International Journal of Industrial Organization 93 (2024) 103056

Contents lists available at ScienceDirect

International Journal of Industrial Organization

journal homepage: www.elsevier.com/locate/ijio

The role of public external knowledge for firm innovativeness[☆]

María García-Vega[a,*], Óscar Vicente-Chirivella[b]

[a] *School of Economics, University of Nottingham, University Park, Nottingham NG7 2RD, United Kingdom*
[b] *Department of Economic Analysis, Universitat de València, Avd de los Naranjos s/n, Valencia 46022, Spain*

ARTICLE INFO

JEL classification:
L25
D22
L24
O31

Keywords:
Public research organizations
Universities
External knowledge
Firm innovativeness

ABSTRACT

Public research organizations (PROs) and universities receive large amounts of public funding for the generation and transmission of knowledge, and companies contract external knowledge from both. An important question for the management of a firm's R&D and for public innovation policies is: What is more beneficial for the generation of firm innovations, external knowledge created by PROs or by universities? In this paper, we assess the impact of external knowledge from PROs versus universities on firm innovativeness. We use information on R&D acquisitions from a panel dataset of more than 10,000 Spanish firms from 2005 to 2014. We show that external knowledge from PROs and universities increases firm innovativeness. Our results suggest that knowledge generated by PROs is more sensitive to the absorptive capacity of the firm than knowledge generated by universities. This has implications for research policy, R&D management, and organizational strategies of firms' knowledge activities. Firms with low absorptive capacities benefit relatively more from knowledge generated by universities than from knowledge generated by PROs. Moreover, R&D managers should plan both their external and internal R&D if they acquire external R&D from PROs.

1. Introduction

Public research organizations (PROs hereafter) and universities are key players in a country's innovation landscape, which is why they typically receive large amounts of public funding for knowledge generation and transfer.[1] External knowledge from PROs and universities is potentially very important for private sector innovation and, consequently, for economic growth. As Arora et al. (2016,

☆ We would like to thank Fabrizio Adriani, Andrés Barge-Gil, Simon Gächter, Johannes Gallé, Elena Huergo, Georg Licht, Catalina Martínez-García, Bettina Peters, Dolores Añón and Martin Wörter for their helpful comments. We thank conference and seminar participants at the EARIE 2021, INFER 2021, EBES 2021, 2022 ZEW Public Finance Conference, University Complutense of Madrid, University of Leicester, ETH (Zurich), CSIC (Madrid), University of Valencia, Ivie (Valencia). Óscar Vicente-Chirivella acknowledges financial support from Grant PID2021-124266OB-I00 funded by MCIN/AEI/ 10.13039/501100011033 and by "ERDF A way of making Europe" and Grant TED2021-130232B-I00 funded by MCIN/AEI/ 10.13039/501100011033. We are grateful to the two referees and the editor Michelle Sovinsky for their very helpful comments and suggestions.

* Corresponding author.
E-mail address: maria.garcia-vega@nottingham.ac.uk (M. García-Vega).

[1] For example, for the year 2017, German PROs received €13.5 bn from R&D public national sources and German universities received €17.3 bn; French PROs received €5.8 bn from R&D public national sources and French universities received €10.2 bn; US PROs obtained $53.9 bn from R&D public national sources and US universities received $67.5 bn. (Source: OECD Main Science and Technology Indicators). Examples of PROs are National Aeronautics and Space Administration (NASA) in US, Max Planck Institutes in Germany, National Centre for Scientific Research (CNRS) in France or Consejo Superior de Organizaciones Científicas (CSIC) in Spain.

https://doi.org/10.1016/j.ijindorg.2024.103056
Received 10 November 2022; Received in revised form 29 January 2024; Accepted 8 February 2024
Available online 10 February 2024
0167-7187/

2018) show, firms are increasingly relying more on external rather than internal knowledge to generate innovations, and a firm's absorptive capacity (that is internal capabilities) is becoming fundamental for integrating this external knowledge. In this paper, we empirically assess, for the first time, the comparative effect between external knowledge from PROs and universities on firm innovation and investigate the role of absorptive capacities as a fundamental mechanism for the differences between the impact of the two types of public external knowledge.

What is more beneficial for the generation of firm innovation: external knowledge generated by PROs or by universities? This is an important question for the management of a firm's knowledge-based activities and its R&D governance in order to maximize innovation output. Answers to this question are also informative for policy makers who want to evaluate the efficiency of public innovation policies. Moreover, studying how internal absorptive capacities contributes to the integration of external public knowledge is key to understanding the internal R&D requirements needed for the innovation process when knowledge is generated by different public providers.

