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Use me when you need me: firms’ co-creation output with universities, scientific impact and the economic cycle

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Abstract

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Background: In this paper, we explore two phenomena involved in the influence of the economic cycle on firms’ scientific knowledge co-creation output. First, according to our University-Industry (U-I) cycle theory, economic growth will either encourage or discourage firms to co-create with universities. The second covers the scientific impact of U-I co-creation output in the economic cycle.
Based on the assumption that collaboration with universities may result in successful knowledge co-creation output, we explore the impact of the economic cycle on U-I scientific knowledge co-creation output and its scientific impact. Our study raises the following hypotheses: (1) Economic growth increases the probability of firms’ scientific knowledge co-creation output (during crises) until an inflection point after which that relationship becomes negative (during expansions). (2) Economic growth increases the scientific impact of firms’ output (during crises) until an inflection point after which that relationship becomes negative (during expansions). (3) Collaboration with universities moderates (positively) the scientific impact of firms’ output throughout the cycle. (4) The probability of U -I co-creation output flattens the curvilinear effect of economic growth on the scientific impact of that output.

Methods: To verify these hypotheses, we use data on Spanish firms’ co-publications and citation with different types of institutions (i.e., universities, research institutes, hospitals, companies) from 2000 to 2016, which includes a pre-crisis phase and a post-crisis phase. The final sample consisted of 15,000 publications, which results in almost 15,000 publications. As a statistical model, we applied a binary logistic regression method to estimate the probability of a firm publication in collaboration with universities, and used a negative binomial model to estimate the effects of scientific impact of firms’ co-creation with universities at different phases of the economic cycle.

Results: Our preliminary findings show that: (1) when the economy grows fast, firms co-publish less with universities and when the economy grows slowly or contracts, firms co-publish more with universities; 2) economic growth increases scientific impact of firms’ co-creation output specially during crises; (3) co-creation with universities improves scientific impact of firms’ co-creation output but it

does not depend on the cycle. Finally, we did not find support that U-I co-creation output flattens the effect of economic growth on the scientific impact in extreme cycles situation neither in the bottom of the crisis nor at the peak of the expansion.

These findings lead us to redirect policy recommendations to promote U-I scientific knowledge co-creation output that could be adapted based on the phase of the economic cycle. In expansions, governments should maintain their support for co-creation and for good quality of firm science; and in crises, the aids should not expect co-creation with universities to have an even larger positive effect than they already have.

Use me when you need me: firms' co-creation output with universities and the economic cycle

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Abstract

According to our university-industry (U-I) cycle theory this paper explores two aspects involved in the influence of the economic cycle on firms' scientific knowledge co-creation output. First, whether economic growth encourages or discourages firms to co-create with universities. Second, whether economic growth improves or worsens the scientific impact of U-I co-creation output. Our study raises the following hypotheses: (1) Economic growth increases the probability of firms' scientific knowledge co-creation output (during crises) until an inflection point after which that relationship becomes negative (during expansions). (2) Economic growth increases the scientific impact of firms' knowledge creation output (during crises) until an inflection point after which that relationship becomes negative (during expansions). (3) Collaboration with universities positively moderates the scientific impact of firms' output. (4) U-I co-creation output flattens the curvilinear effect of economic growth on the scientific impact of firms' output. To verify these, we use data on Spanish firms' publications from 2000 to 2016 and their citations, which includes an expansion and a crisis phase. The final sample consists of 15,000 publications. We apply a logistic regression to estimate the probability of a firm publication in collaboration with universities, and a negative binomial regression to estimate the effects of that probability on the scientific impact of firms' creation output at different phases of the economic cycle.

Our preliminary findings show that: (1) When the economy grows fast, firms co-publish less with universities and when the economy grows slowly or contracts, firms co-publish more with universities. 2) Economic growth also increases the scientific impact of firms' creation output during crises and reduces it during expansions. (3) Co-creation with universities improves the scientific impact of firms' creation output. (4) U-I co-creation output does not flatten the effect of economic growth on firms' scientific impact.

These findings lead us to propose policy recommendations to promote U-I scientific knowledge co-creation output adapted to the phase of the economic cycle. In expansions, governments should maintain their support for U-I co-creation. In crises, governments should not expect co-creation with universities to have an even larger positive effect on firms' scientific quality than they already have, irrespective of the phase of the cycle.

Keywords: University-Industry collaboration, Corporate publications, Scientific impact, Scientific knowledge co-creation, Economic cycle.

