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 start new

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

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 present a puzzle that is difficult to interpret without rigorous analysis. That is the age profile of disclosure and likelihood of publication suggest that faculty may well turn to more applied work later in their careers; but the profile of basic relative to applied work suggest otherwise.

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 their faculty member derives 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 $\rho \geqslant 0$, $U(\cdot)$ 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 simplicity 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 at 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.

In analysis of the system it will be necessary to assume specific functional forms for the utility function U, the licensing production function g and the research production function f. For utility and licensing we consider

$$U = \ln(R^{\theta_1} X^{\theta_2} n^{\theta_3}) \tag{7}$$

and

$$L_t = {a_t}^{\alpha_1}(1 + b_t)^{\alpha_2} K_t^{\alpha_3}. \tag{8}$$

Where $\theta_i > 0$ $(i = 1, 2, 3)$ and $\alpha_i \geq 0$ $(i = 1, 2, 3)$. We further assume that $\alpha_1 \geq \alpha_2$. Note also that the some applied effort is always necessary in order to produce licenses whereas this is not the case for basic effort.

For the research production function we consider the seemingly complex form

$$R_t = \varphi \left[{a_t}^{\gamma_1} {b_t}^{\gamma_2} K_t^{\gamma_3}\right] \ + \ (1 - \varphi) \left[(a_t^{\gamma_1} + b_t^{\gamma_2}) K_t^{\gamma_3}\right]. \tag{9}$$

where the $\gamma_i > 0$ $(i = 1, 2, 3)$ and $\gamma_1 \leq \gamma_2$. However, φ takes on only the two values 0 and 1. When $\varphi = 1$ we have a purely multiplicative form which allows the complementarity of applied and basic work observed by Mansfield (1995) and Zucker *et.al* (1994, 1998). When $\varphi = 0$ we have an additive form in which applied and basic research are substitutes(as implied by Cohen et al. (1994)). An additive form allows the faculty member to specialize in either type of research, but precludes complementarity.

3 Simulations

This system is sufficiently complex that we resort to simulations to characterize the time paths of research efforts and productivity. Nonetheless, under the assumption that $\rho = i = 0$ (as in Ryder *et. al* (1976)), we can show that optimal behavior involves conducting both types of research and taking some leisure when $\varphi = 1$. If, however, basic and applied work are independent (i.e., $\varphi = 0$), complete specialization in either type of work is possible as well as incomplete specialization (i.e., effort in both applied and basic).

Without loss of generality we set current consumption $X_t = 100$ and the initial value of $K_0 = 1$. We solve the system at each period t for variables 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 parameters φ, which determines the form of the production function, γ_i $(i = 1, 2, 3)$ of the research production function, α_i ($i = 1, 2, 3$) of the licensing production function, θ_i ($i = 1, 2, 3$) of the utility function, δ, the rate of depreciation of the knowledge base and s, the share of licensing income that accures to the researcher. All parameters are non-negative. As noted earlier we also assume $\gamma_1 \leq \gamma_2$ and $\alpha_1 \geq \alpha_2$. These assumptions are tantamount to assuming that applied effort is at least as important in creating licenses as is basic research while basic research is at least as important in creating research output as is applied research.

We will conduct a large number of experiments where an experiment is the lifecycle behavior for a given set of parameters. Questions of interest include the following:

i) In what ways does it matter if basic and applied are substitutes ($\varphi = 0$) or complements ($\varphi = 1$)?

ii) In what ways does the potential for licensing income ($s > 0$) affect leisure and the split between basic and applied effort?

iii) While the potential for licensing income ($s > 0$) can alter the split between basic and applied effort, can it not also affect cumulative research over the life cycle?

iv) How does the rate of depreciation of knowledge affect research effort?

Before turning to initial results on life cycle behavior with licensing, it is worthwhile to note that without licensing, life cycle patterns of research are similar to those of Levin and Stephan (1991) with the exception that we explain the type of research conducted. For this purpose we consider $s = 0$ but $\gamma_1 \neq \gamma_2$ (as in the absence of different financial return, $\gamma_1 = \gamma_2$ is equivalent to consideration of a single type of research). In all of our cases $\gamma_1 < \gamma_2$. We use the combinations $(\gamma_1, \gamma_2) = (0.4, 0.5)$, $(0.4, 0.6)$, and $(0.5, 0.6)$ along with $\gamma_3 = (0.05, 0.1, 0.2)$, $\delta = (0.1, 0.2)$, $\theta_1 = (0.1, 0.25)$, $\theta_2 = 0.3$ and $\theta_3 = (0.5, 0.7)$. For each of these 144 combinations 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 a finite number of points between $t = 1$ and $t = T$. Figure 1 provides the average behavior of each of the variables for $\varphi = 0$ (the substitutes model) and Figure 2 provides the average behavior of the variables when $\varphi = 1$ (the complements model).

