INVESTIGACIONES ECONOMICAS. Volumen XIX (2) - Mayo 1995, pp. 291-299

A NOTE ON INCENTIVES AND RESEARCHER PRODUCTIVITY IN SPANISH PUBLIC INSTITUTIONS

Angel DE LA FUENTE*

Instituto de Análisis Económico, CSIC

This paper develops a simple model of moral hazard in research. The model is calibrated and used to assess the adequacy of the existing salary structure in public research institutions in Spain. The results suggest that a greater reliance on incentive schemes could have a significant effect on productivity, lowering the unit cost of scientific output.

1. Introduction

In recent years, universities and other public research institutions in Spain have begun to modify their salary structures, linking pay with productivity through the introduction of incentive schemes. This change in compensation policies has sparked some controversy in the academic community, with some people arguing that incentive schemes are unnecessary and even counterproductive, while others defend the need for an even greater reliance on productivity bonuses linked to some sort of performance evaluation.

In this note, I will argue that incentive pay for researchers makes perfect sense on economic grounds. In Section 2, I develop the theoretical case for incentive schemes using a simple model of moral hazard which draws on Arrow's (1962) discussion of the peculiarities of research as an economic activity. In Section 3, the model is calibrated and used to provide a tentative evaluation of the impact on productivity of the current salary structure of Spanish public research institutions, as well as to analyze the effects of alternative compensation policies. For values of the parameters that I consider rather conservative, the model suggests that current compensation practices provide insufficient incentives for scientific production and that any

* I would like to thank Carmen Ansótegui, Francis Bloch, Carmen Matutes, Rafael Repullo, Xavier Vives, a referee of this journal and the participants in a workshop at the Universidad Autónoma de Barcelona for their helpful comments and suggestions. I gratefully acknowledge financial support from the Spanish Ministry of Education under CICYT grant n.° PB90-0132.

improvement in this area could have a significant impact on average productivity. This conclusion, of course, leaves open the question of exactly what criteria should be used to evaluate performance and does not rule out the possibility that a change in salary structures which is not well thought-out may have adverse effects on morale, productivity or recruitment –but it does suggest that strengthening the link between pay and performance may be a good idea.

2. A model of moral hazard in research

In a classic paper, Arrow (1962) argues that some of the properties of information make it difficult for a market economy to provide sufficient incentives for its optimal provision. One reason is that the public good attributes of this peculiar commodity make the private appropriation of its full economic value almost impossible. A second problem, which has perhaps received less attention in the literature, has to do with the difficulty of adequately diversifying the risks associated with innovative activities. In Arrow's view, the production of information is essentially different in nature from the production of physical goods. Doing research means collecting observations in an attempt to narrow down the range of possible values of the state of the world. Almost by definition, the output of such a process cannot be predicted in advance, and this makes investment in knowledge production fundamentally riskier than that in physical capital. Thus, the link between effort and success in research is particularly uncertain. At the same time, the nature of their task makes the actions of researchers difficult to monitor. This combination of factors gives rise to a moral hazard problem, as outsiders will be unable to determine whether poor performance was the result of bad luck or insufficient effort, and interferes with the efficient allocation of the risks associated with innovation, for the provision of insurance can be expected to reduce the incentive to succeed.

Arrow emphasizes that the resulting difficulties complicate the financing of innovative activities and, in the presence of risk aversion, can be expected to result in a suboptimally low level of investment in this area. I will argue that the situation also has important «internal» implications for the organization of research activities and, in particular, for the optimal compensation of researchers. If actions cannot be observed and success is uncertain, pay must be linked to performance in order to ellicit adequate effort –even if this implies an inefficient allocation of risks. These problems do, of course, arise in many other activities, but probably not often in quite as extreme a form. Hence, we may expect that incentives will be a particularly important determinant of productivity in the case of research. Moreover, incentive schemes would seem to be easier to implement in this area than in many others where it is harder to isolate the output of an individual or a small group.

