**The effects of university-industry relationships and academic research on
scientific performance: Synergy or substitution?**

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Abstract

This paper evaluates whether university-industry relationships (UIR) and academic research activities have complementary effects on the scientific production of university lecturers. The analysis is based on a case study of two Spanish universities. We find that the effects of R&D contracts with industry, and academic research activity on scientific production are synergistic, but only when the R&D contracts account for a low percentage of a lecturer's total funding. This suggests that the positive effect of UIR on a lecturer's scientific production comes fundamentally from the capacity to provide complementary resources (cognitive, technical, and/or financial) for research activities. If lecturers are not involved in research and dedicate most their time to the development of activities related to UIR, their scientific production will be negatively affected.

Key Words: scientific production; university lecturers; traditional research activities; university – industry relationships; complementarity.

Introduction

The analysis of the factors that influence university researchers' scientific production has attracted the interest of economists and sociologists in recent decades. Under the assumption that scientists have the freedom to choose among research topics, early work

in this are focused almost exclusively on sets of characteristics or individual attributes, such as, age, gender, status, work experience or researcher's discipline (Lehman 1960; Zuckerman and Merton 1972; Long 1978). This was later complemented with research which also included explanatory variables for collective factors associated with the characteristics of the institution and department in which the research was developed. These variables include aspects such as department size (Kyvik 1995; Bonaccorsi and Dario 2003), the public or private nature of the institution (Jordan et al. 1989), departmental or institutional culture (Creswell 1986), and the structure funding of research activities. Funding structure includes volume of resources (i.e. annual budget for research activities) and the nature of the funding source. For example, in an early study, Johnes (1988) indicated that the differences in scientific productivity among UK university departments could be explained by the amount of non-governmental funding acquired by the university. Along similar lines, Gulbrandsen and Smeby (2005), for a sample of Norwegian lecturers, found evidence of a positive relationship between external funding (derived from industry) and lecturers' scientific performance.

The reduction in public funding of university research and the emphasis given to research as key factor for industrial innovation, has generated considerably increased private funding for universities and promoted stronger university-industry relationships (UIR) (OECD 2000). Funding sources have been shown to be a determinant of researchers' scientific productivity, which has increased the relevance of this field of study, with a special focus on the effects of UIR on the development of academic research.

In relation to this last point, several authors have indicated their concern for the adverse consequences of these increased interactions with industry on the autonomy of researchers, and on the quality of scientific production (Florida y Cohen 1999). It has been shown, for example, that very close relations with industry can work to penalise the autonomy of the university and to direct the agendas of researchers toward activities with potential economic utility (Martin and Etzkowitz 2000). It has also been shown that the dissemination of research results can be affected because a constant tension between the desire of researchers to publish, and the aim of private sponsors to delay publication in the interests of protecting intellectual property (Dasgupta and David 1994). Nevertheless, despite these concerns, most studies on the subject find a positive relationship between the scientific performance of lecturers and UIR. The literature in this field fall into two categories: those that indicate a positive effect on lecturers' scientific productivity of UIR (Landry et al. 1996; Gulbrandsen and Smeby 2005, Stephan et al. 2004; Calderini and Franzoni 2004; Azoulay et al. 2005; Breschi et al. 2005, 2006; Van Looy et al. 2004-2006; Meyer 2006; Godin and Gingras 2000), and those that indicate that this effect is determined by the degree of UIR (Blumenthal et al. 1996; Bonaccorsi et al. 2006) or the type of interaction activity (Manjarrés-Henríquez et al. 2008). However, the basic argument behind these results is that interactions with industry provide lecturers with access to additional financial resources and relevant knowledge, both of which impact positively on their scientific performance ('resources effect').

The implications of the above are that linkages between industry and academic research, in some case, can be complementary activities and can have synergistic effects on lecturers' scientific productivity. This latter aspect has not been explored in detail and the

existing studies focus on analysing the individual effects of UIR, ignoring possible complementarities between UIR and traditional research activities.

This article examines these complementarities and evaluates whether the effects of UIR and academic research on the scientific production of university lecturers are complementary, at the same time controlling for the effects of a set of individual attributes. The contribution of our research is twofold. The first and more important contribution is that not only do we analyse the individual effects of UIR, we also explore the possible complementarity between UIR activities and traditional academic research with respect to scientific production. The second is that in this work we study a wide set of channels of linkages with industry. This latter aspect has been one of the weak points of many of the existing studies, which have tended to concentrate on analysis of patents as the main channel of interaction between universities and the socioeconomic environment. This, as some authors have suggested, leads to a partial view of the phenomenon, in which an over emphasis on patenting can hide the presence of other linkage activities that are equally as or even more important in the technology transfer process (D'Este and Patel 2005; Cohen et al. 2002).

The study sample is a database of more than 2,000 faculty members from two Spanish public universities (University of Valencia - UV and the Polytechnic University of Valencia - UPV), who have conducted research projects and/or been involved in UIR activities during the 1999-2004 period. The data are analysed at lecturer level and focus on three aspects: UIR, academic research activities and scientific production.

It should be noted that the universities in this study are two of the most important universities in Spain. They also stand out in the Spanish context in terms of their academic research and technology transfer outputs and are representative of the two models of higher education institutions in Spain: general universities and technical universities. General universities are those universities that develop teaching in most fields of knowledge, while Technical Universities restrict their teaching to mainly technical fields, such as engineering and technology.

These distinctive features produce different organizational cultures and, therefore, possibly influence the way that individual attributes and UIR affect the scientific productivity of lecturers. For example, technical universities tend to work with industry, whereas general universities, are more oriented towards basic research and have less of a tradition for linkages with industry.

