

Incentives to Research Activities in European Public Universities

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Abstract

In this paper we study the implementation of policy incentives aimed at increasing the research output at European public universities by university managers and public administrations. Although public universities are subject to significant management rigidities, we provide some interesting policies aimed at increasing their research output. We pay special attention to the principal agent problem between professors and university managers due to the career options that professors face outside the university.

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Key words: efficiency, productivity, professors' salaries, incentives to research, state and federal aid, resource allocation.

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I Introduction

The Council of the European Union (Lisbon 2000) established as an objective for the year 2010 “to become the most competitive, knowledge-based, economy in the world”. One of the pillars to achieve the objective stated in Lisbon was the configuration of a European Space of Higher Education.

Nowadays, there are many challenges which are related to developing a European-wide competitive field that are not addressed in the actual Bologna Process. Among them there are issues related to incentives (to research and teaching activities), to university competition and to university funding. These topics have not been addressed from a European perspective yet and each Member State implements its own policies, which differ widely across States.

Although the European university system is based on public as well as private universities, the latter concentrate most of higher education students in Europe. In this framework public universities exist as autonomous institutions which are often subject to regulation at the national and regional level. This regulation introduces several rigidities: universities are unable to affect their revenues significantly and are highly dependent on conditional public transfers; fixed salaries and incentives to research are established by public administrations instead of universities; there are significant rigidities to move from one university to the other for professors (due in part to non-flexible hiring contracts) and students, etc. Altogether, university managers have significant restrictions to what concerns the management of one of their basic inputs, professors, which depends basically on rigid regulations from the governments.

Given the role of public universities in research and higher education it is very relevant that we study to which extent these rigidities affect university performance. We think that a better understanding of the rigidities and inefficiencies of public universities will facilitate the design of appropriate mechanisms aimed at fostering R&D activities in Europe. We develop a model where universities are subject to rigidities and we provide recommendations concerning the incentives that could be implemented in such a framework in order to increase results in R&D activities at public universities.

Our results show that an efficient allocation of public resources across universities by public administrations requires: i) a combination of economic incentives to professors and transfers to universities, based on the abilities of the professors and the weight given to research by universities, should be used, ii) resources directed to universities should be distributed asymmetrically, and iii) incentives to professors should be designed relative to what they can earn outside the university. To what concerns university managers, we show that efficiency requires that: i) universities should strengthen control on the effort that professors are expected to devote to research activities, ii) teaching loads should be assigned taking into account the ability of the professors to conduct research, therefore resulting in a partial specialization of professors in either research or educational activities, and iii) increases in fixed salaries do not result in increases in research output. Summarizing, the distribution of teaching loads and public resources aimed at improving research output should not be based on uniform and rigid distribution criteria but on a measure of research productivity by professors.

One may argue that some of our recommendations seem really obvious. However, in spite of this we must note that at present some university managers and some public administrations across Europe (with some exceptions) are working in the opposite direction. Although there are significant differences not only amongst universities but also amongst schools and departments we would like to note that in most public universities: i) the teaching load is assigned uniformly, when reductions of teaching loads are implemented, as a compensation for success in research activities, they are rather low, ii) although most universities regulate income-generating activities of professors outside the university, there is a lack of interest by university managers to monitor professors' activities (may be because university managers themselves are professors).

Concerning the regional and national authorities we must remind that they establish the professors' fixed salaries and they design the incentives to research. Very recently, in some countries (e.g. in Spain) we observe that: i) most increases in professors' wages result from increases in fixed salaries, independently of any success in research or any improvement in quality of teaching, ii) personal incentives to researchers are very low compared to the income they can earn outside the university.

Finally, we must note that a rational design of hierarchical structures aimed at delegating decision making to the most appropriate level would require that universities should be able to decide on the economic incentives to their professors. Rationality would suggest that the government transferred resources to universities and that they design the research incentives for their professors. Instead, we do not find this rationality in most public university systems. Very often university managers are not autonomous enough so as to design and implement incentives –not even fixed salaries– aimed at improving the research productivity of their professors. This decisions still corresponds to the governments. That is, professors must negotiate also with governments. This may explain the lack of competition between public universities for talented professors and researchers.

According to this non-rational hierarchical structure of public university systems, we will work in a framework in which universities can only take decisions concerning to which activities their professors must devote their efforts. Additionally, incentives to research (to universities and to professors) will be designed by a public agency. Therefore, although public universities are subject to significant management rigidities, we provide some interesting policies aimed at increasing their research output.

I.1 The literature

There are few theoretical contributions that study the university system. De Fraja and Iossa (2002) and Del Rey (2000) pay special attention to the analysis of competition among universities. In their papers the authors consider research and teaching as an input in the production function for education. Universities assign their resources to teaching and research activities and they compete in order to attract most talented students. However, they assume that all universities receive the same resources and do not consider the possibility that research might generate additional funding. Instead, we consider that research is an income-generating activity.

A different approach is followed in Beath et al (2003). Their paper is in line with the theoretical findings on multi-task principal-agent problems in Hölmstrom and Milgrom (1991a, 1991b), Dewatripont et al (2000) and Laffont et al (2002). In Beath et al (2003) the authors study the links between universities and industry. They develop a model in which the university wants to encourage professors to engage in income-generating activities. Therefore, the problem for the university is to determine the optimal tax that they should impose on applied research and consultancy income.

There are two main differences in our paper with the paper by Beath et al (2003). First, they ignore teaching as an activity while we assume that teaching is an essential activity of professors. Second, they assume that all time available for doing applied research (or consultancy) will generate some revenues to the university. Instead, we assume that the professor can devote his or her time to some activities that do not contribute to increase university's revenues and reputation. Our focus is on the interest of universities in raising revenues –and prestige- by encouraging professors to engage in research activities considering that they are subject to some educational responsibilities, in a framework in which universities cannot monitor the effort that professors are expected to devote to research.

