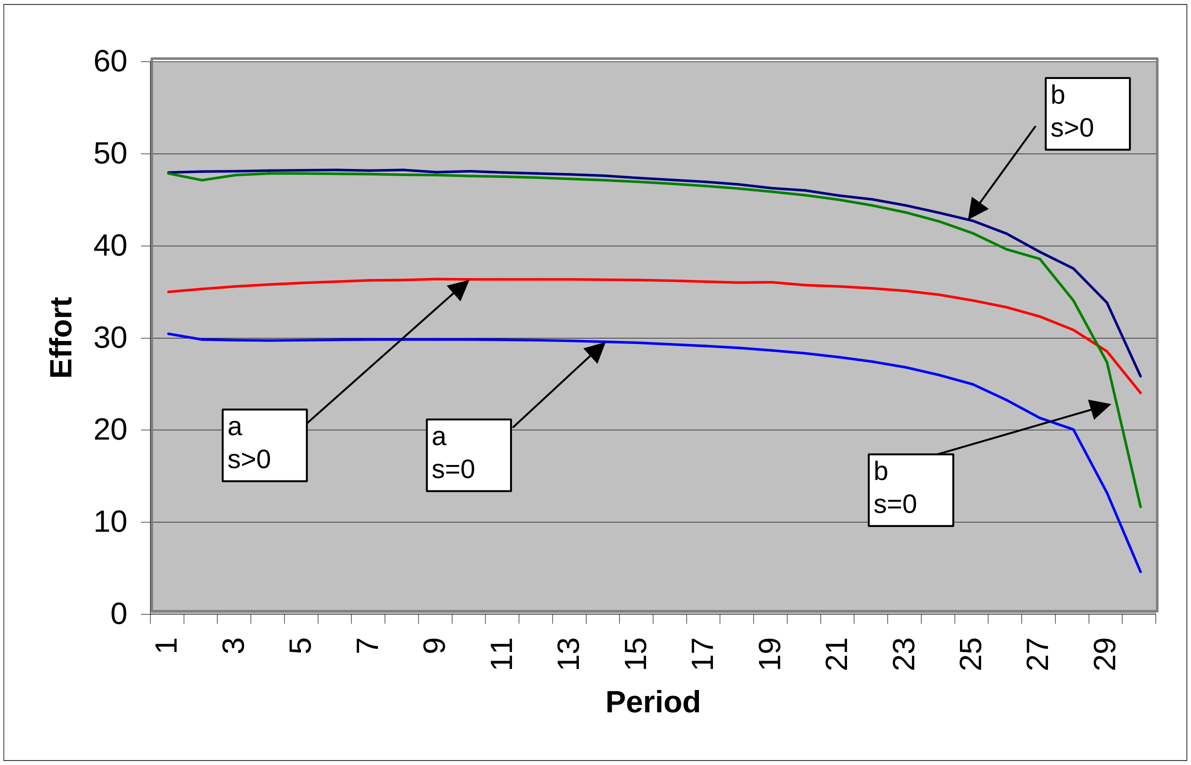

Figure 6. Leisure in the Complements Model

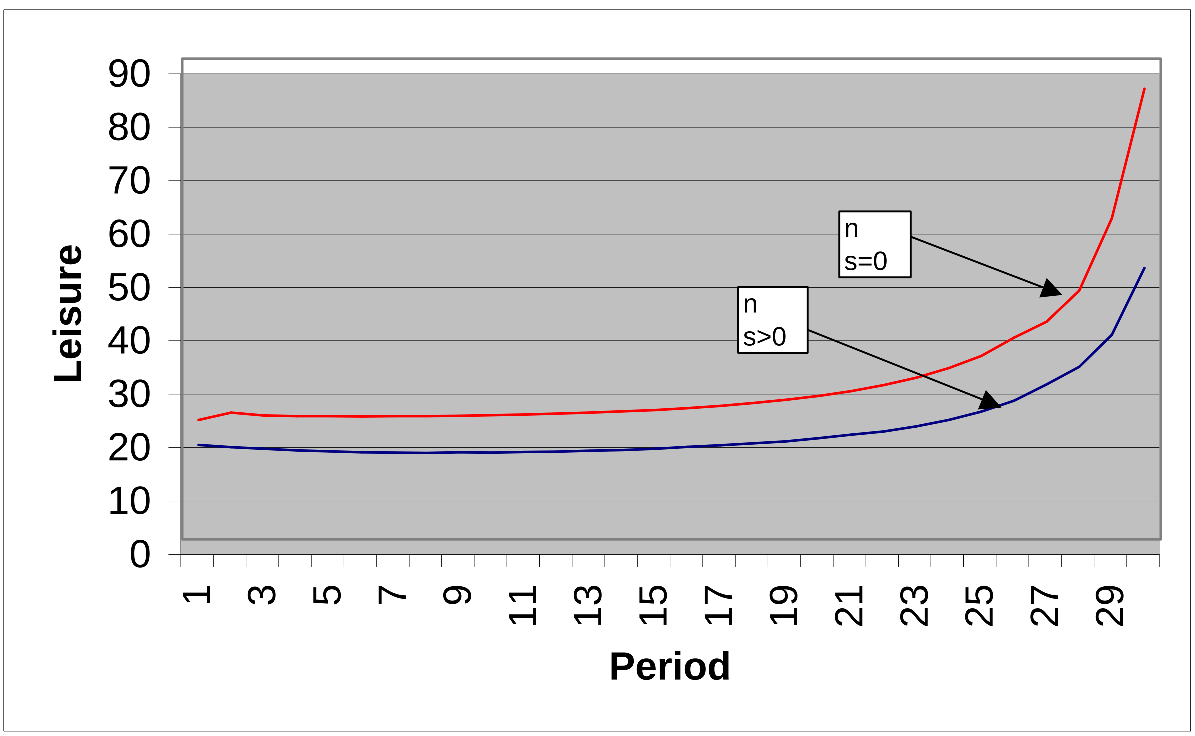

Figure 7. Research (R) and Stock