Knowledge from PROs and universities is a fundamental part of firms' external knowledge flows (Arvanitis et al., 2008; Caloghirou et al., 2021; Cohen et al., 2002; González-Pernía et al., 2015; Tether and Tajar 2008). However, most studies ignore differences between PROs and universities when evaluating the impact of public research on firm innovation. The relative effect of the transmission of knowledge from PROs and universities on firms' innovativeness is not straightforward. The existing literature suggests that universities and PROs are central producers of both basic and applied research around the world (Bentley et al., 2015; Senker, 2006; Cruz-Castro et al., 2012, 2020) and, therefore, there may not be any significant differential effects between the external knowledge of PROs and universities on firm innovation.[2] However, there are differences between PROs and universities that may affect their transmission of knowledge and, consequently, the importance of the moderating role of absorptive capacities to assimilate knowledge (Cohen and Levinthal, 1990).[3] Bozeman (2000) argues that the knowledge produced by PROs tends to be more interdisciplinary and produced with more expensive equipment than that produced by universities. These features may increase the complexity of the PROs' external knowledge which may therefore be more difficult to transfer and to assimilate by private firms than knowledge generated by universities.

According to Lane and Lubatkin (1998), for knowledge transfer to be effective, there must be a similar knowledge base between the organization that is transferring the knowledge and the organization that receives it. As a consequence, firms might need high levels of absorptive capacity to fully assimilate external knowledge from PROs as compared to the absorptive capacity needed to use knowledge transferred from universities.[4] An example of the importance of this matching can be found in the strategy carried out by the Industrial Technology Research Institute (ITRI) in Taiwan.[5] As explained by Intarakumnerd and Goto (2018), in the 70 s the ITRI had the capacity to transfer very complex knowledge, but companies were not ready to exploit that knowledge efficiently. When companies improved their absorptive capacity, the ITRI began to transfer cutting-edge knowledge. Between the 1970s and early 1990s, as Taiwanese firms were lagging behind technologically advanced countries, the ITRI focused on disseminating cutting-edge foreign technologies, and helping firms to develop their absorptive capacity to exploit those technologies. From the late 1990s, leading firms started to conduct in-house R&D and changed their status from ``imitators'' to ``innovators''. As a result, ITRI shifted its focus to help local companies building R&D capabilities and developing cutting-edge products. Since the 2000s, ITRI have vigorously developed next-generation technologies such as artificial intelligence, 5G or cloud technology (ITRI, 2021). Currently, ITRI has links with leading global technology companies such as LG, Microsoft, Janssen Pharmaceutica, Taiwan Semiconductor Manufacturing Company, etc.[6]

Another difference between PROs and universities is the educational mission of universities, which can facilitate the transmission of knowledge to private enterprises. For example, the communication between firms and universities may be more fluid than between firms and PROs due to different cultures and also due to the personal and professional links between former students and academics.[7] As a consequence, the transfer of tacit knowledge from universities might be higher than from PROs. Firms with low absorptive capacity might benefit relatively more from the knowledge generated by universities, while firms might need high absorptive capacity to benefit from the knowledge produced by PROs.

For our empirical analysis, we use a panel dataset from 2005 to 2014 with information on firm external knowledge from more than

[2] For example, Jaffe and Trajtenberg (1996) and Jaffe and Lerner (2001) conclude that, since the 1990s, US public labs have become more similar to universities in terms of the type of research generated.

[3] The role of absorptive capacity is particularly relevant for the assimilation of external public knowledge because public research rarely leads to readily usable product market innovations (Apa et al., 2021; Bloedon and Stokes, 1994; Kobarg et al., 2018; Min et al., 2020). Moreover, the private and public sector have different research cultures, which can lead to different informational barriers (Siegel et al., 2004).

[4] Consistent with this idea is that on average PROs have more technical support for their research than universities. According to the Main Science and Technology Indicators from the OECD, on average, from the total number of R&D workers in PROs, 38 % are technicians and other supporting staff, while this percentage is 22 % in the case of universities. In the case of Spain, 80 % of the total number of R&D employees in universities are researchers, and 20 % technicians and other support staff; for PROs, these percentages are 54 % and 46 %, respectively.

[5] ITRI, established in 1973, is a PRO responsible to and partly supervised by the Ministry of Economic Affairs, whose mission is to promote new industries and modernize existing ones.

