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Optimal Incentives for Income-Generation within Universities[1]

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Abstract

This paper provides a framework with which to model one of the key links between universities and industry – the undertaking of applied research. We assume that the fundamental objective of universities is to undertake fundamental research and that they receive public funding to do so. Nevertheless, faced with tight budget constraints, universities may have incentives to allow their staff to spend some of their time on income-generating activities such as applied research or consultancy. For this opens up two channels by which universities can ease their budget constraint:

(i) by allowing academics to supplement their income, universities will not have to pay such high salaries;

(ii) they can effectively tax the income that academics raise through applied research or consultancy – for example through the imposition "overhead charges".

By easing their budget constraint, universities may be able to take on sufficient extra staff that they increase the amount of fundamental research that they can achieve with the given public budget. The paper develops a model of this link between universities and firms and uses it to determine optimal "tax" that universities should impose on applied research income.

Key Words: R&D, University-Firm Links, Fundamental Research, Applied Research, Income- Generation.

JEL Classification: F13, L13

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Introduction

A lively topic of debate in the recently emerging economics of science is the link between the science base in universities and the application of that science base in industry. The importance of this link for the modern economy is widely recognised by both academics and policy makers. For example, the existence of geographically mediated spillovers from university research to commercial innovation has been explored in a series of econometric studies following the initial work of Jaffe (1989),[2] while the policy importance is nowhere more apparent than in two key policy documents published during 1998. The first of these was the World Bank's *1998 World Development Report*[3] which took knowledge as its theme and the second was the UK Government's White Paper *Our Competitive Future: Building the Knowledge Driven Economy*.[4]

There are a number of dimensions to the link between the science done in universities and the application of science in industry. In this paper we focus on just one – the incentives for universities to encourage academics to engage in income-generating activities such as applied research and/or consultancy. In the UK there has been encouragement both from government and from the funding councils to establish and develop this type of university-industry link. Moreover, with many western governments now operating much tighter fiscal policies, cash-constrained universities in the UK and elsewhere are themselves realising the need to promote income-generating activities if they are to fulfil their mission of generating the maximum amount of fundamental research with limited public funds.

However, to our knowledge there has been no formal economic analysis of the problem of determining the extent to which universities should engage in such activities and the methods they should employ to do so. It is clear that there are a number of important features of the problem that make such an analysis non-trivial.

- Obviously the time spent by academics on income-generating activities comes at the expense of time that could be spent fulfilling the primary objective of universities – the creation and dissemination of fundamental knowledge. This can only be justified if the promotion of this activity eases university budget-constraints to a sufficient extent that they can hire enough extra academics that they more than replace the fundamental research time that is now being devoted to other activities.
- There are two ways in which the promotion of income-generating activities such as applied research and/or consultancy might enable universities to ease their budget constraint. The first is that universities may be able to effectively "tax" the applied/consultancy income earned by academics – for example by the use of "overhead charges". A more indirect route is that, by allowing academics to supplement their income, universities may be able to hold down academic pay, and so

[2] See also the recent book by Barba Navaretti, Dasgupta, Maler and Siniscalco (1998) for a survey of recent academic work in this area.
[3] World Bank (1998), *1998 World Development Report*, Washington, D.C.
[4] DTI (1998), *Our Competitive Future: Building the Knowledge Driven Economy*, Cmnd 4178, HMSO, London.

hire more academics with any given budget. Other things being equal, the first points to a high implicit tax rate, the second to a low one.

- Given the public good nature of knowledge an expansion in fundamental research by universities will also raise the productivity of applied research in the private sector, and so the alternative income that academics could earn in the private sector.

These last two points indicate the importance to universities of being aware of the opportunities for scientists outside the university sector when designing their policies.

In this paper we present a simple model of university-firm linkages through the market for applied research and use it to determine the optimal "tax" that universities should impose on the income that academics earn from applied research. Before proceeding there are three issues we would like to clarify.