In the next section we describe the model with three groups of agents. In the third section we study the interactions amongst the three groups and we analyze the incentives that might be implemented by the public administration in order to foster research activities in public universities. Finally, section four summarizes the conclusions.

II The model

In this paper we consider the role played by three different groups of agents: i) public administrations, ii) university managers, and iii) professors.

In each group agents have some interest in research output. However, they have different goals and different instruments to foster research activities.

First, professors decide the optimal allocation of efforts among different activities aimed at maximizing their utility, which depends on income and research output. We must stress that we are modeling the behavior of a professor who is already working at the university. Therefore, we are not analyzing the market for academics.

Second, university managers decide how much effort professors should devote to research and teaching in order to maximize both university revenues and prestige. University managers cannot offer any pecuniary incentive to professors. Instead, they fix a canon on professor's income generating activities and they decide the time that professors can devote to teaching activities.

Finally, a public agency decides on the optimal allocation of public resources among universities and professors in order to maximize research output. Therefore, the public agency is the only institution that fixes the pecuniary incentives to research that can be directed to universities and professors. According to this model, only the public agency finances higher education and research activities. Although this assumption might not

seem reasonable, we emphasize that by using it we try to reflect the real situation in most public university systems.

We want to show that the optimal design of instruments aimed at maximizing research output must consider the role played by each agent and the interactions among these three agents. We highlight the need to pay attention to the career options that professors face outside the university.

Public Administration

We assume that there is a single public agency that finances the K universities that are located in its jurisdiction.

Public financing has two different components. On the one hand, the public agency distributes a reference budget, assigned considering educational responsibilities¹ (denoted by D_j) and the number of professors in each university. In this paper we will not analyze the allocation of this generic component across universities. On the other hand, public authorities distribute another substantial amount of resources assigned across universities and professors according to some measure of professors' research productivities. We will focus our analysis on the allocation of these resources.

The public agency has two alternative instruments to allocate those resources aimed at increasing research output. We make this distinction because public agencies usually must choose between incentives directed to professors or to universities. Alternatively, they can use them simultaneously. The relevant question is whether it is more efficient to incentive universities rather than professors or both.

On the one hand, the agency can implement direct monetary incentives to professors (we call them personal incentives and they are denoted by s_{rji}) according to a measure of their productivity. On the other, the agency can use an instrument that is directed also to professors but which can be "taxed" by the university. We introduce this possibility because it is very common in public universities that university managers fix a canon on the research income generated by its professors (research projects, public contracts, etc). We call them university transfers (we denote them by w_{rji}) and we assume that the university can fix a canon on these resources (τ). We must note that if the university fixed $\tau=1$ this would be equivalent to a direct transfer from the public agency to the university.

G denotes the amount of resources that will be transferred to universities and professors according to a measure of the productivity of professors: R_{ji} . The public agency has the following budget constraint:

$$G = \sum_{j=1}^K \sum_{i=1}^{N_j} (s_{rji} + w_{rji}) R_{ji} \quad (1.1)$$

R_{ji} is the research output produced by professor i in university j . There are K universities and in each university there are N_j professors (which is considered as exogenous).

¹ This generic component could also contain some transfers associated to ground support for research.

The public agency knows that research output produced by professor i in university j depends on the time that he/she devotes to research activities (t_{rji}), and his or her ability to conduct research (μ_{ji})

$$R_{ji} = \mu_{ji} t_{rji}^\beta \quad (1.2)$$

with $0 < \beta \leq 1$. The decision on t_{rji} depends on the university managers and the professor and it might be affected by the public agency's decision on w_{rji} and s_{rji} . In fact, the design of w_{rji} and s_{rji} is aimed at affecting t_{rji}

We understand that assuming a deterministic relationship between time and research outcome is a strong assumption. There is a random component in this relation so that time devoted to research does not necessarily generate research output. However, we restrict our moral hazard problem to the case in which the public agency and the university cannot control to which activities professors dedicate the time that they are expected to devote to research.

The problem faced by the public agency is to choose the optimal combination of instruments (w_{rji} and s_{rji}) aimed at maximizing aggregate research output

$$\begin{aligned} & \text{Max}_{\{w_{rji}, s_{rji}\}} \sum_{j=1}^K \sum_{i=1}^{N_j} R_{ji} \\ & \text{s.t.} \\ & G = \sum_{j=1}^K \sum_{i=1}^{N_j} (s_{rji} + w_{rji}) R_{ji} \\ & R_{ji} = \mu_{ji} t_{rji}^\beta \end{aligned} \quad (1.3)$$

In order to make the decision process more tractable, sections III.2.a and III.2.b deal with two different problems separately. First, the agency must choose between university transfers and personal incentives. That is, the agency must decide whether to incentive professors or universities, or both. Second, assuming that the university fixes a canon $\tau=1$ (this implies that transfers from the public agency go to universities) we analyze the optimal distribution of university transfers across universities. That is, the agency will decide whether to distribute such transfers uniformly or to distribute them according to productivity measures.

The University

The university provides two products: research output and education to students.

Although education is one of the main responsibilities of universities, in this paper we do not analyze any issue related to the provision of education (quality of education, student selection, fees, etc). We focus on the instruments that universities may implement in order to encourage professors to engage in research activities during the time that they are not teaching.

There are two reasons why research activities are important for universities. The first is that research is an income-generating activity due to the canon fixed on research income earned by professors. The second reason is that the prestige of a university depends, among other things, on the research output of its professors. We model this by assuming that the university is interested in producing research output independently of the income that might be raised from that activity². In this paper we assume that the university is interested in maximizing revenues and prestige.