1. Introduction

Knowledge creation is one of the pillars of well-functioning scientific, innovation and economic systems. Some authors refer to this phenomenon as scientific production (Crespi & Geuna, 2008), R&D output (Cho, Hu & Liu, 2010), research productivity (Gonzalez-Brambila & Veloso, 2007), scientific publication (McKelvey & Rake, 2019) or knowledge production (Gibbons et al., 1994). In this paper, we define "scientific knowledge creation output" as the research output presented in the form of published research papers in international scientific and technical journals.

Several authors have deepened in their studies to determine which factors enhance knowledge creation output: national R&D expenditure (Cho et al., 2010), particularly higher education expenditure on R&D (Crespi & Geuna, 2008), scientific field (Gonzalez-Brambila & Veloso, 2007), firm size (Chakrabarti, 1990), university R&D expenditure and university ranking (Adams & Griliches, 1996), individual age, gender, rank of researchers (Gonzalez-Brambila & Veloso, 2007) and their participation in R&D projects and contracts (Manjarrés-Henríquez et al., 2008), etc.

In contrast to this wide range of studies related to knowledge creation, studies about knowledge co-creation output that are not so abundant. Knowledge co-creation is an interaction between science and society (Regeer et al., 2009), in which actors from academia and different parts of society work together to solve a complex problem and produce new knowledge (Klein et al., 2001; Veen et al., 2013). In particular, university and industry (U-I) knowledge co-creation output is relevant for two reasons: 1) scientific results in the form of co-publications contribute to open science (Azagra-Caro et al., 2019); and 2) knowledge co-creation output promotes industrial innovation and commercialization of academic research (Wong & Singh, 2013).
Firms are increasingly publishing with universities their research outputs. Some findings suggest that U-I knowledge co-creation output is higher in scientific fields like maths, life sciences and natural sciences (Yegros-Yegros et al., 2016), to researchers' age, and national business expenditure on R&D (Azagra-Caro et al., 2019).

U-I knowledge co-creation output is also relevant because the link with the university improves the impact of business science (Lebeau et al., 2008; Rake & McKelvey, 2015). Bornmann et al., (2012) describes the scientific impact as an actual influence of research activities at a given time. Other authors refer to this phenomenon as "scientific utility" (Leimu & Koricheva, 2005), "impact of a research paper" (Narin, 1976) or "quality of a scientific publication" (Narin et al., 1991; Katz & Hicks, 1997; Glanzel & Schubert, 2001). Some predictors of scientific impact that appear in literature of co-creation of knowledge are individual, team, organizational and institutional factors, science field and regional context (Halperin & Chakrabarti, 1987, 1990;

Carayol & Matt, 2006; McKelvey & Rake, 2016; 2019; Yegros-Yegros et al., 2016; Arora et al., 2017).

For both U-I knowledge co-creation output and firms' scientific impact, the role of time has been under-researched; particularly, the effect of the economic cycles. There are some exceptions as the work by Crespi & Geuna (2008), who detect an increasing trend of publications in time. However, its connection with economic growth and cycles is still underexplored. Archibugi et al. (2013) studied the effect of economic crises, but only on R&D expenditures, and Madrid-Guijarro et al. (2013) analysed the innovation output of some firms during an economic downturn and a period of economic growth. Azagra-Caro et al. (2019) studied how the Great Recession affected U-I knowledge co-creation output at a macro level. However, they did not analyse the effects of economic growth nor its interactions with micro-level forces.

We seek to address this gap by developing some hypotheses and their empirical tests on how economic cycles determine U-I knowledge co-creation output and firms' scientific impact. The paper is organized as follows. Section 2 presents a review of the literature and the hypotheses of the study. Section 3 describes the context of the study. Section 4 shows the data on co-publications of companies and Section 5 presents the estimations of the effects of economic growth on U-I knowledge co-creation and firms' scientific impact. Section 6 concludes with policy recommendations and suggestions for future research.

2. Theoretical framework and hypotheses

One of the aspects of the micro-level analysis of knowledge co-creation output that has received less attention is its dynamics over the economic cycle. A business cycle is a series of fluctuations in the GDP around its long-term natural growth rate, with a phase of expansion and a phase of crisis. In expansions, economic growth accelerates, whereas in crises it desaccelerates or even contracts. This concept will be a common point to develop the next two sections of the theoretical framework a) U-I knowledge co-creation output in economic growth and b) Scientific impact of firms' output.

a) U-I knowledge co-creation output in economic growth

The Innovation Studies literature has suggested different views on the impact of an economic cycle on innovation activities. From the perspective of the firms, there are reasons to justify a linear effect of the cycle on U-I knowledge co-creation output. But from a broader perspective that incorporates government participation, it is possibly to expect a curvilinear effect. Next, we will develop the theoretical framework considering both situations to establish our first hypothesis.