To formalize the preceding argument, I will now develop a simple model of moral hazard which can be used to characterize the optimal payment scheme for researchers and to study the effects of various compensation policies on their productivity. We will assume that agents have a utility function of the form

$$U(c,\ 1-e) = \ln y + \gamma \ln (1-e) \qquad [1]$$

where y is income and $e \in [0,\ 1]$ the level of effort on the job. Individuals must choose between «industrial» employment and a research position. After selecting an occupation, industrial workers and researchers choose their level of work effort, produce, and receive their salary.

Both types of workers choose effort levels so as to maxize their expected utility. We will assume, however, that the link between effort and performance is less certain for research than for more routine occupations, and that it is harder to supervise adequately the activities of researchers than those of most other workers, although not their output. To capture this difference in a simple way, we will assume that the effective labour input provided by a worker is proportional to his effort, which is directly observable by firms. On the other hand, a researcher's effort level cannot observed, although his output, i.e. the success or failure of his project, can be easily determined. These assumptions imply that the structure of labour contracts is necessarily different in the two sectors: while firms can pay their employees according to their effort, and offer them a certain wage per efficiency unit of labour, a research institution can only condition payments on observed output. In these circumstances, the optimal research contract does not specify a fixed salary, but a schedule of payments, conditional on the success or failure of the project, which achieves an optimal tradeoff between incentive provision and efficient risk sharing.

The difference in contract structure implies different optimal behaviours on the part of the agents. A worker who exerts effort e_w will have income $e_w w$, where w is the wage *per effective unit of labour.* His problem is therefore

$$\operatorname*{Max}_{e_w} U(we_w,\ 1-e_w) = \ln (e_w w) + \gamma \ln (1-e_w), \qquad [2]$$

which gives

$$e_w^* = \frac{1}{1+\gamma} \qquad [3]$$

Hence, the optimal level of effort, e_w^*, is a function of the relative weights of leisure and income in the individual's utility function. Substituting e_w^* into $U(we_w,\ 1-e_w)$, we obtain the worker's indirect utility function

$$V_w(w) = \ln \frac{1}{1+\gamma} + \gamma \ln \frac{\gamma}{1+\gamma} \qquad [4]$$

We will assume that a researcher's probability of success is proportional to his effort level, e_r. If the contract specifies payments (y_G, y_B) contingent on the success (G) or failure (B) of the project, income becomes a random variable, and the agent's problem can be written.

$$\max_{e_r} \left[pe_r \ln y_G + (1-pe_r) \ln y_B + \gamma \ln (1-e_r)\right], \qquad [5]$$

where $p \leq 1$ denotes the probability of success per unit of effort. Solving [5] gives the optimal level of effort,

$$e(\theta) = \begin{cases} 0, & \text{if } \theta \leq \theta_0 \equiv \exp(\gamma/p) \\ 1 - \dfrac{\gamma}{p \ln \theta}, & \text{otherwise,} \end{cases} \qquad [6]$$

where $\theta = y_G / y_B$ is the ratio of the payments in the two states. Hence, optimal effort increases with the relative weight of income in the utility function, γ^{-1}, the strength of the incentives provided by the contract, summarized by θ, and the probability p that effort will translate into higher earnings. Notice that there is a minimum level of incentives, θ_0, below which optimal effort is zero. The ratio of the payments in the two states must be sufficiently high for the agent to find it worthwhile to exert himself in order to increase the probability of earning the larger payment. We observe also that, since effort increases with the log of θ, the incentive ratio needed to induce a level of effort similar to that of industrial workers will be rather high. Finally, substituting $e(\theta)$ into the objective function, the maximum expected utility of a researcher is given by

$$V_r(y_B, \theta) = \ln y_B + \gamma \ln(1-e(\theta)) + pe(\theta) \ln\theta. \qquad [7]$$

Consider now the situation from the point of view of the manager of the research institution. His problem is to design a contract (y_B, θ) so as to minimize the average cost of scientific production,

$$c(y_B, \theta) = \frac{pe(\theta) y_G + (1-pe(\theta)) y_B}{pe(\theta)} = \left(\theta - 1 + \frac{1}{pe(\theta)}\right) y_B, \qquad [8]$$

subject to the participation constraint

$$V_r(y_B, \theta) \geq V_w(w) \qquad [9]$$

which requires research contracts to guarantee an expected utility level not inferior to that available to agents in the industrial sector. The solution of this problem is characterized in the following proposition.