To consider how licensing affects behavior, behavior where $s = 0$ and $\gamma_1 = \gamma_2$ provides a useful benchmark as in that case research effort would be split equally between applied and basic research regardless of the values of the other parameters. With $s \neq 0$, the relative returns differ and so may effort. We consider the following parameter combinations: $\varphi = (0, 1)$, $\gamma_1 = \gamma_2 = .4$, $\alpha_1 = (0.25, 0.5, 1.0)$, $\alpha_2 = (0.0, 0.1)$, $\alpha_3 = \gamma_3 = (0.05, 0.1, 0.2)$, $\delta = (0.1, 0.2)$ and $s = (0.5, 0.25)$. Figure 3 provides the average behavior of each of the variables for $\varphi = 0$ (the substitutes model) and Figure 4 provides the average behavior of the variables when $\varphi = 1$ (the complements model).

Note that the life cycle behavior is similar in form for the substitutes and complements models.[2] Stock of knowledge increases at a decreasing rate and actually falls late in careers for the complements model. Research also rises at a decreasing rate until late in the career when it begins to fall. Applied effort is always greater than basic effort. The latter falls late in the career while the former rises. Leisure increases late in the career.

Not only will we present average behavior over a set of parameter values, but we will also consider regressions of R_t, A_t, L_t, K_t, a_t, b_t, and n_t on 2nd degree Taylor series in the parameters. Essentially, we will approximate the system with a simple functional form. This will allow for a more detailed understanding of the role of various parameters in determining system values.

To be continued...

[2] Note that we cannot make a strict comparision of these two sets of results even though we use the same sets of parameter values since the same values of γ_1 and γ_2 have different implications for production of research in the complements model *versus* the substitutes model.

