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The steady effect of knowledge co-creation with universities on business scientific impact throughout the economic cycle

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Abstract

Economic ups and downs condition science and innovation. The research strength of business firms and their cooperation with universities are important functions of science systems. The aim of this research is to analyse some of the links between business scientific output co-creation and impact throughout the economic cycle. Economic growth increases the probability of firms increasing both their scientific knowledge co-creation output and their scientific impact (during crises), until reaching an inflection point, after which those relationships become negative (during expansions). Co-creation with universities intensifies the scientific impact of firms' output; however, although in theory this effect should vary according to the economic phase, the evidence shows that it remains steady. In this study, the theory is grounded through interviews with key university and firm co-authors, and an empirical test is conducted on publications from 15,000 Spanish firms between 2000 and 2016 and their citations — a period which includes the Spanish Great Recession (2008–2014). The analysis suggests that policies to promote business co-creation output with universities should be more stable throughout economic cycle: in expansions, governments should maintain the support for co-creation that is typical of crises; in crises, governments should not expect co-creation with universities to have an even greater positive effect on firms' scientific quality than it already has during expansions.

Keywords: Scientific production; University-industry interaction; Co-authored research publications; Economic crisis

1 Introduction

Knowledge creation is one of the pillars of well-functioning scientific, innovation and economic systems. Some companies engage in knowledge creation through the publication of scientific codified knowledge. The benefits of this include enhancing competitive advantage (Hicks, 1995), attracting qualified scientists (Hicks, 1995; Perkmann et al., 2011) and improving technological innovation (Soh & Subramanian, 2014).

Companies may create this scientific codified knowledge in collaboration, notably with universities (Camerani et al., 2018). University scientific knowledge co-creation reinforces the previous benefits for firms and brings additional advantages such as a stronger connection with open science (Agrawal, 2001; Belderbos et al., 2016; McKelvey & Rake, 2016; Wong & Singh, 2013), higher absorptive capacity (Cohen & Levinthal, 1990; Cockburn & Henderson, 2003) and increased business scientific impact (Lebeau et al., 2008; McKelvey & Rake, 2020).

Innovation scholars have long emphasised the influence of economic growth and cycles on firms' scientific and technological activities (Freeman & Louçâ, 2001; Ziemnowicz, 2013). However, for both university-industry knowledge co-creation output and firms' scientific impact, the role played by time has been under-researched, particularly the effect of economic cycles (Barberá-Tomás et al., 2021). Some authors have approached the consequences of economic cycles in other innovation-related activities: Archibugi et al. (2013) studied the effect of economic crises, but only on R&D expenditures; Pellens et al. (2020) observed that public R&D reacts asymmetrically to GDP growth — on average, public R&D expenditures increase in periods of economic upswings but decrease during economic contractions; Madrid-Guijarro et al. (2013) analysed the innovation output of some firms during an economic downturn and a period of economic growth; and Azagra-Caro et al. (2019) studied how the Great Recession affected university-industry knowledge co-creation output at a macro level — however, they did not analyse the effects of economic growth on co-creation output or business scientific impact.

The aim of this research is to analyse some of the links between business scientific output co-creation and impact throughout the economic cycle. To this end some hypotheses are developed along with empirical tests to analyse how economic cycles determine university-industry knowledge co-creation output and firms' scientific impact. By studying both phenomena together, it will be possible to determine whether the contribution of universities to the scientific impact of firms evolves over time due to changes in the probability of joint knowledge co-creation, or in the marginal value of ideas from universities. For the empirical analysis, bibliometric data of co-publications made by Spanish firms between 2000 and 2016 is employed. The findings evidence the inverted U-shaped relationships between business scientific output co-creation or impact and economic growth, and the steady effect of knowledge co-creation with universities on business scientific impact throughout the economic cycle. The results lead to a discussion on the importance of the state component in the co-creation of knowledge, suggesting that public policies should be adapted to different economic situations in order to achieve the best return in terms of quality of business science.

The paper is organised as follows: Section 2 presents a review of the literature and the hypotheses of the study, backed up by interviews with some prolific university and industry co-authors of joint publications[2]; Section 3 describes the context of the study; Section 4

[2] The industry researchers were selected by choosing one of the most prolific firms from the empirical sample in terms of co-publications. This firm had more than 50 co-publications with universities in the last ten years distributed throughout the period of analysis (2008–2016). Evidence was collected from 4 researchers from

shows the data on the co-publications made by companies; Section 5 presents the estimations of the effects of economic growth on university-industry knowledge co-creation and firms' scientific impact; and Section 6 concludes by making policy recommendations and suggestions for future research.

2 Theoretical framework and hypotheses

A business cycle is a series of fluctuations in real gross domestic product (GDP) growth, real personal income, employment and other indicators (NBER, 2008). Fig. 1 presents an overview of major global economic recessions since the 1960s: the first oil crisis (1973–1975), the second oil crisis (1978–1981), the 90s recession (1990–1992) and the Great Recession (2008–2014) — the latter being the most recent incident and the object of the empirical study in this research. Cycles are composed of phases of high economic growth (expansion) and low or negative economic growth (crisis), as presented in Fig. 1 in the years corresponding to the Great Recession.

this firm. In addition, 5 university researchers were selected, among the most prolific co-authors of publications with firms, also distributed between periods of crisis and expansion. Virtual interviews of 30–40 minutes were conducted. More researchers were not included since the information provided began to be redundant.

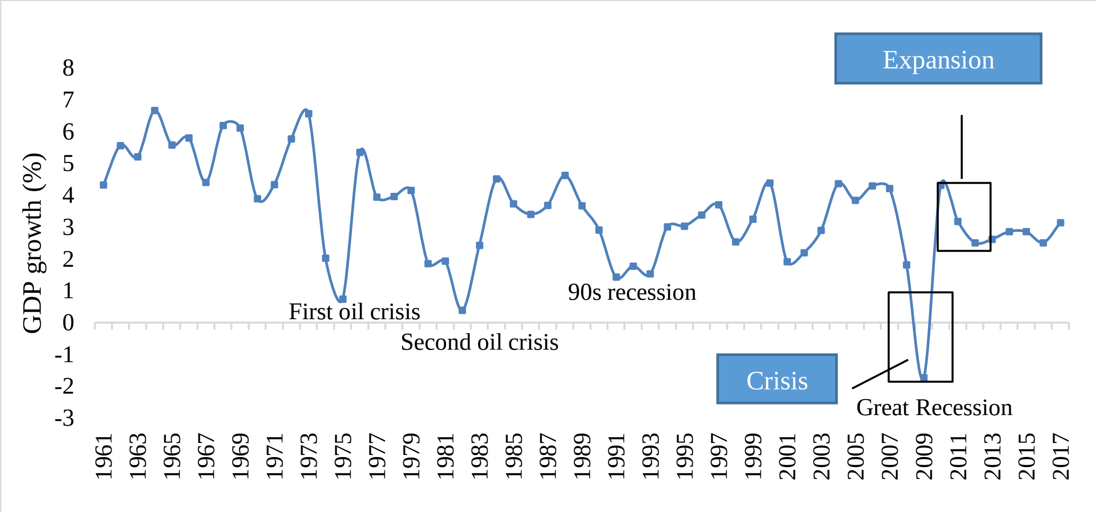

Fig. 1. Economic growth and cycles, 1961–2017 (Source: World Bank website).

2.1. University-industry knowledge co-creation output and economic growth

The impact of economic growth on university-industry knowledge co-creation output is ambivalent. First, the reasons to expect a positive or negative linear effect will be developed, and then the hypothesis of a curvilinear effect due to the growth will be tested.