Increasing U-I knowledge co-creation output in economic growth

Collaboration between university and industry seems to be an attractive factor for companies that create scientific knowledge. The company obtains benefits from creating codified knowledge, such as enhanced competitive advantage (Hicks, 1995), attracting qualified scientists (Hicks, 1995; Perkmann, Neely & Walsh, 2011), improving technological innovation (Soh & Subramanian, 2014). Besides, the open innovation model in firms integrates external actors and resources into firm own innovation processes. Many authors argue that collaboration with universities is also beneficial for the company to be connected to the open science community (Agrawal, 2001; Belderbos et al., 2016; McKelvey & Rake, 2016; Wong & Singh, 2013) and to develop absorptive capacity (Cockburn & Henderson, 2003).

Co-creation activities with universities boost business R&D. During economic growth, firms reach financial stability and, therefore, the cash flow of the company can finance the investment in R&D (Hall 1992; Himmelberg & Petersen, 1994; Rafferty & Funk, 2008). The more R&D intensive firms are, the higher their possibilities to link with universities (Vedovello, 1998) to generate knowledge co-creation output. Another force that influences knowledge co-creation is the human factor. Firms will benefit from enhanced access to qualified human capital and useful external scientific information (Comacchio et al. 2012), as from higher problem-solving capacity (Rosenberg & Nelson, 1994). Also, this collaboration may result in successful knowledge co-creation output (Azagra-Caro et al., 2019). Companies may consider these benefits in the decision to collaborate with universities, and economic growth may favour the choice. Economic growth facilitates that the company seeks to attract and retain qualified scientists, which is why it offers its researchers good salaries, infrastructure and opportunities to publish research results (Hicks, 1995). Corporate researchers will have more time and economic resources to deal with academic researchers. Based on this, we postulate: Economic growth increases the probability of firms′ scientific knowledge co-creation output with the university.

Decreasing U-I knowledge co-creation output in economic growth

The reality is that the rewards for absorbing external knowledge are uncertain. Following this model for companies involves investing time, money and other resources. According to Hess & Rothaermel (2011), when companies participate in formal university collaborations, they may experience a loss in research productivity because of knowledge redundancies and high costs in the management and monitoring of research results. These transaction costs are one of the main barriers for companies to collaborate. Bruneel et al. (2010) and Katz & Martin (1997) distinguished two types of barriers to U-I collaboration: orientation-related barriers and transaction-related barriers. Orientation-related barriers refer to the difference in the institutional culture of the firm and university (Laursen & Salter, 2006), which have distinctive incentive systems and norms and play different roles in society. Transaction-related barriers refer to the

difficulty of companies to control investment in R&D and how expensive can be developing the ability to absorb and manage external knowledge (Laursen & Salter, 2006).
Faced with this risk, companies may prefer to rely on their resources and capabilities to develop new products and knowledge internally (Laursen & Salter, 2006). It is logical to think that economic growth endows companies with the ability to self-finance their own R&D projects (Schumpeter, 1939; Hall, 2002; Hud & Rammer, 2015). Therefore, they may not be interested in collaborating with organizations with different institutional norms. Hence, we may expect the following relationship: Economic growth decreases the probability of firms' scientific knowledge co-creation output with the university.

The contrast of these two postulates makes us refine the description of the effect of economic growth on co-creation output for each phase of the cycle.

U-I knowledge co-creation output: increasing during crises and decreasing during expansions

Due to crisis, firms facing financial constraints are likely to reduce their investment in R&D (Schumpeter, 1939, Freeman et al., 1982). There are no certainties of the returns of the R&D investment (Chrisman & Patel, 2012), the risk aversion of companies is considerable, and firms are less willing to invest (Laughhunn et al., 1980). In this scenario, the government plays a significant role. The crisis causes dual effects on policymaking: on the one hand, the shock affects innovation systems, reducing R&D public budgets; on the other hand, governments increase their efforts to maintain innovation capacity and employment levels (Hud & Hussinger, 2015). More specifically, government policies try to counterbalance the negative effects of the recession by promoting U-I research cooperation. D'Agostino & Moreno Serrano (2016) showed in their study that the positive effects of R&D cooperation on innovation activities were stronger in times of economic turbulence than in expansion. This makes recessions a friendly environment for companies to innovate (Filippetti & Archibugi, 2011). Some examples of government policies that have faced the effects of the economic crisis are Canada, Japan and Argentina. In Canada, although federal and provincial governments reduced education funding programs (Naimark, 1989) because of the crisis during 1970, the support to Canadian universities did not stop. Provincial governments continued developing programs to promote the U-I relationship in science and technology (Doutriaux & Baker 1995; Liévana, 2010). Japan, in the 1990s, experienced a "lost decade" due to economic stagnation. The government supported university-industry collaboration by promoting technology transfer in 1998 (Whittaker, 2001). In Argentina, during the 1990s, the government promoted a series of plans for research collaboration (Thorn, 2005).
Policymakers as a way to minimize 'government failures' in the allocation of subsidies and to increase the effectiveness of public–private R&D collaboration follow a 'picking-the-winner strategy' (Shane, 2009; Cantner & Kösters, 2009). In so doing, program agencies select consortia with previous experience and proven ability to generate results. The more collaboration output has more likely to apply for R&D subsidies. They will rate the outputs