of Knowledge (K) in the Complements Model

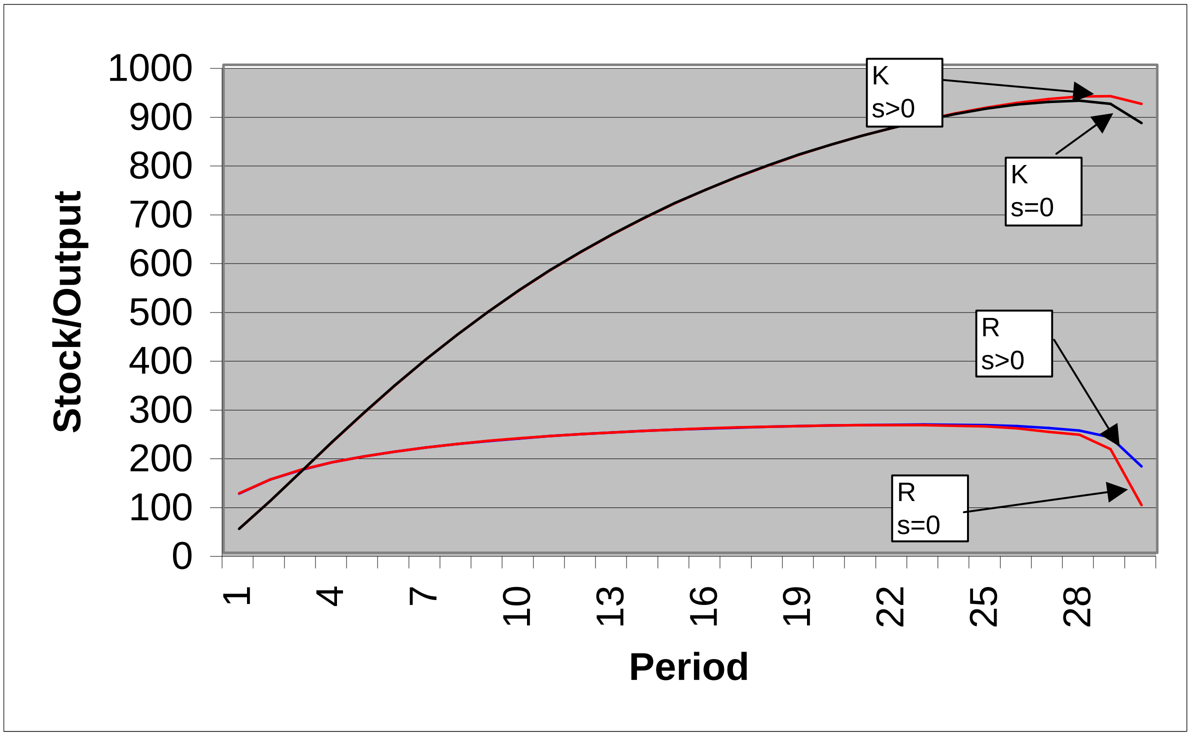

Figure 8. License Output in the Complements Model