2.1.1. Increasing or decreasing university-industry knowledge co-creation output in economic growth

The scientific knowledge creation output of firms is driven by business R&D (Halperin & Chakrabarti, 1987; Chakrabarti, 1990; Cincera & Dratwa, 2011; Arora et al., 2017). Economic growth favours the financial stability of firms, and, therefore, that the cash flow of the company finances investment in R&D (Hall, 1992; Himmelberg & Petersen, 1994; Rafferty & Funk, 2008). The more R&D-intensive that firms are, the higher their absorptive capacity, the more open their external search strategies (Perkmann and Walsh,

2007) and the higher their scientific co-creation output with universities (Vedovello, 1998; Azagra-Caro et al., 2019). This implies a positive relationship between economic growth and firms' scientific co-creation output with universities.

Some interviewees highlight the role of university researchers in knowledge co-creation during economic growth.

> *For a company that's growing, it's not in their interest to publish; they don't derive any advantage or benefit from it. Nevertheless, it's rare for a company to oppose a proposal made by the university. It's the university's researchers who, in their own interest, must be able to take the initiative and take charge of the publication.*
> (University Researcher 9)

However, opposing arguments can also be found. Companies need to invest time, money and other resources to absorb external knowledge, but the rewards are uncertain. 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 (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). Economic growth endows companies with the ability to self-finance their own R&D projects (Schumpeter & Fels, 1939; Hall, 2002; Hud & Rammer, 2015). Therefore, they may not be interested in collaborating with organisations with different institutional norms, or, if they are, they may have more power to retain intellectual property and not publish the results (Azagra-Caro et al., 2019).

Industry researchers provide evidence of a negative relationship between economic growth and firms' scientific knowledge co-creation output with universities, as the following statement shows:

> *As the company grows, its interest in publishing decreases. During the first years of the crisis [2008–2010] the company was in the process of creating a knowledge base and researching at a basic level. From 2012 onwards, the company started to have its own knowledge of certain technologies and processes, which it didn't want to share, so it stopped publishing the results of the research.*
>
> (Industry Researcher 2)

There are, therefore, reasons to justify both a positive and a negative effect of economic growth on co-creation output. It will now be argued that one effect or the other will prevail according to the phase of the growth cycle.

2.1.2. University-industry knowledge co-creation output: increasing during crises and decreasing during expansions

In a crisis, firms facing financial constraints are likely to reduce their investment in R&D (Schumpeter & Fels, 1939; Freeman, 1987), and the low demand during recessions also negatively affects firm's R&D (Shleifer, 1986). The crisis has a dual effect 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; Aghion et al., 2012). More specifically, government policies seek to counterbalance the negative effects of the recession by promoting university-industry research cooperation. D'Agostino & Moreno Serrano (2016) showed that the positive effects of R&D cooperation on innovation activities were stronger in times of economic turbulence than in expansion, and innovation also stimulates cooperation with universities (Azagra-Caro et al., 2014). This makes recessions a friendly environment in which companies can innovate (Filippetti & Archibugi, 2011; Pellens et al., 2020).

This postulate coincides with the following statement made by a university researcher during an interview:

> *Normally, when there is a crisis, companies stop doing research or postpone it; however, the public sector invests money so that companies can receive assistance for doing research in the form of loans of which a percentage is forgivable. Then you suddenly find yourself having greater possibilities for collaboration with companies and projects with companies in which there is mutual interest.*
>
> (University Researcher 7)

Some examples of national government policies that have tackled the effects of the economic crisis can be found in Canada, Japan, Argentina and Mexico. In Canada, although federal and local governments reduced education funding due to the 1970s oil crises, they did not stop providing Canadian universities with support and continued developing programmes to promote the university-industry relationship in science and technology (Naimark, 1989; 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 crisis of the 1990s, the government promoted a series of plans for research collaboration (Thorn, 2005). Mexico, in 2008 and 2009, was facing the worst moment of the Great Recession. Despite this, the government launched an Incentive

Programme for Innovation (2009–2013) that included economic incentives for companies in association with public-private universities or research centres.

A similar response can be found at the supranational level, by the European Community (EC) during the Great Recession. Of the four Specific Programmes under the EC's Seventh Framework Programme (FP7), the largest budget was for the Cooperation Programme, whose objective was to strengthen research collaboration between universities and firms, especially transnational cooperation (Veugelers & Cassiman, 2005; Szücs, 2018). Some statements made by university researchers also coincide with this insight, even highlighting the situation of university-industry research collaboration in phases of economic crises:

> *In our case, between 2008 and 2014, there was no decrease in projects in collaboration with companies. It was a good period. It was even a bit more intense with local companies, because at that time there were interesting topics such as renewable energies, solar thermal energy [...]. At that time the European Commission organised a programme to co-finance projects between companies and universities in the aeronautical field, so we started a series of topics.*
>
> (University Researcher 7)

Policymakers, as a way to minimise "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, programme agencies select consortia with previous experience and a proven ability to generate results. Evaluators rate the outputs generated in the collaboration process by considering, among other aspects, the number of co-publications and their citation impact. Hence, firms will find that co-publishing with universities revalorises during crises (Azagra-Caro et al., 2019). This view is acknowledged in the following statement from a researcher:

> *[In our company we are] very strong when it comes to project submissions. We were particularly active in the framework of FP7 projects [2007–2013], in which co-publications were associated with these projects.*
>
> (Industry Researcher 4)

In fact, Azagra-Caro et al. (2019) confirm that firms' R&D spending fosters university-industry knowledge co-creation output, but after a certain threshold, the relationship becomes negative; i.e., it follows the shape of an inverted U: increasing during recession (with low business R&D growth), and decreasing during an expansion (with high business R&D growth). 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 research becomes unproductive. This explains how innovation performance can decline after an excessive amount of corporate research (Koput, 1997).

To be precise, the following postulates are made:

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

2.2. The scientific impact of firm's co-creation output with universities and economic growth

Economic cycles are expected to affect the scientific impact of university-industry co-creation output. To test this theory, three hypotheses will be developed. The first concerns the effect of economic cycles on firms' scientific impact, and the second describes the effect of university collaboration on firms' scientific impact. Subsequently, a third hypothesis will be tested, concerning the moderating effect of scientific co-creation with universities in the relationship between cycles and scientific impact.

2.2.1. Firms' scientific impact: increasing during crises and decreasing during expansions

Scientific impact is measured in terms of the popularity, influence, novelty or usefulness of a research publication (Cohen et al. 2010). In the context of firms, many of these attributes may depend on the phase of the cycle. Filippetti et al. (2009) observed that the innovation behaviour of firms follows different patterns in times of crises. Actually, the growth of firms relies significantly on increasing production capacity and workforce during expansions, but it relies even more on increasing R&D budgets during crises, despite the difficulties (Köksal & Özgül, 2007). Crises nurture the innovations that lead to recovery; creative destruction lies beneath growth cycles, and during crises, firms are more likely to pioneer new pathbreaking scientific and technological ideas which will have a potential impact (Schumpeter, 1942). This is compatible with the idea that firms develop more science-based innovation, and thus better science, during downturns.

Some extracts from interviews with company researchers on the performance of the scientific impact of firms illustrate how the cycle led to new pathways in their R&D strategy.

> *The company's marketing activities were disrupted by the economic crisis [the Great Recession]. At the innovation level, it also had an impact that, in this case, may have been positive. That is to say, any disruption and any interruption in activity led to a search for new lines of work. In this sense, we were urged to search for alternative routes for process optimisation or the creation of alternative materials that could be used to reduce production costs.*
>
> (Industry Researcher 1)

University researchers emphasised the particular characteristics of research conducted during times of crisis that may have positively influenced the scientific impact of the co-publications made by firms:

> *During a crisis, there are fewer companies willing to carry out research; however, even though not much research is carried out during a crisis, that which is tends to be more thorough. The results that arise from this research have a more appealing scope, more time and resources are devoted to refining the work, and their contribution is often highly focused on the social requirements of the context, thereby generating a great deal of interest.*
>
> (University Researcher 9)

These reflections allow the next postulate to be made:

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).