In terms of funding, the C&D Foundation 2005 report ranks UV and UPV 4th and 7th respectively among Spanish universities in terms of public funding (Fundación CyD 2005), but only UPV appears in the top ten universities for amount of private funding per lecturer. UPV is also the most active in UIR. On the other hand, the C&D Foundation report ranks UV 5th among Spanish universities in terms of number of scientific publications per lecturer, which demonstrates its strong tradition in basic research.

The remainder of the paper is structured as follows. Section 2 provides the theoretical and empirical background. Section 3 presents some methodological aspects of the empirical

study, and describes the data used in the statistical analysis. Section 4 presents the results and Section 5 provides the main conclusions of our study.

2. Literature review

In this section we review two key aspects of the literature that analyses the determinants of scientific productivity: individual attributes of lecturers, and UIR. These aspects have generally been studied separately in the literature, with special emphasis on issues the attributes of researchers. Our review will provide a joint picture of the factors that determine lecturers' scientific productivity.

2.1. Individual attributes

As referred to in the previous section, the early studies on the scientific productivity of university faculty included as explanatory factors, individual characteristics, such as, age, position in the institution, gender and scientific discipline. Among these, the relationship between age and scientific productivity has received particular attention from economists and sociologists. Although the results obtained have been varied, most studies suggest an inverted U-shaped relation between these variables, that is, scientific productivity increases with age but only up to a certain point, at which it remains constant or even decreases (Zuckerman and Merton 1972; Weiss and Lillard 1982; Levin and Stephan 1991). Moreover, it has been indicated that this relation is not homogenous and varies based on the researcher's field or discipline (Clark and Lewis 1985; Levin and Stephen 1989). In the 1960s, Lehman 1958, 1960) showed that scientists that belong to the most

fundamental disciplines reached their peak of productivity sooner than those in more empirically based disciplines. However, it has also been shown that among other attributes, age is a relatively poor predictor of faculty scientific productivity and that the lecturer's position in the institution is more reliable as a determinant. For example, Knorr et al. (1979) demonstrate that age is not a significant factor when the effect that exercises the administrative task is controlled for. Also, authors as Cole and Cole (1972), Long (1978) and Carayol and Matt (2006), found that researchers occupying higher positions in the university hierarchy (full time senior professors) showed greater scientific productivity than their more junior colleagues (assistant and associate professors). Another characteristic that has been related to scientific productivity is gender. The earliest studies on this issue show that women tend to publish less than their male colleagues (Cole and Zuckerman 1984), although it has also been shown that this result can be attributed to gender differences associated with position and other factors (Xie and Shauman 1998; Smeby and Try 2005). Discipline is another factor that has been associated with scientific productivity and work has been done on its effects individually and jointly with other attributes such as age. Carayol and Matt (2006) found that, taking Mathematics as the reference discipline; Social Sciences and Humanities exercised a significant and negative effect on lecturers' scientific productivity. Dundar and Lewis (1998) found important differences in the average number of articles published by US university researchers, depending on field: whereas a typical faculty member in social sciences published approximately 2.5 articles between 1988 and 1991, colleagues in the biological sciences published 9 articles during the same period. However, Dundar and Lewis (1998) indicate that these results reflect differences in publication trends in these fields rather than differences in levels of productivity in each discipline.

2.2 UIR and scientific production

From an economics point of view, authors such as Dasgupta and David (1994) point out that universities and industry operate under different systems. The former, based on the principles of ‘public science; emphasizes the free, rapid and impartial dissemination of research results; the latter, based on the principles of ‘private science’, search for the appropriation and commercial exploitation of knowledge. Because of these differences, very close interaction between the two spheres can ultimately be ‘costly’ in terms of the production and diffusion of knowledge. Nelson (2001) argued that a strong commercial orientation in academic research may be weakening the traditional commitment of university researchers to publish and contribute to public science. These arguments reflect some of the main concerns that have emerged with relation to the negative effects that greater involvement of universities with industry could generate for scientific performance, based on publication delays, increased secrecy, and the private appropriation of university research outputs.

Despite these concerns, there is empirical evidence that lecturers are combining increasingly traditional activities of research with activities with industry (Lee 1996; Azagra et al. 2006; Powers 2004; Lee and Rhoads 2004). Moreover, most studies in this area find a positive relation between lecturers’ scientific performance and various forms of linkage with the socioeconomic environment, such as, patenting, industry funding, and collaboration and co-publication with industry. Most of these studies use patents as a proxy for UIR, and find that inventors publish more than their non-inventor colleagues (Azoulay et al. 2005; Breschi et al. 2005, 2007; Van Looy et al. 2004, 2006; Meyer

2006). Also, studies that take account of industry funding, show that researchers who are funded by industry are more productive than colleagues that are not (Blumenthal et al. 1996; Gulbrandsen and Smeby 2005). Finally, and in line with these findings, researchers involved in co-authorship with industry, publish more and receive more citations to their work than their non-collaborating colleagues (Godin and Gingras 2000; Hicks and Hamilton 1999; Van Looy et al. 2004).

The fact that university lecturers are involved in both research and UIR activities, and that these latter can have a positive effect on their scientific production, suggests that these activities are complementary to the extent that the development of one increases the effectiveness of the other (Milgrom and Roberts 1990). Complementarity, in this context, goes far beyond the joint development of the two types of activities and assumes the generation of synergistic effects on scientific performance: the greater the linkages with industry, the greater the effectiveness of the lecturer's academic research, and vice versa.