generated in the collaboration process by considering, among others, the number of co-publications and citation impact. Given this term, firms will increase the value of attracting scientists from academia as a strategy for repowering their scientific knowledge output. Therefore, firms and universities may find that co-publishing revalorizes (Azagra-Caro et al., 2019).

We contend that the behaviour of U-I knowledge co-creation output is not linear in time, but will change according to the phase of the economic cycle.
Azagra-Caro et al. (2019) confirm in their study the hypothesis that, initially, the higher the amount of industry R&D spending, the higher U-I knowledge co-creation output, but after a certain threshold, the relationship becomes negative. The relationship between industry R&D inputs and U-I knowledge co-creation follows the shape of an inverted U. Such a shape is typical of concomitant phenomena: Laursen & Salter (2006) establish that the benefits of openness are subject to diminishing returns, which indicates that there is a point at which additional search becomes unproductive. It explains that innovation performance can decay after an excessive amount of corporate research (Koput,1997). Thus, there are arguments to argue that U-I knowledge co-creation output may be declining at some point in the economic cycle. Consequently, we can be more precise and postulate:

Hypothesis 1. Economic growth increases the probability of firms' scientific knowledge co-creation output (during crises) until an inflection point after which that relationship becomes negative (during expansions).

In the case of the relationship of the scientific impact and the cycle, it will be analysed focusing, first on the behaviour of companies and second on the influence of the university in this relationship.

b) Scientific impact of firms' output.

Scientific impact of firms' output: increasing during crises and decreasing during expansions

The impact of a publication is increasingly changing with time (Ziman, 1968). According to Lebeau et al. (2008), the impact of publications increases in phases of economic growth. In periods of high boom, radical innovations are crowded out, and people are too busy developing existing technologies (Mensch, 1975). Hence, the company pay less attention to the impact of new scientific knowledge output. In contrast, during crises, firms increase R&D budgets despite the difficulties (Haluk et al., 2007) to try something completely new. Possibly this is the effect that Schumpeter refers as Creative destruction (Schumpeter, 1942). This concept is explained by a change in the opportunity cost of reallocating productive assets from manufacturing to R&D, which are relatively low because of a limited demand (Stiglitz, 1993, Aghion & Saint-Paul, 1998). Schumpeterian notion of creative destruction postulate that crisis opens new opportunities, so innovation activities, including scientific knowledge performance, will improve the firms' scientific impact. We therefore anticipate that:

Hypothesis 2: Economic growth increases the scientific impact of firms' output (during crises) until an inflection point after which that relationship becomes negative (during expansions).

Scientific impact of firms' scientific knowledge co-creation output in collaboration with universities

Scientific co-production with universities has a positive effect on business science (Lebeau et al., 2008). One example of this is the Canadian case where scientific impact of university–industry collaboration is increasing from 1988-2005, and it is higher than that of sole university papers and industry papers (Lebeau et al., 2008). Collaborations between academia are more successful because this type of institution is credited with certain advantages that make one role have more impact than any other. Some of these attributes are: first, university science tends to be more basic, so that broaden the firm's perspective. In terms of citation impact, university scientists are more often concentrating on basic knowledge (Frenken et al. 2005). Second, the academic experience of peer review and publication process. Third, the capacity of Knowledge diffusion (Frenken et al. 2005), not only because the academic researchers have a big network but also because many authors facilitate the dissemination in the research community through the personal communications (Aksnes, 2003; Goldfinch et al. 2003). A paper published in co-authorship with researchers from university guarantees the visibility of an article when they share information in conference and workshop presentations, discuss it informally with colleagues, and distribute preprints to colleagues (Katz & Martin, 1997).
Additionally, there are some determinants involved in the scientific impact of U-I collaboration such as co-authorship, interdisciplinary, multi-institutional (Narin et al. 1991, Katz & Hicks 1997, Goldfinch et al. 2003, Leimu & Koricheva, 2005). Therefore, we propose:

Hypothesis 3: Collaboration with universities moderate (positive) the scientific impact of firms' output during expansions and during crises.