1. The first is the distinction between the issues being addressed in this paper and those concerning the "commercialisation" of public research. The latter concerns the terms and conditions under which academics make the results of their own fundamental research available to others – especially those in the private sector. There are certainly important issues to be addressed here, and the topic has been the subject of much recent research, particularly in relation to the pharmaceutical industry - see for example Jensen and Thursby (1998), Siegel, Waldman and Link (1999), Cockburn, Henderson and Stern(1999), Darby and Zucker (1999). However, since we wish to focus on other issues of university funding, in this paper we will assume that fundamental research is made available under the normal scientific conditions. That is, it is made available free of charge in academic journals as soon as possible, with academic rewards being conditioned on being first to publish. By applied research or consultancy we mean the bringing to bear of the discoveries of fundamental research on applied problems arising in industry. Academics undertaking such work can draw on not just their own fundamental research, but on the entire body of published fundamental research. It is the fact that, in order to pursue their own basic research, university scientists have had to master a wide body of fundamental research that gives them the capability to undertake applied research.
2. In what follows we will assume that all fundamental research is done in universities. We recognise that some fundamental research is, in practice, also done in firms. There are various reasons why this should happen. Firms may feel it is necessary to fill gaps in the universities' research portfolios. They may do it to get patents and earn financial rewards from these (e.g. genome research). They may do it to ensure that they have the necessary understanding to effectively absorb the results of university research. However, since the focus of research in this paper is on incentives within universities, the assumption that firms do no fundamental research is not important.
3. Finally, we assume that all transfers of resources from firms to universities are in the form of income. In practice of course firms sometimes transfer real resources – for example by giving academics access to expensive equipment that is not available in university laboratories. However this is a detail that does not affect the substance of the issues explored here.

Section 2 The Model

There are three types of agent in our model: firms, scientists and universities.

2.1 *Firms*

In the interests of survival, firms are dependent on continual improvements in the quality of their products or processes. These improvements come from applied research. We assume that **all** the various types of fundamental research that are undertaken by universities can be applied to helping firms generate higher profits through improved products or processes of production. Thus applied research is to be understood very widely to encompass improved management/legal services as well as the more usual applications of engineering, physical or bio-chemical sciences. Applied research should be understood to encompass a wide range of activities embracing genuine research through to what might more usually be classified as consultancy.

As mentioned above, we assume that, although firms recognise the link between applied and fundamental research, given the generic nature of the latter, they do not themselves undertake any fundamental research. We suppose that firms do not do applied research in-house, but obtain it from independent applied researchers/consultants working in the private sector or universities, and that the market for applied research is perfectly competitive. Let π be the value of quality improvement, and p the price of applied research/consulting services. In what follows we will treat π as exogenous, while p is definitely an endogenous variable that is influenced by the behaviour of universities.

We denote the demand for consulting services by any firm by the function $Z^d\left(\frac{\pi}{p}\right)$. If there are F firms then the total demand for applied research/consultancy is $FZ^d\left(\frac{\pi}{p}\right)$.

2.2 *Scientists*

We assume that the economy has a supply of individuals who have been trained as scientists. These individuals can enter three occupations.

(i) <u>University Scientists</u>.

University scientists undertake fundamental research, but may choose to spend some time undertaking applied research. We assume that in order to undertake fundamental research, they have to spend a fixed amount of time each period in keeping up with the latest scientific developments[5]. This is independent of the size of the existing knowledge

[5] See Cohen and Levinthal (1989) for the idea that, in order research to undertake research, it is necessary to invest resources in developing the capacity to absorb other people’s ideas.

base. We normalise the units of time so that university scientists have 1 unit of time available to spend on either pure research, r or applied research $a = 1 - r$.

We assume that if a university scientist spends an amount of time r, $0 \le r \le 1$ on fundamental research, and if the knowledge produced by all scientists is K, then the amount of fundamental knowledge this individual scientist produces is given by the production function $f(r, K)$. This is a conventional production function. In particular, we assume that

$$f(r,0) \equiv 0; \quad f(0,K) \equiv 0;$$

$$\forall K > 0, \quad f_r(0,K) = \infty; \quad f_{rr}(r,K) < 0; \quad f_r(r,K) \to 0 \quad as \quad r \to \infty$$

$$\forall r > 0, f_K(r,0) = \infty; \quad f_{KK} < 0; \quad f_K(r,K) \to 0 \quad \text{as} \quad K \to \infty. \qquad (1)$$

Assumption (1) implies that there is value in building the knowledge base. At very low levels of knowledge, time spent in fundamental research will be highly productive. However as the knowledge base grows, there are diminishing returns for any given time spent in the activity.