In a study based on interviews with scientists at five US universities, Siegel et al. (2003) found that 65% of researchers reported that interaction with industry had positively influenced their research. Some scientists reported that these interactions improved the quantity and quality of their basic research, stating explicitly that, 'There is no doubt that working with industry scientists has made me a better researcher. They help me refine my experiments and sometimes have a different perspective on a problem that sparks my own ideas' (Siegel et al. 2003, p. 42). Thus, interactions between university and industry do not imply knowledge transfer only from university to industry; the transfer takes place in both directions. Breschi et al. (2005) suggest that the resolution of industry problems may be both economically valuable and scientifically relevant, even to the point of opening up

new disciplines and lines of research. Moreover, through UIR, researchers gain access to industry R&D facilities as well as additional financial resources that may be used for the purchase of equipment or hiring of additional personnel for research (Breschi et al. 2005; Kline and Rosenberg 1986). These factors contribute to improving research performance and constitute another argument in favour of the existence of complementarity.

However, it would be wrong to state that UIR are always beneficial to the development of university research or, alternately, to suggest that more linkages will mean higher levels of scientific production. In fact, in a previous study (Manjarrés-Henríquez et al. 2008), we found that the effect of UIR on scientific production depends on the interaction tools used. Specifically, when UIR involve activities with a high scientific-technological content (R&D contracts) this exercises a significant and positive effect on scientific production, but only up to certain level, after which there are decreasing marginal returns to scientific output (Manjarrés-Henríquez et al. 2008). This is related to the effect of ‘squeeze time’, that is, that those researchers who receive larger amounts of industry funds may find strong economic incentives to take time from their research to do ‘industrial work’.

3. Data and Methodology

3.1 Data

The empirical study is based on two of the larger universities in the Valencian Higher Education system, UV and UPV. These two universities account for 64% of the lecturers

and nearly 57% of the university students in the region. The data were provided by the Vice Rectors of Research, through the UV and UPV Technology Transfer Offices (TTOs) and include information on UIR, academic research, scientific production and researcher characteristics for the 1999-2004 period.

For UIR, the database provides information on four types of linkages with industry: R&D contracts, technological support and consultancy contracts, contracts for specific training, and contracts for the provision of services. There are data on both the number and value of UIR activities. Although the database also contains information on patents, these do not represent a major activity in terms of either frequency or economic impact. The analysis of UIR activities shows that R&D contracts represent the activity associated with the highest income, accounting for 52% of the total funding obtained during the period analysed. In terms of academic research, the database provides information on research projects conducted by lecturers through competitive public grants from regional, national and European public bodies. As in the case of UIR, the data collected report both the number and value of academic research activities.

Figure 1 shows that UIR and public grants experienced positive growth during 1999-2004, but that UIR grew at twice the rate of public grants (16% and 8% annual growth, respectively). The funding from linkages with industry increased from €17million in 1999 to almost €43million in 2004, i.e. it more than doubled in the period. This result coincides with trends in the OECD countries (OECD 2000).

The database also provides information on the numbers of articles published by each researcher, in journals indexed in the Thomson Institute for Scientific Information (ISI) database during 2003-2004. One of the characteristics of this variable is that the distribution is highly skewed; the majority of lecturers (64%) did not publish during the period analysed, and 10% of them generated almost 50% of the publications. Thus, publications follow a Lotka (1926) distribution: scientific results tend to be concentrated among a minority of lecturers. Finally, with regard to researcher characteristics, the database provides information on three aspects: work experience, position in the institution and academic discipline.

The data are analysed at lecturer level. In our study we consider only faculty members who have been in charge of a research project supported by competitive public funding, and/or activities contracted by external agents, during the period 1999-2004.¹ The final sample includes 2,034 professors/lecturers, (hereafter we use the term researchers to refer to both categories).

3.2 Variables and Econometric Analysis

To achieve our objectives we estimated two econometric models:

$$SP = \beta_1 R \& D + \beta_2 AR + \beta_3 OTHER_UIR + \beta_4 EXP + \beta_5 EXP^2 + \beta_6 POS + \sum_{i=7}^{11} \beta_i DISC + \beta_{12} UNIV$$

(model 1)

¹ Note that our unit of analysis refers to the lecturers responsible for research projects or activities contracted by external agents. Thus, the sample considered in this study (2,034 lecturers) is smaller than the total population of lecturers involved in these activities.

$$SP = \beta_1 R \& D + \beta_2 AR + \beta_3 OTHER_UIR + \beta_4 EXP + \beta_5 EXP^2 + \beta_6 POS + \sum_{i=7}^{11} \beta_i DISC + \beta_{12} UNIV + \beta_{13} R \& D * AR$$

(model 2)

The first model aims to analyse the effects of UIR, academic research activities and individual attributes on scientific output. The second model includes an interactive term as an additional explanatory variable,² derived by multiplying R&D by AR (R&D*AR). This model aims to evaluate whether R&D contracts and research activities have a complementary effect on scientific production (SP).

Scientific production, the dependent variable in the two models, is measured as the number of articles published by a researcher in journals indexed in the Thomson ISI database, during 2003-2004. Although analysis of international journals articles presents some limitations (e.g., relative quality of work and journal, multiple authorship, types of publication, etc.), it is used as an indicator of scientific production because this is the primary means of diffusing academic research findings (Martin 1996; Smeby and Try 2005), and publications are central to good performance in the scientific community (Crane 1965; Merton 1968).

UIR are analysed based on only those formal activities developed through contractual agreements during 1999-2004 period. These activities are classified into two groups according to their scientific technological level (Manjarrés-Henríquez et al. 2008). In the first group we include only those linkage activities based on the development of R&D contracts (*R&D*); in the second group we include contracts for technological support and

² This interactive term indicates how the effect of academic research on scientific production varies when the *R&D* variable is modified by one unit.

consultancy, for specific training, and for the provision of services (*Other_UIR*). R&D contracts and the activities included in *Other_UIR* are all carried out for the benefit of external agents. However, whereas R&D contracts involve activities aimed at the generation of knowledge, the activities in the second group are directed towards the resolution of specific problems. These distinctive features of UIR activities allow us to classify them within activities with high and low scientific technological level (*R&D* and *Other_UIR* respectively).