The objective function of university j follows:

$$U(I_j, R_j) = I_j + \varphi_j R_j \quad \text{with } \varphi_j > 0. \quad (1.4)$$

where φ_j measures the importance of research output to the university. With this specification the university might decide that the professors devoted some effort to research activities even when there are no revenues associated to them.

I_j denotes net income received by the University j that follows:

$$S(D_j) + S(R_j) - w_d N_j \quad (1.5)$$

The university has two different sources of revenues. On the one hand, it receives transfers from public administrations. We could associate these transfers to a generic and direct subsidy to the university that depends on educational responsibilities (D_j). In this paper we consider these responsibilities as fixed and we do not focus on the funding system that determines the amount of resources that a university receives³. The university uses these revenues to cover costs. $S(D_j)$ represents public transfers net of costs, except professors' wages, that are treated separately. We assume that

$$S(D_j) - w_d N_j \geq 0 \quad (1.6)$$

The university employs N_j professors at a wage w_d . Therefore, $w_d N_j$ is the total cost of its professors. w_d denotes the fixed salary paid to a professor, which is the same for all professors and it is considered as exogenous to university managers. We assume that N_j is exogenous to the model.

On the other hand, the university obtains additional revenues (denoted by $S(R_j)$) by taxing the income that professors earn from their research. We assume that the university fixes a canon (τ_{ji}) on the income earned by each professor ($w_{rji} R_{ji}$) from his or her research.

The income retained by university managers from the money generated by its N_j professors follows:

$$S(R_j) = \sum_{i=1}^{N_j} \tau_{ji} w_{rji} R_{ji} \quad (1.7)$$

² Reputation may have a direct impact on university revenues because it is a crucial variable to attract students and because it allows universities to increase private funding. However, in this paper we avoid dealing with this issue.

³ That is why we do not introduced S(D) in the problem faced by the administration.

The university knows also that the research output of any of the professors depends on the ability of professor i to undertake research (μ_{ji}), and the effort that the professor devotes to research:

$$R_{ji} = \mu_{ji} t_{rji}^\beta \quad (1.8)$$

In brief, the problem faced by the university is: i) to decide the effort that each of the professors devote to both teaching and research, and ii) to decide the optimal canon on research income. That is:

$$\begin{aligned} & \text{Max}_{\{t_{dji}, t_{rji}, \tau_{ji}\}} \left[S(D_j) + \sum_{i=1}^{N_j} \tau_{ji} w_{rji} R_{ji} - N_j w_d \right] + \phi_j \sum_{i=1}^{N_j} R_{ji} \\ & \text{s.t} \\ & R_{ji} = \mu_{ji} t_{rji}^\beta, \text{ with } 0 < \beta < 1 \\ & D_j = \sum_{i=1}^{N_j} t_{dji} \text{ with } D_j \text{ fixed} \\ & \tau \in [0, 1] \\ & T = t_{rji} + t_{dji} + t_{cji} \end{aligned} \quad (1.9)$$

Where T is the total amount of time that professors are expected to work at the university and $T - t_{dji}$ is the time available for undertaking research or consultancy. t_{cji} denotes the effort that the professor might devote to activities that cannot be monitored, and therefore taxed, by the university. When the university can monitor professor's activities t_{cji} will be zero. We assume that each professor devotes the same time to the university.

According to our specification, the university cannot use direct monetary incentives to encourage professors to devote some of their time to research. Universities use two alternative instruments. On the one hand, the university decides the time that professors allocate to teaching activities (this time comes at the expense of the time that they can spend on research). On the other hand, the university decides the canon on income earned by professor i due to his or her research activities.

The professor

We work in a context in which professors might do several activities. In this paper we assume that a professor i at university j may devote the time he or she is expected to spend at the University to three alternative activities: i) research (t_{rji}), ii) dissemination of knowledge –teaching- (t_{dji}) and iii) additionally, we assume that the professors can dedicate some of their time to corporate consulting⁴ (t_{cji}). Each individual is supposed to have an exogenously determined endowment of ability both to do consultancy (denoted ϕ_{ji}) and to do research (denoted by μ_{ji}).

⁴ We could also assume that they could devote some time to university management. However, we will not consider these activities in our analysis.

Both research and consultancy are income-generating activities. However, there are significant differences between the two. We assume that research income (derived from applied research or technical assistance to public or private institutions) is under the control of the university⁵ and that university managers might decide to fix a canon on those revenues. Alternatively, consultancy refers to those activities that the professor might develop without control of the university (e.g. working in his or her own firm or teaching occasionally in other universities). These activities are canon-free given that they cannot be monitored.

The time that the professor must allocate to teaching is fixed by university managers and it is taken as given by professors. Therefore, the decision of the professor concerns only to the time available for doing research and consultancy ($T^* - t_{dji}$) where $T^* - t_{dji} \geq 0$.

T^* can be considered as the amount of time that the professor is going to dedicate to his or her job at the university (we assume it is the same for all professors). For simplicity we assume that T^* is exogenous (although it is the solution to a leisure-consumption problem) and that there is a coincidence between T^* and T (the time that the university expects that the professor will devote to teaching and research activities).

Therefore, the time constraint faced by the professor i is

$$T - t_{dji} = t_{rji} + t_{cji} \quad (1.10)$$

A professor's utility function $u(y_{ji}, R_{ji})$, where y_{ji} is income and R_{ji} is research output, follows

$$U(y_{ji}, R_{ji}) = y_{ji} + \varepsilon_{ji} R_{ji}, \quad \text{with } \varepsilon_{ji} > 0. \quad (1.11)$$

where ε measures the importance of research to the professor. As long as $\varepsilon_{ji} \neq 0$, professors are motivated to engage in research even if there are no rewards to research.