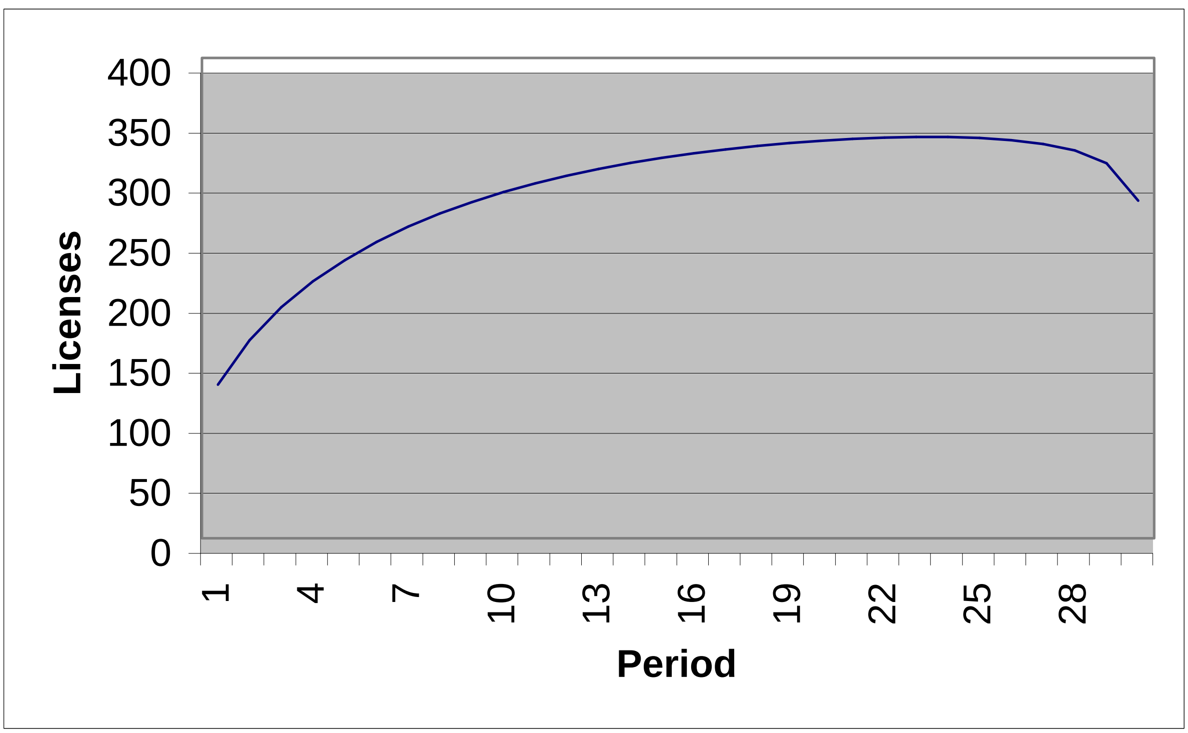

Figure 9. Basic and Applied in the Substitutes Model

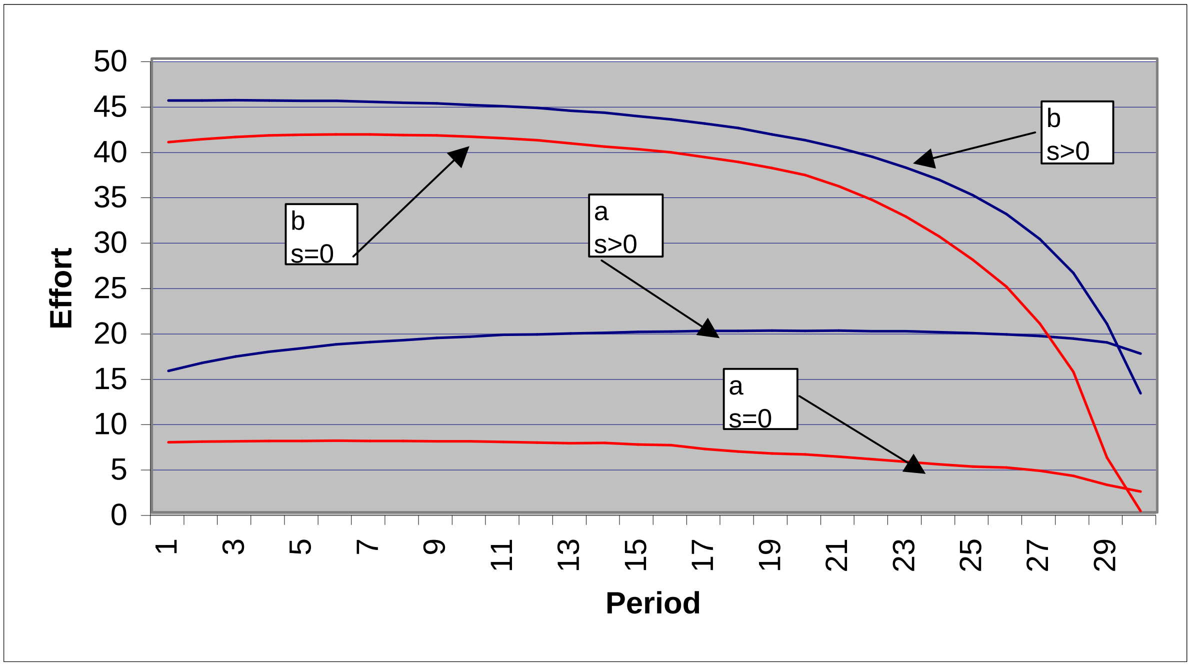

Figure 10. Leisure in the Substitutes Model