2.2.2. The scientific impact of firms in collaboration with universities

Scientific co-production with universities may increase the quality of industrial science in three ways. First, university science tends to be more basic, related to general principles and forward looking, which is likely to broaden the perspective of firms (Frenken et al., 2005). Second, scientific production is at the core of the academic profession, much more so than for companies; universities are more familiar with institutions like peer-review and can offer firms an increase in quality by shaping results according to the standards of the scientific circuits. Third, scientific co-production with universities opens up access for firms to new diffusion networks, and thus to enhanced recognition of quality, through conference and workshop presentations, informal discussion with colleagues, preprints, etc. (Katz & Martin, 1997; Aksnes, 2003; Goldfinch et al. 2003). Some of these arguments can be reflected in the statements researchers make on their experience:

> *Universities always endeavour to publish the results of their research with companies, because the CVs of doctoral students, professors and lecturers are supported by the measure of their publications. Therefore, any work done by the company with a university group is bound to boost its quality, in terms of its presentation as well as its analysis, writing and dissemination.*

(University Researcher 7)

Empirical evidence suggests that this is the case. For example, the impact of university–industry scientific publications was higher in Canada (1988–2005) than that of purely university papers and industry papers (Schmoch & Schubert, 2008; Lebeau et al., 2008; McKelvey & Rake, 2020). Abramo et al. (2020) provide empirical evidence that during the period of 2010–2015, largely coinciding with the Great Recession in Italy, until reaching the start of recovery in 2017, private-public collaboration had a positive effect on the impact of publications.

Hence, it can be expected that scientific co-production with universities will have a positive effect on business science.

Hypothesis 3. Scientific co-production with universities increases firms' scientific impact.

2.2.3. The moderating effect of economic growth in the relationship between university co-authorship and the quality of business science

It has been argued that scientific co-production with universities increases firms' scientific impact irrespective of the growth cycle; i.e. this positive effect is expected at any point in time. However, another situation is expected in which the contribution from universities will be more meaningful. Although little theorising has been made about this aspect, on the one hand, enhanced public support to university-industry cooperation during crises (section 0) is based on the assumption that universities are *particularly* useful in crises. On the other hand, the idea of a more valuable contribution from universities would be compatible with some recommendations stemming from the open innovation paradigm for firms to open up to universities in order to tackle crises (Chesbrough, 2020; Hughes, 2011). Some statements made by university researchers also concur with the idea that during crises firms are more open to novel ideas from universities, which could have a greater scientific impact, as shown by the following excerpt:

> *Certain issues come into vogue when crises arise and call certain realities into question. Researchers working on these issues take advantage of the moment to propose solutions that previously may not have been interesting to the company. My research group and the companies with which I collaborated worked on projects with themes that were in vogue. The crisis gave rise to innovative ideas that, due to the relevance of the subject matter at that time, had a high impact in publications.*
>
> (University Researcher 7)

If this higher (lower) relevance of universities during economic downturns (upturns) translates into better cooperative science outlets, the following hypothesis could be established:

Hypothesis 4. Economic growth decreases the positive effect of scientific co-creation output with universities on the scientific impact of business science.

3 Research context

The above hypotheses will be tested in the context of the Spanish Great Recession. Fig. 2 shows how Spain mimicked the world trend; i.e. an economic acceleration (2000–2007) followed by an economic contraction (2008–2011), only that in Spain the contraction lasted longer (till 2014). The world Great Recession began in the United States with the collapse of Lehman Brothers in September 2008, due to failures in economic and financial regulation, and was followed by a financial crisis in the rest of the world (Grusky et al., 2011). Attempting to stabilise their economies, some governments developed bailout policies to save companies from bankruptcy. The world economy recovered between 2010 and 2012. Spain, however, experienced a lower recovery. The Spanish Great Recession started with the collapse of the property bubble in 2008, and it was deepened with the effects of the global financial crisis and by very high levels of unemployment and poverty (Meardi, 2014).

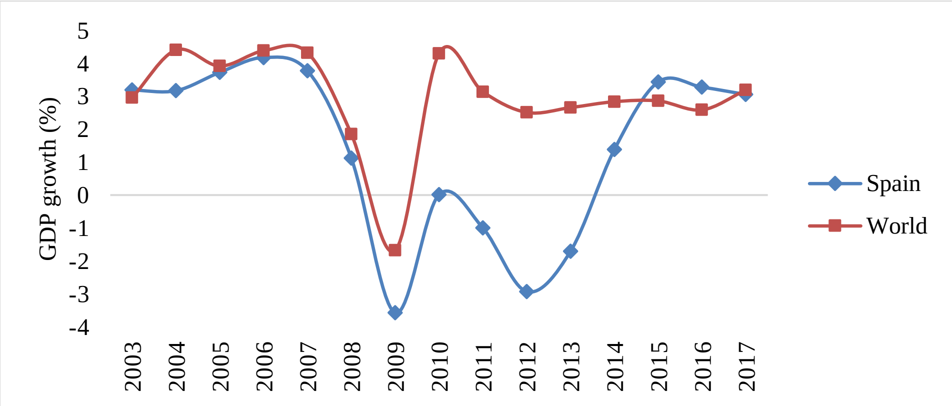

Fig. 2. Spanish GDP growth (Source: World Bank website).

The Spanish Great Recession had immediate effects on Spanish science and innovation. On the private side, there was a reduction in the number of firms that introduced technological and non-technological innovations, by 43% and 55%, respectively (COTEC Foundation, 2018). On the public side, government R&D spending stagnated in 2008 and 2009, and in 2010 it decreased heavily (Cruz-Castro & Sanz-Menéndez, 2016), affecting research institutions that depend on public financing such as universities and public research centres. However, public opinion was more favourable to considering science and technology as a policy priority (Sanz-Menéndez and Van Ryzin, 2015), and some regional governments and specific types of firms could effectively sustain business R&D efforts and collaborations despite the difficulties (García-Sánchez and Rama, 2020; Cruz-Castro et al., 2018).

From 2006 to 2017, the Spanish government instituted three programmes to support business R&D cooperation. Their main objective was to promote public-private alliances by providing direct public funding to universities and other research organisations to develop applied research activities in collaboration with private companies. Fig. 3 shows the evolution of the individual budgets of these three collaborative programmes and in terms of the percentage of the total national R&D budget. The CENIT programme (2006–2010) was launched as part of the INGENIO 2010 Strategy, funded by the Centre for Industrial Technological Development (CDTI). The launch of this first programme took place in 2006, when the economy was expanding, although this expansion phase was about to end. In 2009, a Ministerial order considered CENIT as part of the 2008–2011 Spanish National R&D&I Plan (Orden CIN/1.559/2009). The last two years of the CENIT programme finalised under this framework (2009–2010), although the 2008–2011 Plan already incorporated a reinforced programme for public-private collaboration named INNPACTO. The launch of this second programme occurred in 2008, when the economy plummeted. The INNPACTO programme was promoted by the Ministry of Economy and Competitiveness and lasted for three years of the crisis (2010–2012). Fig. 3 shows that INNPACTO allocated a higher percentage of collaborative resources than CENIT. The structure of this programme continued from 2013 to 2019 under the name of the Challenges-Collaboration Programme. This third programme started in 2013, when the economy began to recover, with a reduced percentage of collaborative budget compared to INNPACTO, but still higher than that of CENIT. These data reflect the fact that the percentage of budget allocation to promote business R&D collaboration was significantly higher during the crisis than during the expansion.