Proposition: The level of effort in the optimal contract, e_r^*, is the unique solution to the equation

$$\gamma\,[\theta(e) - 1]\,(1-pe) = \left(\frac{1-e}{e}\right)^2 \qquad [10]$$

where $\theta(e) = \exp\left(\frac{\gamma}{p(1-e)}\right)$ is the inverse function of $e(\theta)$.

Proof: Inverting the agents' decision rule $e(\theta)$ (which is a monotonic function), we obtain the required value of θ as a function of the desired level of effort,

$$\theta = \theta(e) = \exp\left(\frac{\gamma}{p(1-e)}\right) \qquad [11]$$

where we see that $\theta(0) = \theta_0 > 1$ and $\theta(1) = \infty$. Using this expression, the manager's problem can be written

$$\underset{e,\,y_B}{\text{Min}}\; c(e,\ y_B) = \left(\theta(e) - 1 + \frac{1}{pe}\right) y_B \text{ subject to } V_r\,[y_B,\ \theta(e)] \geq V_w(w)$$

Substituting [11] in [9], the participation constraint can be written

$$\ln y_B \geq V_w(w) - \gamma\left(\ln\,(1-e) + \frac{e}{1-e}\right). \qquad [12]$$

Since [12] will be binding at an optimum, the problem reduces to (taking logs):

$$\underset{e}{\text{Min}}\; \ln\, c(e) = \ln\left(\theta(e) - 1 + \frac{1}{pe}\right) + \left(V_w(w) - \gamma\left(\ln\,(1-e) + \frac{e}{1-e}\right)\right).$$

Differentiating this expression, we see that

$$\frac{d\ln\, c(e)}{de} \leq 0 \text{ if and only if } B(e) \equiv \gamma\,[\theta(e)-1]\,(1-pe) \leq \left(\frac{1-e}{e}\right)^2 \equiv A(e). \qquad [13]$$

It is easy to check that the function $A(e)$ is decreasing with $A(0) = \infty$ and $A(1) = 0$, whereas $B(e)$ is increasing with $B(0) = \gamma\,(\theta_0-1)$ and $B(1) = \infty$.[1] Hence, there is a unique value, e_r^*, of e for which $A(e) = B(e)$. Since $c(e)$ is decreasing to the left of e_r^* and increasing to its right, e_r^* solves the optimal contract problem. ❐

[1] The only possible difficulty lies in checking the monotonicity of $B(e)$. Direct computation will show that $B'(e) > 0$ if and only if $(1-p)\theta\ \ln\,\theta > p(1-e_r)\ (\theta-1-\theta\ \ln\,\theta)$. Since the left-hand side of this expression is positive, the result holds provided the right-hand side is negative, which is true for any $\theta > 1$.

Implicit differentiation of [10] shows that the optimal level of effort increases with p and decreases with the relative weight of leisure in the utility function, γ. Evaluating [13] with $e_r = e_w^*$, it is easily seen that $e_r^* \leq e_w^*$, i.e. that researchers exert less effort than workers at an optimum.[2] Given e_r^*, the optimal incentive ratio is given by $\theta^* = \theta\,(e_r^*)$ and y_B^* can be obtained from [12]. It can be shown that the optimal incentive ratio increases with the relative weight of leisure and is a U-shaped function of p with a minimum (for given γ) at the value of p for which pe_r^* 2/3.[3]

3. Incentives and productivity in Spain

To use the preceding model to assess the effect on productivity of existing compensation policies or possible alternatives to them, we have to do two things. One is to assign values to its various parameters; the other is to «collapse» a rather complicated salary structure into a summary measure which may be plugged into a one-period model.

To determine what parameter values may be reasonable, recall that the optimal incentive ratio, θ^*, increases with the relative weight of leisure and is a U-shaped function of p for given preference parameters. To get a conservative estimate of θ^*, I will assume agents value income much more than leisure and set p to a value close to that which minimizes the optimal incentive ratio. In particular, I will assign a value of 1/9 to γ, and set p equal to 0.8. This implies that agents employed in industry work at 90% of their potential capacity, and that the probability of success would be 0.72 if researchers exerted the same effort as workers. It seems fair to say, then, that the moral hazard problem is assumed to be relatively small but, even so, we will see that the optimal incentive ratio is significantly higher than the one implied by the current salary structure.