The R&D variable is calculated as the percentage of a researcher's total funding that comes from R&D contracts. This variable is measured using an ordinal variable that can take four possible values: 0 if the researcher has not obtained funding from R&D contracts; 1 if amount of funding from R&D contracts does not exceed the first quartile of the researcher's total budget; 2 if the amount is between the first and second quartiles; and 3 if the amount due to R&D contracts is between the second quartile and 100% of the researcher's total budget. We preferred this to a dichotomic variable because it represents a measure of intensity of the R&D contracts developed by the researcher. *Other_UIR* is defined as a dummy variable that takes the value of 1 if the researcher has obtained funding from at least one of the three UIR activities included in this variable and 0 otherwise. As mentioned in Section 2, there is preliminary empirical evidence that the researcher's linkages with the socioeconomic environment can have a positive influence on their scientific production. We consider that the effect that UIR exercises on a researcher's scientific output depends on the channel of interaction. We have evidence from previous work (Manjarrés-Henríquez et al. 2008), that only R&D contracts has a

positive effect, and that other types of linkages with industry can inhibit scientific production.

The variable academic research (*AR*) includes research projects developed by researchers funded by public grants, at regional, national and/or European level, during 1999-2004. The *AR* variable is measured as a dummy variable that take the value 1 if the researcher has received at least one competitive public grant at regional, national or European level and 0 otherwise. In contrast to activities contracted by external agents, the activities included in this group are directed basically to the creation of new knowledge and are largely defined by the researcher's particular interests. Bearing in mind that one of the requirements to obtain public grants is the fact that the lecturer has published his/her previous research findings in international journals, we consider this to be a proxy variable of his/her "earlier publication". Thus, we can expect this variable to be positively related to the researcher's scientific production.

We can see from the definition of the variables that scientific output relates to the period 2003-2004, while the variables for UIR and research activities refer to a longer time period (1999-2004). This distinction was made to take account of the time lapse between research activity and the publication of results. Other studies use similar techniques (Gulbrandsen and Smeby 2005).

Based on our literature review and the available information, we include, three of most important variable identified as researcher's individual attributes: work experience (*EXP*), position (*POS*) and scientific discipline (*Disc*). *EXP* is a proxy for work experience and is

measured as the number of quinquenios³ obtained by the researcher. The variable *POS* is related to the researcher's position and is measured on an ordinal scale that takes account of faculty grading. In Spain, the highest scale corresponds to university professor. As Carayol and Matt (2006) suggest, researchers occupying higher positions in the university hierarchy may show greater production based on their better ability to acquire and exploit external and internal resources (status effect). In others words, senior professors, due to their reputation and prestige, tend to have cumulative advantages over their junior colleagues, which lead to higher scientific productivity (Clark and Lewis 1985; Long 1978). We also include in our model an additional variable, calculated as the square of the value of work experience (*EXP*)², to test whether the effect that experience exercises on scientific productivity is, as some authors have suggested (Merton and Zuckerman 1972; Dundar and Lewis 1998), positive up to a certain level.

The variable *Disc* is related to the field of research to which the lecturer belongs and has five modalities: Social Sciences and Humanities, Agrarian Sciences, Natural and Exact Sciences, Medical Sciences, and Engineering and Technology. Although these modalities are aggregated, we assume that the disciplines that shape them have common characteristics, such as, social and normative work conditions, working methods and techniques.

Finally, in order to evaluate whether the characteristics of the academic institution have an effect on scientific production, we include the researcher's university (*UNIV*) as an

³ In Spain, the quinquenio (five year period) is a form of recognition granted to university professors based on teaching experience, and affects their salaries. Quinquenios are granted every five years, following an evaluation process. Thus, a professor who has been teaching for 20 years could possess up to 4 quinquenios. Quinquenios are generally automatic and thus, can be used as a proxy for teaching experience.

additional control variable. Although the two universities are both public institutions, we control for the effect of this variable because they have some differences in terms of age, size and subject specialisation. UV is one of the oldest universities in Spain (500 years) and is also the largest university in the region; its teaching activity is mainly oriented towards the social sciences. UPV was created in the 1960s and its teaching activities are mainly oriented towards engineering and technology. This allows us to test whether organizational and cultural differences in these universities have a significant effect on researcher's scientific productivity. The *UNIV* variable is defined as a dummy variable that takes the value of 1 if the researcher belongs to UV and 0 if he or she belongs to UPV.

A more detailed description of the variables is presented in Table 1.

TABLE 1 about here

3.3 Statistical methods

As mentioned above, the dependent variable in this study is scientific production. This is a non-negative integer, with a highly skewed distribution, significant overdispersion and a large number of zeros. Several authors have drawn attention to the risk of using traditional statistical methods, such as linear regression, analysis of variance or correlations, to analyse such variables. To account for any shortcomings, we estimated the econometric specifications outlined in the previous section, using a Negative Binomial

model,⁴ which captures the nature of the dependent variable analysed (Cameron and Trivedi 1998).

We also checked the model for multicollinearity, which emerges when two or more explanatory variables are highly correlated. The presence of this phenomenon can cause errors in the estimation and confusion in the attribution of effects; thus, it could be that some of the effects on scientific output attributed to UIR is due to other variables, such as the status of researcher. To control for and detect this undesirable phenomenon in the model outline, we calculated two statistical tests: tolerance and variance inflation factors (Table 2). The values calculated for these tests were well below the levels that other researchers have considered to be the threshold for multicollinearity problems (Norusis 1998). Thus, we can assume that the contribution of each variable in the model is independent from the rest of the variables considered, and that its magnitude does not depend on the analytical strategy adopted (Ato and López 1996).

TABLE 2 about here

4. Results

Table 3 presents the results of the negative binomial regression. Chi-square values for the degrees of freedom in the models seem to indicate rejection of the null hypothesis that all parameters except the intersection are equal to zero at a 1% significance level.