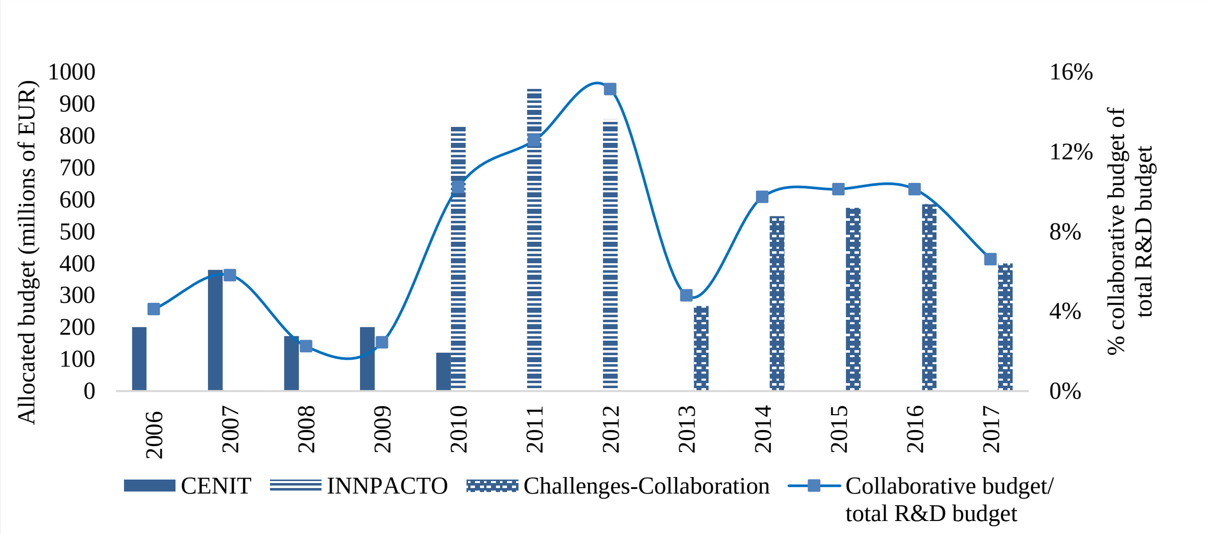

Fig. 3. Public-private R&D collaboration programmes. Source: prepared by the authors with data from the Spanish Ministry of the Treasury (2018) and the Spanish Official State Gazette (2019).

4 Data and methods

Bibliometric data are a way to measure knowledge co-creation output and its scientific impact. In this study, university-industry knowledge co-creation output is measured through data on their co-publications. There is an ongoing debate on the use of university-industry co-publications as a proxy for joint scientific output. For instance, authors such as Katz & Martin (1997) and Lundberg et al. (2006) consider that university-industry co-publications are not a representative indicator of all the scientific output that can be generated from joint collaboration. However, authors such as Calvert & Patel (2003), Tijssen et al. (2009) and Abramo et al. (2009) have validated this approach, arguing that the number of co-publications is related to the occurrence of cooperation in research.

For the purposes of this study, the scientific impact of a publication is measured by the number of citations of the publications from each unit. Despite several criticisms to the use of citation counts, some authors considered it to be an appropriate statistical indicator of quality research (Cole, 1992).

The affiliation data for the authors was collected from the Web of Science records of papers that were published between 2000 and 2016 and contributed by any Spanish organisation. The resulting 188,458 Spanish addresses were classified as universities, firms and other organisations (hospital, research centre, joint institute, public organisation, non-profit organisation). The unit of analysis used is the publication. The sample consists of the publications made by firms and their co-publications with other organisations, which translates into almost 15,500 publications, having excluded citation and team size outliers. If the non-firm organisation is a university, it is a university-industry co-publication. Publications are duplicated if different types of co-authoring organisations exist; however, in the econometric estimations of this study, this will be controlled by weighting the share of the number of organisational affiliations.

Economic growth is measured through the Spanish GDP annual growth rate (source: Spanish National Statistics Institute). To match publication and GDP data, a time-lag of two years has been assumed, since the effect of economic growth on publications is not immediate. The sign and significance of the estimated coefficients in the regression analysis do not change after testing with three-, four- and five-year lags.

Table 1. Variable definitions and descriptive statistics

Variable role	Variable name	Description	Mean	Std. Dev.	Min.	Max.
Dependent variables	*University co-authorship*	1 if a Spanish firm publication is co-authored with a university, 0 otherwise.	0.47	0.50	0.00	1.00
	Scientific impact	Citation counts: Number of citations of firm publications	5.49	11.69	0.00	770.00
Independent variables	ΔGDP_{t-2}	Gross Domestic Product	1.45	2.61	-3.50	5.29
	ΔGDP^{2}_{t-2}	Gross Domestic Product squared	8.49	6.91	-3.50	27.98
Control variables	*Firm size*	Number of firm publications, divided by 100	0.29	0.46	0.00	2.02
	Foreign collaboration	Number of foreign organisations	0.64	3.10	0.00	86.00
	Team size	Number of authors	5.53	14.37	1.00	498.00
	Multidisciplinarity	Number of different fields of the firm publication	1.18	0.41	0.00	3.00
	Science field					
	Social sciences	1 if the scientific field of the firm publication is social science, 0 otherwise	0.02	0.13	0.00	1.00
	Physical sciences	1 if the scientific field is physical sciences, 0 otherwise	0.22	0.41	0.00	1.00
	Technology	1 if the scientific field is technology, 0 otherwise	0.22	0.42	0.00	1.00
	Life sciences	1 if the scientific field is life sciences, 0 otherwise	0.72	0.45	0.00	1.00
	Region	18 dummy variables, one per Spanish autonomous community (NUTS-2 regions). Most co-publications located in Madrid (31%) and Catalonia (29%).				

Table 1 provides the mean and standard deviations of the sample. A little less than half of the sample are co-publications of firms with universities. Fig. 4 and Fig. 5 are constructed to provide some descriptive insight into the trend of university co-authorship and firms' scientific impact in the economic cycle.

As Fig. 4 shows, university co-authorship increased from 0.29 in 2000 to 0.54 in 2016. The main increase occurred between 2008 and 2009, at the beginning of the Great Recession. Actually, the evolution of university co-authorship exhibits a countercyclical behaviour, it being clearer during the crisis, which roughly corresponds to the prediction of Hypothesis 1.

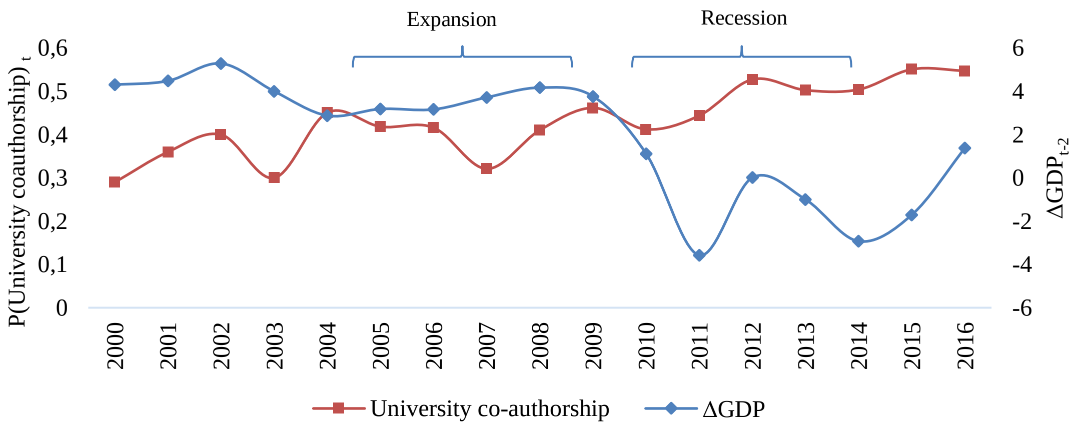

Fig. 4. Countercyclical behaviour of university-industry co-creation output.