In Spain, public research is conducted mainly through the state university system and the Consejo Superior de Investigaciones Científicas (CSIC). Salary structures are very similar in both institutions. A researcher's income is the sum of several components: a base salary which depends on the individual's academic rank, a seniority component which increases automatically with time, and a productivity complement that depends on the results of periodic evaluations of the researcher's performance. Evaluations are of two types: internal (conducted by each institution every five years) and external (conducted by a National Evaluation Committee). Internal evaluations focus on teaching and «service» performance and, in practice, are automatically granted. External

[2] On the other hand, their expected earnings include a risk premium to compensate them for the fact that their income is uncertain. Since these two forces work in opposite directions and either one may prevail, a researcher's expected earnings under the optimal contract may be more or less than the income of an industrial worker.

[3] An increase in p reduces the incentive ratio required to induce any given level of effort. However, optimal effort increases with p, giving rise to a second effect which works in the opposite direction. When e_r is already high, additional effort comes only with sharply increasing incentive ratios and the second effect dominates.

ones are conducted at the researcher's request and evaluate his or her scientific production over a six-year period according with set guidelines on publications. Individuals are awarded a point for each successful evaluation, and their annual productivity bonus is the product of the number of points they have accumulated and a set amount which increases slightly with their rank. Table 1 shows the base salaries for the three professional categories in the CSIC, the seniority component (salaries are raised by the shown amount every three years of service), and the amount of the productivity bonus (per point) for each rank. The salary structure in public universities is almost identical, except that there are only two academic ranks (assistant and full professor).

TABLE 1
Salary Structure in the CSIC (Spanish pesetas per year)

	Researcher	Senior Researcher	Research Professor
Base Salary	3,913,770	4,379,994	4,945,290
Productivity bonus (1 point)	182,304	203,676	225,060
Seniority increment (every 3 yrs)	65,376	65,376	65,376

To summarize all this information, I will use the discounted value of a researcher's after-tax income stream. Although a lot of information is of course lost in the process, this procedure should, if anything, overstate the incentives provided by the current pay system, as the only monetary incentives that remain after the second promotion are the productivity bonuses. On the other hand, by limiting ourselves to salaries, we are ignoring the fact that external income from teaching and research or consulting contracts typically increases with the researcher's rank, a fact which tends to generate a steeper earnings profile.

I compute the annualized equivalent of the discounted value of a reseacher's after-tax lifetime earnings using a 3% discount rate and assuming a professional life of 35 years.[4,5] The calculation is repeated under a best –and a worst– case scenario: y_B corresponds to an individual whose salary increases only with seniority while y_G includes all possible productivity bonuses plus two promotions after three and six years respectively. The value of the incentive ratio $\theta = y_G/y_B$ implied by the current salary structure is 1.42; that is, effort leads, at best, to a 42% increase in the individual's income.[6] Notice that, to

[4] A higher discount rate would lower the computed value of θ. However, the results are rather insensitive to the assumed value of this variable. The estimated value of θ falls approximately by two hundredths of a point for each one-point increase in the discount rate.

[5] After-tax income is computed separately for each year and then discounted. I use 1994 tax rates and assume that researchers file an individual return, have no income from capital and take no deductions except the one for «dependent labour». After-tax income is defined as gross income minus personal tax and social security contributions.

[6] The present value of a researcher's after-tax income is 68.73 million ptas. in the worst case and 97.5 in the best-case scenario. The annualized equivalent amounts would be 3.1 and 4.4 million ptas. per year, respectively.

the extent that internal evaluations tend to be automatically granted in practice, this procedure will overestimate the value of θ implicit in the current salary structure.

