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Institute of Economics
Scuola Superiore Sant'Anna

Piazza Martiri della Libertà, 33 - 56127 Pisa, Italy
ph. +39 050 88.33.43
institute.economics@sssup.it

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Stefano Bianchini [a,f]
Francesco Lissoni [b,e]
Michele Pezzoni [c,e]
Lorenzo Zirulia [d,e]

[a] BETA, University of Strasbourg, France
[b] GREThA UMR 5113, University of Bordeaux, France
[c] GREDEG, University of Nice-Sophia Antipolis, France
[d] Department of Economics, University of Bologna, Italy
[e] CRIOS, Universita' Bocconi, Milan, Italy
[f] Institute of Economics, Scuola Superiore Sant'Anna, Pisa, Italy

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The economics of research, consulting, and teaching quality: theory and evidence from a technical university[1]

Stefano Bianchini[a,f], Francesco Lissoni[b,e], Michele Pezzoni[c,e], and Lorenzo Zirulia[d,e]

[a] BETA, Université de Strasbourg, France
[b] GREThA UMR 5113, Université de Bordeaux, France
[c] GREDEG, Université de Nice Sophia-Antipolis, France
[d] Dipartimento di Economia, Università degli studi di Bologna, Italy
[e] CRIOS - Università Bocconi, Milan, Italy
[f] Institute of Economics, Scuola Superiore Sant'Anna, Pisa, Italy

Abstract

We investigate the effect of both research and consulting on teaching quality in higher education, at the individual level. We propose a theoretical model in which academics allocate effort between the three activities, over a two period time horizon, under the assumption of positive spillovers from research to both consulting opportunities and teaching, and of life cycle effects on incentives. Propositions from the model are tested against data from a mid-sized Italian engineering faculty. We find that teaching quality is negatively related to consulting and positively related to research experience. However, both relationships are not linear, due to the importance of several mediating factors, such as seniority and the role of scientific publications as a signal for attracting consulting opportunities.

Keywords: higher education; teaching quality; academic consulting; research productivity; economics of science

1. Introduction

Trade-offs and complementarities between contemporary universities' three missions (education, research, and, for want of a more comprehensive term, knowledge transfer to industry) have long been the object of enquiry of both social scientists and practitioners. Feedbacks and conflicts can arise both at the organizational level, as a result of universities' strategic choices concerning the weight to assign to the three activities, and at the individual level, due to academics' responses to immediate economic incentives and long-term career strategies (Etzkowitz 2004; Bonaccorsi and Daraio 2007; Sanchez-Barrioluengo 2014). The organizational and individual levels are related, to the extent that the way universities regulate their faculties' time allocation and duties affect both the economic incentives and the career perspectives of individuals. Yet,

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we have only a partial understanding of the efficiency of universities' regulations. This is due to the lack of evidence on the signs and the intensity of spillovers from research and technology transfer to education, and between one another, as well as to the paucity of theoretical models of individual academics' decisional processes (witness the limited references on the topic in Stephan's [1996, 2010] classic surveys).

In this paper, we address these gaps in the literature by focusing on selected activities through which individual academics pursue the three missions. In particular, we concentrate on the quality dimension of teaching (as measured by students' evaluations) and on how it related to both publishing (an output measure of research efforts) and consulting (a traditional, though under-studied, form of knowledge transfer to industry).

We propose a dynamic model in which individual academics allocate their effort to the three activities over a two period time horizon, under several assumptions on the trade-offs and complementarities between the activities, as well as on the mediating effects of academic seniority and disciplinary affiliation. We derive a number of testable propositions on how research experience and consulting opportunities affect teaching quality. First, we posit a negative effect of seniority on teaching quality for all disciplines where consulting opportunities abound and hardly depend on scientific reputation, with the other cases being characterized by some degree of ambiguity. Second, we identify a non-linear effect of research productivity on teaching quality: (i) positive in disciplines where consulting opportunities do not depend on scientific reputation, (ii) negative in disciplines with limited consulting opportunities, and (iii) ambiguous in opportunity-rich disciplines, but only for academics with a strong scientific reputation. Finally, we suggest that consulting opportunities may generate a positive effect on teaching quality for senior scholars, conditional on scientific reputation being necessary to exploit them; in all other cases, the effect is negative.

We test our propositions against a 3-year panel of SETE (Students' Evaluation of Teaching Effectiveness) data at the course and instructor level, which we obtained from an Italian mid-sized engineering faculty (Bianchini, Lissoni, and Pezzoni 2013). Under a set of assumptions on the consulting opportunities that the local economy offers to academics from the various disciplines represented in the faculty, we find empirical results that are consistent with most of our theoretical propositions.

The remainder of the paper is structured as follows. After a brief review of the literature (Section 2), we set out our theoretical model (Section 3). Data and empirical methodology are described in Section 4, which also includes background information on the university under observation. Section 5 reports our results and discusses them. Section 6 concludes.

2. Background literature

In recent years, the evaluation of universities and their staff's activities has become a dominant theme in the discussion on the European higher education system (Geuna and Martin 2003; Daraio et al. 2011; Rebora and Turri 2013). Much of the public debate and most policy proposals have focused on the evaluation of research, both at the individual and at the departmental level. Overall, these assessment exercises, and the redistributive policies based upon them, deal with the creation of individual incentives to engage in high quality research, and to create positive economic spillovers from such research via technology transfer and other "third mission" activities. Despite many pleas in that direction, much less attention has been paid to the evaluation of teaching quality, also in light of the possible trade-offs and complementarities with the other two activities.

As a result, we have no comprehensive evidence on these matters. Most of the empirical studies produced so far have considered only two activities at a time. On the one hand, the economic literature on university–industry technology transfer has explored the link between research productivity and academic patenting or academic entrepreneurship, and it has usually found a positive association (Thursby and Thursby 2002; Breschi, Lissoni, and Montobbio 2007; Carayol 2007; Lissoni et al. 2008; Czarnitzki and Toole 2010; Crespi et al. 2011; see also: Lawson 2013; Perkmann et al. 2013). In addition, recent findings have shown that such university–industry relationships can influence scientists' research agendas, but not necessarily for the worse (Hottenrott and Lawson 2014). On the other hand, the higher education literature has explored the teaching-research nexus in depth. In particular, Ramsden and Moses (1992), Hattie and Marsh (1996), and Jenkins (2004) find a (weak) positive correlation among the two dimensions, but their evidence is not theoretically grounded, as well as tenuous and quite controversial.

The teaching–technology transfer link is the least explored. Lee and Rhoads (2004) focus on consulting activities and find them to have a negative impact on teaching commitment. Landry et al. (2010), based on a sample of Canadian researchers from different research fields, explore the complementarities and trade-offs between six activities undertaken by academics: publishing, teaching, informal knowledge transfer, patenting, engaging in spin-off formation and consulting services. While publishing, patenting, spin-off creation, consulting and informal knowledge transfer appear to be complementary, teaching and publishing are found to be substitutes. Along the same line, Sanchez-Barrioluengo (2014) finds research and technology-transfer to be positively correlated, but also to negatively affect teaching quality.

As for the theoretical literature, this is very limited and it generally represents individual academics as economic agents who must choose how to allocate their time between two activities only. Early contributions by McKenzie (1972) and Becker Jr. (1975) look at the time allocation between research and teaching as a simple (and static) utility maximization problem. More recently, Walckiers (2008) considers the viewpoint of a university, which offers a menu of contracts to professors differing in their preferences for teaching and research. He shows that bundling the two activities is optimal in most cases. El Ouardighi, Korgan, and Vranceanu (2013) also consider the problem of professors' time allocation between research and teaching, but from a dynamic perspective. They show that when spillovers between the two activities exist in both directions, specialization is most likely to emerge. Faria (2002) models a scholar's allocation of time between academia and professional activities outside it, and finds a negative impact of opportunities for such activities (associated to political and business networks) on research productivity.

Useful, albeit sparse inputs to a comprehensive theory come from the mix of theoretical and empirical analyses of academics' incentives to pursue one or another of the activities under consideration. Concerning research, a 'taste for science' hypothesis has been put forward (Stern 2004), which suggests that academics are intrinsically motivated to do research, up to the point of being ready to pay for it, in terms of lost opportunities to engage in more financially rewarding activities (see also Stephan 2012). This is consistent with some findings on academic entrepreneurship. Jensen, Thursby, and Thursby (2003) report that top scientists may abstain from disclosing potentially marketable technologies, as they would face higher opportunity costs (in terms of distraction from research) if required to engage in development activities (see also Thursby and Thursby 2003).

Based on a survey of PhD students in life sciences, physics and chemistry at U.S. institutions, Roach and Sauermann (2010) show evidence of a 'taste for teaching' as well. Teaching is considered as 'interesting' or 'extremely interesting' by about 70% of their sample, while the corresponding percentage for commercialization activities is around 40%.