Fig. 5 shows a substantial increase in firms' scientific impact, especially during the expansionary period. During the crises, stagnation is observed, albeit with fluctuations, before recovering at the end of 2016. Hence, the scientific impact of firms in some way behaves as predicted by Hypothesis 2, it being clearer in expansion.

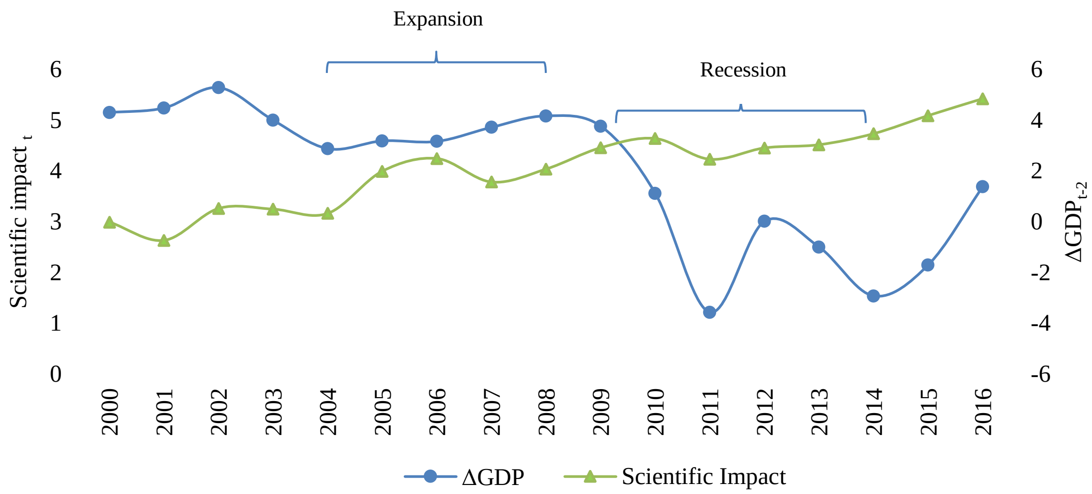

Fig. 5. Countercyclical behaviour of scientific impact of firm publications.

The empirical analysis involved two models. First, binary logistic regression was used to estimate the probability of a firm publication in collaboration with universities:

$$P(\text{University co-authorship}_{ijt}) = f\left(\Delta GDP_{t-2}, \Delta GDP^{2}_{t-2}, \theta_{ijt}\right) \quad (1)$$

The dependent variable, university co-authorship, takes the value of 1 if a Spanish firm publication is co-authored with a university, 0 otherwise; *i* is the publication; *j* the firm; and *t* is time. The independent variables used in both groups of models are ΔGDP and ΔGDP^2, the squared term corresponding to the possibility of non-linearities in the data; and θ includes a set of control variables.

Second, a negative binomial model was used to estimate the scientific impact of the creation output of firms. The dependent variable used is the scientific impact, based on a two-year citation window (publication year and the following two years).[3] The form of the proposed models is:

[3] This two-year window is imposed by the recency of the data: the last publication year analysed is 2016, and citation data was available until 2018. Some may consider this to be a limitation of the study. Wang et

$$\text{Scientific impact}_{ijt} = f\big(\Delta GDP_{t-2}, \Delta GDP^{2}_{t-2}, \text{University co-authorship}_{ijt}, \text{University co-authorship}_{ijt} * \Delta GDP_{t-2}, \theta_{ijt}\big) \quad (2)$$

5. Results

5.1. Probability of university-industry co-publication

The results from the logistic estimation of Equation 1 are shown in Table 2. Column 1 includes control variables only, based on previous studies of industry (co-)publications (e.g. Halperin & Chakrabarti, 1987; Carayol & Matt, 2006; McKelvey & Rake, 2016; 2020; Yegros-Yegros et al., 2016; Arora et al., 2017). The control variables generally have the expected results on the full sample, but they vary according to the phase of the cycle. Smaller companies are relatively more eager to co-publish with universities, both pre- and post-crisis. These results probably reflect that small, highly specialised firms have the necessary capacities and resources to acquire public funds for collaborative R&D projects (Wanzenboeck et al., 2014); however, this contrasts with Giunta et al. (2016), who indicate that larger firms co-publish more than smaller ones. The coefficient of foreign collaboration is positive and significant in the full sample and the post-crisis period. The coefficients of team size are not significant in the full sample nor in pre-crisis, but during the crisis the effect is negative and significant. The coefficients of

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al. (2017) mentioned that a suitable metric for scientific impact requires a citation time window of at least three years. They confirmed that using shorter citation time-windows could bias the impact of novel research. However, other authors indicated that citation patterns are different for each scientific field (Garfield, 1972; Moed, 2006; Althouse et al., 2009). For example, in life sciences and physical sciences, the citations peak arises two years after publishing, and these are the most abundant fields in the sample used in this study. In addition, several papers have argued that a two-year lapse after publication is useful as an indicator of the long-term quality and this is a sufficiently robust indicator of scientific impact (Adams, 2005; Dorta-Gonzalez & Dorta-Gonzalez, 2013).

multidisciplinarity are positive in the full sample and before the crisis, and they are not significant afterwards.

Column 2 shows that the coefficient of ΔGDP is negative and significant, which means that the probability of firms' co-publications with universities is countercyclical. However, according to the negative and significant coefficient of ΔGDP^2 (Column 3), this occurs after a threshold, and before that the effect of economic growth is positive. To corroborate the presence of an inverted U-shape, the test suggested by Lind and Mehlum (2010) was also used. The test verifies an inverted U-shaped relationship between GDP growth and the probability of co-publication. Hence, the evidence supports Hypothesis 1: economic growth maintains an inverted U-shaped quadratic relationship with university co-authorship. In crisis, when economic growth decelerates or contracts, the negative relationship between economic growth and university-industry co-publications becomes positive.

Table 2. Logistic model estimation of university co-authorship

	1 Full sample	2 Full sample	3 Full sample	4 Pre-crisis (2000-2008)	5 Post-crisis (2009-2016)
ΔGDP_{t-2}		-0.09**	-0.11**	-0.11**	0.05*
		(0.01)	(0.01)	(0.03)	(0.02)
ΔGDP^2_{t-2} (H1)			-0.02**		
			(0.00)		
Firm size	-0.47**	-0.47**	-0.46**	-0.44**	-0.56**
	(0.05)	(0.05)	(0.04)	(0.07)	(0.07)
Foreign	0.04**	0.03*	0.03*	0.01	0.08**
collaboration	(0.01)	(0.01)	(0.01)	(0.02)	(0.02)
Team size	-0.01	-0.01	-0.01	0.02	-0.07**
	(0.00)	(0.00)	(0.00)	(0.02)	(0.01)
Multidisciplinarity	0.16*	0.14*	0.15*	0.28**	0.01
	(0.07)	(0.07)	(0.07)	(0.10)	(0.10)
Science field	Significant	Significant	Significant	Significant	Significant
Region	Significant	Significant	Significant	Significant	Significant
Constant	-0.04	-0.04	0.12	-0.22	0.71**
	(0.10)	(0.10)	(0.10)	(0.19)	(0.15)
Observations	15,457	15,457	15,457	7,553	7,904
χ^2	883	975	996	463	472
p	0.00	0.00	0.00	0.00	0.00
R^2	0.07	0.08	0.09	0.08	0.09
Log-likelihood	-5,079.32	-5,028.74	-5,010.81	-2,618.05	-2, 299.93

* $p<0.10$, ** $p<0.05$, *** $p<0.01$. Robust standard errors in brackets. No multicollinearity according to VIF. Weighting variable: share of number of organisational affiliations.