Figure 1. Substitutes with no Licensing

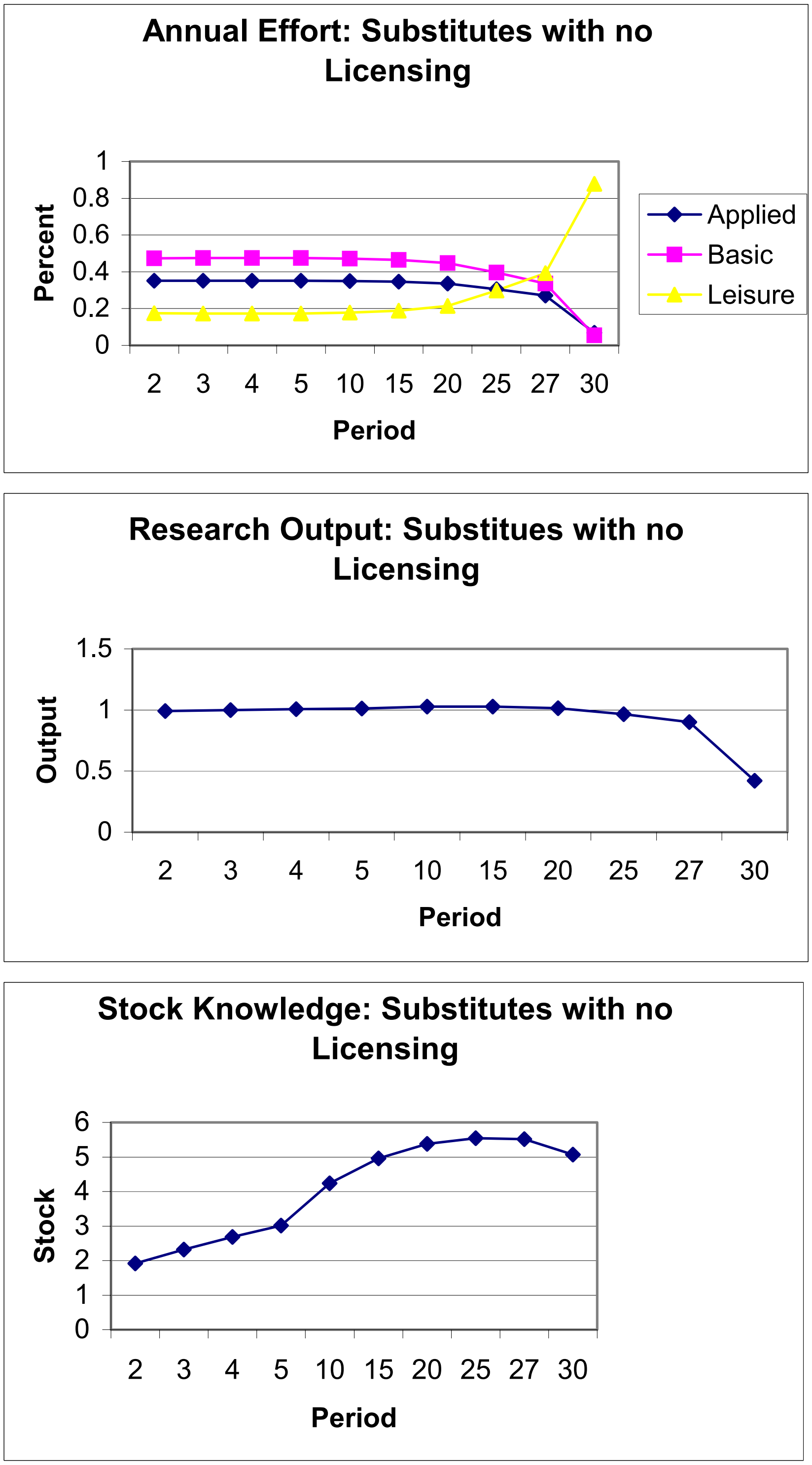


Figure 2. Complements with no Licensing

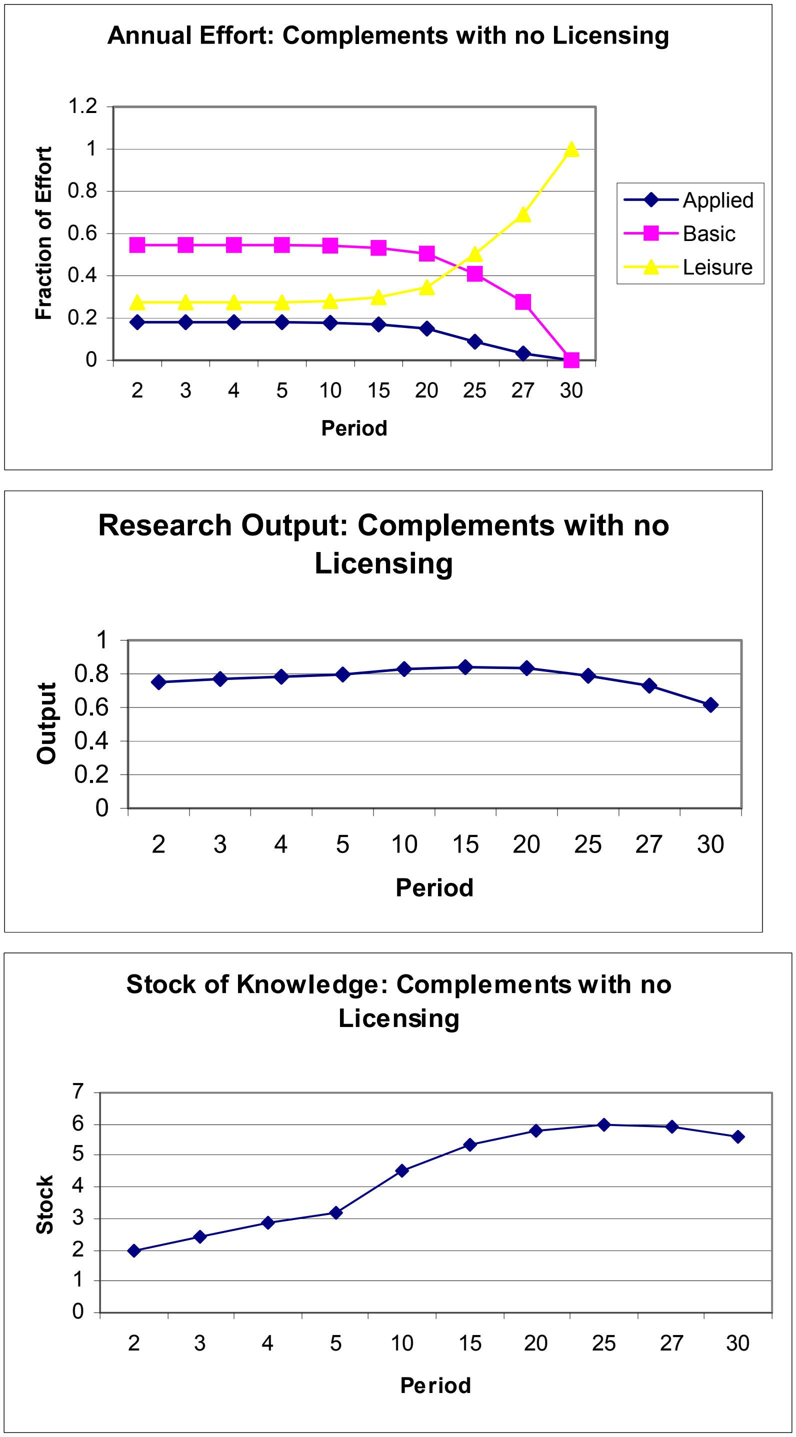
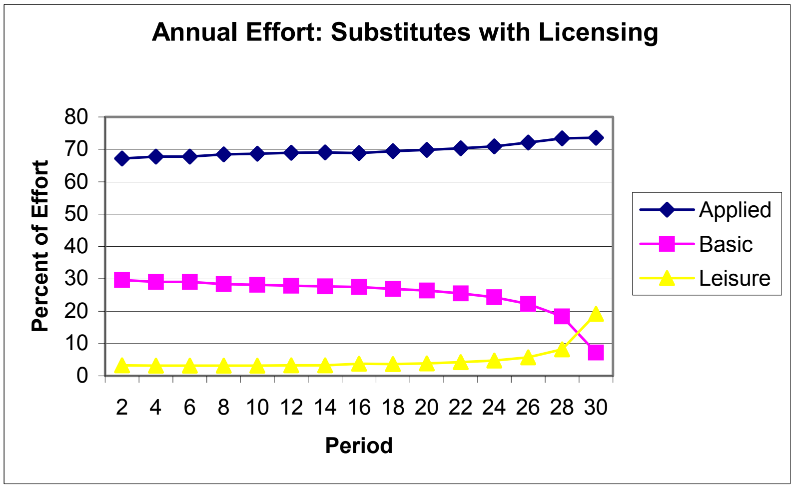
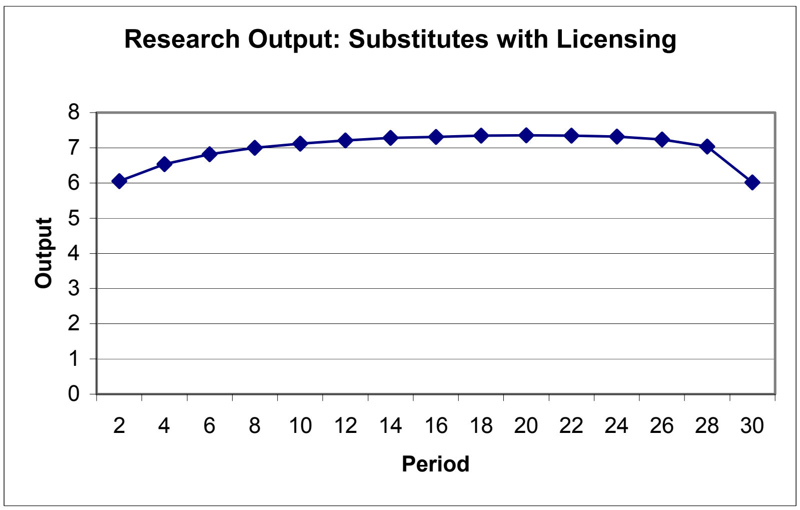