⁴ We first ran a Poisson specification, but a test for over dispersion rejected the constraint of the Poisson model at the 1% level, suggesting application of a negative binomial specification.

TABLE 3 about here

The results in Table 3 show the estimation and significance of the regression models with researcher's scientific production as the dependent variable. Model 1 can be considered the baseline model and shows the main effects of the explanatory variables analysed. This model indicates that the effect of UIR on scientific production varies, depending mainly on the type and intensity of the linkage channel. UIR classified as low scientific technological level (*Other_UIR*) have a significant and negative effect on scientific production. These results show that too much emphasis on the development of routine activities for industry can detract from the 'entrepreneurial university' model and render the institution simply a 'consulting university' with poor scientific indicators (Geuna 1999; Arocena and Sutz 2005).

On the other hand, when the linkage is established via an R&D contract, UIR can have a positive effect. A possible explanation for this phenomenon is that R&D contracts are the only joint activities that generate new knowledge. However, it should be remembered that these types of contracts invariably include confidentiality clauses, which hinder the diffusion of results. Consequently, the high significance of this variable in our regression model could be due to indirect effects, derived from the higher level of resources obtained and the learning that is embedded in these types of activities. Nevertheless, these results reinforce the fact that engaging in UIR does not penalise university research per-se. However, this effect is only significant if the percentage of R&D contracts does not exceed the second quartile of the researcher's total budget. These results show that

although R&D contracts do have a positive effect, this effect is significant only up to a certain level, after which it loses significance.

Likewise, and as expected, the results indicate that academic research has a positive and significant effect on scientific production and even account for coefficients with higher values for all the explanatory variables analysed in the regression. This variable, unlike *R&D*, complies with the condition of ‘the more the better’.

In terms of researchers’ characteristics model 1 and model 2 both show that position in the university has a positive and significant effect on scientific production, while experience has no effect. These results reflect the patterns found in prior studies and emphasize that the effect of experience is weak when aspects related to position or recognition within the institution are included in the analysis⁵ (Carayol and Matt 2006; Knorr et al. 1979; Zuckerman and Merton 1972). However, the significant and negative sign of the coefficient of experience-squared (EXP^2), show an inverse relationship between scientific production and work experience. These findings are evidence of the presence of life-cycle effects, where outputs first rise with age and then decline (Levin and Stephan 1991).

The results for the *Disc* show that, taking Social Science and Humanities as the reference, Exact and Natural Sciences and Medical Sciences have a major positive effect on publication. These findings are evidence of the influence of internal dynamics and context, within disciplines, on the scientific output of researchers (Wanner et al. 1981;

⁵ In fact, a previous regression confirmed that when the variable status is excluded, EXP has a significant and positive impact on production. The regression is available from the author upon request.

Carayol and Matt 2006). Moreover, the results show that the characteristics of the researcher's academic institution have no effect on scientific production. Although UV and UPV have different models of higher education, because they are governed by the same public politics of higher education, there are no significant differences in patterns of publication. These results suggest that, in the context analysed, differences among scientific fields play a higher role in researchers' scientific productivity than differences at university level.

Analysis of complementarities is included in model 2 through the interaction between the variables for *R&D* and academic research ($R\&D*AR$). The interactive term is significant and has negative sign. At first sight, this result would seem to indicate that an increase in the value of one of the variables diminishes the effect on scientific production of the other, which suggests the existence of a possible substitution effect. However, this result should be interpreted with some caution. Several authors have indicated that interpretation of the marginal effect between two variables in a non-linear regression model is more complex than consideration only of the significance and the sign of their coefficients. The interaction effect may have different signs for different values of the covariables (Norton et al. 2004; Hoetker 2007). To cope with this, we calculated the marginal means for scientific production, taking account of the different levels of *R&D* and *AR*, and holding all other covariates at their mean values (Table 3). We can see that when the researcher is involved in academic research activities ($AR=1$) and the *R&D* contracts does not exceed the first quartile of his or her total budget ($R\&D=1$) the marginal mean of scientific production is highest. When *R&D* contracts increases

($R\&D=2$, and $R\&D=3$), the marginal mean, derived from the combination of $R\&D$ and AR , diminishes.

TABLE 3 about here

To further clarify the interpretation of the effect of the interactive term, Figure 2 depicts⁶ the effects of the AR variable on scientific production, for several levels of the $R\&D$ variable, holding all other covariates at their mean values. We can see first that when the $R\&D$ variable changes from 1 to 3 the slope of the line describing the relationship between AR and scientific production, diminishes.⁷ This suggests that if the proportion of $R\&D$ contracts with external agents is low in the researcher's total budget, the marginal effect of academic research on the scientific production might increase compared to the high levels of the $R\&D$ variable. Even when $R\&D$ contracts represent the major part of a researcher's budget ($R\&D=3$), the marginal mean of scientific production, when the researcher carries out academic research ($AR=1$) is smaller than when the researcher has no $R\&D$ contracts.

In summary, the results of our analysis provide evidence of complementarity between $R\&D$ contracts and academic research activities, but only when $R\&D$ contracts account for a low percentage of the researcher's total funding. When most of his or her funding comes from $R\&D$ contracts we can see evidence of a substitution effect between these variables on scientific production (Figure 2). Thus, UIR activities and academic research activities can be affected by the resources effect and the problem of squeeze time.

⁶ This graphic representation enables a better understanding of the interactive effect than the interpretation of a single coefficient alone (Hoetker, 2007).

⁷ When the $R\&D$ variable changes from 1 to 3 the slope of the line diminishes from 1.9 to 0.7.