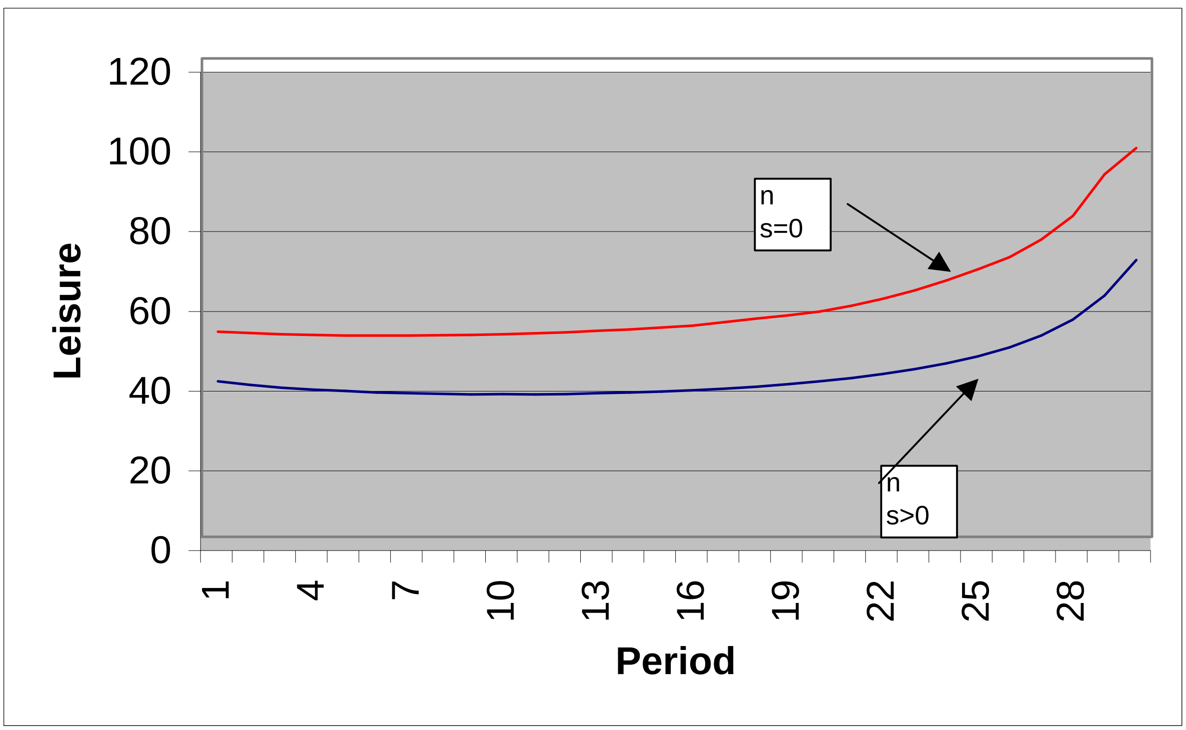

Figure 11. Research (R) and Stock of Knowledge (K) in the Substitutes Model

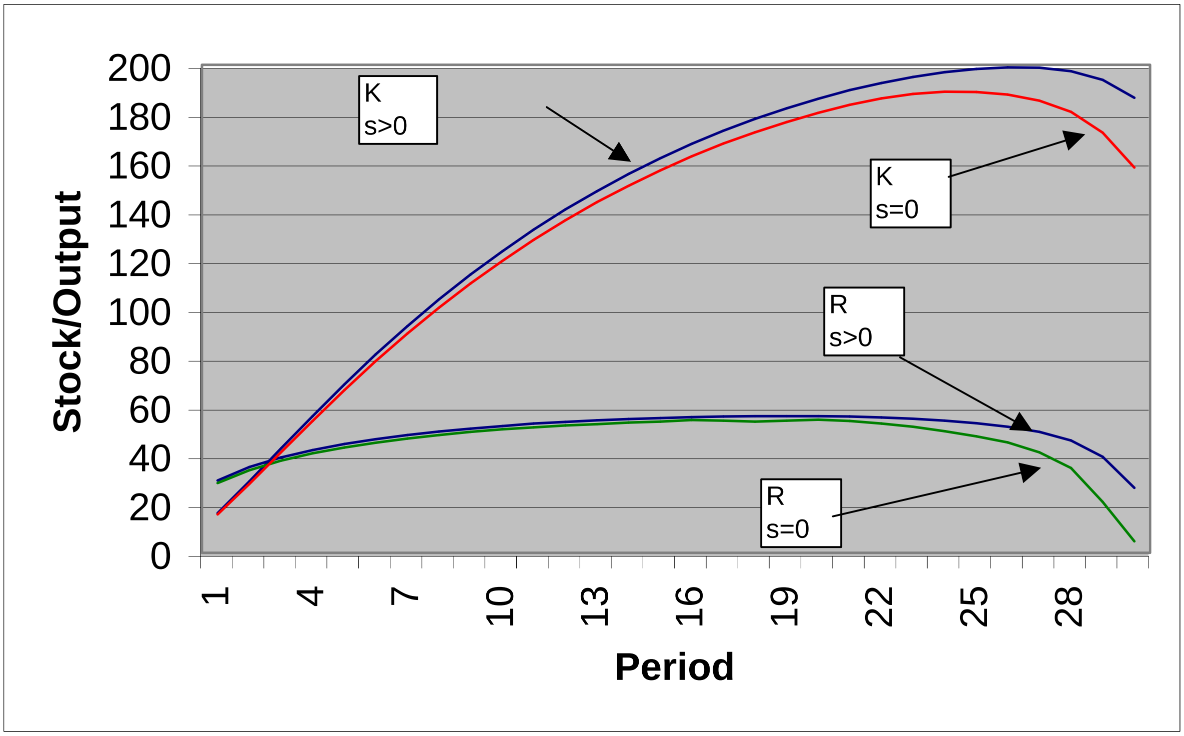