[6] See https://www.itri.org.tw/english/index.aspx

[7] Contractual technology transfers require a high-involvement relationship (Perkmann and Walsh, 2007; Fontana et al., 2006; D'Este and Patel, 2007) that embodies both codified as well as tacit knowledge. Universities, which combine basic and applied research with a broader education mission, might have a comparative advantage over PROs to transfer their tacit knowledge because of their teaching experience (Debackere and Veugelers, 2005; OECD, 2002). For instance, Kunttu (2017) provides evidence of the importance of the educational origin in long-term university–industry relationships.

10,000 Spanish firms. Our dataset provides unique information on firm R&D acquisitions distinguishing between acquisitions from PROs and from universities. Using this information, we construct measures of external knowledge or technology transfers from PROs and universities.[8] We first measure the impact of each type of external knowledge relative to a control group of firms without external knowledge. We calculate the average treatment effect of external knowledge on firm innovativeness distinguishing by type of provider. Our results reveal that, compared to firms with no external knowledge, knowledge transfers from only PROs increase product innovations by 7.3 %; transfers from only universities increase product innovations by 7.4 %; and transfers from both PROs and universities increase product innovation by 4.8 %. However, these effects are not different at standard statistical levels. This suggests that in terms of firm innovativeness, there are no significant differences between the external knowledge coming from PROs and those coming from universities.

Next, we restrict our sample to firms with transfers of external knowledge, either from PROs or universities. Using a propensity score reweighting estimator, we show that the relative effect of knowledge transfer from PROs versus universities is moderated by the level of firm absorptive capacity; that is, the intensity of a firm's internal R&D capability. We find that, for firms with low levels of absorptive capacities, the effect of external knowledge from universities on firm innovativeness is higher than the effect of knowledge from PROs. As a firm's absorptive capacity increases, the differential effect becomes smaller. This suggests that technology transfers from PROs are sensitive to the level of firm absorptive capacities. Firms need to have medium or high levels of absorptive capacity to profit more from the knowledge generated by PROs than from universities.

Our results are robust to several robustness checks, including heterogeneity in treatment timing, comparing separately each type of external knowledge provider to firms without external knowledge, and generalization concerns: We find the same results for the external knowledge acquired from foreign PROs and foreign universities. This suggests that our findings are not driven by specific institutional characteristics of Spanish PROs or universities, but that it is a more general result. We also find that there are positive spillovers mostly coming from universities. Our results suggest that spillovers from universities are higher than those from PROs. A possible explanation is that universities can transfer their knowledge in a more accessible way than PROs. The teaching mission of universities is consistent with this idea. Another possibility is that the commercial R&D of PROs is more complex than that of universities and, therefore, firms need to have a high absorptive capacity to assimilate it.

While the impact of university-industry collaboration on firms' innovation performance has been analyzed previously (Yu and Lee, 2017; Szücs, 2018; Kafouros et al., 2015; Vega-Jurado et al., 2017; García-Vega and Vicente-Chirivella, 2020; Añón, 2016; among others),[9] to our knowledge, there is no evidence on the *comparative importance* of knowledge transfers from PROs and universities on firms' innovativeness, which is key for firms to design their optimal strategy to acquire external knowledge and for the design of public innovation policies. We contribute to the literature by providing the first evidence on the importance of absorptive capacity for the relative effectiveness of public knowledge transfer from universities and PROs. We also highlight the role of both PROs and universities as key organizations for knowledge transfer to the private sector.

Our results have implications for the management of R&D and organizational strategies of firms' knowledge activities. From an applied perspective, our results suggest that some firms might have less incentive to invest in their internal R&D if they can acquire external knowledge from universities. In contrast, R&D managers might plan both their external and internal R&D if they acquire external R&D from PROs. Consequently, federal and regional policies for funding universities and PROs might influence firms' innovations and strategic R&D decisions in different ways.

The rest of the paper is organized as follows. In Section 2, we provide the related literature. In Section 3, we summarize the main features of the Spanish institutional framework of PROs and universities that are relevant for our study. In Section 4, we describe the data and empirical methodology. In Section 5, we present our baseline results, robustness checks, and describe results for other firm characteristics. As robustness checks, we compare the effect of each type of external knowledge provider separately to firms that do not acquire external knowledge, and determine the moderating effect of absorptive capacity; we control for heterogeneity in treatment timing and treatment intensity; we use alternative measures of absorptive capacity; we control for pre-innovation output; we control for persistence of treatment; we perform a placebo test by randomly assigning the treatment to the non-treated firms; we eliminate potential outliers, and we address the issue of external validity or generalization of our results. Finally, in Section 6, we discuss the implications and conclude.