Conclusion

This paper looked at the effects of UIR on scientific productivity and the way in which these are related to traditional research activities, focusing on the complementary or substitutive nature of these activities on the scientific production of university researchers. The analysis controls for the effect of set variables associated with the individual attributes of researcher, and the scientific discipline and profile of the researcher's university. Among the previous control variables, we can highlight the results related to the effects of scientific discipline and profile of the university, which indicate that the dynamics within each discipline have a greater influence on the patterns of scientific publication than the dynamics of institutions. These results suggest that epistemological communities could exercise a greater influence on the behaviour of researchers than the cultural and organizational characteristics of a university.

The most relevant results from this study are that UIR can have a positive effect on scientific production, depending on the type and the intensity of the linkage activity. For example, if the linkage is based on activities with high scientific or technological content (*R&D* contracts), but only up to a certain level of intensity. These results have two important implications. On the one hand, they show that the development of routine activities for industry can result in loss of scientific production, and on the other hand, they warn of the risks of too much emphasis in UIR activities even when they are based on *R&D*. This highlights that, at least in this context, the condition of "more is better" does not apply to UIR activities.

Analysis of the complementarity between academic research activities and UIR, demonstrate this point. Our results indicate that *R&D* contracts with industry and academic research activities have synergistic effects on scientific production, but only when *R&D* contracts account for a small percentage of a researcher's total funding, otherwise, there are decreasing marginal returns to scientific output. These results go beyond the results from previous studies in the sense that they emphasize that the positive effects of UIR on researchers' scientific production are based mainly on the access to the resources (cognitive, technical, and/or financial) that complement research activities. This finding shows that the development of linkage activities with the environment only marginally affects the researcher's scientific productivity. The benefits of such activities on scientific output are conditional on their effective integration with academic research activities. If researchers are not involved in research and dedicate most of their time to the development of UIR activities, their scientific production will be negatively affected, although this applies only to high scientific and technological level activities.

The above results have important implications for the design of university policies. Although they show that UIR does not penalize per se a researcher's scientific productivity, they underline that the indiscriminate promotion of these types of activities could result in lower scientific performance. Therefore, some policies promoting UIR as a substitute of the public funds for research, raise concerns regarding the negative impact those policies could have on scientific contribution.

The challenge for the governmental institutions and the universities in general is to design better targeted policies aimed at achieving an appropriate balance between second and

third mission activities, and to take advantage of the complementarities that exist between them. However, it should be emphasised that the previous balance will be determined by the role the university wants to play in the social, academic or business spheres.

Future research in this area should analyse whether these findings on complementarity between UIR and academic research activities are moderated by other variables, such as industry characteristics, researchers' collective characteristics, and geographic context.

References

- Arocena, R., & Sutz, J. (2005). Latin American Universities: From an original revolution to an uncertain transition. *Higher Education*, 50, 573-592.
- Ato, M., & López, J.J. (1996). *Análisis estadístico para datos categóricos*. Madrid: Síntesis.
- Azagra, J., Archontakis, F., Gutierrez, A., & Fernández. I. (2006). Faculty support for the objectives of university–industry relations versus degree of *R&D* cooperation: The importance of regional absorptive capacity. *Research Policy*, 35, 37-55.
- Azoulay, P., Ding, W., & Stuart, T. (2006). The Impact of Academic Patenting on the Rate Quality and Direction of (Public) Research. *NBER Working Paper* 11917.
- Blumenthal, D., Campbell. E., Anderson, M., Causino, N., & Seashore-Louis, K. (1996). Participation of life-science faculty in research relationships with industry. *New England Journal of Medicine*, 335, 1734-1739.
- Bonaccorsi, A., & Daraio, C. (2003). Age effects in scientific productivity. The case of the Italian National Research Council (CNR). *Scientometrics*, 58, 35–48.

- Breschi, S., Lissoni, F., & Montobbio, F. (2005). The scientific productivity of academic inventors: New evidence from Italian data. *CESPRI Working Paper* 168.
- Breschi, S., Lissoni, S., & Montobbio, F. (2007). The scientific productivity of academic inventors: New evidence from Italian data. *Economics of Innovation and new Technology*, 16(2), 101-118.
- Calderini, M., & Franzoni, C. (2004). Is academic patenting detrimental to high quality research? An empirical analysis of the relationship between scientific careers and patent application. *CESPRI Working Paper* 162.
- Cameron, A.C., & Trivedi, P.K. (1998). *Regression analysis of count data*. Cambridge University Press.
- Carayol, N., & Matt, M. (2006). Individual and collective determinants of academic scientists productivity. *Information Economics and Policy*, 18, 55- 72.
- Clark, S.M., & Lewis, D.R. (eds.) (1985). *Faculty Vitality and Institutional Productivity: Critical Perspectives for Higher Education*. New York: Teachers College Press.
- Cohen, W.M., Nelson, R.R., & Walsh, J.P. (2002). Links and Impacts: The Influence of Public Research on Industrial R&D. *Management Science*, 48(1), 1-23.
- Crane, D. (1965). Scientists at Major and Minor Universities: A Study of Productivity and Recognition. *American Sociological Review*, 30(5), 699-714.
- Creswell, J. W. (1986). *Measuring Faculty Research Performance. New Directions for Institutional Research* 50. San Francisco: Jossey-Bass.
- D'Este, P., & Patel, P. (2005). University – Industry Linkages in the UK: What are the Factors Determining the Variety of University Researches' Interactions With

Industry? Paper presented at the *DRUID Summer Conference* 2007. Copenhagen June 27-29. 2005.

Dasgupta, P., & David, P.A. (1994). Towards a new economics of science. *Research Policy*, 23(5), 487-521.

Dundar, H., & Lewis, D. (1998). Determinants of research productivity in higher education. *Research in Higher Education*, 39(6), 607-631.

Florida, R., & Cohen, W.M. (1999). Engine or infrastructure? The university role in economic development. In: Branscomb, L.M., Kodama, F., Florida, R. (Eds.), *Industrializing Knowledge. University-Industry Linkages in Japan and the United States*. MIT Press, Cambridge MA/London, pp. 589-610.