To obtain a more intuitive understanding of the effect of economic growth in each phase of the cycle, the data is split into pre- and post-crisis periods. Column 4 shows that the effect of GDP growth before the crisis is significant with a negative sign. On the contrary, Column 5 shows that impact of GDP growth rate, during and after the crisis, is significant and positive.

The combined effect is presented in a residual plot for logistic regression (see Fig. 6). In this plot, it is clear that the residuals follow a quadratic pattern; the relationship between GDP growth and university co-authorship varies depending on the phase of the cycle. For example, when GDP growth decelerates fast (more than -2%), it is expected that the probability of co-publication will increase. However, when GDP growth decelerates slowly or accelerates, the probability of university co-authorship decreases. Hence, it can be concluded that firms' co-publication with universities is unlikely when the economy is expanding and more likely when the economy is slowing down.

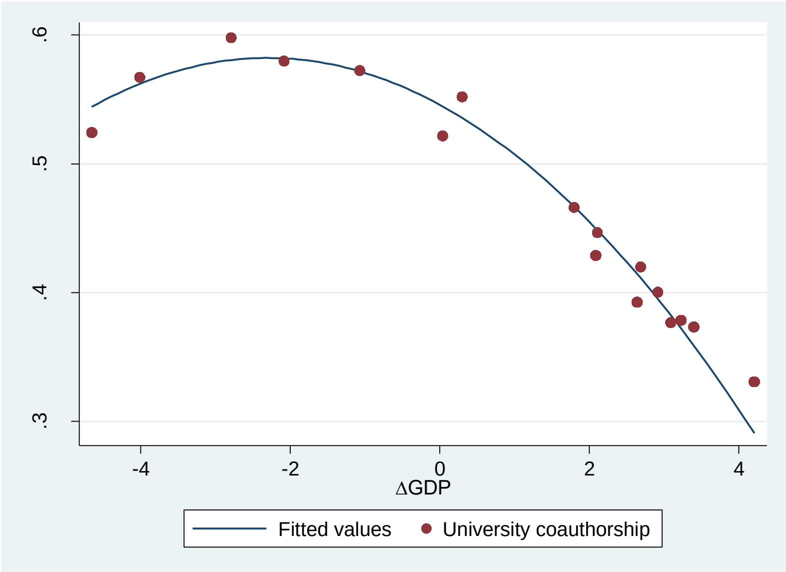

Fig. 6. Curvilinear effect of GDP growth on university co-authorship: Plot of the residuals of logistic model estimation.

5.2. Scientific impact of industry publications

The second group of estimations focuses on the scientific impact of publications. The results of the negative binomial regressions appear in Table 3. All estimations include fixed effects for the region and science field. Regarding control variables, Column 1 shows that all of them have positive, significant effects on scientific impact. The positive sign of *firm size* implies the greater the size of firms, the greater the scientific impact of their publications. The positive sign of *foreign collaboration* indicates that international co-publications may be more beneficial than national ones (Goldfinch et al., 2003), although some authors indicate that it depends on the country of collaboration (Schmoch

& Schubert 2008). *Team size* appears to have a positive effect, probably because there are more authors researching and communicating with other researchers, who subsequently cite them (Aksnes, 2003; Frenken et al., 2010; Mckelvey & Rake, 2020). Finally, *multidisciplinarity* indicates a positive effect, probably due to the association of this variable with high-quality research results.

Column 2 shows the negative lineal effect of ΔGDP on the scientific impact of firms' creation output; i.e. the overall countercyclical behaviour of this scientific impact. However, the coefficient of ΔGDP^2 is statistically significant and reveals a negative quadratic relationship with scientific impact, as observed in Column 3: that is, in crisis, when the economy stagnates and slows down, the scientific impact of firms increases; however, when the economy recovers, the scientific impact of firms decreases. The test by Lind and Mehlum (2010) confirms the presence of an inverted U-shape relationship between GDP growth rate and the scientific impact of firms' creation output. Hence, this result confirms Hypothesis 2.

The effect of knowledge co-creation with universities, university co-authorship, on firms' scientific impact is positive and significant, regardless of whether ΔGDP^2 is excluded (Column 2) or included (Column 3). Hence, co-creation with universities increases scientific impact. This confirms Hypothesis 3.

Column 4 adds an interaction between university co-authorship and ΔGDP. It does not provide a significant result, implying that the economic growth does not moderate the effect of university co-authorship on firms' scientific impact; therefore, Hypothesis 4 is not confirmed.[4] Taken together with the verification of Hypothesis 1, the results suggest

[4] University co-authorship was also studied in interaction with ΔGDP^2 in order to test whether the scientific co-creation output with universities flattened the curvilinear effect of economic growth on the scientific impact of business science; however, no significant results were obtained.

that university contribution to the scientific impact of firms grows in crises because the probability of co-authorship increases, not because co-authorship yields better results than in expansions.

The results in columns 5 and 6 break down the sample by period. For the pre-crisis sample, GDP growth rate has a significant and negative effect on firms' scientific impact, whereas for the post-crisis sample, GDP growth rate has a positive significant effect. University co-authorship has a similar positive effect.

Table 3. Negative binomial model estimation of scientific impact

	1 Full sample	2 Full sample	3 Full sample	4 Full sample	5 Pre-crisis (2000-2008)	6 Post-crisis (2009-2016)
ΔGDP_{t-2}		-0.03**	-0.04**	-0.04**	-0.10**	0.03*
		(0.01)	(0.01)	(0.01)	(0.02)	(0.01)
ΔGDP^2_{t-2} (H2)			-0.01**	-0.01**		
			(0.00)	(0.00)		
University co-authorship (H3)		0.16**	0.15**	0.15**	0.18**	0.12**
		(0.03)	(0.03)	(0.03)	(0.04)	(0.04)
University co-authorship * ΔGDP_{t-2} (H4)				-0.01		
				(0.01)		
Firm size	0.13**	0.16**	0.16**	0.16**	0.13**	0.15**
	(0.03)	(0.03)	(0.03)	(0.03)	(0.04)	(0.04)
Foreign collaboration	0.08**	0.08**	0.07**	0.07**	0.11**	0.05**
	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)
Team size	0.06**	0.06**	0.06**	0.06**	0.07**	0.04**
	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)	(0.01)
Multidisciplinarity	0.26**	0.28**	0.29**	0.29**	0.45**	0.19**
	(0.04)	(0.04)	(0.04)	(0.04)	(0.07)	(0.06)
Science field	Significant	Significant	Significant	Significant	Significant	Significant
Region	Significant	Significant	Significant	Significant	Significant	Significant
Constant	0.93**	0.90**	0.99**	0.99**	0.68**	1.23**
	(0.07)	(0.07)	(0.07)	(0.07)	(0.12)	(0.09)
Observations	14,528	14,528	14,528	14,528	6,971	7,557
χ^2	467	545	575	575	403	221
p	0.00	0.00	0.00	0.00	0	0
R^2	0.01	0.02	0.02	0.02	0.02	0.01
Log-likelihood	-18,653.42	-18,614.93	-18597.40	-18,597.33	-8,913.15	-9,626.47

* p<0.10, ** p<0.05, *** p<0.01. Robust standard errors in brackets. No multicollinearity according to VIF. Weighting variable: share of number of organisational affiliations.