Finally, Lach and Schankerman (2004, 2008) provide strong evidence that, when it comes to technology transfer activities, academic scientists are highly sensitive to financial incentives. In particular, their decision to disclose their patentable research results to the university depends heavily on the royalty-sharing schemes put in place by the administration. This sensitiveness may be mediated by age and seniority. Thursby and Thursby (2004) find that the propensity of faculty members to engage in collaboration with industry may depend not only on personal preferences and personal interests, but also on life cycle effects. In this respect, older scientists may be more willing to cash in on their knowledge assets than their younger colleagues, who are bound to research and publishing by the need to climb up the academic ladder (Audretsch and Stephan 1996). This may hold true especially for professors of continental European countries, whose academic environment is characterized by lower competition and higher job security than the U.S. one. Nevertheless, technology transfer activities, and consulting in particular, may be related not only to income opportunities or commercialization efforts, but also directly linked to academics' research projects, i.e. being motivated by the desire to gain insights or to access research materials. The distinction is important because of its impact on the nature of spillovers towards research (Perkmann and Walsh 2008).

When considering academics' incentives to engage in technology transfer we should also pay attention to demand factors, especially when comparing researchers from different disciplines. A broad distinction can be drawn between basic science (including mathematics) and engineering (applied) fields, with the former offering fewer consulting opportunities than the latter. Lee and Rhoads (2004), based on a survey of U.S. faculty members, suggest that 52% of engineering academics engage in consulting, while the corresponding percentage is 24.2% for mathematics and 29.2% for physical sciences. Based on a sample of UK academics, D'Este and Patel (2007) find that engineers are markedly more prone to get involved in consultancy activities than mathematicians and physicists. In their sample 81% of researchers in mechanical engineering, 74.4% in civil engineering and 69.8% in electrical and electronic engineering interact with companies through external consulting, whereas such percentages drop to 37.4% for physicists and to only 20.4% for mathematicians. Similar findings come from Landry et al. (2010), who compare engineers and natural scientists and from

Rentocchini et al. (2014), who show that more than 70% of Spanish academics in engineering engage in consulting, as opposed to 40% in other disciplines.

3. A theoretical model of effort allocation between teaching, research and consulting

3.1 Model description

We present, in a stylized fashion, the problem of dynamic effort allocation by an individual academic between three basic activities:[2]

1. teaching: not only intended to represent classroom time (which we treat as exogenously given), but also preparation (which most affects teaching quality);
2. research: aimed at publishing in peer-reviewed journals;
3. consulting: which encompasses a broad range of firm-directed knowledge transfer activities, unrelated to ongoing research and paid for by the customers, rather than the university (from professional advice to laboratory testing, expert witnessing or small-scale entrepreneurship).

We assume the academic to be active in two periods: period 1, when she is a 'junior' scientist; and period 2, when she is 'senior'.[3] We assume that, in each period, the academic has an effort endowment τ to allocate between teaching (e_T), research (e_R), and consultancy (e_C). Empirically, we cannot observe the academic's effort nor the time she allocates to the different activities. However, we will observe both a proxy for the quality of her teaching, based on students' assessment (this will be the dependent variable in our empirical exercise), and for her research productivity, measured by the stock of publications. For that reason we posit in the model their theoretical counterparts, expressed by the following relations:

$$q_T^1 = q_T^1(e_T^1) \tag{1}$$

$$q_R^1 = q_R^1(e_R^1) \tag{2}$$

$$q_T^2 = q_T^2(e_T^2, e_R^1) \tag{3}$$

$$q_R^2 = q_R^2(e_R^2) \tag{4}$$

In period 1, teaching quality (q_T^1) and research productivity (q_R^1) are assumed to be strictly increasing and (weakly) concave functions of teaching and research effort respectively. In period 2, research productivity (q_R^2) depends solely on research effort in the same period, again via a strictly increasing and concave

[2] Alternatively, one could think of the academic allocating time between the different activities. For this assumption to be defendable, time allocation must be intended as actual use of time by the academic, rather than the "formal" (i.e. contractual) allocation of time across activities. Such contract specifications, which are present in some university systems, are absent in Italy. Notice that this interpretation is consistent with the assumption that effort is not observed, which is conventional in economic analysis (e.g. in principal-agent models).

[3] In our model, we do not distinguish between academic rank and seniority. In the empirical analysis, both rank and age will be used as independent variables.

function, while teaching quality depends positively on current teaching effort and non-negatively on past research effort, being q_T^2 concave in both arguments.[4] Finally, e_T^2 and e_R^1 are complementary in q_T^2, i.e. the cross partial derivative is non-negative. This implies that the teaching-related effort is the more fruitful the larger the stock of scientific knowledge accumulated over time.[5]

The academic's utility function is time-invariant, as follows:

$$u(q_T, q_R) = u_T(q_T) + u_R(q_R) + m, \tag{5}$$

where u_T and u_R (strictly increasing and concave functions), are respectively the benefits from teaching quality and research productivity, while m is the income. Income comes only from consultancy,[6] in the form of fees per time unit φ. In particular, given a consultancy fee φ, income can be expressed simply as φe_C. Consultancy fee φ plays a key role in the model and it is assumed to be influenced by three of the academic's characteristics: her scientific discipline, seniority, and past research productivity.

Disciplines matter to the extent that they offer different consulting opportunities. In particular, we assume a broad divide to exist between basic and applied sciences (engineering), with the latter facing a large demand for consulting, especially from small and medium sized firms (we will elaborate more on this in Section 4). The model captures this heterogeneity by means of a continuous parameter x affecting φ, with disciplines ordered by increasing consulting opportunities, i.e. $\varphi_x > 0$, where φ_x is the partial derivative of the consulting fee with respect to x.

As for seniority, we assume φ to change over an academic's career, with φ^2 (fee in period 2, when the academic is 'senior') being greater or equal than φ^1 (fee in period 1, when the academic is 'junior'). The assumption is meant to capture the effect on consulting opportunities that seniority may have per se, for instance by going along with the academic's social capital inside and outside the university.

Finally, we assume $\varphi_R^2 \geq 0$, where φ_R^2 denotes the partial derivative of the consulting fee in the second period with respect to research productivity in period 1. φ^2 depends non-negatively on research productivity in period 1 because scientific reputation (derived from publications) can act as a signal for perspective buyers of consultancy services. In the analytical solution we will also have to consider φ_{RR}^2 and φ_{xR}^2, representing respectively the second derivative of φ^2 with respect to q_R^1 (with $\varphi_{RR}^2 \leq 0$) and the cross partial derivative with respect to x and q_R^1, on whose sign we stay agnostic.

The academic plans her efforts in order to maximize her overall utility, defined as the sum of utility in the two periods (we assume no discounting to take place). Notice that a link between the two periods exists because research productivity in the first period affects both teaching quality and the economic returns from consulting in the second period.

[4] Notice that it is the research effort, not the research productivity, that impacts on teaching quality. This is because the latter builds on scientific knowledge irrespective of this being published or not.
[5] Notice that we are not considering any experience effect in teaching nor in research, which would have complicated the entire setting without adding further insights.
[6] We do not consider explicitly the professor's wage, which is not problematic as long as it does not depend on past or current research and teaching effort. This assumption is discussed in the following section.

3.2 A discussion of the assumptions

A brief discussion of our assumptions is in order.

First, our utility function implies, consistent with the 'taste for science' and 'taste for teaching' literature, that both teaching and research provide an intrinsic 'satisfaction' to the academic, while consultancy provides income, but no intrinsic 'satisfaction'. As for teaching generating no income, we can rationalize such assumption by stressing that, in most universities worldwide, it is common for academics to be paid a fixed wage for teaching or, more generally, that explicit monetary incentives associated to teaching are of limited importance (especially if compared to profit opportunities from consulting). Similarly, while we recognize that research excellence has a positive impact on career advancement, we assume it not to generate additional income. This is indeed the case in all university systems (such as the Italian one in the time period spanned by our data) where seniority affects wages as heavily as rank advancement and/or rank advancement itself is considerably based on seniority (and any additional income from advancement is negligible compared to income gains from consulting).[7]

Second, we do not distinguish between the substantive quality of teaching (as reflected by the instructor's contribution to the students' understanding of the subject) and the one perceived, or reported, by students, which may also be influenced by the instructor's personality or the expected success in passing exams. We are forced to make such assumptions by the data at our disposal, which come exclusively from students' evaluations, as it is most often the case in the literature.[8]

Third, we assume disciplines to differ only in terms of consulting opportunities, which implies that i) marginal utilities from research and teaching efforts do not depend on the discipline; ii) disciplines do not affect teaching quality, as perceived by students. The latter is probably a more restrictive assumption (as students may enjoy some courses more than others, depending on the discipline) but we will argue that, in the case of our empirical exercise, this is not a problematic issue.