We assume that universities find it impossible to monitor either the inputs or outputs of individual scientific research, and so scientists are paid a fixed salary $w > 0$ that is independent of the amount of time actually spent on fundamental research.

University scientists can also undertake work on applied research/consultancy. We assume that the effort devoted to absorbing the fundamental research of others before undertaking their own fundamental research is sufficient to enable university scientists to undertake applied research. We also suppose that productivity of an applied researcher depends on the amount of fundamental research that is available to be applied. So if a university scientist spends an amount of time a, $0 \le a \le 1$ on applied research, then the amount of applied research that is produced is given by the production function $y(a, K)$. This is a conventional production function. In particular, we assume that

$$y(a,0) \equiv 0; \quad y(0,K) \equiv 0$$

$$\forall K > 0, \quad y_a(0,K) = \infty; \quad y_{aa}(a,K) < 0; \quad y_a(a,K) \to 0 \quad as \quad a \to \infty \qquad (2)$$

$$\forall a > 0, \quad y_K(a,0) = \infty; \quad y_{KK}(a,K) < 0; \quad y_K(a,K) \to 0 \quad as \quad K \to \infty$$

If a scientist spends an amount of time a, $0 \le a \le 1$ on applied research, then the amount of income earned is $p \cdot y(a,K)$.

We assume that although universities cannot observe the effort that goes into applied research, they can observe the income, and, through a variety of devices, can effectively "tax" this income. Let t, $0 \le t \le 1$ be the tax rate, and let $\tilde{p} = p(1-t)$ be the net price that university scientists earn from doing applied research.

Finally, to avoid the obvious problem of shirking by university scientists, we assume that all scientists are motivated to do fundamental research. This arises from the importance of priority in science. From the work of Merton (1957),[6] there are convincing arguments that the goal of scientists is to establish priority of discovery by being the first to communicate a new result and that an important part of the reward structure in science comes from being first.[7] Moreover those who have studied the behaviour of scientists point to the importance of the satisfaction of solving a puzzle - Hagstrom (1965), Hull (1988). Taken together, these considerations suggest that time spent on fundamental research will be an important argument in the utility function of scientists.[8]

In what follows we therefore assume that all scientists have a utility function $u(y,r)$ where y is income and r is time spent on fundamental research. We assume that this satisfies all the usual properties – it is strictly increasing in both arguments, strictly quasi-concave, and both goods are normal. We also assume that

$$u_r(y,r) \to \infty \quad as \quad r \to 0 \qquad (3)$$

Thus choosing a university career will give a scientist a level of utility

$$v^1(w,\tilde{p},K) = \max_{0 \le r \le 1} \quad u[w + \tilde{p}\psi(1-r,K), r]. \qquad (4)$$

It is clear that $v^1(\cdot)$ is a strictly increasing function of all three arguments.

Let

$$R(w,\tilde{p},K) = \arg\max_{0 \le r \le 1} \quad u[w + \tilde{p}\psi(1-r,K), r] \qquad (5)$$

be the solution to the above optimisation problem.

From (3) it follows that university scientists will always devote some time to fundamental research – i.e. $R(w,\tilde{p},K) > 0$. From (2) it follows that as long as there is some reward to applied research then scientists will spend some time doing it. Formally if $\tilde{p} > 0$ - i.e. if

6 See also Dasgupta and David (1987).

7 Paula Stephan (1996) identifies three parts to the reward structure: eponymy, prizes and publication. The importance of reputation should not be underestimated as it provides a non-market method of correcting the market failures associated with knowledge. Arrow (1987) also notes that "The incentive compatibility literature needs to learn the lesson of the priority system; rewards to overcome shirking and the free-rider problem need not be monetary in nature". As Stephan notes (p. 1206), "A reward system based on reputation also provides a mechanism for capturing the externalities associated with discovery. The more a scientist's work is used, the larger is the scientist's reputation and the larger are the financial rewards. It is not only that the reward structure of science provides a means for capturing externalities. The public nature of knowledge encourages use by others, which in turn enhances the reputation of the researcher."