Figure 12. License Output in the Substitutes Model

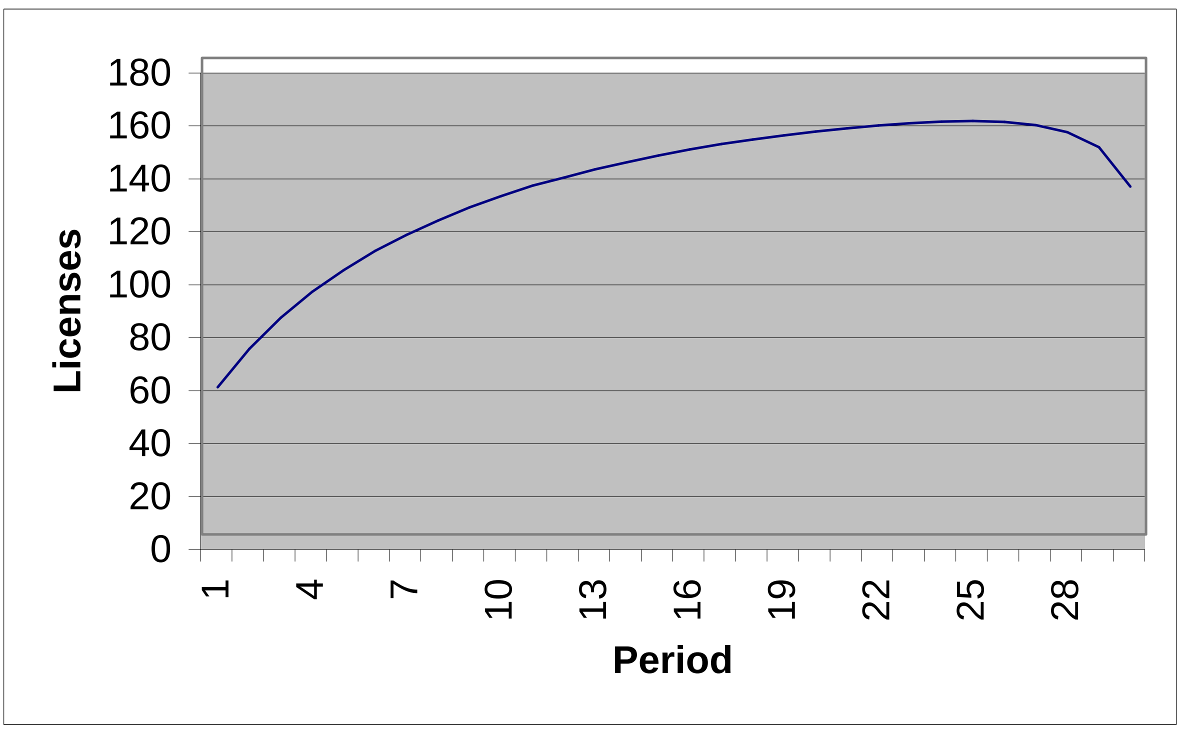

Figure 13: Basic and Applied in the Development model under