Last, but not least, we posit the existence of unidirectional and positive spillovers from research to both teaching quality and consulting fees, that is we exclude any reverse spillovers to research and any feedback between teaching and consulting. We justify such assumptions as follows. On the one hand, they are more than enough to generate quite complex interactions between the incentives to conduct the three activities. On the other, they are justified because of our empirical application. As for the lack of effect from consulting to research, we are interested only in those consultancy services that merely involve the use of existing knowledge, defined as 'opportunity-driven' consulting by Perkmann and Walsh (2008). The assumption would be less justifiable for more 'research-driven' forms of consulting.[9] As for assuming no benefits from consulting to teaching quality, this may face the objection that academics' involvement with industry may bring along several opportunities to improve existing educational programs, or to create new ones (see

[7] Nevertheless, such an effect would have simply increased the return from research effort in the first period.

[8] Section 4.1.1 is fully devoted to a discussion of the issue of teaching quality evaluation through students' questionnaires.

[9] Formally, positive spillovers between research and consulting could be represented by assuming $u_R(e_R; e_C)$, with u_R being increasing in both arguments and the cross-derivative being positive. Such an assumption would increase the allocation of effort to research and consulting and reduce teaching effort.

Stephan 2001, for some historical examples). More generally, university–industry relations (including consulting) may benefit students by creating new or better job opportunities. While not denying the importance of these two effects, we observe that the former materializes over the medium to long term (as changing syllabi requires time), while the latter mostly concerns graduate students or, in the case of undergraduates, has to be mediated by the universities' job placement offices. This leaves our model best suited to capture the short-term impact of consulting on the care devoted by academics to prepare classroom activities and teaching materials, as well as their availability to students outside the classroom.

3.3 Analytical solution

The model is solved by backward induction. In period 2, after plugging the time constraint into the utility function, the academic solves the following unconstrained maximization problem:

$$\max_{e_T^2, e_R^2} u_T(q_T^2) + u_R(q_R^2) + \varphi^2(x, q_R^1)(\tau - e_R^2 - e_T^2). \tag{6}$$

The first order conditions (FOCs) are:[10]

$$u'_T(q_T^2) q_T^{\prime,2}(e_T^{*,2}) = \varphi^2(\mathrm{x}, e_R^1) \tag{7}$$

$$u'_R(q_R^2) q_R^{\prime,2}(e_R^{*,2}) = \varphi^2(\mathrm{x}, e_R^1) \tag{8}$$

In period 1, the academic maximizes the total utility over two periods. By applying the envelope theorem to obtain $\frac{du^{*,1}}{de_R^1}$, we can derive a second set of FOCs:

$$u'_T(e_T^{*,1}) q_T^{\prime,1}(e_T^{*,1}) = \varphi^1(\mathrm{x}) \tag{9}$$

$$u'_R(q_R^1) q_R^{\prime,1}\left(e_R^{*,1}\right) + u'_T(q_T^2) q_{TR}^{\prime,2}\left(e_T^{*,2}, e_R^{*,1}\right) + \varphi_R^2 q_R^{\prime,2}\left(e_R^{*,2}\right)\left(\tau - e_T^{*,2} - e_R^{*,2}\right) = \varphi^1(x) \tag{10}$$

In order to simplify the analysis of the model, but without affecting in any significant way the results, in what follows we will consider specific functional forms for $q_T^1, q_R^1, q_T^2, q_R^2$:[11]

$$q_T^1 = \alpha_T \, e_T^1 \tag{11}$$

$$q_R^1 = \alpha_R \, e_R^1 \tag{12}$$

[10] As usual notation, in (7) and (8) $u'_T(q_T^2)$, $u'_R(q_R^2)$, $q_T^{\prime,2}\left(e_T^{*,2}\right)$ and $q_R^{\prime,2}\left(e_R^{*,2}\right)$ represent first derivatives. The same is in (9) and (10).

[11] (11)-(14) satisfy all the conditions we impose on q_T and q_R in Section 3.1. We notice that the linear formulations in (11)-(14) is not particularly restrictive as long as $u_T(q_T)$ and $u_R(q_R)$ are strictly concave.

$$q_T^2 = \alpha_T\, e_T^2 + \alpha_{TR} e_R^1 + \beta_{TR} e_T^2 e_R^1 \tag{13}$$

$$q_R^2 = \alpha_R\, e_R^2 \tag{14}$$

with all the parameters in (11)-(14) being positive. The first order conditions become:

$$u_T'(q_T^2)\left[\alpha_T + \beta_{TR} e_R^{*,1}\right] = \varphi^2(\mathrm{x}, e_R^1) \tag{15}$$

$$u'_R(q_R^2)\alpha_R = \varphi^2(\mathrm{x}, e_R^1) \tag{16}$$

$$u_T'(q_T^{*,1})\alpha_T = \varphi^1(\mathrm{x}) \tag{17}$$

$$u_R'(q_R^1) + u_T'(q_T^2)\left[\alpha_{TR} + \beta_{TR} e_T^{*,2}\right] + \varphi_R^2 \alpha_R \left(\tau - e_T^{*,2} - e_R^{*,2}\right) = \varphi^1(x) \tag{18}$$

3.4 Model implications

From the model, we derive the equilibrium relations involving teaching quality and:

1. academic seniority (seniority effect);
2. past research productivity (research productivity effect);
3. consulting opportunities (consulting opportunity effect).

The seniority effect is given by the difference between $q_T^{1;*}$ and $q_T^{2,*}$:

$$q_T^{2,*} - q_T^{1,*} = \alpha_T \left(e_T^{2,*} - e_T^{1,*}\right) + \alpha_{TR} e_R^{*,1} + \beta_{TR} e_R^{*,1} e_T^{2,*} \tag{19}$$

The sign of (19) is ambiguous because:

- $\alpha_{TR} e_R^{*,1} + \beta_{TR} e_R^{*,1} e_T^{2,*}$ is positive, but
- $e_T^{2,*} - e_T^{1,*}$ has an ambiguous sign. To understand why, compare equation (15), the first order condition for teaching effort in period 2, and (17), the corresponding first order condition for period 1. On the one hand, the marginal cost of teaching (i.e. the consulting fee) is higher in the second period than in the first one, which suggests a lower equilibrium value of the teaching effort in the second period. At the same time, though, the marginal utility of teaching is also higher in the second period, since $\beta_{TR} e_R^{*,1}$ is positive (equation (15), left hand side), which suggests a higher equilibrium value of the teaching effort in the second period.

It is only by considering the role of discipline-specific consulting opportunities that we can partially resolve this ambiguity. The easiest case to analyze is that of disciplines where consulting opportunities abound, but scientific reputation does not act a signal (φ_R^2 close to zero). In this case, we expect a negative seniority effect. Since φ^1 is large and φ_R^2 small, the incentives to invest in research in period 1 are low, which results in a low value for $e_R^{*,1}$. As for the incentives to invest in teaching effort in period 2, since φ^2 is high, we can expect both $e_R^{*,2}$ and $e_T^{*,1}$ to be small and $e_T^{*,2} - e_T^{*,1}$ to be negative. By plugging small values for $e_R^{*,1}$, $e_R^{*,2}$ and $e_T^{*,1}$, and a negative value for $e_T^{*2} - e_T^{*,1}$ in equation (19) we may easily obtain a negative seniority effect.

In disciplines with limited consulting opportunities (i.e., with values for φ^1 and φ^2 both low and similar) we can predict a positive, or moderately negative effect of the academic seniority. In this fields, investment in research in period 1 tends to be high because φ^1 is small. This has a positive direct effect on teaching quality in period 2 and it positively affects the marginal return of teaching effort. At the same time, the similarity of values for φ^1 and φ^2 implies that the marginal costs of teaching is relatively constant over time, which leads to positive, or moderately negative $e_T^{2,*} - e_T^{1,*}$. While ambiguity still persists in this case, a testable implication of the model is that, when comparing disciplines with few consulting opportunities with disciplines with many ones, but not based on scientific reputation, the seniority effect should be larger in the first case than in the second, irrespectively of the sign of the effect.

The case for which ambiguity cannot be easily resolved concerns disciplines with many consulting opportunities, but conditional on scientific reputation. Here academics invest heavily in research when juniors, with positive direct and indirect effects on teaching quality when seniors, but, at the same time, more incentives to consult.

Ambiguity also surrounds the research productivity effect, i.e. the impact of past research productivity on present teaching quality. In the model, this corresponds to $\frac{dq_T^{*,2}}{dq_R^{*,1}}$ (by definition there is no past research in period 1).