Geuna, A. (1999). *The Economics of Knowledge Production. Funding and the Structure of University Research*. Edward Elgar. Cheltenham. UK.

Godin, B., & Gingras, Y. (2000). Impact of collaborative research on academic science. *Science and Public Policy*, 27(1), 65-73.

Gulbrandsen, M., & Smeby, J. (2005). Industry funding and university professors' research performance. *Research Policy*, 34, 932-950.

Hicks, D., & Hamilton, K. (1999). Does University-Industry Collaboration Adversely Affect University Research? *Issues in Science & Technology* Online 74-75 (Summer 1999).

Hoetker, G. (2007). The use of logit and probit models in strategic management research: Critical issues. *Strategic Management Journal*, 28, 331-453.

Johnes, G. (1988). Determinants of research output in economic departments in British universities. *Research Policy*, 17(3), 171-178.

- Jordan, J. M., Meador, M., & Walters, S. J. K. (1989). Academic research productivity, department size and organization: further results. *Economics of Education Review*, 8(4), 345-352.
- Kline, K., & Rosenberg, N. (1986). An overview of innovation. In Landau R., and Rosenberg, N. (Eds.). *The Positive Sum Strategy: Harnessing Technology for Economic Growth*. Washington. D.C.: National Academy Press.
- Knorr, K., Mittermeier, R., Aichholzer, G., & Waller, G. (1979). Individual publication productivity as a social position effect in academic and industrial research units. In: Andrews. F. (Ed.). *The Effectiveness of Research Groups in Six Countries*. Cambridge University Press pp. 55–94.
- Kyvik, S. (1995). Are big university departments better than small ones? *Higher Education*, 30(3), 295-304.
- Landry, R., Traore, N., & Godin, B. (1996). An econometric analysis of the effect of collaboration on academic research productivity. *Higher Education*, 32, 283-301.
- Lee, J., & Rhoads, R. (2004). Faculty entrepreneurialism and the challenge to undergraduate education at research universities. *Research in Higher Education*, 45(7), 739-760.
- Lee, Y.S. (1996). Technology transfer and the research university: a search for the boundaries of university-industry collaboration. *Research Policy*, 25, 843-86.
- Lehman, H.C. (1958). The chemist most creative years. *Science*, 127, 1213–1222.
- Lehman, H.C. (1960). The decrement in scientific productivity. *American Psychologist*, 15, 128–134.
- Levin, S., G. & Stephan, P. E. (1989). Age and research productivity of academic scientists. *Research in Higher Education*, 30(5), 531-549.

- Levin, S.G., & Stephan, P.E., (1991). Research productivity over the life cycle: evidence for academic scientists. *American Economic Review*, 81, 114–132.
- Long, J.S. (1978). Productivity and academic positions in the scientific career. *American Sociological Review*, 43 (December), 889-908.
- Lotka, A. J. (1926). The frequency distribution of scientific productivity. *Journal of the Washington Academy of Sciences*, 16, 317-323.
- Manjarrés-Henríquez, L., Gutiérrez-Gracia, A., & Vega-Jurado, J. (2008). Coexistence of university –industry relations and academic research: barrier to or incentive for scientific productivity. *Scientometrics*, 76(3), 561-563.
- Martin, B., & Etzkowitz, H. (2000). The origin and evolution of the university species. *VEST*, 13, 3-4.
- Martin, B.R. (1996). The use of multiple indicators in the assessment of basic research. *Scientometrics*, 36(3), 343-362.
- Merton, R.K. (1968). The Matthew Effect in Science. *Science*, 159(3810), 56-63.
- Meyer, M. (2006). Academic Inventiveness and Entrepreneurship: On the Importance of Start-up Companies in Commercializing Academic Patents. *The Journal of Technology Transfer*, 31(4), 501-510.
- Milgrom, P., & Roberts, J. (1990). The economics of modern manufacturing: Technology strategy and organization. *American Economy Review*, 80, 511-528.
- Nelson, R.R. (2001). Observations on the post-Bayh-Dole rise of patenting at American universities. *Journal of Technology Transfer*, 26(1-2), 13-19.
- Norton, E.C., Wang, H., & Ai, C. (2004). Computing interaction effects and standard errors in logit and Probit models. *The Stata Journal*, 4, 134-167.

- Norusis, M. J. (1998). *SPSS 8.0: Guide to Data Analysis*. Prentice Hall. Upper Saddle River. NJ.
- OECD, (2000). *University Research in Transition*, Paris, OECD.
- Powers, J. (2004). R&D funding sources and university technology transfer: what is stimulating universities to be more entrepreneurial? *Research in Higher Education*, 45(1), 1-23.
- Roessner, J.D. (1993). What companies want from the federal labs. *Issues in Science and Technology*, 10 (1), 37-42.
- Schartinger, D., Schibany, A., & Gassler, H. (2001). Interactive relations between university and firms: empirical evidence for Austria. *Journal of Technology Transfer*, 26, 255-268.
- Siegel, D.S., Waldman, D.A., Atwater, L.E., & Link, A.N. (2003). Commercial knowledge transfers from universities to firms: improving the effectiveness of university-industry collaboration. *Journal of High Technology Management Research*, 14(1), 111-133.
- Smeby, J., & Try, S. (2005). Departmental contexts and faculty research activity in Norway. *Research in Higher Education*, 46 (6), 593-619.
- Stephan, P.E., Gurmu, S., Sumell, A.J., & Black, G. (2007). Who's Patenting in the University? Evidence from the Survey of Doctorate Recipients. *Economics of innovation and New Technology*, 16(2), 71-99.
- Van Looy, B., Callaert, J., & Debackere, K. (2006). Publication and patent behavior of academic researchers: Conflicting, reinforcing or merely co-existing? *Research Policy*, 35, 596-608.