In extreme situations of impact of business science the link with university, smooth the effects of the cycle

The impact of business science is lower at the extreme points of the economic cycle. Previous studies have emphasised, on the one hand, in situations of very low or negative growth rate (at the bottom of the crisis) companies may not dedicate efforts in publishing high quality papers. According to Ouyang (2011), liquidity constrains effect outweighs the opportunity cost effect of R&D investment. On the other hand, a very high growth rate (at the peak of the expansion) companies may be more likely to dedicate efforts to product innovation. Therefore, in both cases, extreme points would decline the impact of firms' scientific knowledge output. In contrast to the company's behavior, the university will encourage the quality of scientific knowledge codification regardless of the extreme situation of the company. The interest of the university in improving the quality of science is intrinsically linked to its nature; therefore, the phase of the cycle is not an element for the university to reduce the scientific impact. For this reason, we postulate the lower the impact of business science is, the more meaningful the contribution from universities will be. Universities will perform a higher role in enhancing the impact of business science if this is low, and low and lower if the company is already producing good science. This suggests:

Hypothesis 4: The probability of U-I co-creation output flattens the curvilinear effect of economic growth on the scientific impact of that output.

3. Context

We will test our hypotheses in the context of one economic cycle in a concrete country, Spain. An economic cycle contains a single economic boom and in sequence, another period of economic contraction. Therefore, we will explain the Spanish economic context in 2000-2007 (expansion) and 2008 to 2016 (contraction). At the beginning of 2000 until 2005, economic growth was strong with an above-average growth rate. During this expansive phase, the Spanish government has constantly increased spending on civil R&D. However, the emphasis on promoting university-industry collaboration began with the launch of the National R&D Plan for the period 2004-2007.

The productivity growth rates started to fall in 2006, and for 2007 the Spanish economy had contracted, which ended the phase of expansion. In the second half of 2008, the crisis deepened until it reached to 2009 when the economy was formally in recession. This period of contraction is known as the Great Recession. In this period, there were numerous immediate effects on Spanish R&D. On the public side, the government stagnated R&D spending for two years and in 2010 introduced big cuts in R&D budgets (Cruz-Castro & Sanz-Menéndez, 2016); affecting research institutions that depend on public financing such as universities, national and regional research centres. On the private side, due to economic output slowed the demand for investment and consumption dried up, Spanish private sector experimented a 55% of reduction in the number of firms that make non-technological innovation and 43% of that preform technological innovation during 2008-2016 (COTEC Foundation, 2018). There were a few exceptions like fast growing firms and some high innovative firms that sustained a high innovation performance during the crisis (Archibugi et al., 2013).
Despite the crisis, the government has opted to maintain the instruments to support business R&D through cooperation. Several programs have been promoting national public-private collaboration in Spain. They performed CENIT program launched from 2006 to 2010, INNPACTO launched in 2008-2011 and the Challenges-Collaboration program that started in 2013 that remains until today.

4. Data and methods

Bibliometric analysis could be a way to assess the knowledge co-creation output and scientific impact of that output. Even though there is a highly debated among researchers that the number of publications and citations are not a reliable indicator of the level of performance of research output, it is the most common and accepted.

We measure U-I knowledge co-creation through the number of U-I co-publications, which we refer to as UICopub. Other empirical studies have validated this approach: authors such as Calvert & Patel (2003), Tijssen et al. (2009, 2012) or Abramo et al. (2009) based their studies on co-publications arguing that they are related to the occurrence of cooperation in research. In order to assess the scientific impact of a publication, we consider the number of citations as an appropriate proxy to measure the impact of scientific publications.

Our authors' affiliation data has been collected from the Web of Science records of papers that have been published between 2000 and 2016 and contributed by any Spanish organization. The resulting 188.458 Spanish addresses have been (manually) classified as academic organizations, research centres, hospital and clinical organization, public administrations bodies and private firms. Our sample consists of firms' publications and co-publications with other organizations, which translates in almost 15,500 publications. If the non-firm organization is a university, it is a U-I co-publication. We define P(UICopub) as the probability of a firm co-publication to be a U-I co-publication, versus the probability of being a firm publication or a co-publication with other organization (firm, hospital, research center, mixt institute, public organization, non-profit organization). It is worth mentioning before the unit of analysis is the publication. Publications are duplicated if different types of co-authoring organizations exist.

We measure economic growth through the Spanish GDP annual growth rate (source: Spanish National Statistics Institute). To match publication and GDP data, we have assumed a time-lag of two years, after testing with three, four and five years of lag, since the effect of economic growth on publications is not immediate.