8 For some evidence on this see Levin and Stephan (1991).

$t < 1$ - then $R(w, \tilde{p}, K) < 1$. However if $t = 1$ and there are no rewards to applied research then university scientists will devote all their time to fundamental research – i.e. $R(w, 0, K) = 1$.

Conventional labour supply theory tells us that *R*(.) is a decreasing function of *w*. However, for standard reasons, at this level of generality it is impossible to predict the effects of either $\tilde{p}$ or K on the amount of fundamental research that is done.

(ii) <u>Private Sector Scientists</u>

The second career that a scientist can pursue is to work as an applied researcher/consultant in the private sector. In this occupation there is no opportunity for fundamental research. Nevertheless, applied scientists have to draw on the fundamental research base in order to do their applied work, and so have to spend some time mastering/absorbing this fundamental research. We assume that it takes less time to absorb the fundamental research when it is being used solely for applied work, so that a total amount of time $1 + g, \quad g > 0$ is available for undertaking applied research.

Consequently the income of a private sector scientist will be $p \cdot y\,[1 + g, K]$, and the associated level of utility if a scientist pursues this career will be

$$v^2(p, K) \equiv u\left[p \cdot y\,(1 + g, K), 0\right] \qquad (6)$$

(iii) <u>"Management"</u>

Finally we assume that a scientist can pursue a career totally unrelated to science. We assume that the annual income in this career is $\tilde{w} > 0$ - which is exogenous. The utility that a scientist will obtain by pursuing this career is

$$v^3(\tilde{w}) = u(\tilde{w}, 0)\,. \qquad (7)$$

2.3 *Universities*

As pointed out above, the fundamental issue on which we wish to focus concerns the incentives that universities give their scientists to devote some of the time that they could have spent on fundamental research to undertaking income-generating applied research for private firms. Accordingly, for the purposes of this paper, we will ignore teaching as an activity and assume that the primary objective of universities is to maximise the amount of basic/fundamental research they can achieve with given resources.

We take it that this fundamental research is conducted across a wide spectrum of different disciplines ranging from medicine and biochemistry to law and social sciences. As mentioned above, we are ignoring issues to do with the commercialisation of fundamental research, and assume that, given its special characteristics[9] fundamental research is organised in what is now recognised as the conventional scientific fashion[10]. Thus scientific output is produced and instantly disseminated free of charge under a priority system.

We ignore the problems arising from having teams from different universities competing for the same prize, and assume that all universities operate as a single integrated university sector.

Income to fund the production of this fundamental knowledge comes from two sources:
(a) a public fund $B > 0$,
(b) the revenue retained by universities from the income generated by university scientists through the applied research they do for firms.

If university scientists each spend an amount of time r, $0 \le r \le 1$ on fundamental research, and if the university sector taxes the income that scientists earn from applied research, then, if the university sector employs n scientists at a wage w, these have to satisfy the university budget constraint:

$$w \cdot n \le B + t \cdot p \cdot \psi(1 - r, K), \qquad (8)$$

while the amount of fundamental knowledge produced by the university sector, K, has to satisfy the condition

$$K = n \cdot \phi(r, K) \quad . \qquad (9)$$

Equation (9) implies that every scientist's contribution adds to the knowledge base and so the research paths along which they are all working are complementary. It also makes clear that everyone can benefit from drawing on this knowledge in doing their own research, and that all information is fully shared. This approach to the modelling of scientific endeavour captures in a straightforward way the description of it attributed to Einstein as "standing on the shoulders of giants".