a Tenure System, with Licensing

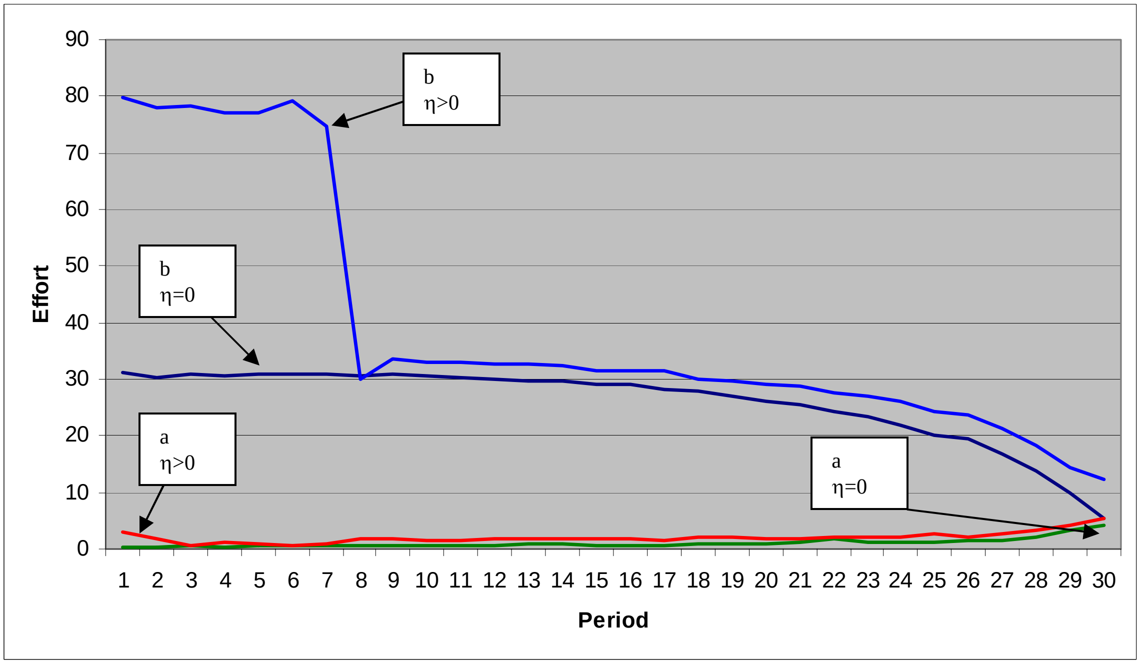

Figure 14: Leisure in the Development model under a Tenure System, with Licensing