On the one hand, past research has positive direct and indirect effect on teaching quality as shown in equation (13). On the other hand, a high research output as junior may increase the consultancy fee in the second period, thus increasing the marginal cost of teaching and reducing the equilibrium teaching effort $e_T^{*,2}$. Formally, we obtain:

$$\frac{dq_T^{*,2}}{dq_R^{*,1}} = \frac{1}{\alpha_R}\frac{dq_T^{*,2}}{de_R^{*,1}} = \alpha_R + \beta_{TR} e_T^{*,2} + (\alpha_T + \beta_{TR} e_R^{*,1}) \frac{de_T^{*,2}}{dq_R^{*,1}} \tag{20}$$

which after some manipulations, can be formulated as:[12]

$$\frac{dq_T^{*,2}}{dq_R^{*,1}} = \frac{1}{\alpha_R}\left[\frac{u_T'(q_T^2)\,\beta_{TR} - \varphi_R^2 \alpha_R}{-u_T''(q_T^2)\,(\alpha_T + \beta_{TR} e_R^{*,1})}\right] \tag{21}$$

[12] In equation (21) and following, $u_T''(q_T^1)$, $u_T''(q_T^2)$, $u_R''(q_R^1)$ and $u_R''(q_R^2)$ stand for second derivatives.

In equation (21), the denominator is positive (since $u''_T(q_T^2)$ is negative by assumption), but the numerator has an ambiguous sign, because both $u'_T(q_T^2)\,\beta_{TR}$ and $\varphi_R^2\alpha_R$ are positive. To solve, or at least reduce the ambiguity, we will further assume that φ_R^2 is relatively constant: in other words, the signaling effect of research output for consulting is not characterized by strong decreasing returns. Coupled with the earlier assumption that $u_T(q_T^2)$ is concave, and therefore $u'_T(q_T^2)$ decreases with research productivity, it implies that the research productivity effect is either: i) always positive; ii) always negative; iii) or first positive and then negative (clearly, i and ii are special case of iii). An alternative look, which we will also explore in the empirical analysis, is through the mediating effect of scientific fields. If we compare fields with low consulting opportunities with fields with large, but non research-sensitive opportunities (both having low values for the term $\varphi_R^2\alpha_R$) then the research productivity effect is expected to be negative in the first case (because $e_R^{*,1}$ is high) and positive in the second case (because $e_R^{*,1}$ is low). Instead, for fields in which opportunities are large and research sensitive (i.e. $e_R^{*,1}$ reaches intermediate values), predictions are less clear-cut.

We finally consider the consulting opportunity effect. By applying the implicit function theorem on (15)-(18), we obtain:

$$\frac{de_T^{*,2}}{dx}=\frac{\varphi_x^2+\varphi_R^2\alpha_R\frac{de_R^{*,1}}{dx}+u'_T(q_T^2)\beta_{TR}\frac{de_R^{*,1}}{dx}-u''_T(q_T^2)\left(\alpha_T+\beta_{TR}e_R^{*,1}\right)\left(\alpha_{TR}+\beta_{TR}e_T^{*,2}\right)\frac{de_R^{*,1}}{dx}}{u''_T(q_T^2)(\alpha_T^T+\alpha_{TR}^T e_R^{*,1})^2} \tag{22}$$

$$\frac{de_R^{*,2}}{dx}=\frac{\varphi_x^2+\varphi_R^2\alpha_R\frac{de_R^{*,1}}{dx}}{u''_R(q_R^2)(\alpha_R)^2} \tag{23}$$

$$\frac{de_T^{*,1}}{dx}=\frac{\varphi_x^1}{u''_T(q_T^1)(\alpha_T)^2} \tag{24}$$

$$\frac{de_R^{*,1}}{dx}=\frac{\varphi_x^1-\alpha_R\,\varphi_{xR}^2(\tau-e_T^{*,2}-e_R^{*.2})-u'_T(q_T^2)\beta_{TR}\frac{de_T^{*,2}}{dx}+\varphi_R^2\alpha_R\,(\frac{de_R^{*,2}}{dx}+\frac{de_T^{*,2}}{dx})}{u''_R(q_R^1)(\alpha_R)^2+u''_T(q_T^2)\left(\alpha_{TR}+\beta_{TR}e_T^{*,2}\right)^2+\alpha_R\,\varphi_{RR}^2(\tau-e_T^{*,2}-e_R^{*.2})} \tag{25}$$

Equation (24) is negative in force of our previous assumptions, which means that we expect consulting opportunities to negatively affect teaching effort (and therefore teaching quality) of junior scholars.

With additional assumptions, we solve the ambiguity involving (22) and (23), concerning the sign of marginal effects of consulting opportunities on period 2's teaching and research efforts, respectively. We ensure (23) to be negative by assuming that the direct effect of more consulting opportunities on period 2's fee (φ_x^2) more than compensate the indirect effect associated to more consulting opportunities in period 1 ($\varphi_R^2\alpha_R\,\frac{de_R^{*,1}}{dx}$)[13]. That is: $\varphi_x^2+\varphi_R^2\alpha_R\,\frac{de_R^{*,1}}{dx}>0$, from which $\frac{de_R^{*,2}}{dx}<0$. We ensure (22) to be negative as well

[13] For consulting opportunities depending on past research, this indirect effect is as follows: by reducing the research effort in the first period, high period 1's consulting fees may in fact reduce consulting fee in period 2.

by assuming that $\varphi_x^2 + \varphi_R^2 \alpha_R \frac{de_R^{*,1}}{dx}$ is not only positive, but large enough to compensate any indirect effect occurring via the impact that $\frac{de_R^{*,1}}{dx}$ has on the marginal return on teaching effort.

What is left ambiguous is (25), which tells us whether junior scholars' teaching quality is positively or negatively affected by consulting opportunity. On the one hand, more consulting opportunities increase the marginal cost of research effort. On the other hand, they also increase the return on research effort, at least in those fields in which scientific reputation is important. With (22) and (23) both negative, and therefore $\frac{de_R^{*,2}}{dx} + \frac{de_T^{*,2}}{dx}<0$, the sign of (25) is determined by the sign and absolute values of φ_{xR}^2 and the absolute value of φ_R^2. When both are negligible, as in disciplines in which consulting opportunities do not depend on scientific reputation, then the numerator is positive and as a result $\frac{de_R^{*,1}}{dx}$ is negative. If not, predictions are less clear-cut, and depend on the absolute value of φ_R^2 and φ_{xR}^2 , as well as on the sign of the latter. For instance, when both are large and positive, $\frac{de_R^{*,1}}{dx}$ may also turn out to be positive.[14]

In order to summarize the results obtained, Table 1 reports the predictions of the model.

Table 1. Model predictions for Seniority, Research productivity, and Consulting opportunity effects

		General predictions	**Predictions by discipline (as function of consulting opportunities and role of scientific reputation)**		
			(1) Few opportunities	(2) Many opportunities, reputation-based	(3) Many opportunities, non reputation-based
Type of effect:	Seniority	Ambiguous (either positive or negative)	Positive (or less negative than in (2))	Negative	Ambiguous
	Research productivity	Nonlinear (from positive to negative)	Negative	Positive	Ambiguous
	Consulting opportunity	Negative for junior scholars, ambiguous for senior scholars	-	Negative for both junior and senior scholars	Negative for junior scholars, ambiguous for seniors

4. Data and methodology

4.1 Data

All data for our empirical exercise come from the engineering faculty of an Italian mid-sized public university (14,000 students, mostly undergraduates; 563 faculty members) established in 1982, as a spin-off

[14] In this case, the complementarity between consulting opportunities and reputation leads the academic to invest in research in order to increase the consulting opportunities in period 2.

of a larger and older institution located at around 100km of distance. It is part of what was conceived, at its birth, as a 'territorial university', i.e. one that should cater for the local demand of qualified technicians and professionals, and contribute to technology transfer at the local level. In the period under consideration, it consisted of four main departments, built around as many broad groups of disciplines: (i) basic science (i.e. physics, chemistry, mathematics); (ii) civil engineering; (iii) electronic engineering; (iv) mechanical engineering. As for academic ranks and teaching loads, at the time of data collection the Italian academic ranking system was a three-layered one, with full professors (professore ordinario) as the most senior figures, followed by associate and assistant professors (professore associato and ricercatore, respectively). All positions were tenured, with teaching loads set locally, within a range set by national legislation (see Lissoni et al. 2011, and references therein).[15]

Teaching evaluation data come from archival records reporting SETE results for all courses from academic year 2005/06 to 2007/08.[16] Questionnaires were distributed at the end of each course and compiled on the spot by all the students attending classes on evaluation day, under the supervision of another student, and not by the instructor (as a guarantee of anonymity; see Appendix A for a template).

Our observations are courses. For each course we know the instructor's name, age, gender, the number of courses which she was in charge of, and whether she belonged to the faculty staff or was an external appointee (at the time of the evaluation). In case of tenured instructors (the only ones we retain for our exercise), we have information on their rank and discipline, as well the number of total publications and citations listed under their name in the Web of Knowledge database, published by the Institute for Scientific Information, from 1975 to the first observation year. In addition, we also have information about the number of patents held by the instructor, as registered at the U.S. and/or European patenting offices.

Summing up, our database consists of unbalanced panel data, composed of 1,546 observations on 175 tenured professors over three observation years, during which no internal organizational changes took place.