This completes the description of the model. In the next section we show how the model can be solved to determine the amount of fundamental knowledge that will be produced for any given "tax" rate t, and hence the value of t that will maximise K for any given budget B.

[9] These include the generic nature of research, the high risk attached to it, the strong complementarities between the outputs of individual researchers (standing on giants shoulders).
[10] See for example Merton (1957) and Dasgupta and David (1987).

Section 3 Analysis of the Model

The most interesting (and tractable) case is where scientists are active in all three occupations.

If scientists are indifferent between a university career and a career in "management" then we must have

$$v^1[w, p(1-t), K] = u(\tilde{w}, 0)\,, \qquad (10)$$

while if scientists are indifferent between a career as private sector scientists and a career in "management" then we must have

$$u\left[p\psi(1+\gamma, K), 0\right] = u(\tilde{w}, 0)\,,$$

i.e.

$$\psi(1+\gamma, K) = \tilde{w}\,. \qquad (11)$$

If we substitute (5) into (8) and (9) we get:

$$w \cdot n = B + t \cdot n \cdot p \cdot \psi\left[1 - R(w, p(1-t), K), K\right] \qquad (12)$$

and

$$K = n \cdot \phi\left[R(w, p(1-t), K), K\right]. \qquad (13)$$

Equations (10) – (13) constitute a system of 4 equations in the 4 endogenous variables: *w*, *n*, *p* and *K* in which we are interested. While simple, the model captures all the considerations raised in the introduction:

- the complex tensions that universities face in deciding whether allowing academics to do applied research will increase the amount of fundamental research that they do;
- the two different routes by which universities can ease the budget constraint by giving academics opportunities to engage in income-generating activities;
- the need to pay attention to the various career options that academics face outside the university sector;
- the fact that fundamental knowledge affects the productivity of private sector researchers.

By solving these equations we can determine how the amount of fundamental knowledge depends on the "tax" rate, and hence the optimal tax rate – that which maximises *K*.

However, given the complexity of the interactions involved, it is impossible to say very much at this level of generality. To make further progress, we have therefore had to resort to the use of specific functional forms and to numerical simulations.

Section 4 An Example

Suppose that the production and utility functions take the following specific functional forms:

$$\varphi(r,K) = r^{\alpha} K^{1-\alpha}, \quad 0 < \alpha < 1$$
$$\psi(a,K) = a^{\beta} K^{1-\beta}, \quad 0 < \beta < 1$$
$$u(w,r) = w + \delta r^{\beta}, \quad \delta > 0$$

The production functions are just conventional Cobb-Douglas production functions. We have not imposed the requirement that the production functions should be the same for fundamental and applied research should be the same, and so have allowed the possibility that the coefficients α and β could be different. We have taken now view on their relative magnitude.

The utility function is quasi-linear in income. This brings an important simplification since it means that there will be no income effects in the individual scientist's supply function for fundamental research. The parameter δ is a crucial parameter since it measures the importance of fundamental research to scientists. However, δ cannot be too large, otherwise we will end up with solutions in which scientists end up working in universities for nothing. So we certainly need to bound δ by the condition that

$$\delta < \tilde{w}.$$

We will see later on that we will have put further restrictions on the magnitude of δ.

The major simplifying restriction that we have made is that the power coefficient on r in the utility function is the same as that which appears in the production function for applied research. This is made purely in the interests of tractability.

These special functional forms satisfy all the conditions we imposed in Section 2.

Given these assumptions, the individual supply of fundamental research takes the form:

$$R(\tilde{\pi},K) = \frac{\delta^{\frac{1}{1-\beta}}}{\delta^{\frac{1}{1-\beta}} + K\tilde{\pi}^{\frac{1}{1-\beta}}} \qquad (14)$$

while the associated indirect utility function becomes

$$v^{1}(w,\tilde{\pi},K) = w + \left[\tilde{\pi}^{\frac{1}{1-\beta}} K + \delta^{\frac{1}{1-\beta}}\right]^{1-\beta}.$$

Consequently equation (10) becomes:

$$w = \tilde{w} - \left[\tilde{p}^{\frac{1}{1-b}} K + d^{\frac{1}{1-b}} \right]^{1-b} . \qquad (15)$$