We consider four different sources of income: i) a fixed salary w_d that is the same for all professors, ii) net income earned from research [$w_{rji} (1 - \tau_{ji}) R_{ji}$], iii) consultancy income ($w_c A_{ji}$) and iv) personal incentives offered by a public agency (s_{rji}) which depend also on a measure of research productivity and are not taxed by the university. For simplicity we assume that both w_{rji} and s_{rji} are public transfers. Therefore, income follows:

$$y_{ji} = w_d + w_{rji} (1 - \tau_{ji}) R_{ji} + w_c A_{ji} + s_{rji} R_{ji}. \quad (1.12)$$

A_{ji} denotes consultancy output that depends on the amount of effort devoted to this activity and on the professor's ability (ϕ_{ji}). A_{ji} follows

$$A_{ji} = \phi_{ji} t_{cji}^\alpha \quad (1.13)$$

Research output follows:

⁵ Quite often public universities determine that some activities (e.g. applied research or technical assistance to public or private institutions) must be under university control and they fix a canon on the income obtained by the professor. Also, some universities fix a canon on income obtained by professors from research projects.

$$R_{ji} = \mu_{ji} t_{rji}^\beta \quad (1.14)$$

For the sake of simplicity, we impose that the productivities of time devoted to consultancy and to research be the same, that is, $\alpha=\beta$.

According to the specification in (1.13) and (1.14) research and consultancy outputs might be zero for $\mu_{ji}=0$ or $\phi_{ji}=0$, respectively. In these two instances we might find corner solutions for t_{rji} and t_{cji} . However, as long as a professor has some ability in doing research, he or she will devote some effort to it.

We assume decreasing returns to the time spent in any of the activities. Therefore, we assume $0<\beta<1$. For $\beta=1$ we would derive corner solutions. This means that the professors might choose $t_{rji}= T-t_{dji}$ and $t_{cji}=0$ or $t_{cji}= T-t_{dji}$ and $t_{rji}=0$ regardless of the abilities being positive.

Summarizing, the problem faced by the professor i is to decide to which activities he or she is going to allocate his or her time in order to maximize his or her utility:

$$\begin{aligned} & \text{Max}_{\{t_{cji}, t_{rji}\}} w_d + w_{rji}(1-\tau_{ji})R_{ji} + w_c A_{ji} + s_{rji} R_{ji} \\ & \text{s.t} \\ & A_{ji} = \phi_{ji} t_{cji}^\beta \\ & R_{ji} = \mu_{ji} t_{rji}^\beta \\ & T - t_{dji} = t_{rji} + t_{cji} \end{aligned} \quad (1.15)$$

For simplicity, the previous problem is based on some restrictions that derive from working in a static framework. This has several implications. First, w_d does not depend on the number of years the professor has been working at the university. Second, the fixed salary does not depend on his or her ability to conduct research or on his or her research output. However, in most public universities there are different categories of professors each of them with a different fixed salary that depends somehow on professor's research productivity. Third, we do not consider the possibility that the professor improves his or her abilities by investing on education.

The professor's decision depends mainly on the university's capacity to monitor the time that he or she is expected to devote to research. In case of perfect monitoring, the professor cannot decide between consultancy and research so that $t_{cji}=0$.

III Results

In this section we present the results that derive from the analysis of the interaction among all agents.

Given that the optimal decision by the public agency depends on the relationship between professors and universities, we will first analyze that relationship. We analyze the interaction between professors and university managers taking as given any kind of economic incentives decided by the public agency.

We then analyze the role played by the public agency, who takes into account the previous relationship. We analyze two different sets of policies. First, we study the optimal composition of economic incentives to research. The public agency must choose between direct -and canon-free- incentives to professors and transfers that can be taxed by the university. Second, assuming that the university could expropriate all professors' revenues associated to research (which occurs under the assumption of perfect monitoring), we study the distribution of resources across universities by the public agency.

In the following sections we restrict our attention to the case of decreasing returns to scale.

III.1 Universities and professors: teaching versus research.

We study the distribution of the teaching load among all professors and the decision on the canon that the university is going to implement.

We consider two alternative hypotheses. First, we assume that the university can monitor the effort that the professor is expected to devote to research and to teaching. This is equivalent to assuming that the professor cannot dedicate any time to consultancy. Second, we work under the assumption that the university can only monitor the effort that its professors devote to teaching, but that it cannot monitor their research efforts effectively.

III.1.a Perfect monitoring

In this framework there are no activities alternative to research, therefore the canon has no effect on the professor's decision concerning the time he or she is willing to devote to research. That is, $t_{cji}=0$ and $t_{rji}=T-T_{dji}$. Additionally, in this situation the optimal canon would be $\tau=1$, which means that transfers to professors through w_{rji} are equivalent to university transfers

In this situation the university solves

$$\begin{aligned}
 & \text{Max}_{\{t_{dji}, t_{rji}\}} \quad [S(D_j) + \sum_{i=1}^{N_j} w_{rji} R_{ji} - N_j w_d] + \varphi_j \sum_{i=1}^{N_j} R_{ji} \\
 & \text{s.t} \\
 & R_{ji} = \mu_{ji} t_{rji}^\beta, \text{ with } 0 < \beta < 1 \\
 & D_j = \sum_{i=1}^{N_j} t_{dji} \text{ with } D_j \text{ fixed} \\
 & N_j T = \sum_{i=1}^{N_j} t_{dji} + \sum_{i=1}^{N_j} t_{rji}
 \end{aligned} \tag{1.16}$$

The effort that professors in university j should devote to research that maximizes the objective function follows

$$t_{rji}^* = \left[\frac{[w_{rji} + \varphi_j] \mu_{ji} \beta T}{w_d} \right]^{\frac{1}{1-\beta}} \quad (1.17)$$

Under the assumption of heterogeneity of abilities, the previous solution indicates that it is optimal for the university to assign the teaching load according to the abilities that the professors have in producing research output. The larger the abilities, the lower the teaching load should be. Additionally, the larger the level of income generated by the professors the larger the efforts that the professor will be asked to devote to research. This does not mean that professors with some ability to do research will not teach. This depends on T (the number of hours they can work), on the aggregate teaching load (D_j), on the number of professors, and on the number of professors with no abilities to do research.