Table 2. Number of professors by academic rank and scientific field

Rank/Field	Basic science	Civil eng.	Electronic eng.	Mechanical eng.	Total
Assistant	10	17	14	25	66
Associate	13	11	13	17	54
Full	6	15	13	21	55
Total	29	43	40	63	175

[15] Full and associate professors in our university had the same compulsory teaching workload (120 classroom hours), while the national legislation established no or reduced workloads for assistant professors, depending on their seniority. As a matter of fact, most assistant professors did teach as much as their seniors, as refusing to do so would have been a considered a display of uncooperative behavior (due to the high student/professor ratios and limited funding for attracting valuable external instructors), with negative consequences for promotion. At the same time, while faculty members were free to take on additional courses and be paid for them, not many took up this opportunity and those who did generally taught only one extra course. In any case, in the regressions, we control for extra teaching loads. Notice finally that some courses were assigned to external instructors, such as young master's degree graduates (not yet enrolled in a PhD program), professors from other universities, or local professionals. In these cases, we exclude them from our regressions. With a few exceptions, all courses consisted of 60 hours of classroom teaching and delivered the same number of credits.

[16] During the three years of observation, the faculty of engineering offered seven different bachelor's degrees and ten master's degrees.

Table 3. Stock of publications, citations, and patents by scienfitic field

Scientific field	Mean	Std	Min	Max
Stock of publications				
Basic science	15.93	23.71	0	83
Civil eng.	2.67	4.25	0	15
Electronic eng.	7.03	7.39	0	33
Mechanical eng.	2.83	4.25	0	22
Stock of citations (publications)				
Basic science	241.21	468.84	0	1662
Civil eng.	23.41	40.09	0	166
Electronic eng.	69.66	78.95	0	359
Mechanical eng.	31.03	63.78	0	327
Stock of patents				
Basic science	0.20	0.68	0	3
Civil eng.	0.19	0.79	0	5
Electronic eng.	0.98	1.74	0	6
Mechanical eng.	0.76	1.83	0	9
Stock of citations (patents)				
Basic science	0	0	0	0
Civil eng.	0	0	0	0
Electronic eng.	3.95	10.68	0	55
Mechanical eng.	2.05	7.32	0	41

Table 2 reports the number of instructors by scientific field and academic rank at the beginning of the time span (2005).[17] The sample is quite uniform across both rank and field. The department of basic science is the smallest, with only six full professors. In contrast, the department of mechanical engineering is the largest, followed by civil and electronic engineering. Overall, and in each department, the number of assistant professors is slightly higher than that of assistant and full professors.

We measure the past research effort of each professor by using either her stock of publications (proxy for quantity) or her stock of citations (proxy for quality). Table 3 provides some descriptive statistics. Consistent with the existing literature on scientific productivity of scientists (Stephan 2010), we do observe an extremely high asymmetry, that is a coexistence of many unproductive professors (no publications) with a few very productive ones. Furthermore, we find significant differences across departments, with basic science exhibiting a higher average number of past publications and citations. While this difference may

[17] Only few professors changed their academic rank during the time window considered, whilst none moved to other departments (disciplinary fields).

depend upon the specificity of the knowledge production process of each discipline (with physicists and mathematicians typically publishing more than engineers; see King 2004), some circumstantial evidence exists that points to a more substantive explanation. In particular, the latest nation-wide research evaluation assessment conducted in Italy (VQR 2004–2010), ranked the department of basic science well above the national average (for universities of the same size), while the engineering departments were about average.

As for measuring consulting activities, we do not dispose of information at the individual level, as this would require accessing sensitive data that are very hard, if not impossible, to obtain.[18] Luckily, cross-disciplinary differences in terms of consulting opportunities are large enough to allow us to test our model's predictions by focusing merely on a set of dummy variables, which capture each individual academic's disciplinary affiliation. We base our argument on both some general statements on the science–industry relationship, as provided in Section 2, and on some remarks on how the relationship unfolds in the specific university under study and its surrounding economy.

The university is located in a high-GDP, manufacturing-intensive area of northern Italy dominated by metalworking and mechanical industries. Within the private sector, the largest demand of graduates in engineering comes from the small and medium enterprises (SMEs), which represent the backbone of the local economy and work mostly as specialized suppliers of components and machines for scale-intensive and traditional sectors, both in Italy and worldwide. This suggests that members of the engineering faculty's four departments face sensibly different demands of consulting services:

- For civil engineers, local consulting opportunities abound, as they arise from a large demand for projects and expert assessment of infrastructure as well logistic and production sites, coming from both firms and local administrations.
- Similarly, mechanical engineers help meeting the large demand for professional expertise expressed by the many local SMEs when dealing with their core metalworking and mechanical business.
- As for electronic engineering, they face a mix of local demand (for consultancy concerning process innovation and the insertion of electronics and IT in mechanical products), as well some national demand, often mediated by consortia of universities.
- Members of the basic science department, on the contrary, have very limited consulting opportunities, due to the local and national paucity of science-based industries.

[18] Some previous studies collected information on consulting and other knowledge-transfer activities through surveys on a large sample of scientists. This approach does not seem attractive in our case, due to the relatively small size of the sample and an expected high rate of non-response. Alternatively, one could ask access to departmental records of contracts signed by individual academics with companies for activities such as testing, quality control advice, architectural and civil engineering projects and other activities that fall squarely in out definition of consulting. At the time when the data were collected, however, obtaining the data on teaching evaluation was already a major success, which we did not want to jeopardize by asking other highly sensitive data. Data on these contracts are indeed made available by universities to the Ministry of Education, but at an aggregate level. Referees suggested to measure consulting activities with patents signed by academics in our sample, but we think this not to be appropriate (though we control for them). First, academic patents concentrate largely in fields which are absent from the faculty of engineering we study (that is, they are mostly found in Pharma & BioTech, followed by Organic Chemistry). Second, patents are by definition the results of the creation of new knowledge, as they protect novel and nonobvious ideas, while by consulting we intend mainly the transfer of established knowledge. Third, a large literature point out that academic patenting and publishing are highly complementary, with academic inventors being top scientists in their fields (Foray and Lissoni 2010).

Some recent results from the VQR 2004-2010 confirm this view. These data include, among others, information on revenues per capita obtained by each university department from contract research and professional services. While being just a fraction of what individual academics earn from their overall consulting activities,[19] these revenues can be used to rank departments. They are the largest in the department of civil engineering, followed by mechanical and electronic engineering, and, much distanced, by all disciplines represented by the department of basic science (ANVUR 2013).

Some evidence in the same direction comes from the academic patenting data (see again Table 3). The total number of patents is limited, and a few professors hold most of them. Most notably, the electronic and mechanical engineers exhibit the highest share of patents per professor, most of which are not owned by the universities but by private firms (more than 70% of the total), which suggests that they are the result of consulting or, at most, contract research.

Finally, the four broad disciplines differ also in terms of the importance that scientific reputation may have to increase an individual academic's consulting opportunities. In the absence of a strong publishing tradition (especially in peer-reviewed journals), and in consideration of eminent local nature of demand for consultancy, civil engineering is the field with the least value of scientific reputation as signal. For the same reason, at the opposite end we find all disciplines in basic science, with electronic and mechanical engineering in between.

4.1.1 The measurement of teaching quality: a note on SETE data and self-selection

Albeit widely used, especially by administrators and scholars, SETE data have been the object of several controversies. Their reliability rests on the assumption that students are well positioned to monitor their instructor's performance, thanks to their classroom experience. Year after year, the SETE methodology has become more comprehensive and accurate, with the insertion of more specific evaluation criteria and more precise implementation guidelines.

The main criticism to SETE data portrays them as flawed by the biased incentive they would provide to instructors. The latter would be pushed to engage in popularity contests among students, which would have little to do with the students' effective learning, or would affect it negatively (Emery, Kramer, and Tian 2003; Braga, Paccagnella, and Pellizzari 2014). We notice, however, that the SETE data collected in our engineering faculty were not meant to have, nor they ever had, any impact on the instructors' utility, as they did not affect wages or career advancement (this was and still is the case for most Italian universities). They were collected only to comply with existing legal requirements and never published or discussed in faculty meetings.[20] Only the instructor (along with the dean of the faculty) knew her evaluation results, and all

[19] They mainly originate from the few contracts that the individuals prefer to sign via the department, rather than personally, whenever they need to use some of the department's facilities or as part of informal arrangements (aimed at trading some revenue vs more freedom to take time to attend to personal business matters).

[20] In Italy, SETE data collection, by means of standard questionnaires (possibly adapted by the individual institutions), is promoted by the National Committee for the Evaluation of the University System, a governmental agency created in 2000 with the specific

adjustments of teaching style or syllabi were entirely left to the instructor's goodwill.[21] Finally, still nowadays, Italian universities never request individual SETE data from job applicants, nor consider them in decisions on promotions. In conclusion, this passive attitude towards teaching evaluation is reassuring for our use of data, as we may expect that instructors never acted strategically upon them.