5.3. Split sample analysis by scientific field

It was determined whether the sign and significance of the coefficients of the independent variables vary across scientific fields in the first level of aggregation of Web of Science subject categories (Life sciences & Biomedicine, Physical sciences, Technology).[5] Table 4 Columns 1 to 3 confirm the inverted U-shaped relationship between GDP growth rate and the probability of university co-authorship for every science field. Columns 4 to 6 confirm the negative effect of squared GDP growth rate and the positive effect of university co-authorship on business scientific impact for every science field.

With regard to the interaction between university co-authorship and ΔGDP on firms' scientific impact, Columns 4 and 5 support the original result of the non-effect in the case of Life sciences and Physical sciences; however, in the case of Technology, Column 6 shows that economic growth increases the positive effect of scientific co-creation output with universities on the scientific impact of business science. The significance of the estimated coefficient is weak (less than 10%), but the fact that it contradicts Hypothesis 4 deserves some discussion. A possible explanation of this distinctive feature is that in periods of positive economic growth, technologically innovative firms become important drivers of the higher innovation investment (Archibugi et al., 2013). In expansionary phases, technological firms are willing to expand innovation though the formalisation of R&D interactions and capitalisation of technological opportunities (Perez, 2003; Archibugi et al., 2013). This upswing in the economy would also lead to an improvement in the impact of business science as the novelty of new technology increases (Foster et al., 2015; Tahamtan et al., 2016).

[5] Social sciences and Arts & Humanities were excluded, due to the small number of observations. This is not surprising, given that data referring to this field are not sufficiently covered by WoS (Hicks, 2004).

Another explanation, especially in the case of Technology, is that firms' scientific impact may receive greater benefits from scientific co-production with academic partners who provide predominantly basic knowledge, while the research of technological firms focuses mostly on applied activities, which leads to better quality research output (Scandura & Iammarino, 2021).

Table 4. Logistic model estimation of university co-authorship and negative binomial model of scientific impact, by scientific field

	University co-authorship			Scientific impact		
	1 Life sciences	2 Physical sciences	3 Technology	4 Life sciences	5 Physical sciences	6 Technology
ΔGDP_{t-2}	-0.06**	-0.09**	-0.23**	-0.03**	-0.04**	-0.10**
	(0.01)	(0.02)	(0.02)	(0.01)	(0.01)	(0.02)
ΔGDP^2_{t-2} (H1&2)	-0.02**	-0.03**	-0.05**	-0.01**	-0.01*	-0.02**
	(0.00)	(0.01)	(0.01)	(0.00)	(0.00)	(0.01)
University co-authorship (H3)				0.07*	0.17**	0.43**
				(0.03)	(0.05)	(0.07)
University co-authorship*ΔGDP_{t-2} (H4)				-0.00	0.01	0.05*
				(0.01)	(0.02)	(0.03)
Firm size	-0.80**	-0.25**	0.15	0.12**	0.08	0.25**
	(0.07)	(0.09)	(0.13)	(0.03)	(0.05)	(0.07)
Foreign	0.07**	-0.04	0.08	0.05**	0.09**	0.11**
collaboration	(0.01)	(0.03)	(0.08)	(0.01)	(0.02)	(0.03)
Team size	-0.03**	0.01	0.00	0.06**	0.04**	0.06**
	(0.01)	(0.01)	(0.02)	(0.00)	(0.01)	(0.01)
Multidisciplinarity	1.16**	0.14	0.57**	0.28**	-0.03	0.53**
	(0.12)	(0.10)	(0.1)	(0.06)	(0.06)	(0.07)
Science field	Significant	Significant	Significant	Significant	Significant	Significant
Region	Significant	Significant	Significant	Significant	Significant	Significant
Constant	-0.89**	0.96**	-0.09	0.93**	1.45**	0.30*
	(0.17)	(0.20)	(0.20)	(0.09)	(0.12)	(0.14)
Observations	11,144	3,393	3,448	10,584	3,242	3,136
χ^2	724	147	333	330	169	1,909
P	0.00	0.00	0.00	0.00	0.00	0.00
R^2	0.10	0.05	0.12	0.01	0.01	0.03
Log-likelihood	3,088.37	1,319.59	-1,395.78	-12,283.95	-5,390.90	-4,897.21

* p<0.10, ** p<0.05, *** p<0.01. Robust standard errors in brackets. No multicollinearity according to VIF. Weighting variable: share of number of organisational affiliations.

5.4. Robustness checks

A set of robustness tests were applied to the findings. First, it was decided to refine the analysis regarding firm size variable. In previous estimations, in order to maintain the number of observations from the full sample, the total number of co-publications from firms was used as a proxy variable for firm size. However, to provide a more precise empirical examination, an additional regression analysis was conducted in which firm size calculation was based on the number of employees and profitability based on the return on investment (ROI) of firms (Hartmann et al., 2006; Kamien & Schwartz, 1978). To this end, the System of Analysis of Iberian Balance Sheets (SABI database), compiled by Bureau van Dijk, was used to control for firm-level data. Information on approximately 30,000 companies was downloaded. Matches were found for 500 firms from 2,426 companies in the total sample by using a company name-matching algorithm and manual review. The results in Table 5 confirm previous finding and reinforce the support for Hypotheses 1 to 3, but not 4.

Table 5. Logistic model estimation of university co-authorship and negative binomial model estimation of business scientific impact: SABI-matched subsample

	1 University co-authorship	2 Scientific impact
ΔGDP_{t-2}	-0.09**	-0.05**
	(0.02)	(0.01)
ΔGDP^2_{t-2} (H1&2)	-0.02**	-0.01**
	(0.01)	(0.00)
University co-authorship (H3)		0.12**
		(0.05)
University co-authorship * ΔGDP_{t-2}(H4)		-0.02
		(0.02)
Employees_{t-2}	0.00*	-0.00**
	(0.00)	(0.00)
Profitability (ROI) $_{t-2}$	0.00	-0.01*
	(0.00)	(0.00)
Foreign collaboration	0.02	0.05**
	(0.04)	(0.02)
Team size	0.00	0.06**
	(0.01)	(0.01)
Multidisciplinarity	-0.02	0.19*
	(0.13)	(0.07)
Science field	Significant	Significant
Region	Significant	Significant
Constant	0.01	-0.10*
	(0.19)	(0.04)
Observations	5,320	5,061
χ^2	432	262
p	0.00	0.00
R^2	0.14	0.02
Log-likelihood	-1,653.48	-6,594.34

* p<0.10, ** p<0.05, *** p<0.01. Robust standard errors in brackets. No multicollinearity according to VIF. Weighting variable: share of number of organisational affiliations.

Second, a robustness check was performed to overcome the limitations regarding the use of citation counts as an indicator of scientific impact. Frenken et al. (2010) mentioned that this measure does not consider the relative impact or the citation behaviour across disciplines. Therefore, a different specification of the second dependent variable was considered, the Field Normalised Citation Score (FNCS). The indicator aims to normalise citation counts for differences between fields, so that the computation of scientific impact is not influenced by/independent of the subject category of a paper (Rehn et al., 2007). To calculate FNCS, the relative number of citations of a single publication (2-year windows) was divided by the average of citations received by all Spanish papers in the same subject fields and the same period. Consider the following example: a Spanish paper published in 2016 belongs to two categories: “Biomedicine” and “Physical Sciences”, their FNCS would be the number of citations received in 2016, 2017 and 2018 divided by the average number of citations of all publications in “Biomedicine” in 2016, plus the number of citations received in those same years divided by the average of citations of all publications in “Physical Sciences” in 2016 and divided by 2.

To check the scientific impact of the co-creation of firms using the FNCS indicator the Tobit model was applied, because FNCS presents continuous observations that take values greater than zero, which reflects a censored data distribution. It was noted that the results in both models do not change. The results in Table 6, Column 1, support the finding of an inverted U-shaped relationship between ΔGDP and the scientific impact of the creation output of firms. In the pre-crisis sample, a significant and negative effect of GDP growth rate is observed on firms’ scientific impact, whereas for the post-crisis sample, GDP growth rate has a positive significant effect. Moreover, the effect of knowledge co-creation with universities, university co-authorship, on the scientific impact of firms confirms the result that co-creation with universities increases scientific impact.