Alternatively, we can use the expression

$$t_{rji}^* = \left[N_j T - D_j \right] \frac{\left([w_{rji} + \varphi_j] \mu_{ji} \right)^{\frac{1}{1-\beta}}}{\sum_{i=1}^{N_j} \left([w_{rji} + \varphi_j] \mu_{ji} \right)^{\frac{1}{1-\beta}}} \quad (1.18)$$

This expression indicates that professor i will be able to devote more or less time to research, of all available time for research $[N_j T - D_j]$ and in comparison with the other professors, depending on the relative contribution of his or her research to the objective function of the university. According to the previous equation, distributing the teaching load uniformly is not efficient unless there is no heterogeneity of agents.

In this framework it is important to stress the role that the public agency could play. In this framework professors cannot devote their time to consultancy, therefore there is no need to design direct economic incentives for them. The public agency cannot change the professor's decision through direct economic incentives because in this framework personal transfers (s_{rji}) would not have any impact on their decision, not even on the university's decision. However, as we see in (1.18) the allocation of research incentives across universities $\{w_{rji}, i=1 \dots N_j\}$ by the public agency will affect the relative distribution of teaching and research loads to professors.

III.1 b The university cannot monitor the effort that professors are expected to devote to research.

In this situation, the problem for the university changes slightly. We assume that the university can only monitor the effort that professors should devote to teaching but not the effort that professors are expected to devote to research. Therefore, the university has to consider that professors can assign –without the university's notice- some of their available time for research to alternative activities such as external consultancy. Therefore, the decision by the university must be taken considering the optimal decision of professors regarding t_{rji} and t_{cji} and particularly how the canon might affect their decision. We must then compute the professor's optimal decisions first.

Taking from granted heterogeneity across individuals, we assume that the university could also establish a different canon for each professor.

The professors' optimal decision is obtained by solving the problem stated in (1.15). The professor takes w_d , s_{rji} , w_{rji} and τ_{ji} as given.

Under the assumption of decreasing returns to scale ($0 < \beta < 1$) taking first-order conditions results in:

$$\frac{t_{cji}}{t_{rji}} = \left(\frac{w_c}{(w_{rji} (1 - \tau_{ji}) + s_{rji} + \varepsilon_{ji}) \mu_{ji}} \phi_{ji} \right)^{\frac{1}{1-\beta}} \quad (1.19)$$

$$T - t_{dji} = t_{rji} + t_{cji} \quad (1.20)$$

Using (1.19) and (1.20) yields an expression for an optimal solution for t_{rji}^{**}

$$t_{rji}^{**} = \left(\frac{T - t_{dji}}{1 + \left(\frac{w_c}{(w_{rji} (1 - \tau_{ji}) + s_{rji} + \varepsilon_{ji}) \mu_{ji}} \phi_{ji} \right)^{\frac{1}{1-\beta}}} \right) \quad (1.21)$$

According to the expression in (1.21) we observe that the time that the professor will effectively devote to research depends on his or her relative abilities in each of the activities, on the earnings received from each activity and on the importance that professors give to research. In particular, we observe that t_{rji} depends: i) positively on his or her ability to work in research, and ii) negatively on his or her ability to work in consultancy. Not surprisingly, the canon fixed by the university has a negative effect on the effort that the professor will devote to research. Additionally, as long as the difference between earnings from consulting activities with respect to those from research increases, the effort devoted to research decreases. Finally, as expected, increases in the amount of fixed salary (w_d), do not affect the professor's decision on t_{rji} .

From equation (1.21) we see that if the professor has some ability in research ($\mu_{ji} \neq 0$) and ($\varepsilon_{ji} \neq 0$), he or she will always devote some time to it even if there is no income attached (e.g. for $w_{rji} = 0$ and $s_{rji} = 0$). This means also that even if the canon fixed by the university was ($\tau_{ji} = 1$) he or she would still devote some time to research. However, the professor will undertake some consultancy only if he or she has some ability ($\phi_{ji} \neq 0$) and he or she receives a compensation for it ($w_c \neq 0$). Therefore, under the assumption of decreasing returns, corner solutions depend on the abilities of the professors in each of the activities and on the returns associated to them.

Once we know the decision by the professor, the problem for the university becomes

$$\begin{aligned}
& \text{Max}_{\{t_{dji}, \tau_{ji}\}} \left[S(D_j) + \sum_{i=1}^{N_j} \tau_{ji} w_{rji} R_{ji} - N_j w_d \right] + \varphi_j \sum_{i=1}^{N_j} R_{ji} \\
& \text{s.t} \\
& R_{ji} = \mu_{ji} t_{rji}^{*\beta}, \text{ with } 0 < \beta < 1 \\
& D_j = \sum_{i=1}^{N_j} t_{dji} \text{ with } D_j \text{ fixed,} \\
& \text{with } \tau_{ji} \in [0,1] \\
& N_j T = \sum_{i=1}^{N_j} t_{dji} + \sum_{i=1}^{N_j} t_{rji}^{**} + \sum_{i=1}^{N_j} t_{cji}^{**} \\
& t_{rji}^{**}, t_{cji}^{**}
\end{aligned} \tag{1.22}$$

t_{rji}^{**} and t_{cji}^{**} correspond to the decision taken by the professor in case of non-monitoring. These values correspond to expressions (1.21) and (1.19).