Neither is self-selection of students in high teaching-quality vs. low-quality courses an issue, as the engineering faculty students' curricula were and still are set rigidly by a mix of legal and local regulations. Students can choose among a fairly high number of curricula, grouped according to their professional orientation (business, civil, electronic and mechanical engineering), but have very few or no optional courses and only one instructor is available for each course.[22] Courses are assigned to instructors largely on a seniority basis, with senior faculty members choosing both for themselves and for their junior colleagues, to whom they are usually tied by a strong master/apprentice relationship. This could introduce a bias in our data, with more senior scientists choosing courses from which they expect higher student' evaluations; as we will see, however, we find that seniority is negatively associated to students' evaluations (when the association is significant). Thus, if the bias exists, it does not invalidate our results.

4.2 Methodology

We proceeded in two steps. First, we explored the students' questionnaires by means of exploratory factor analysis (EFA), in order to build a synthetic indicator of teaching quality, and further synthetic indicators of environmental conditions that may affect students' judgment. We retained three factors, which, based on the correlation with single items of the questionnaire, we defined as: "teaching quality" of the professor; "overall quality" of the degree; and "infrastructure quality" (more details in Appendix B).

Second, we ran a regression model with teaching quality as the dependent variable, and the instructor's characteristics (academic rank, stock of publications or citations and disciplinary affiliation) as the main explanatory variables. As for controls, we considered both the environmental conditions in which each course took place (such as the overall quality of the degree, the quality of infrastructure, the size of the class, the level of the degree - bachelor vs. master - and time dummies) and some further individual characteristics of the instructor. Among the latter, besides age and gender, we considered the individual’s overall teaching load and previous experience with the course taught (whether she was teaching it for the first time or not).[23] For the complete list of independent variables and their basic descriptive statistics, see Appendix C.

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purpose to coordinate the evaluation activities of public universities, which constitute the vast majority of Italian higher education institutions. As a matter of fact, the data were never used.

[21] Bianchini (2014), using the same data, shows that students' evaluations do not provide any feedback to improve future teaching performance, either at the university or the individual level.

[22] Self-selection might still occur across degrees. However, Bianchini, Lissoni, and Pezzoni (2013) show that students' characteristics, which vary across degrees, do not have any significant impact on their teacher evaluations.

[23] Our original exercise also included, among the controls, the instructor's stock of patents (or alternatively the stock of patents’ citations), which one may assume to be a proxy of external commitment, but we never found it significant. Notice however that Goel and Göktepe-Hultén (2013), for a sample of German scientists, find that consulting, i.e. the form of interaction with industry that is most relevant in our case, has no robust impact on academic patenting.

Our time series is very short, and no major changes in the organization of the courses, or assignment to instructors, occurred during the observation period. As our main concern was mainly to preserve the sample size we implemented a pooled cross-section model (Ordinary Least Squares estimation), including a set of time dummies to account for potential macro-level changes.[24] Since the same courses are most often taught by the same instructors over the years, we needed to account for the possible correlation in the error terms over time. We dealt with this problem by clustering the standard errors at the professor level. Finally, robust standard errors are obtained via bootstrap procedure.[25]

Based on the theoretical conclusions formulated in Section 2, we produced three different model specifications. Model (1) looks at the seniority, research productivity and consulting opportunity effects, without distinguishing between disciplines. The research productivity effect is investigated considering a nonlinear (quadratic) formulation. In model (2), we interact seniority (academic ranks) with the disciplines, with "assistant professor in basic sciences" as the reference category. Finally, model (3) keeps the interaction between rank and discipline, but substitutes the nonlinear effect of productivity with the interaction between stock of publications and disciplines.

5. Results

Table 4 reports the estimated coefficients for the main explanatory variables whereas Appendix D contains the estimates for the full list of controls. All specifications exhibit a satisfactory explanatory power (R^2 always close to 0.50).

Although we are cautious in claiming the existence of a causal relationship, results from model (1) show that the seniority, research productivity and consulting opportunity effects are broadly in line with the predictions of our theoretical model.

Concerning rank (which proxies for the "seniority" variable in our theoretical model), we notice that, on average, both associate and full professors obtain lower evaluations than assistant professors, although the estimated coefficient for associate professors is smaller in magnitude and not statistically significant. In other words, the ambiguity that characterizes the model prediction is solved in favour of a negative seniority effect. We interpret it as the result of the larger consulting opportunities available to full professors.

As for research productivity, we find an inverted-U relationship between the stock of publications and teaching quality, as predicted.[26] Research productivity has an initial positive association with teaching

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[24] Since most information is captured by time-invariant variables (i.e. scientific field, academic rank, stock publications), controlling for individual fixed-effects would make it impossible to carry out our empirical exercise. The issue of possible unobserved effects is however not too problematic in our framework. Indeed, as for an unobserved teaching ability, this would be problematic if correlated with some of our explanatory variables (in particular field) but we do not have reason to believe that this is the case. As for an unobserved general ability, which could induce a spurious correlation between teaching and research, one can notice that we control both for age and rank. Our argument is that given age, higher rank should in fact capture, at least partially, an ability effect.

[25] Standard errors are obtained out of 200 replications, which are enough to obtain convergence. Notice that the same patterns of statistical significance are obtained applying the standard sandwich-White procedure.

[26] The stock of citations never turns out to be significant and to be parsimonious we have omitted the specification from Table 4. Following the suggestion of a referee we weighted the publications with a depreciation factor to put less value on the past research activities. We use the standard depreciation equation that is $Stock\ Pub\ Depr = \sum_{i=1}^{Stock\ Pub} \frac{1}{(1+r)^{2005-year_{pub_i}}}$ where Stock Pub is the

quality, but diminishing returns may kick in over a certain threshold (approximately 33 publications over a professor's life cycle). Our theoretical model suggests that this happens when, for high publication levels, the marginal impact of publications on teaching quality (via the effect on the academic's utility function) becomes too small to compensate for the negative effect associated with the larger number of consulting opportunities that come with a solid scientific reputation. It is important to notice that in our case professors with more than 33 publications are observed only in basic science (see Table 3), so that we could expect a different effect of research productivity in this field. This, as we will see, is what we obtain in regression (3).

Finally, the consulting opportunity effect is negative. With basic science as the reference case, this corresponds to negative and significant coefficients for all other disciplines. In other words, when one does not distinguish by academic rank, an average lower commitment to teaching is observed in profession-oriented disciplines, whose members tend to face extra-academic engagements.

Our model predicts that the seniority effect could differ across disciplines and the consulting opportunity effect across ranks. For that reason, we estimate model (2), where we interact academic rank and discipline dummies. First, as predicted by the model, associate and full professors of civil engineering (where consulting opportunities are unrelated to the academic's scientific status), perform constantly worse than assistant professors. Second, no seniority effect is observed in basic science (where consulting opportunities are limited), witness the lack of significance of estimated coefficients for academic ranks. Finally, for mechanical and electronic engineering, in which consulting opportunities are affected by scientific productivity, but the model predictions are not clear-cut, we also find negative coefficients irrespective of ranks. However, the magnitude of the coefficients for associate and full professor in civil engineering are similar, whereas for mechanical and electronic engineering the coefficient is larger (in absolute value) for full professors. We interpret this result as suggesting that, in civil engineering, seniority is not as important for getting consulting opportunities as in other engineering disciplines, where it seems that the impact of scientific reputation on consulting opportunities prevails on the effect on teaching quality.

Finally, in model (3) we further explore the research productivity effect, based on interaction of the stock of publications with the field dummies. We find that the marginal effect of publications is not significant for basic science and mechanical engineering, while it is positive and significant both for electronic and, especially, for civil engineering. As shown in Table 3, civil engineering and basic science represent the two extremes in terms of propensity to publish. Therefore, in light of our theoretical model, we interpret this evidence as suggesting that past research commitment is particularly beneficial to teaching quality when scientists tend to publish less, and the consulting opportunities abound (as is the case for civil engineering). Conversely, the marginal effect of past research productivity is null when scientists publish a lot and consulting opportunities are limited (as in the basic sciences). Last, some mixed evidence emerges in those disciplines with an average propensity to publish and abundant consulting opportunities (mechanical and electronic engineering).

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count of publications until 2005, $year_{pub_i}$ is the year of publication of paper i, and r is the depreciation rate. We assign to the parameter r three different values, namely 0.02, 0.05 and 0.08. Results are in line with those presented in Table 4 and available upon request.