Table 1 provides the means and standard deviations of the sample. A little less than half of the sample are firms' co-publications with universities. Fig 1 and 2 are constructed to provide some descriptive insight into the of the trend of the P(UICOPUB) and firms' scientific impact on the economic cycle.

Table 1. Descriptive statistics of variables used in the regression models

Variable	Mean	Std. Dev.	Minimum	Maximum
P(UICopub)	0.47	0.50	0.00	1.00
Citations	5.49	11.69	0.00	770.00
ΔGDP_{-2}	1.01	2.70	-3.57	5.29
ΔGDP_{-2}^2	8.31	6.85	0.00	27.98
Firm size	29.26	46.81	0.00	202.00
inex	0.66	3.14	0.00	86.00
Co-authors	8.67	14.55	1.00	498.00
Multidisciplinarity	1.18	0.41	0.00	3.00

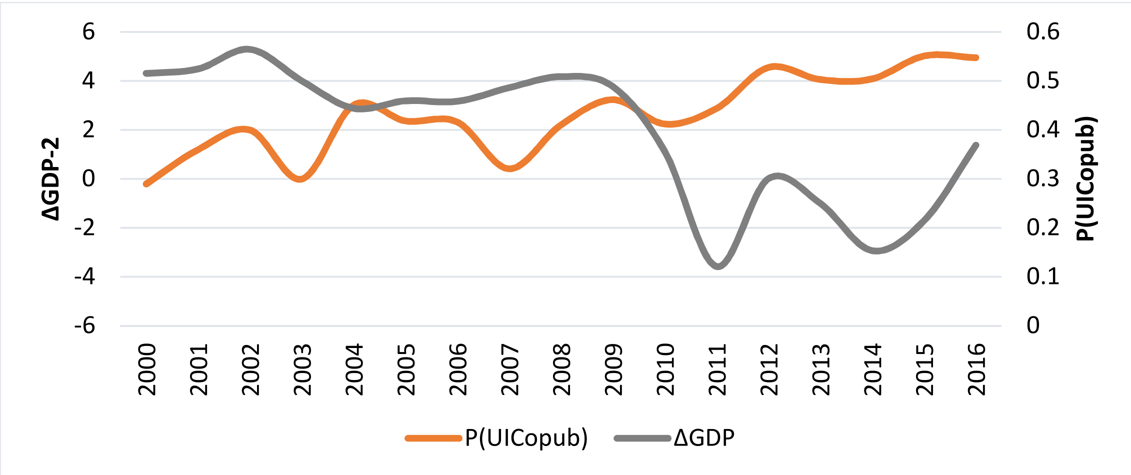

Fig. 1. Evolution of P(UICopub), 2000-2016, and GDP growth rate, 1998-2014 (lagged two periods).

As figure 1 shows, P(UICopub) increased from 0.29 in 2000 to 0.54 in 2016. The main increase is in 2008-2009 at the beginning of the Great Recession. The evolution of P(UICopub) and GDP growth rate exhibit a scissor shape, being closer during the expansion and more distant during the crisis.

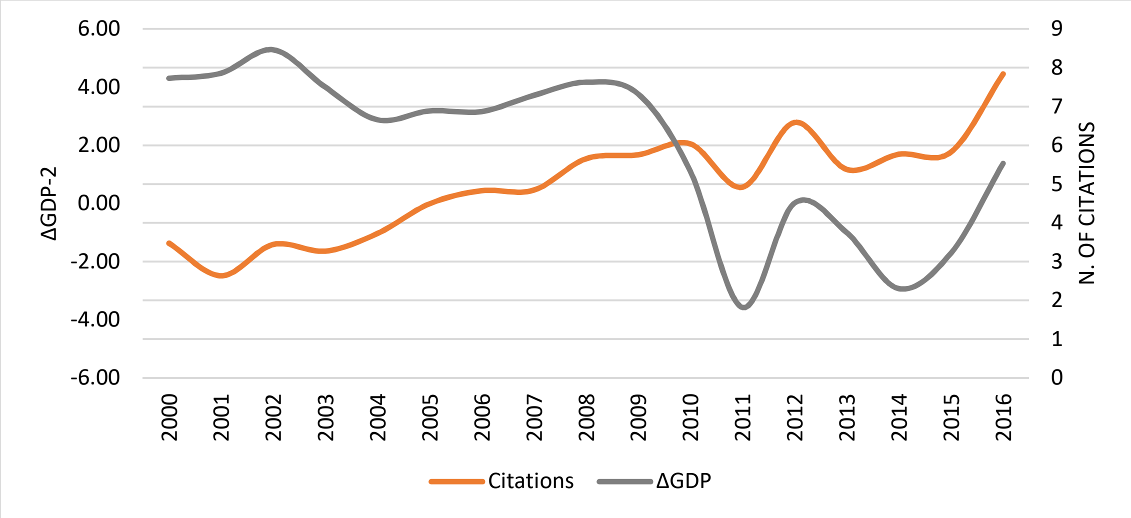

Fig. 2. Evolution of Scientific impact 2000-2016, and GDP growth rate, 1998-2014 (lagged two periods).