Taking first-order conditions results in:

$$t_{rji} = \left[\frac{[\tau_{ji} w_{rji} + \varphi_j] \mu_{ji} \beta T}{w_d} \right]^{\frac{1}{1-\beta}} \tag{1.23}$$

$$\left[\frac{\beta[\tau_{ji} w_{rji} + \varphi_j]}{1 + \left(\frac{w_c \phi_{ji}}{(w_{rji} (1-\tau_{ji}) + s_{rji} + \varepsilon_{ji}) \mu_{ji}} \right)^{\frac{1}{1-\beta}}} \right]^{\frac{1}{1-\beta}} = [w_{rji} (1-\tau_{ji}) + s_{rji} + \varepsilon_{ji}]^{\frac{2-\beta}{1-\beta}} \left[\frac{\mu_{ji}}{w_c \phi_{ji}} \right]^{\frac{1}{1-\beta}} \tag{1.24}$$

Apparently, there is no difference between equation (1.23) and (1.17), except to what concerns the canon that the university is going to fix. In this section, the optimal canon is not necessarily $\tau=1$ because university managers must take into account the professors' reactions to τ . However, this equation suggests that for a positive canon ($0 < \tau < 1$), the university's decision on professors' optimal research efforts would be lower than the one in the previous situation, as expected.

Expression in equation (1.23) suggests also that the university should distribute the teaching load according to the professor's abilities. However, the optimal decision still depends on the optimal canon.

After some computations with equation (1.24) and using the implicit function theorem we find⁶ the relationship between the optimal canon and each of the parameters (keeping the other parameters constant):

⁶ Computations to find these relationships have been carefully revised and are available to readers upon request.

$$\tau_{ji}^* = f(w_{rj}^+, \varphi_j^-, s_{rj}^+, \varepsilon_{ji}^+, \mu_{ji}^+, w_c^-, \phi_{ji}^-) \quad (1.25)$$

Although we cannot find an explicit expression for the optimal canon and for the effective effort that will be devoted to research (t_{rji}^{***}), considering the expression in (1.24) and the relations contained in (1.25) we can conclude that

$$t_{rji}^{***} = g(w_{rji}^+, \varphi_j^+, s_{rji}^+, \varepsilon_{ji}^+, \mu_{ji}^+, w_c^-, \phi_{ji}^-) \quad (1.26)$$

In (1.26) we present the relationships between the research effort that the professor will effectively devote to research and each of the parameters (the other parameters remaining constant). These relationships suggest again that the university should not assign teaching loads uniformly. Instead, it should consider the individual characteristics of the professors: professors with higher abilities and with higher motivation to undertake research should have lower teaching loads, while professors with lower skills for research and more ability to undertake consultancy work should be assigned greater teaching loads. That is, the university should favor a partial specialization of professors into research and teaching activities

To what concerns the role played by the public agency, equation (1.26) suggests that any positive variation in w_{rj} or s_{rj} would increase the time that professors would devote to research. In this framework we see that both instruments affect positively both university's and professor's decisions. However, the impact of both instruments might be different. In the next section we analyze the decision on w_{rj} and s_{rj} by the public agency.

Under some particular assumptions we can derive some additional results.

If a professor's ability for consultancy is zero (that is for $\phi_{ji}=0$) or if he or she does not earn any income from this activity ($w_c=0$), this professor devotes his or her non-teaching time to research, and the university will decide $\tau=1$. In this case the solution is the same as in perfect monitoring (see the expression in 1.17), as expected.

Similarly, if the professor's ability to do research is zero ($\mu_{ji}=0$) then it is optimal for the university that professors devote their efforts to teaching exclusively. In this situation the university does not fix any tax.

Summarizing, although in this framework university managers cannot implement economic incentives to professors but still they can take some decisions to improve their professors' productivities. They will do so mainly through the distribution of the teaching loads and the canon implemented on research income. Finally, we want to stress that our results depend crucially on the assumption that the university has perfect information on professor's abilities.

III.2 The role of public authorities: public incentives to research activities in public universities.

This is the last step in our decision process. In this section we analyze the determinants of an optimal distribution by the public agency of a budget aimed at maximizing research output in public universities. The public agency must decide to incentive professors and/or universities. In order to do so, the agency must consider university's and professors' optimal decisions that were provided in the previous sections.

We will analyze two different problems. First we analyze the optimal combination of personal incentives and university transfers. Second, we study the optimal distribution of resources among universities.

For the sake of simplicity, we assume that professors at the same university have the same abilities. This means that we are assuming:

$$\varepsilon_{ji} = \varepsilon_j, \quad \phi_{ji} = \phi_j, \quad \mu_{ji} = \mu_j \quad \text{for } \forall i \text{ in university } j.$$

There is however, heterogeneity among universities. Therefore:

$$\varepsilon_j \neq \varepsilon_k, \quad \phi_j \neq \phi_k, \quad \mu_j \neq \mu_k \quad \text{for } j \neq k$$

Under the expression for aggregate research output follows:

$$R_j = \sum_{i=1}^{N_j} \mu_j t_{rji}^\beta = N_j \mu_j t_{rj}^\beta \quad (1.27)$$

III.2.a Personal income incentives to professors (s_r) versus university transfers (w_r)

In this section we analyze the decision of the public agency on w_{rj} and s_{rj} aimed at increasing the research output by the professors at university j . The public agency will decide considering the decisions by the professors and the universities in a framework with non-monitoring. Needless to say that under perfect monitoring the agency would decide that $s_{rj}=0$, because there is no need to motivate the professors with canon-free incentives given that they cannot devote their efforts to alternative activities.

In (1.26) we have seen that both instruments affect the effort that the professor will effectively devote to research positively. However, these efforts differ because they have different impacts on universities and professors.

The tractability of the model requires that the agency considers τ^*_j as given, analytical results cannot be derived otherwise. This means that the public agency does assume that the university managers will not change τ^*_j once the public agency's decision has been taken.