Figure 3. Substitutes Model with Licensing





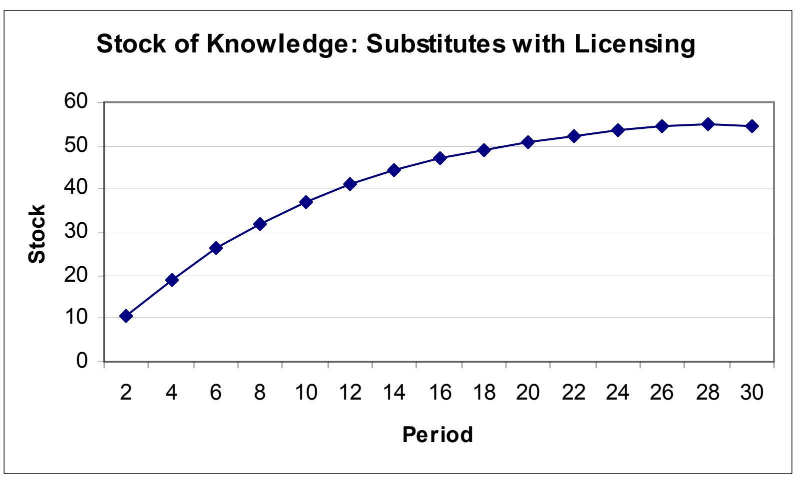


Figure 4. Complements Model with Licensing