2. Related literature and contributions

Our paper is mostly related to the literature that studies the effects of PROs and universities on firm innovation. For a sample of German firms, Beise and Stahl (1999) found that, approximately, 40 % of firms reported that their innovations could not have been developed without the research from public laboratories and another 40 % reported that their innovation could not have been developed without knowledge transfers from universities. Eom and Lee (2010) analyze, for a sample of Korean firms, the determinants

[8] Previous studies that consider R&D acquisitions at the firm level are García-Vega and Vicente-Chirivella (2020), Medda et al. (2005) and Vega-Jurado et al. (2017), among others.

[9] See Perkmann et al. (2013, 2021) for a review of the literature on university-industry relations.

of industry-university and industry-government research institutes (IGRIs) cooperation and its impact on firms' performance. They find that cooperation with universities and cooperation with IGRIs has a similar positive effect. However, once they controlled for endogeneity, this positive effect turned negative and became statistically insignificant at standard levels, which indicates the importance of selection.

In contrast to these articles, we explore the effect of *contractual* technology transfers, or external knowledge, measured as R&D acquisitions on firm innovation and we use, among others, matching techniques to address the potential selection bias problem. Moreover, we specifically analyze differences between the effectiveness of external knowledge from universities or PROs and account for differences in absorptive capacities. García-Vega and Vicente-Chirivella (2020) using the same dataset than this paper, find a positive effect of university technology transfers on firm innovativeness. Differently from them, we do not restrict our study to universities, but analyze and compare the possible differential effects between the external knowledge that is provided by universities and PROs. This comparison is one of the main contributions of our paper.

To our knowledge, there is no evidence on the comparison between the effects of PROs and universities on private industry. We believe that this is important gap of knowledge because universities and PROs are the fundamental providers of public knowledge in most countries, and both receive large amounts of public funding. Therefore, understanding how PROs and universities differ in terms of their direct and indirect effects as well as firm heterogeneity are important elements for the design of efficient public R&D policies and for firms' R&D management. Another difference of our paper with respect to García-Vega and Vicente-Chirivella (2020) is that we examine firms' determinants to obtain external knowledge from different public providers. A further contribution is that we find that absorptive capacity plays a fundamental role in moderating the effect of knowledge transfers from PROs and universities. This shows that different firms benefit differently from the external knowledge generated by universities and PROs and sheds light on their different role within the public research system. Apa et al. (2021) and Kobarg et al. (2018) explicitly recognize the impact of absorptive capacity on firms' ability to gain from university-industry collaborations. In contrast to these studies, we distinguish between PROs and universities. We consider the possibility that the moderating role of absorptive capacity may not be the same for universities and PROs.

Szücs (2018) investigates the effect of the EC's Seventh Framework Programme (FP7) that ran from 2007 to 2013 in the EU, which enhanced cooperation between universities, research centres (not exclusively public) and private firms on firm innovation. The author finds a positive effect of cooperation with universities for innovation and no effect of cooperation with research centres. In contrast to Szücs (2018), we compare the effect of external contractual knowledge generated in public institutions instead of cooperation and we specifically study public research organizations. An advantage of contractual R&D is that we can account for the direction of the knowledge transfer which facilitates identification. Another fundamental difference is that we study the effect of *public* external knowledge on private innovation. Our contribution is that we can specifically distinguish between PROs and public universities and therefore study their differential effect on innovation. Furthermore, we provide evidence for the role of absorptive capacity to explain the differential effects between technology transfers from PROs and universities.

Finally, some related papers investigate the importance of sources of information and formal and informal collaborations from public institutions. Barge-Gil and Vivas-Augier (2019) compare the effect on sales from new-to-the-market products for firms collaborating with universities and those collaborating with knowledge-intensive business services. Capron and Cincera (2004) study the determinants that explain the use of difference sources of information, including universities. Fudickar and Hottenrott (2019) investigate the impact of formal and informal interactions with publicly funded scientific research on the innovativeness of German start-ups. They find that firms engaged in these interactions were more likely to introduce new products and services to the market and that absorptive capacities played a fundamental moderating role for the effectiveness of technological collaborations. In contrast to these studies, our paper distinguishes between the impact of external knowledge from PROs and universities. Moreover, we specifically analyze their determinants and their differential effects.