Table 4. Regression results

	(1) TQ	(2) TQ	(3) TQ
RANK RC	Ref		
RANK PA	-0.1512		
	(0.1144)		
RANK PO	-0.3121**		
	(0.1380)		
STOCK PUB	0.0274**	0.0267**	
	(0.0129)	(0.0133)	
STOCK PUB SQ	-0.0004*	-0.0004*	
	(0.0002)	(0.0002)	
BASIC SCIENCE	Ref		
CIVIL	-0.4385***		
	(0.1535)		
ELECT	-0.5214***		
	(0.1386)		
MECH	-0.4716***		
	(0.1328)		
BASIC SC * RC		ref	ref
CIVIL * RC		-0.3181*	-0.5804***
		(0.1911)	(0.1875)
ELECT * RC		-0.4278*	-0.6103**
		(0.2498)	(0.2515)
MECH * RC		-0.4361*	-0.5664**
		(0.2303)	(0.2233)
BASIC SC * PA		-0.0747	0.0290
		(0.2331)	(0.2260)
CIVIL * PA		-0.6614**	-0.8678***
		(0.3111)	(0.2846)
ELECT * PA		-0.5259**	-0.7542***
		(0.2424)	(0.2750)
MECH * PA		-0.5765***	-0.6601***
		(0.2105)	(0.2052)
BASIC SC * PO		-0.2682	-0.2025
		(0.2783)	(0.2948)
CIVIL * PO		-0.6393**	-1.1302***
		(0.2503)	(0.2838)
ELECT * PO		-0.8553***	-1.1419***
		(0.2644)	(0.2964)
MECH * PO		-0.6996***	-0.7891***
		(0.2213)	(0.2197)
BASIC SC * STOCK PUB			-0.0030
			(0.0056)
CIVIL * STOCK PUB			0.0780***
			(0.0250)
ELECT * STOCK PUB			0.0298**
			(0.0152)
MECH * STOCK PUB			0.0070
			(0.0168)
Controls	Yes	yes	yes
Obs	1,546	1,546	1,546
R^2	0.5018	0.5052	0.5276

Notes: ***, ** and * indicate significance on a 1%, 5% and 10% level, respectively.
Bootstrapped standard errors (200 runs) are reported in parenthesis.

The most important objection one can raise against to the proposed interpretation of our results is that discipline dummies may capture several factors other than consulting opportunities, all of which could affect students' evaluations. First, academics active in some disciplines could be systematically better teachers (say, basic scientists could be more gifted or enjoy teaching more than engineers). However, we are not aware of any evidence supporting this view.[27]

Second, students could generally prefer courses in some disciplines, and consistently evaluate them better than the others. But in our case, we can safely presume engineering students to have a preference, if any, for engineering disciplines over purely scientific ones. Thus, we may conclude that, at most, our estimated coefficients for such disciplines suffer from a positive bias, which is compatible with our interpretation. A counterargument to this conclusion could be the following. If students have a preference for engineering courses, this would positively affect their expectations in terms of the instructor's performance. As high expectations can be more easily disappointed, this could lead to lower evaluations. In this case, our estimated coefficients would be negatively biased, which runs against our interpretation. This possibility is not easy to dismiss. However, we ran separate regressions for undergraduate and graduate courses and found no significant differences in terms of estimated coefficients. As the "high expectation" explanation is more likely to apply to graduate rather than undergraduate students (the former being positively selected, among other things, by their academic interests), we draw some comfort from the result.[28]

6. Conclusions and policy implications

Our paper contributes to an emerging research agenda on the complex relationships between universities' three missions (teaching, research and technology transfer). In particular, we have examined the link between research productivity, consulting activities, and teaching quality at the individual level. We have attached great importance to mediating factors, such as academic seniority and the disciplinary affiliation of individuals. The former influences the link between research, consulting and teaching quality via several life cycle effects; the latter does the same due to the different levels of demand for consulting services faced by academics in different disciplines. We outline these complex interactions by means of a stylized model, according to which academics distribute their research, consulting and teaching efforts over a two period horizon, with past research influencing positively both the quality of teaching and (in some disciplines but not others) the amount of consulting opportunities.

Some of our results confirm previous evidence, whereas the majority of our findings add to the literature by pointing out large differences across disciplines, which we explain with differences in the extent of consulting opportunities and their dependence on scientific reputation. As for the seniority, for instance, studies from the 1950s and the 1960s found a positive effect (e.g. Downie 1952), but the relation turned out to be insignificant in some studies from the 1970s and the 1980s (e.g. Linsky and Straus 1975). We do find a

[27] In contrast, evidence from economics and business schools (e.g. Ponzo and Scoppa 2013) shows that mathematics instructors receive significantly worse evaluations from students.

[28] The results of these regressions are available upon request.

non-significant effect, but only for basic science. In contrast, for engineering professor, who enjoy more consulting opportunities, the effect is negative.

As for the research–teaching nexus, we prove it to be nonlinear and heavily dependent on cross-disciplinary differences, which may account for the inconclusiveness of the evidence produced so far by the literature.

Finally, our negative findings, for some disciplines, on the consulting–teaching nexus are in line with Lee and Rhoads (2004) on U.S. data, but in disagreement with those of Landry et al. (2010), who detect no correlation between the two activities.

Despite these contributions, our study suffers from a number of limitations. First, we did not have access to micro-level indicators of academics' level of engagement in consultancy activities. Our conclusions are based on the coefficients estimated for a set of disciplinary dummies, in a context in which we can safely presume differences in consulting opportunities were greater across disciplines than across individuals within each discipline. However, in order to generalize our results to less controlled contexts, we should try to collect information at the individual level, which in turn would require to build a larger sample.

Second, it would be interesting to test our model over a longer time horizon, possibly including more than one university and extending the analysis to more disciplines, possibly in the social sciences and the humanities (see the recent discussions in Amara, Landry, and Halilem 2013; and Olmos-Penuela, Castro-Martinez, and D'Este 2014). Finally, different proxies of teaching quality, less dependent on subjective judgment, might provide more robustness to our findings.

As for policy implications, our findings suggest that, from a social welfare viewpoint, the optimal mix of academic activities varies by discipline. In general, consulting opportunities are detrimental to teaching quality, at least in the narrow way in which we defined it. This suggests that, in principle, this particular form of technology transfer ought to be disciplined by universities, but in a smart way. In disciplines where consulting opportunities abound, but only for reputed scientists, more leniency should apply, as consulting opportunities enhance early life cycle investment into research activities, which in turn may also benefit teaching quality. The opposite holds in those sectors where consulting does not build on scientific excellence, and ends up detracting from teaching quality. Here the contracts binding the academic to the university should focus on teaching, either by imposing (and enacting) restrictions on consulting activities, or by requiring the academic to share a significant amount of her revenue with the university (that is, by taxing consulting revenues).

The second option, besides lowering to some extent the academic's incentive to engage in consulting, would bring cash to universities at a time when governments require them to step up their self-financing capabilities. Notice that this policy recommendation would be pretty radical if proposed for university systems in countries such as Italy and several other continental European countries, in which equality of treatment is ensured by national legislation. In such systems, the central government fixes both the wages and, by-and-large, the teaching duties of academics regardless of the discipline and of individual administrative and organizational work. This leaves little freedom to university administrators when it comes to regulating or incentivizing their staff's other activities. As a consequence, academics in consulting-oriented disciplines hardly share their consulting revenues, nor can be pushed to do research when this is unnecessary for improving their consulting opportunities. Notice that these policy conclusions are in line with those of Sanchez-Barrioluengo (2014), who suggests that Spain's "one-size-fits-all" model of universities as centers of excellence in education, research and third mission initiatives relies upon unrealistic expectations on the interaction between the three activities.

Notice also that the intensity of the link between scientific reputation and consulting opportunities may differ across universities, it being conditional on local demand for technology transfer, depending on the mix of industries and R&D intensity characterizing the economic systems in which the universities are embedded.

Finally, our recommendations need to be assessed against the extent of potential beneficial effects of consulting that may compensate for lower teaching quality, such as the stage and job opportunities that academics with close contacts with industry can bring along.

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Appendix

Appendix A - Questionnaire template

Section A (organization of the degree)

A1. Is the overall workload for the academic period acceptable?

A2. Is the overall organization for the academic period acceptable?

Section B (organization of the course)

B3. Have the arrangements for examination been clearly defined?

B4. Are the hours of teaching activities respected?

B5. Is the teacher actually available for explanation/clarification?

Section C (teaching)

C6. Is the prior knowledge owned sufficient to understand?

C7. Does the teacher stimulate interest towards the subject?

C8. Does the teacher explain the topics in a clear way?

C9. Is the relationship between workload and granted credits acceptable?

C10. Is the teaching material adequate for learning purposes?

Section D (infrastructure)

D12. Are the classrooms adequate for lessons?

D13. Are the classrooms and the equipment adequate for exercises?

Section E (interest and satisfaction)

E14. Am I interested in the course topics?

E15. Overall, am I satisfied with the course?

Note: the items related to the underlying latent factor of teaching quality are highlighted in bold (see Appendix B for details).