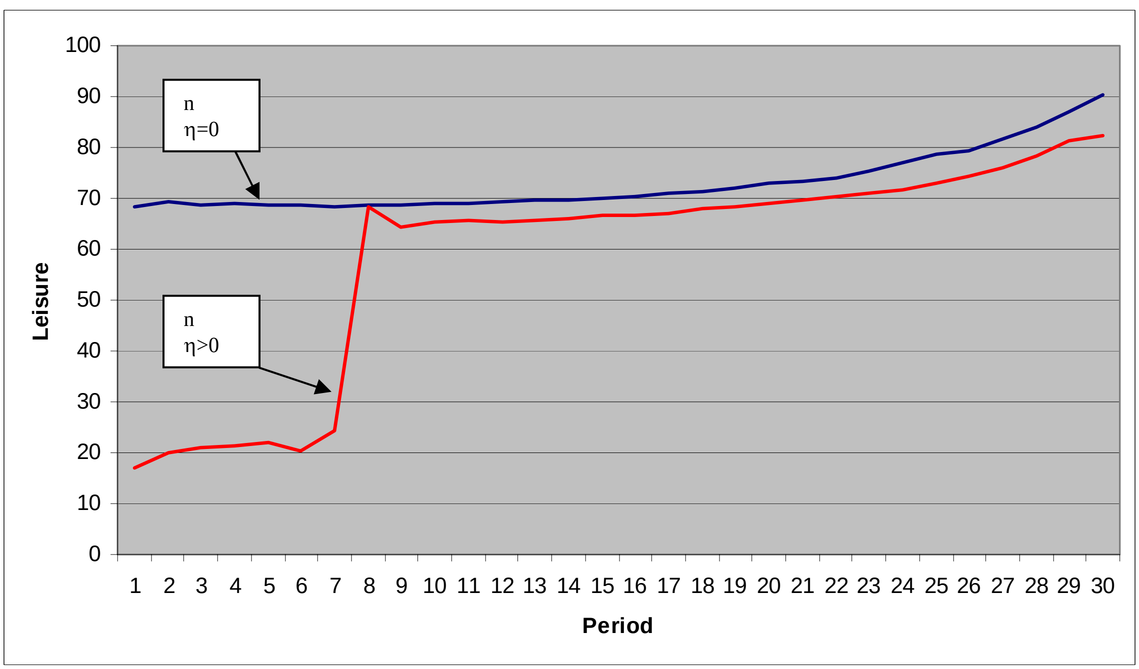

Figure 15: Research (R) and Stock of Knowledge (K) in the Development model under a Tenure System, with Licensing