The problem faced by the public agency is to find the optimal allocation of personal and university transfers in order to maximize the university's research output.

$$\begin{aligned}
& \text{Max}_{\{w_r, s_r\}} R_j \\
& \text{s.t.} \\
& G = w_{rj} + s_{rj} \\
& R_j = N_j \mu_j t_{rj}^{**\beta} \\
& t_{rj}^{**} = \left[\frac{\left(\frac{\mu_j \beta T}{w_d} \right) [\tau_j^* w_{rj} + \varphi_j]}{1 + \left(\frac{w_c}{(w_{rj} (1 - \tau_j^*) + s_{rj} + \varepsilon_j)} \frac{\phi_j}{\mu_j} \right)^{\frac{1}{1-\beta}}} \right]^{\frac{1}{1-\beta}}
\end{aligned} \tag{1.28}$$

Where t_{rj}^{**} is the university's optimal decision on the effort that professors will devote to research activities effectively, considering that there is no perfect monitoring (it is derived from problem 1.22). τ_j^* is the optimal tax that it is be implemented by university j . G is the total incentive that is going to be implemented per unit of research output.

First order conditions provide

$$\begin{aligned}
\frac{\partial t_{rj}}{\partial w_{rj}} &= \frac{\partial t_{rj}}{\partial s_{rj}} \\
G &= s_{rj} + w_{rj}
\end{aligned} \tag{1.29}$$

decision on the optimal level of personal transfers follows

$$(1 - \beta) \frac{[G - \tau_j w_{rj} + \varepsilon_j]^{\frac{2-\beta}{1-\beta}}}{\left(\frac{w_c \phi_j}{\mu_j} \right)^{\frac{1}{1-\beta}}} + (2 - \beta) \tau_j w_{rj} = [\varphi_j - (1 - \beta)(G + \varepsilon_j)] \tag{1.30}$$

Again, we cannot find any analytical solution for w_{rj}^* and s_{rj}^* . However, after some computations with equation (1.30) and using the implicit function theorem we find

$$s_{rj}^* = f(w_c^+, \phi_j^+, \mu_j^-, \varphi_j^+, \varepsilon_j^-, \tau_j^+) \tag{1.31}$$

and

$$w_{rj}^* = f(w_c^-, \phi_j^-, \mu_j^+, \varphi_j^-, \varepsilon_j^+, \tau_j^-) \tag{1.32}$$

As we can observe in (1.31), when designing incentives to professors, the public agency must consider the professor's ability in consultancy work and the income that a professor could earn from this activity: the greater the abilities and the income the larger should the personal transfer be. However, optimal personal transfers depend negatively on the professor's ability to conduct research: the larger his or her research abilities, the lower the need to incentive him or her and resources could be partially directed to universities. The opposite is true regarding w_{rj}^* .

The public agency takes into account also the canon that the university fixes on the income generated by the professor: the larger the canon, the larger the amount of personal transfers. This occurs because the public agency is compensating the disincentive that the canon causes on the professor's decision to conduct research.

Altogether, the public agency's decision on personal and university transfers considers the opportunity cost of the professor of devoting efforts to research instead of to consultancy.

Finally, another interesting implication from (1.32) is that the decision of the public agency depends also on how important is research for professors and universities regardless of the income that they might obtain from that activity. The more willing the professor is to do research regardless of the income he or she might obtain, the lower the personal transfer will be. On the contrary, the larger the non-income effect of research output for the university, the lower the optimal amount of university transfers is. Therefore, the agency should favor the agent with a lower propensity to do research without being remunerated.

III.2.b Differentiation versus uniformity in the distribution of resources across universities.

In this section we are interested in analyzing the distribution of incentives across universities. The agency must decide the size of the incentives (w_{rj}) that each university receives. It may decide either to differentiate between universities (may be concentrating all resources in one university) or, alternatively, to distribute them uniformly.

In order to do so, we assume that universities can monitor the activities of their professors. We saw that under perfect monitoring the optimal canon the university will fix is $\tau=1$. This means that although transfers are directed to professors, this is equivalent to transferring resources to universities, because they expropriate all of professor's revenues through the canon. Given that incentives to professors do not affect university's decisions, we can assume that $s_{rj}=0$.

There is another important assumption to be remarked. We assume that universities are not subject to teaching loads; that is, restriction $D_j = \sum_{i=1}^{N_j} t_{dji}$ in problem (1.16) does not apply. Still, we maintain the time constraint for the professors. Without this assumption the problem of the agency would not make any sense because the distribution of time for research activities by universities would not depend on w_{rj} . Due to the homogeneity assumption, see equation (1.18), the time that the university would decide that the professors should devote to research follows

$$t_{rji}^* = \left[\frac{N_j T - D_j}{N_j} \right] \quad (1.33)$$

The efforts that professors would devote to research depend only on the number of professors in that university and the aggregate teaching load.

The public administration's budget constraint follows

$$G = \sum_{j=1}^K w_{rj} \quad (1.34)$$

where G is the amount of resources that the agency wants to devote to incentive research per unit of research output. Therefore we do not consider any restriction regarding the aggregate amount of resources that could be devoted to this program.

The problem faced by the public agency is

$$\begin{aligned} & \text{Max}_{\{w_{rj}, \dots, w_{rk}\}} \sum_{j=1}^K R_j \\ & \text{s.t.} \\ & G = \sum_{j=1}^K w_{rj} \\ & R_j = N_j \mu_j t_{rj}^{**\beta} \\ & t_{rj}^{**} = \left[\frac{[w_{rj} + \varphi_j] \mu_j \beta T}{w_d} \right]^{\frac{1}{1-\beta}} \end{aligned} \quad (1.35)$$

t_{rj}^{**} is the optimal decision by the university in case that the aggregate teaching load restriction does not apply.