Appendix B – Teaching quality measure

We implemented an EFA on all items of the questionnaire (except one in Section C, which concerns laboratory activities and it is relevant for only a small minority of courses) to unveil the latent structure explaining the covariance of the original data. Table B1 shows basic descriptive statistics for these items. The outcome of this procedure consisted of a synthetic indicator of teaching quality and further synthetic indicators of environmental conditions that may affect students' judgment. More precisely, we made use of the principal axis method in extracting the latent factors. In order to obtain the estimation of the prior communality we computed the squared multiple correlation between a given variable and the other observed variables. Last, we allowed factors to be correlated with each other using the 'promax' rotation method (the factors are uncorrelated at the time they are extracted, it is only later that their orthogonality constraint is relaxed). Table B2 shows that only three factors have an eigenvalue larger than one. Factor 1 accounts for 74% of the common variance, followed at great distance by factors 2 and 3 (which explain respectively 15% and 12%), with all the following factors scarcely relevant. We retain these latent factors for our analysis. From Table B3, we notice that the three factors lend themselves to an immediate interpretation as 'latent variables', as they are correlated, respectively, with sections B, C, E, A and D of the questionnaire. As for interpretation, factor 1 is readily identified with teaching quality, while factors 2 and 3 capture quality of the overall organization of the degree (what we define as overall quality) and infrastructure quality.

Table B1. Descriptive statistics for each item (teaching dimension)

Item	Mean	Std	Min	Max
A. Organization of the degree				
A1_M - period workload	2.51	0.45	1	4
A2_M - period schedule	2.64	0.39	1	4
B. Organization of the course				
B3_M - exam mode	3.11	0.48	1.33	4
B4_M - punctuality	3.36	0.38	1.33	4
B5_M - willingness	3.28	0.35	1.90	4
C. Teaching				
C6_M - preliminary notions	2.78	0.43	1.30	4
C7_M - raise interest	2.88	0.52	1	4
C8_M - clarity	2.96	0.51	1	4
C9_M - credits	2.73	0.49	1	4
C10_M - teaching material	2.82	0.44	1	4
D. Infrastructure				
D12_M - classroom	3.17	0.38	1.44	4
D13_M - laboratory	3.08	0.42	1	4
E. Interest and satisfaction				
E14_M - general interest	3.08	0.46	1	4
E15_M - overall satisfaction	2.88	0.49	1.25	4

Table B2. Eigenvalues of the reduced correlation matrix

Factor	Eigenvalue	Difference	Proportion	Cumulative
1	6.397	5.120	0.736	0.736
2	1.277	0.249	0.147	0.883
3	1.028	0.533	0.118	1.001
4	0.495	0.339	0.057	1.058
5	0.156	0.061	0.018	1.076
6	0.095	0.090	0.011	1.086
7	0.004	0.028	0.001	1.087
8	-0.023	0.041	-0.003	1.084
9	-0.065	0.013	-0.007	1.077
10	-0.078	0.033	-0.009	1.068
11	-0.111	0.040	-0.013	1.055
12	-0.150	0.004	-0.017	1.038
13	-0.154	0.021	-0.018	1.020
14	0.175		0.020	1.000

Table B3. Factorial structure (three latent factors retained)

	Teaching qual. (factor 1)	Overall qual. (factor 2)	Infrastructure qual. (factor 3)
A. Organization of the degree			
A1_M - period workload	-14	96*	-4
A2_M - period schedule	3	80*	-3
B. Organization of the course			
B3_M - exam mode	76*	-8	-3
B4_M - punctuality	69*	-11	-4
B5_M - willingness	81*	-10	8
C. Teaching			
C6_M - preliminary notions	28	32	21
C7_M - raise interest	80*	9	1
C8_M - clarity	87*	5	-5
C9_M - credits	11	68*	5
C10_M - teaching material	67*	14	0
D. Infrastructure			
D12_M - classroom	1	-1	84*
D13_M - laboratory	-4	0	84*
E. Interest and satisfaction			
E14_M - general interest	43*	28	9
E15_M - overall satisfaction	82*	18	-2

Note: Each factor loading is limited to decimal points, rounded to the nearest integer, and multiplied by 100, thus eliminating the decimal point. The asterisks appear next to the factor loading the absolute value of which is greater than 0.40.

Appendix C – Descriptive statistics

Table C1. Variable description

Variable name	Description
Main variables	
TQ	Overall teaching quality (factor 1 – synthetic indicator)
RANK ASSIS	Dummy = 1 if professor's academic rank is 'assistant'
RANK ASSOC	Dummy = 1 if professor's academic rank is 'associate'
RANK FULL	Dummy = 1 if professor's academic rank is 'full'
BASIC SCIENCE	Dummy = 1 if professor's disciplinary field is basic science
CIVIL	Dummy = 1 if instructor's disciplinary field is civil engineering
ELECT	Dummy = 1 if professor's disciplinary field is electronic engineering
MECH	Dummy = 1 if professor's disciplinary field is mechanical engineering
STOCK PUB	Professor's stock of publications from 1975 to the first observation year
Controls	
AGE	Professor's age
GENDER	Dummy = 1 if professor's gender is female
STOCK PUB CIT	Professor's stock of citations from 1975 to the first observation year
STOCK PAT	Professor's stock of patents
STOCK PAT CIT	Professor's stock of patents' citations
NEW PROF	Dummy = 1 if the professor teaches the course for the first time
LOW LOAD	Dummy = 1 if the professor teaches one course per year
MIDDLE LOAD	Dummy = 1 if the professor teaches two or three courses per year
HIGH LOAD	Dummy = 1 if the professor teaches more than three courses per year
CLASS SIZE	Number of delivered questionnaires
BA PROG	Dummy = 1 if the degree level is bachelor
MA PROG	Dummy = 1 if the degree level is master
OVERALL QUAL	Overall quality of the degree (factor 2 – synthetic indicator)
INFRAST QUAL	Infrastructure quality (factor 3 – synthetic indicator)
TD 2005	Time dummy (academic year 2005/06)
TD 2006	Time dummy (academic year 2006/07)
TD 2007	Time dummy (academic year 2007/08)

Table C2. Descriptive statistics of the main varibles and controls

Variable	Mean	Std	Min	Max
Main variables				
TQ	0.01	0.97	-3.23	2.47
RANK ASSIS	0.25	0.43	0	1
RANK ASSOC	0.35	0.48	0	1
RANK FULL	0.40	0.39	0	1
BASIC SCIENCE	0.17	0.37	0	1
CIVIL	0.22	0.42	0	1
ELECT	0.23	0.42	0	1
MECH	0.38	0.49	0	1
STOCK PUB	6.18	9.82	0	83
Controls				
AGE	44.89	9.01	28	69
GENDER	0.25	0.43	0	1
STOCK PUB CIT	68.94	170.13	0	1662
STOCK PAT	0.59	1.43	0	9
STOCK PAT CIT	1.91	7.63	0	55
NEW PROF	0.02	0.15	0	1
LOW LOAD	0.16	0.37	0	1
MIDDLE LOAD	0.73	0.44	0	1
HIGH LOAD	0.11	0.31	0	1
CLASS SIZE	39.13	34.54	3	213
BA PROG	0.48	0.49	0	1
MA PROG	0.52	0.49	0	1
OVERALL QUAL	-0.01	0.95	-3.62	3.45
INFRAST QUAL	0.01	0.89	-4.19	2.37

Appendix D – Estimated coefficients for control variables

Table D1. Control variables in Table 4 of main text: estimated coefficients

	(1) TQ	(2) TQ	(3) TQ
AGE	-0.0122*	-0.0118*	-0.0120*
	(0.0068)	(0.0069)	(0.0067)
GENDER	-0.1003	-0.1022	-0.0695
	(0.1034)	(0.1075)	(0.1007)
STOCK PAT	0.0358	0.0335	0.0424
	(0.0342)	(0.0324)	(0.0341)
NEW PROF	-0.0664	-0.0517	-0.0285
	(0.1384)	(0.1382)	(0.1475)
LOW LOAD	ref	ref	ref
MIDDLE LOAD	0.0322	0.0442	0.0193
	(0.0975)	(0.1025)	(0.1024)
HIGH LOAD	0.1184	0.1019	0.1213
	(0.1708)	(0.1888)	(0.1870)
CLASS SIZE	-0.0000	0.0001	-0.0004
	(0.0012)	(0.0012)	(0.0012)
BA PROG	ref	ref	ref
MA PROG	0.1581***	0.1609***	0.1594***
	(0.0536)	(0.0537)	(0.0521)
OVERALL QUAL	0.5564***	0.5572***	0.5486***
	(0.0351)	(0.0352)	(0.0348)
INFRAST QUAL	0.2347***	0.2356***	0.2289***
	(0.0339)	(0.0329)	(0.0317)
Time dummies	yes	yes	yes
Obs	1,546	1,546	1,546
R^2	0.5018	0.5052	0.5276

Notes: ***, ** and * indicate significance on a 1%, 5% and 10% level, respectively. Bootstrapped standard errors (200 runs) are reported in parenthesis.