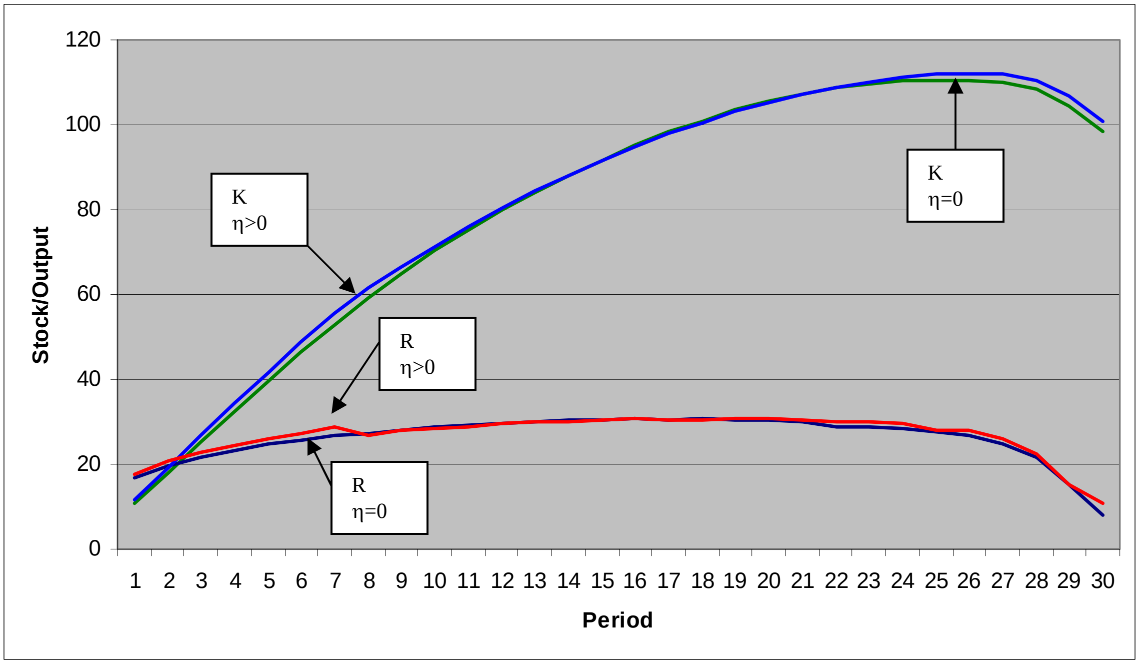

Figure 16: Basic and Applied under a Tenure System, with Licensing

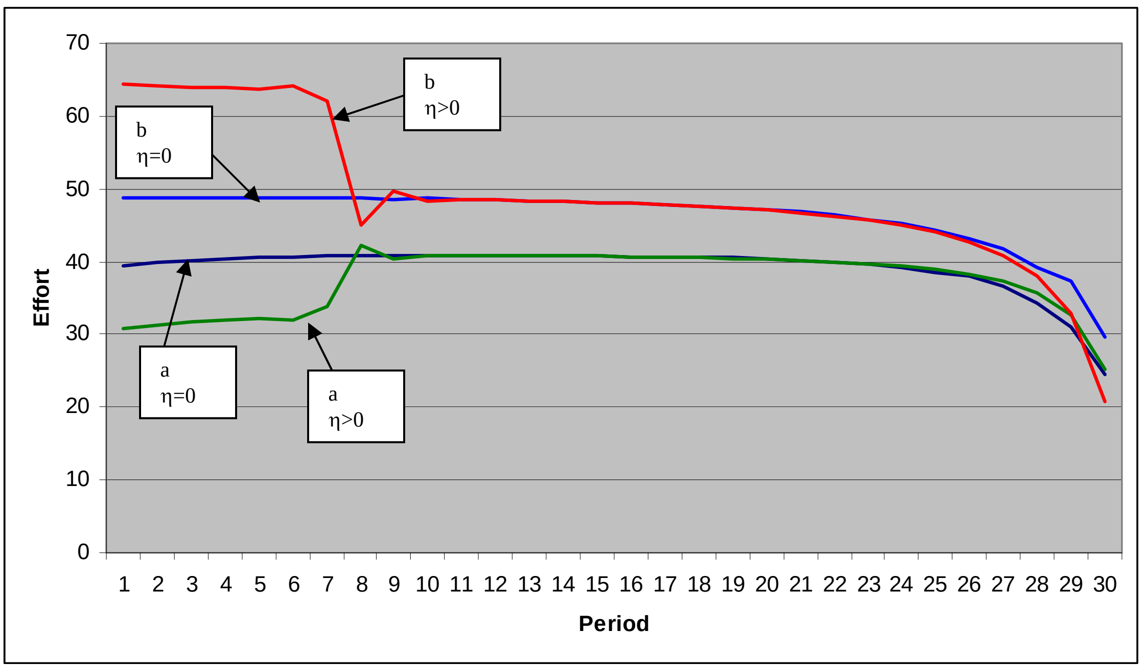

Figure 17: Leisure under Tenure System, with Licensing

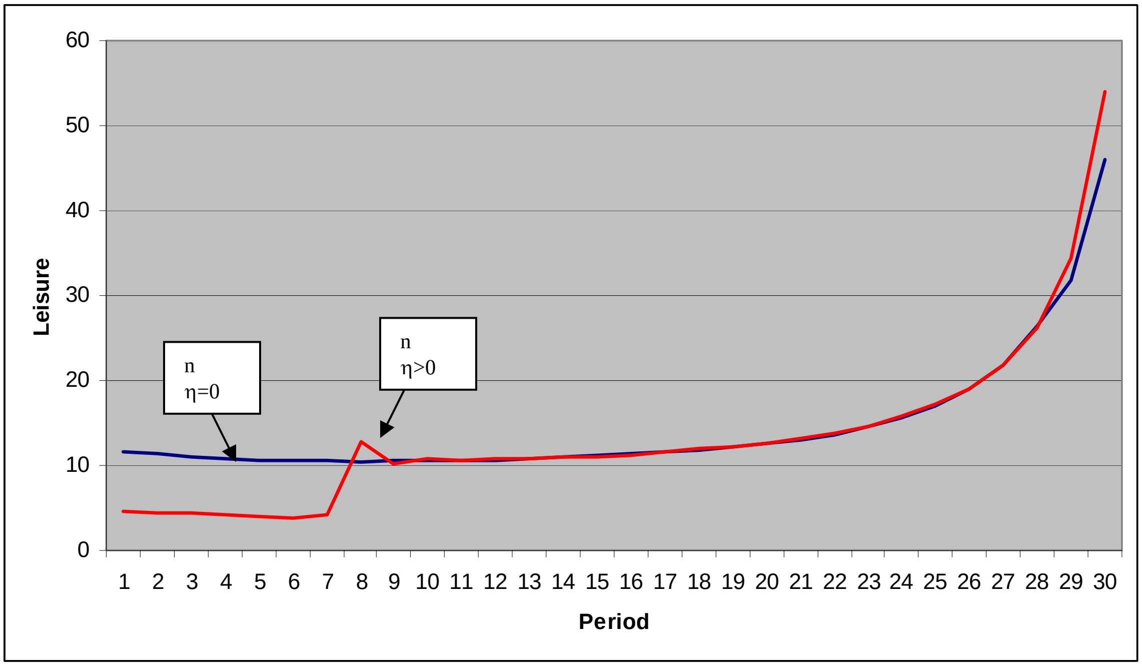

Figure 18: Research (R) and Stock of Knowledge (K) under Tenure System, With Licensing