For simplicity, we assume that there are two universities only and that they have the same number of professors ($N_j = N_k$).

The solution depends crucially on the value for the parameter β . On the one hand, for $\beta = 1/2$ we find a corner solution. The allocation of transfers follows the condition:

$$\begin{aligned} & \text{if } \mu_k > \mu_j, \text{ then } w_{rk} = G, \text{ and } w_{rj} = 0 \\ & \text{if } \mu_k < \mu_j, \text{ then } w_{rj} = G, \text{ and } w_{rk} = 0 \\ & \text{if } \mu_k = \mu_j, \text{ then any distribution has the same impact on research output.} \end{aligned} \quad (1.36)$$

We also find corner solutions as far as $\mu_j = 0$ or $\mu_k = 0$. In both situations the public agency would transfer all resources to one university.

However, it is important to remark that in this context allocating all transfers to one university j does not imply that professors in the other university k do not conduct research, as long as φ_k in that university k is not zero. This result implies that research will be conducted also in the university with the less productive professors but that this university will not receive any transfers. All transfers would be directed towards the university with the most talented professors.

On the other hand, if the parameter $\beta \neq 1/2$, then the solution to the problem provides

$$\left(\frac{\mu_j}{\mu_k}\right) = \left(\frac{w_{rj} + \varphi_j}{w_{rk} + \varphi_k}\right)^{\frac{1}{1-2\beta}} \quad (1.37)$$

$$G = w_{rj} + w_{rk} \quad (1.38)$$

The incentive that the university j will receive follows:

$$w_{rj}^* = \frac{(G + \varphi_k) \left(\frac{\mu_j}{\mu_k}\right)^{\frac{1}{1-2\beta}} - \varphi_j}{1 + \left(\frac{\mu_j}{\mu_k}\right)^{\frac{1}{1-2\beta}}} \quad (1.39)$$

Although one may expect that the agency should always favour the university in which professors are more talented for research, this is not always true. It depends on the value for β .

As we can observe in equation (1.39), for $\beta < 1/2$, the public agency will transfer more resources to the university with the most talented professors. That is, the larger the talent of the professors at university j , the larger the amount of transfers that this university will receive per unit of research output. On the contrary, for $\beta > 1/2$, the public agency will transfer more resources to the university with the less talented professors.

Additionally, the larger the propensity of a university j to obtain research output regardless of the income retained from that activity, the lower the transfer is. This is due to the fact that university j is highly motivated to conduct research relative to k so that incentives should be directed to university k .

Another interesting result is that in equilibrium the ratio of efforts allocated to research in both universities depends on the ratio of abilities of their professors:

$$\left(\frac{t_{rj}^*}{t_{rk}^*}\right) = \left(\frac{\mu_j}{\mu_k}\right)^{\frac{2}{1-\beta}} \quad (1.40)$$

The previous expression indicates that in equilibrium, as far as $\mu_j \neq \mu_k$, professors in both universities will devote different amounts of efforts to research. We must note that these differences remain after the intervention of the public agency and they are not due to differences in the number of professors or differences in aggregate teaching loads, which have not been considered in this section. Therefore, the distribution of public transfers across universities is favoring that professors in one and another university devote different efforts to research, according to their capacities.

However, differences in the abilities of the professors will translate into more or less differences in their efforts devoted to research depending on the value of the parameter β . If $\beta < 1/2$, larger differences in the abilities of the professors doing research at university j with respect to those at university k will imply larger differences in the efforts that those at j will devote to research. Alternatively, if $\beta > 1/2$ larger differences in the abilities of the professors doing research at university j with respect to those at

university k will imply shorter differences in the efforts that those at j will devote to research.

IV Conclusions

In this paper we find two sets of conclusions.

On the one hand, we provide the decisions that can be implemented by university managers in order to maximize income and research output at their university. Although those recommendations are associated to management issues, they are important to what concerns the generation of research output by professors.

First, both under perfect and imperfect monitoring frameworks, universities should assign teaching loads to the professors asymmetrically, according to their abilities in conducting research. This result suggests that professors should specialize either in research or in teaching. Uniform distributions of teaching loads are rather inefficient because they reduce the revenues that the university can obtain from research activities.

Second, in case of lack of monitoring of the efforts that professors are expected to devote to research, universities should strengthen control on the efforts that professors could devote to those activities that do not provide any additional income to the university or any impact on university's prestige. Otherwise, the reduction of teaching loads aimed at increasing research output by professors could end up generating only private income to professors.

Third, in case of non-monitoring, universities should fix their canon on professor's income-generating activities taking into account the negative effects of that canon on the efforts that professors might be willing to devote to research rather than to consulting activities. As far as the canon increases, there is an increase in the relative income obtained from consultancy and this makes research activities less attractive.

On the other hand, we provide some hints on the policies that could be implemented by the public agency in order to maximize aggregate research output at universities. The public agency should use a mix of incentives to professors and to universities. In doing so, the agency should consider:

First, the fact that universities can or cannot monitor the efforts that professors are expected to devote to research activities. In case of perfect monitoring, there is no need to incentive professors and resources should be devoted to incentive universities. In case of non-monitoring the agency should use a mix of instruments aimed at motivating both professors and universities. Devoting all resources to direct economic incentives to professors would not be efficient.

Second, the public agency must design the personal incentives to professors considering the net income received by professors for their research activities relative to the income they can get in doing corporate consulting. If the differences are very large, small personal incentives will have a negligible impact on research activities.

Third, when assigning resources across universities, the public agency should distribute them asymmetrically, favoring those universities that have higher skilled professors for

doing research. However, the public agency should also incentive those universities which are not so interested in research (professors in that university could be as skilled as professors at other universities but their university is not interested in their professors conducting research).

Fourth, the previous recommendations will be useless if universities, for a given level of teaching responsibilities, cannot increase the number of their professors.

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