The effort level corresponding to the observed θ is 0.603. Assuming the participation constraint is binding, the average (net-of-tax) cost per researcher is 87.11% of his potential (after-tax) outside earnings, and the lower payment (y_B) comes to 72.5% of the same amount. Both figures seem reasonable and are consistent with the widespread perception that average research salaries are significantly lower than those available in industry to personnel with similar qualifications.

TABLE 2
Average cost of research output under different scenarios

	Existing salary structure (1)	Optimal contract (2)	Double productivity bonus	
			same y_B (3)	adjusted y_B (4)
θ	1.42	2.20	1.63	1.98
e_r	0.60	0.82	0.72	0.80
$y_B/e_w w$	0.72	0.56	0.72	0.60
$C/e_w w$	0.87	1.00	0.99	0.97
$c/e_w w$	1.81	1.52	1.72	1.53

Note: c is average cost per unit of research output; C is the average earnings of a researcher. All variables are shown net of taxes and normalized by the average (after-tax) earnings of industrial workers, which would amount to 4.28 million under our assumptions.

Table 2 shows the incentive ratios, effort levels and unit costs associated with the observed pay structure and three counterfactual compensation schemes. The results of the exercise suggest that increasing the weight of the incentive component in overall compensation could have a significant effect on productivity and on the average cost of research output.

Column (2) describes the optimal contract, defined as the one which minimizes the after-tax wage bill per unit of research output[7]. This contract specifies an incentive ratio of 2.2 and induces an effort level (0.824) significantly above the one implied by the current compensation system (column (1)). Under the optimal contract, average researcher after-tax income would increase, relative to the current situation, by 14.55%, and average productivity would be 36.67% higher, implying a reduction in unit

[7] Notice that this contract will be optimal from the point of view of the public sector as a whole, but not necessarily from that of the contracting research institution, which will probably fail to internalize the fact that part of its wage bill reverts to the government through income taxes. Since a progressive tax system raises the cost of incentives, the optimal contract from the point of view of each particular institution will specify a lower θ than the one shown here. A precise characterization of such contract, however, would require a multi-period model in order to incorporate the details of the tax structure.

costs of 16.2%. The lower payment (y_B = 2.4 million) is 17% lower than the current after-tax base salary for entry positions.

Column (3) shows the effect of doubling the amount of the productivity bonuses while leaving base pay unchanged. Average after-tax salaries would increase by 13.5% but productivity would increase by 19.5% relative to the current system, yielding a 5% decrease in net-of-tax unit costs. In terms of gross-of-tax wages, it can be shown that unit costs would fall by 1.66%. Hence, a doubling of the productivity bonuses would roughly pay for itself through induced productivity gains. On the other hand, this contract would leave considerable room for reducing base pay (y_B) without violating the participation constraint. Holding y_G constant at its value in [3], y_B can be reduced by 17.4%. The resulting contract (column (4)) comes rather close to the optimum and yields a 15.9% reduction in unit costs.

4. Conclusion

In this note, I have argued that research productivity could be increased by modifying the compensation practices currently followed in public research institutions. Although the single-period, all-or-nothing model I have used is much too simple to serve as a basis for detailed policy recommendations and relies on very specific assumptions, it is perhaps adequate to make the point that the special characteristics of research call for a greater reliance on incentive schemes which, at the moment, are mostly symbolic in Spain. The quantitative estimates I report should be seen as extremely tentative, but they may provide a rough estimate of the relevant magnitudes and suggest, in any event, that it may be important to consider the incentive effects of research institutions' pay structures.

References

Arrow, K. (1962): «Economic Welfare and the Allocation of Resources for Invention», in *Collected Papers of Kenneth J. Arrow, Vol. 5: Production and Capital*, Harvard Univerity Press, Cambridge, Mass., 1985, pp. 104-119.

Resumen

Este artículo desarrolla un sencillo modelo de riesgo moral en la investigación. Tras calibrarlo, el modelo se utiliza para evaluar la idoneidad de la estructura salarial existente en las instituciones públicas de investigación en España. Los resultados sugieren que un incremento del peso de los incentivos en la remuneración de los investigadores podría tener un efecto significativo sobre la productividad, reduciendo el coste unitario de la producción científica.

Recepción del original, noviembre de 1994
Versión final, mayo de 1995