If we eliminate *n* from the equations (12) and (13) and then substitute (14) into the resulting expression we obtain:

$$K = \left\{ \frac{B}{\tilde{w} - \dfrac{d^{\frac{1}{1-b}} + \dfrac{\tilde{p}^{\frac{1}{1-b}} K}{1-t}}{\left[d^{\frac{1}{1-b}} + \tilde{p}^{\frac{1}{1-b}} K \right]^{b}}} \right\}^{\frac{1}{a}} \frac{d^{\frac{1}{1-b}}}{d^{\frac{1}{1-b}} + \tilde{p}^{\frac{1}{1-b}} K} \qquad (16)$$

From (11) we get:

$$\tilde{p}^{\frac{1}{1-b}} K = s \left[\tilde{w}(1-t) \right]^{\frac{1}{1-b}} , \qquad (17)$$

where $s = \dfrac{1}{(1+g)^{\frac{b}{1-b}}} < 1.$

Substituting (17) into (16) we obtain

$$K^{e} = \left\{ \frac{B}{\tilde{w} - \dfrac{d^{\frac{1}{1-b}} + s \tilde{w}^{\frac{1}{1-b}} (1-t)^{\frac{b}{1-b}}}{\left[d^{\frac{1}{1-b}} + s \left[\tilde{w}(1-t) \right]^{\frac{1}{1-b}} \right]^{b}}} \right\}^{\frac{1}{a}} \frac{d^{\frac{1}{1-b}}}{\left[d^{\frac{1}{1-b}} + s \left[\tilde{w}(1-t) \right]^{\frac{1}{1-b}} \right]} \qquad (18)$$

It is straightforward to check that when t = 0, the denominator in the first term on the RHS of (18) becomes $\tilde{w} - \left[d^{\frac{1}{1-b}} + s\tilde{w}^{\frac{1}{1-b}} \right]^{1-b}$, which is positive as long as

$$d < (1-s)^{1-b}\,\tilde{w}.$$

That is, as long as

$$x + s < 1, \tag{19}$$

where $x = \left(\frac{d}{\tilde{w}} \right)^{\frac{1}{1-b}} < 1$.

We assume from now on that (19) holds.

Then (18) defines an equilibrium value of K for all $t \in [0, 1]$. We can re-write (18) as

$$K^e = \frac{M}{J(t; a, b, s, x)} \tag{20}$$

where M is a constant and

$$J(t; a, b, s, x) = \left[1 - \frac{x + s(1-t)^{\frac{b}{1-b}}}{\left[x + s(1-t)^{\frac{1}{1-b}} \right]^{b}} \right]^{\frac{1}{a}} \left[x + s(1-t)^{\frac{1}{1-b}} \right]. \tag{21}$$

J (.) is a function of t, but with four parameters a, b, s and x.

As discussed above, the parameters a and b measure the intrinsic productivity of skilled labour in fundamental and applied research respectively. From the definitions given above, it is clear that the parameter s is a measure of the time available for doing research in universities compared to the time available in the private sector, given the additional time that is required to keep up with the subject if scientists are to do fundamental research. We could think crudely of s as being a measure of the costs of doing fundamental research. The parameter x however is another measure of the intrinsic attractiveness of doing fundamental research.

Finally it is interesting to note that we get the following expression for, w, the ratio of the equilibrium salary of university scientists to the salary they would earn in “management”:

$$w(t) = \frac{w}{\tilde{w}} = 1 - \left[s\,(1-t)^{\frac{1}{1-b}} + x \right]^{1-b} \qquad (22)$$

This is a strictly increasing function of *t*, since obviously the more heavily universities “tax” outside income, the higher are the salaries they have to pay in order to attract scientists to work in the university sector.

4. 1 Numerical Simulations

We begin by fixing a and b and calculate the optimal tax rate as a function of s and x. A typical set of results is shown in Table 1.