Figure 2 shows a substantial increase in firms' scientific impact, especially during expansionary period. During crisis, we observe a stagnation with ups and downs. Finally, scientific impact recovered steeply increasing from an average of 5.8 in 2015 to 7.80 in the last year.

Our empirical analysis considered two groups of models for testing first the P(UICopub) and subsequently, the scientific impact. Models 1-3, use a binary logistic regression method to estimate the probability of a firm publication in collaboration with universities P(UICopub) Based on hypothesis 1 identified in the theoretical framework, we formulate the following empirical specification:

$$P(UIC_{lmt})=f(\Delta GDP_{t-2}, \Delta GDP^2_{t-2}, \theta_{lmt}) \quad \textbf{Eq 1}$$

The dependent variable P(UIC) takes the value of either 1 if a Spanish firm publication is co-authored with a university, 0 otherwise, *l* is the publication, *m* are the firms, and *t* is time. The independent variables used in both groups of models are ΔGDP and ΔGDP^2_{-2} — the squared term corresponding to the possibility of non-linearities in the data. The annual GDP growth rate lagged two years in all models.

Models 4-7, use a negative binomial model to estimate the effects of that probability on the scientific impact of firms' creation output. Our dependent variable is the number of citation based on two-year citation window. To test hypothesis 4, we introduced a couple of variables of interaction (moderating) effects such as P(UIC) x ΔGDP and P(UIC)*ΔGDP^2. The form of the proposed models are:

$$Citations_{lmt}=f(\Delta GDP_{t-2}, \Delta GDP^2_{t-2}, P(UIC_{lmt})*\Delta GDP_{t-2}, P(UIC_{lmt})*\Delta GDP^2_{t-2}, \theta_{kmt}) \quad \textbf{Eq 2}$$

Our estimation approach includes in both group of models, a pre-crisis and a post-crisis estimation. Our control variables in both groups of models encompass firm size, co-authors, foreign collaboration, multidisciplinarity, science field, and region. Firm size was measured through the number of co-publications from a firm. Research areas were classified into the five broad Web of Science's categories: Social Sciences, Arts & Humanities, Physical Sciences, Technology and Life Sciences. Regions are defined as NUTS-2 regions.

5. Results of models

The results from the logistic estimation of Eq. 1 are shown in **Table 2.** The coefficient of GDP growth rate (tested with zero, one, two and three time lags) is negative and significant, which means that economic growth reduces the probability of firms' co-publications. The negative and significant coefficient of $\Delta\mathrm{GDP}^2$ confirms that it maintains a negative quadratic relationship with P(UICopub). Models 2 and 3 reveal the different reaction of the P(UICopub), both in a pre and post-crisis phase. Hence, the evidence supports hypothesis 1. In crisis, when economic growth decelerates or contracts, the former negative relationship between economic growth and U-I co-publications becomes positive.

Table 2. Logistic model estimation of P(UICopub)

Variable	1 Full sample	2 Pre-crisis (2000-2008)	3 Post-crisis (2009-2016)
ΔGDP	-0.11**	-0.11**	0.05*
	(0.01)	(0.03)	(0.02)
$\Delta\mathrm{GDP}^2$	-0.02**		
	(0)		
Firm size	-0.00**	-0.00**	-0.01**
	(0)	(0)	(0)
inex	0.03*	0.01	0.08**
	(0.01)	(0.02)	(0.02)
Co-authors	-0.01	0.02	-0.07**
	(0)	(0.02)	(0.01)
Multidisciplinarity	0.15*	0.28**	0.01
	(0.07)	(0.1)	(0.1)
Science field	Included	Included	Included
Region	Included	Included	Included
Sector	Included	Included	Included
Constant	0.12	-0.22	0.71**
	(0.1)	(0.19)	(0.15)
N	15445	7544	7901
Chi2	997	464	472
p	0	0	0
R2	0.09	0.08	0.09

*P<0.1; **P<0.05; ***P<0.01. Standard errors in parenthesis. Weighting variable: share of number of organisational affiliations.

In terms of control variables, firm size variable has a significant negative influence on the probability of firms' co-publication with universities. Smaller companies are relatively more eager to co-publish with universities.