Table 6. Tobit model estimation of normalised scientific impact

	1 Full sample	2 Pre-crisis (2000-2008)	3 Post-crisis (2009-2016)
ΔGDP_{t-2}	-0.00	-0.10*	0.06*
	(0.01)	(0.04)	(0.02)
ΔGDP^2_{t-2} (H2)	-0.01**		
	(0.01)		
University co-authorship (H3)	0.44**	0.46**	0.48**
	(0.07)	(0.10)	(0.09)
University co-authorship * ΔGDP_{t-2} (H4)	-0.04		
	(0.02)		
Firm size	0.45**	0.40**	0.41**
	(0.07)	(0.12)	(0.09)
Foreign collaboration	0.16**	0.22**	0.11**
	(0.03)	(0.05)	(0.03)
Team size	0.03	0.01	0.07**
	(0.03)	(0.03)	(0.01)
Multidisciplinarity	0.63**	0.80**	0.44**
	(0.11)	(0.16)	(0.14)
Science field	Significant	Significant	Significant
Region	Significant	Significant	Significant
Constant	1.37**	1.33**	1.33**
	(0.22)	(0.30)	(0.20)
Observations	14,544	6,788	7,756
χ^2			
p	0.00	0.00	0.00
R^2	0.01	0.01	0.01
Log-likelihood	-15,915.11	-7,816.29	-8,054.86

* $p<0.10$, ** $p<0.05$, *** $p<0.01$. Robust standard errors in brackets. No multicollinearity according to VIF. Weighting variable: share of number of organisational affiliations.

Fig. 7 illustrates the specific contribution of universities in the scientific impact of co-creation of knowledge. The scatter plot and regression lines describe the quadratic pattern of Tobit residual estimations. The effect of GDP growth on the normalised scientific impact of university and industry co-creation is higher with universities than with other type of institutions, in both phases of the cycle.[6]

[6] The results are also robust to the exclusion of the firm size outliers or the exclusion of firm co-publications with joint university-government labs.

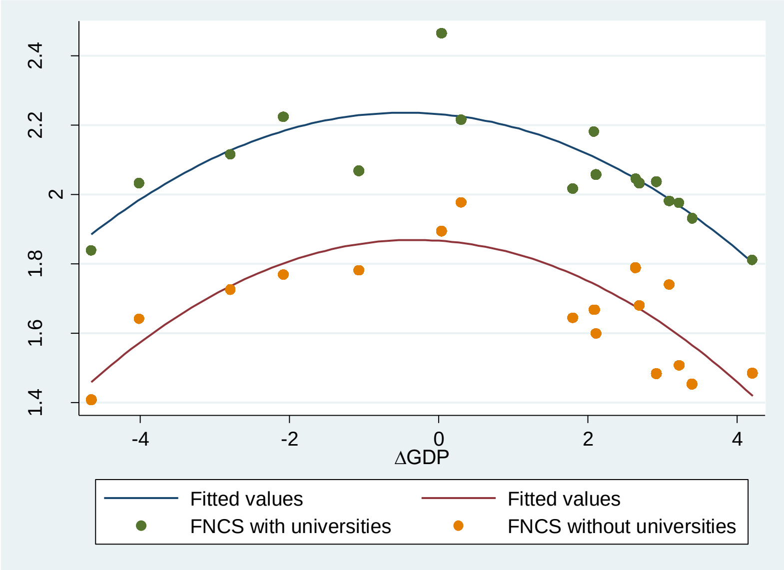

Fig. 7. Curvilinear effect of GDP growth on normalised scientific impact: Plot of the residuals of Tobit model estimation, with and without universities.

6. Conclusions

Knowledge is at the core of economic growth and the basis of the social welfare model (Schmookler, 2013; David & Foray, 2003). Past research has shown that university-industry scientific knowledge co-creation output and firms' scientific impact depend on individual, organisational and institutional factors (Halperin & Chakrabarti, 1987; Carayol & Matt, 2006; McKelvey & Rake, 2016; 2020; Yegros-Yegros et al., 2016; Arora et al., 2017). This research analyses how time also matters, and specifically how university-industry scientific knowledge co-creation output and firms' scientific impact react to the different phases of the economic cycle.

This study proposed a type of university-industry cycle theory, according to which economic growth maintains a curvilinear relationship with the co-creation of scientific knowledge of firms with universities, it being negative during expansions but positive during recessions. By using a large database of co-publications made by Spanish firms with universities in the context of the Great Recession, empirical support has been identified confirming that the scientific impact of the knowledge output of firms reacts with a similar curvilinear behaviour to growth; and also that scientific co-creation output with universities increases firms' scientific impact at any given moment in time.

The findings suggest that public policies to reinforce R&D cooperation must be nuanced according to each stage of the economic cycle. In times of recession, the impulse taken by the co-production of knowledge owing to the mobility of public resources will reinforce the collaboration of the industry (D'Agostino & Moreno Serrano 2016), but it should be strengthened by facilitating industry collaboration and accelerating the publication of co-creation output. Nevertheless, government investment in R&D cooperation should be adjusted more to the collaboration needs of universities, so they can fill any gaps they have and strengthen their research performance in order to be able to capitalise its returns in the future. Moreover, governments must avoid public resources moving to companies *en masse*, which in the long term will harm the co-creation of knowledge, resulting in companies leading the way in science, and universities being unable to react to crises with autonomy. In times of expansion, it seems necessary to improve support to co-creation as a means of enhancing the quality of firms' science, in part to anticipate a possible crisis that may come later.

These results apply particularly to the Life sciences and Physical sciences, to sustain the level of scientific knowledge co-creation during expansions. In the science field of Technology, an additional advantage of growth is that it boosts the contribution of university co-authorship to firms' scientific impact. This suggests that, contrary to common wisdom and usual policies, the promotion of the co-creation of knowledge of firms with universities in the science field of Technology makes particular sense during expansions. Hence, this study recommends tailored policy efforts to support university-industry knowledge according the phase of the cycle and the scientific field.

The research has limitations and poses avenues for future inquires. The observed changes in business scientific coproduction with universities according to the growth cycle may be explained by underlying changes in the frequency and type of interaction channels used, so further analysis of these channels would enrich understanding. The study focuses on scientific cooperation and impact, so analogous questions could apply to technological cooperation and impact. The empirical evidence is on one country and one growth cycle only, so expanding the dataset to other countries and longer time spans would help verify the theory. The data is on national co-publications only and not on international co-publications, so it cannot be confirmed nor refuted whether a different pattern occurs in co-publications of firms with foreign universities.

It is worth mentioning that in the course of this study the coronavirus pandemic shock the economies of the world. In 2020, the global economy suffered a rapid economic downturn to recession due to an unprecedented crisis characterised by changes in the behaviour of individuals due to enforced social distancing, strict quarantines, and changes in daily life patterns (Stoll, 2020). It is not only the economy that has suffered from the effects of the pandemic, but also people’s physical and mental health. As damaging and harmful as the pandemic is, the effects on knowledge co-creation are expected to continue on the same positive path that follows crisis phases that this study shows, although they will probably be more accentuated.

Crises are threats to the economy, but they also present challenges that, if well managed, can become opportunities (Buheji & Ahmed, 2020). The context and the results obtained from this work show that studying economic growth and science co-created by companies and universities is a current issue. The way in which governments face economic turns, through their innovation policies, will be decisive in anticipating crises and emerging from them stronger.

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