Table 1: Optimal Tax Rates (a = b = 0.5)

		x											
		0	0.01	0.05	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
		0	0	0	0	0	0	0	0	0	0	0	0
	0.01	1	.8995	.7753	.6822	.5505	.4495	.3644	.2893	.2215	.1591	.1011	.0465
	0.05	1	.8974	.7706	.6756	.5412	.438	.3511	.2745	.2053	.1416	.0823	.0267
	0.1	1	.8946	.7643	.6667	.5286	.4226	.3333	.2546	.1835	.1181	.0572	-
	0.2	1	.8882	.75	.6464	.5	.3876	.2929	.2094	.134	.0646	-	-
	0.3	1	.8805	.7327	.62	.4655	.3453	.2441	.1548	.0742	-	-	-
s	0.4	1	.8709	.7113	.5918	.4226	.2929	.1835	.0871	-	-	-	-
	0.5	1	.8586	.6838	.5528	.3675	.2254	.1056	-	-	-	-	-
	0.6	1	.8419	.6464	.5	.2929	.134	-	-	-	-	-	-
	0.7	1	.8174	.5918	.4226	.1835	-	-	-	-	-	-	-
	0.8	1	.7764	.5	.2929	-	-	-	-	-	-	-	-
	0.9	1	.6838	.2929	-	-	-	-	-	-	-	-	-

This table shows a number of things:

- virtually any tax rate is optimal depending on the magnitude of s and x;
- the optimal tax rate is a strictly decreasing function of both s and x;
- for given x, the tax rate declines rather slowly with s, whereas, for given s, the tax declines much more sharply with x.

Obviously as x increases, the more attractive do academics find fundamental research, and so a lower tax rate is required in order to induce them to do applied research. This is consistent with the theoretical findings of Holmstrom and Milgrom (1991) on multi-task principal-agent problems.[11] As s increases then private sector applied research becomes more and more comparable to fundamental research in terms of the amount of time that is required to master the knowledge base. This increases the sensitivity of university academics to salary differentials, and so calls for a lower tax rate.

It turns out that whenever $a = b$ then the ratio of the university salary to the "management" salary – evaluated at the optimal tax rate - equals the optimal tax rate. That is $w(\hat{t}) = \hat{t}$. So the above table also gives the associated values of w.

Finally, numerical simulations reveal that the optimal tax rate is an increasing function of a and a decreasing function of b. When $a \neq b$ then it is no longer the case that $w(\hat{t}) = \hat{t}$, and indeed $\hat{t} \geq (<) w(\bar{t})$ as $a \geq (<) b$. Nevertheless the two numbers remain very close together in absolute magnitude.

Section 5. Conclusions

The development and strengthening of the links between universities and industry is currently a topic of major interest to both governments and the public bodies that fund the university systems in the UK and the rest of Europe as well as in the United States.[12] It is important that a framework is developed that will allow this link to be carefully modelled and systematically analysed.

In this paper we have provided a framework in which to think about the complex issues facing universities in deciding what incentives to give academics to pursue income-generating activities. In particular we have tried to capture the various ways in which the promotion of income-generating activities can ease university budget constraints, and the need for universities to recognise the range of outside opportunities that academics face.

Within our framework we have shown that there are four factors that affect the optimal incentives for income-generation: the productivity of researchers in both fundamental and applied research: the intrinsic desirability of fundamental research to academics, and the relative amounts of time that need to be spent in keeping up with one's subject in both fundamental and applied research. While the importance of the first three factors may be thought to be relatively "obvious", the role of the fourth almost certainly is not.

Given the difficulty of measuring these factors, one very simple "rule-of-thumb" that emerges from our work is to use the ratio of academic salaries (exclusive of income-generating money) to the salaries they could command in non-science jobs in the private sector as a first-order guide to the appropriate "tax" rate on income-generating activities.

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[11] There is also evidence of this from empirical work. Stern (1999) has shown the presence of a wage/right-to-publish trade-off in US biotechnology.

[12] The US Congress recently changed the legislation on property rights as they apply to publicly funded science. Academic scientists can now themselves patent discoveries made from publicly funded research.

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