The second group of estimations shows a negative binomial model, we use the number of citations as a dependent variable, and the results are presented in **Table 3**. Model 4 shows the effect of the GDP growth rate on the scientific impact of firms' output. The coefficient estimates of ΔGDP^2 is statistically significant and reveals a negative quadratic relationship with scientific impact, providing support for hypothesis 2. As expected, the effect of firms' scientific impact in collaboration with universities P(UICopub) is positive and significant, suggesting that collaboration co-creation with universities increases scientific impact, but regardless of the cycle. This last result confirmed hypothesis 3. Model 5 presents the effects of the interaction terms between P(UICopub) and ∆GDP and ΔGDP^2. None of the interaction variables provides significant results; therefore, hypothesis 4 is not confirmed. Models 6 and 7 present results in line with hypothesis 1 already confirmed. For a pre-crisis sample, GDP growth rate has a negative and significant effect on firms' scientific impact, which means in expansion the higher GDP growth rate, the less impact for firms' output, whereas in a post-crisis phase GDP growth rate has a positive significant effect. This suggests in crisis a raise of GDP growth rate the more impact for firms' output.

All estimations include fixed effects for region and science field. To verify the robustness of the results, we test by scientific field, excluding non-collaborative firms' scientific production, excluding outliers, excluding mixed centres and applying treatment effects models.

Table 3. Negative binomial model estimation of scientific impact (Sci)

Variable	**4 Full sample**	**5 Full sample**	**6 Pre-crisis (2000-2008)**	**7 Post-crisis (2009-2016)**
∆GDP	-0.05**	-0.05**	-0.09**	0.03*
	(0.01)	(0.01)	(0.02)	-(0.01)
ΔGDP^2	-0.01**	-0.01**		
	(0)	0)		
P(UICopub)	0.14**	0.15**	0.19**	0.11**
	(0.03)	(0.05)	(0.04)	(0.04)
P(UICopub)*GDP		(0		
		-0.01		
P(UICopub)*GDP^2		(0		
		-0.01		
Firm size	0.00**	0.00**	0.00*	0.00**
	(0)	(0)	(0)	(0)
Inex	0.10**	0.10**	0.09**	0.11**
	(0.02)	(0.02)	(0.02)	(0.03)
Co-authors	0.04**	0.04**	0.03	0.04**
	(0.01)	(0.01)	(0.02)	(0.01)
Multidisciplinarity	0.30**	0.30**	0.48**	0.18**
	(0.05)	(0.05)	(0.07)	(0.06)

Science field	Included	Included	Included	Science field
Region	Included	Included	Included	Region
Sector	Included	Included	Included	Sector
		-0.01		
Constant	1.21**	1.21**	1.02**	1.32**
	(0.09)	(0.09)	(0.16)	(0.1)
Lnalpha				
Constant	0.16**	0.16**	0.18**	0.10**
	(0.03)	(0.03)	(0.04)	(0.03)
Observations	15020	15020	7139	7881
chi2	330	331	229	193
P	0.00	0.00	0.00	0.00
r2_p	0.03	0.03	0.02	0.03

6. Conclusions

Past research has shown that U-I scientific knowledge co-creation output and firms' scientific impact depend on individual, organizational and institutional factors. Our research analyses how time also matters, and specifically how U-I scientific knowledge co-creation output and the scientific impact react to the different phases of the economic cycle. We have proposed a U-I cycle theory according to which economic growth maintains a negative relationship with firms' co-creation of scientific knowledge with universities during expansions, but positive during recessions. In addition, we find that the scientific impact of firms' knowledge output also reacts to the cycle and follows an inverted u-shaped relation. To strengthen our theory, we also prove that the co-creation with universities increases scientific impact, but does not soften the effect of the cycle.

By using a large database of Spanish firms' co-publications with universities in the context of the Great Recession, we have found empirical support to the theory.
These findings could have important implications for public policy to reinforce R&D cooperation policies during every phase of the economic cycle. To refine D'Agostino & Moreno Serrano (2016) idea that R&D cooperation is necessary before and during the crisis as an instrument to sustain the scientific production; we suggest that government incentives should be directed towards the companies adjusting to the needs of collaboration of each stage of the economic cycle. In times of expansion maintain support to co-creation and quality of firm science; and in times of recession, do not expect universities to have an even larger positive effect than they already have.

Our research presents several limitations. The data is on national co-publications only and not on international co-publications, so we cannot deny that different pattern occurs in firms' co-publications with foreign universities. We are gathering these extra data to corroborate our findings. Finally, more control variables are necessary, which we are in the process of building, and we are preparing a case study to deepen in the phenomenon.

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