- Van Looy, B., Ranga, M.J., Callaert, J.K., Debackere, K., & E. Zimmermann, E. (2004). Combining entrepreneurial and scientific performance in academia: towards a compounded and reciprocal Matthew-effect? *Research Policy*, 33, 425-441.
- Wanner, R., Lewis, L., & Gregorio, D. (1981). Research Productivity in Academia: A Comparative Study of the Sciences, Social Sciences and Humanities. *Sociology of Education*, 54 (4), 238-253
- Weiss, Y., & Lillard, L.A. (1982). Output variability, academic labor contracts, and waiting times for promotion. *Research in Labor Economics*, 5, 157–188.
- Xie, Y., & Shauman, K. A. (1998). Sex differences in research productivity: new evidence about an old puzzle. *American Sociological Review*, 63(6), 847-870.
- Zuckerman, H.A., & Merton, R.K. (1972). Age. aging. and age structure in science. In: Riley. M.R.. Johnson. M.. Foner. A. (Eds.). *A Sociology of Age Stratification: Aging & Society*. vol. 3. Russel Sage foundation. New York. Reprinted in: Storer. N.W. (Ed.). 1973. *The Sociology of Science: Collected Papers of R.K. Merton*. Chicago University. Chicago Press. pp. 497–559.

Table 1. Description of the variables

Variable	Description	Scale	Mean	S.D
<i>Depend variable</i>				
SP	Scientific Production	Nº of articles published by each researcher in journals ISI 2003-2004 period	1.46	2.82
<i>University-Industry Relationships</i>				
Other_U IR	Low scientific technological level: technological support and consultancy, training and provision of services	Dummy Variable 0-1		
		1, If the researcher has obtained funding from at least one of the three UIR activities during 1999-2004 period	0.53	0.50
		0, otherwise		
R&D	High scientific technological level: R&D Contracts	Ordinal Variable 0-3	0.75	1.16
		0, if the researcher has not obtained funding from R&D contracts during 1999-2004		
		1, if amount of R&D contracts does not exceed the first quartile of the researcher's total budget		
		2, if the amount is between the first one and the second quartile and 3, if the amount due to R&D contracts is between the second quartile and 100 % of researcher's total budget		
<i>Academic Research</i>				
AR	Academic Research: public grants from regional, nationals and European bodies	Dummy Variable 0-1		
		1, if the researcher has received at least one public grant at regional, national or European level during 1999- 2004 period.	0.58	0.49
		0, otherwise		
<i>Researcher characteristics</i>				
EXP	Work experience	Number of "quinquenios" obtained by the professor during their life work: 1"quinquenio" is equal to 5 years of experience	3.08	1.95
EXP ²	Square Work experience	Squared of the value of "quinquenios" obtained by the professor during their life work	13.28	12.28
POS	Position inside of the university	Scale ordinal of 0-4, where 4 is the highest scale and corresponds to university professor	2.40	1.44
<i>Scientific discipline</i>				
DISC	Researcher's Research field	Categorical variable		
		DISC_1, Social Sciences and Humanities		
		DISC_2, Agrarian Sciences		
		DISC_3, Natural and Exact Sciences		
		DISC_4, Medical Sciences, and		
		DISC_5, Engineering and Technology		
<i>Characteristics of the university</i>				
UNIV	University to which the researcher belongs	Dummy Variable 0-1		
		1, if the researcher belongs to UV	0.52	0.49
		0, if the researcher belongs to UPV		

Table 2. Multicollinearity tests

Variable	Tolerance	VIF
<i>Other_UIR</i>	0.689	1.45
<i>R&D</i>	0.908	1.10
<i>AR</i>	0.607	1.64
<i>EXP</i>	0.514	1.94
<i>POS</i>	0.483	2.07
<i>UNIV</i>	0.754	1.32

Table 3. Negative Binomial Regression for the models 1 and 2

Independent variables	<i>Scientific Production</i>		<i>Scientific Production</i>	
	Model 1		Model 2	
	<i>B</i>	<i>S.E.</i>	<i>B</i>	<i>S.E.</i>
<i>Researcher's characteristics</i>				
<i>POS</i>	0.35***	0.02	0.33***	0.27
<i>EXP</i>	0.07	0.05	0.09	0.05
<i>EXP</i> ²	-0.02**	0.01	-0.17**	0.06
<i>Characteristics of the university</i>				
<i>UNIV</i>	0.08	0.05	0.06	0.05
<i>Discipline</i>				
<i>Dis_2</i>	2.05***	0.13	2.05***	0.13
<i>Dis_3</i>	2.32***	0.08	2.33***	0.08
<i>Dis_4</i>	2.61***	0.95	2.64***	0.95
<i>Dis_5</i>	1.88***	0.99	1.91***	0.99
<i>Dis_1</i>	0			
<i>Academic research</i>				
<i>AR</i>	0.98***	0.63	1.34***	0.09
<i>University - Industry Relationships</i>				
<i>OTHER_UIR</i>	-0.13***	0.04	-0.01	0.04
<i>R&D</i>			0.18***	0.03
49%-100%	0.018	0.06		
19% - 49%	0.14**	0.06		
0%-19%	0.37***	0.05		
0%	0			
<i>Complementarity analysis</i>				
<i>R&D*AR</i>			-0.20***	0.04
Chi-square values	2940.839***		2913.515***	
* ** <i>P</i> < 0.01				
** <i>P</i> < 0.05				
* <i>P</i> < 0.1				

We use the first discipline (Social and Humanities Sciences) as the reference group.

FIGURES

Figure 1. Growth of UIR activities and academic research 1999-2004 period.

Figure 2. Effect of the interaction between *R&D* and *AR* on scientific production.