3. The Spanish institutional framework

Before explaining our dataset, we summarize the main features of the Spanish institutional framework of PROs and universities that are relevant for our study. As in most countries, the Spanish innovation system has different objectives and organizational forms.[10] Spanish R&D organizations can be grouped as follows: Higher education, PROs, businesses, and private non-profit institutions (OECD, 2021).[11]

In Spain, there are five main PROs, which are directly overseen by the central government. The Spanish National Research Council (CSIC), the National Centre for Energy, Environment and Technological Research (CIEMAT), the National Institute for Aerospace Technology (INTA), the National Health Institute Carlos III (ISCIII) and the Astrophysics Institute of the Canary Islands (IAC). CSIC is by far the largest Spanish PRO and includes 120 specialized and transdisciplinary centres which carry out all kinds of fundamental and

[10] See OECD (2021) for a review of the Spanish Science, Technology and Innovation System.

[11] Higher education includes public and private universities, plus other higher education institutions. In Spain, 90 % of R&D spending in higher education institutions is carried out by public universities; private universities account for 7 % and other higher education institutions account for 3 %. For the sake of simplicity, we will refer to higher education as universities. In terms of PROs, this includes central government public research organizations, other research organizations dependent on the central government, public research organizations dependent on regional governments and other centres. The share of R&D expenditure of ``other centres'' within the total expenditure of PROs is less than 10 %. Therefore, in our definition of PROs "other centres" will be excluded (Source: INE Estadística sobre actividades de I + D.)

applied research (Cruz-Castro et al., 2012).[12] The remaining four centres are highly specialized and mission-oriented.[13] PROs under regional control are small in terms of number of researchers and budget, but they have more flexibility than central government research centres. Both central and regional centres primarily focus on research.

Spain has 83 universities. Fifty of these are public and thirty-three are private. In Spain, private universities are mostly teaching-focused and, therefore, R&D activities by higher education institutions are carried out in public universities. Public universities are financially dependent on the autonomous regions and undertake research in all areas of knowledge.

4. Data, characteristics of firms with external knowledge, and methodology

4.1. The data

Our dataset comes from a yearly survey of Spanish firms (*Panel de Innovación Tecnológica, PITEC*) from 2005 to 2014. The Spanish National Institute of Statistics constructs this database based on annual responses to the Spanish Community Innovation Survey (CIS).[14] This is a unique dataset that includes representative samples of the universe of firms that are trying to innovate in Spain. The initial sample is based on 128,420 firm-year observations in total, which accounts for an unbalanced panel of 10,392 companies.

In the dataset, the company reports its *external R&D expenditures* distinguishing between type of providers.[15] The survey distinguishes between external R&D expenditures from PROs and from universities. With that information, we construct the following dummy variables to measure the different types of external knowledge transfers: *PROs only*, which is a dummy variable that takes the value one if the firm reports acquiring R&D only from PROs; *universities only*, which refers to firms that purchase R&D services only from universities; and *PROs and universities*, which corresponds to firms that acquire external R&D from both PROs and universities. Measures of external knowledge transfers similar to ours are used by García-Vega and Vicente-Chirivella (2020), Fudickar and Hottenrott (2019), Vega-Jurado et al. (2017) and Medda et al. (2005). On average, the percentage of firms in the sample that obtain external knowledge from PROs is only 0.66 %, and the percentage of firms with external knowledge from PROs and universities is 0.71 %. These numbers compare with 4.70 % of firms that obtain external knowledge from universities only.

In Table 1, we present the descriptive statistics of the data. In column (1), we show the means of the key variables for firms that obtain external knowledge from PROs only; in column (2), we present averages for firms with external knowledge from universities only; in column (3), we show means for companies that obtain external knowledge from both PROs and universities; and, in column (4), we present averages for firms without external knowledge from PROs or universities, which we denote as *non-transfers*. In Tables A1a and A1b in the Appendix, we show the differences of means and a *t*-test of the difference of means of these variables.

In Panel A of Table 1, we show the volume of external knowledge by provider, measured as the proportion of internal R&D. In the sample, the average and the standard deviation of the expenditure of R&D acquisitions and internal R&D are very similar between the groups in columns (1) and (2).[16] The difference of means in Table A1a in the Appendix shows that there are not differences at statistical levels between the two variables. These features suggest that although more firms obtain knowledge transfers from universities than from PROs, independently of the type of provider, the average expenditure on external knowledge per firm is similar between groups. The descriptive statistics in column (3) suggest that firms that obtain external knowledge from both types of providers spend approximately 7.8 % more from universities than from PROs.[17]

Our main dependent variable is product innovation, which is one of the most commonly used proxies for innovation (Caloghirou et al., 2021). This variable is a dummy variable that takes the value one if a firm reports having introduced new or significantly improved products in the current or previous two years. In the robustness section, we also consider as dependent variables other measures that account for output intensity such as sales from new products to the market, and other innovation outputs such as quality

[12] Of the total budget allocated to central PROs in 2021, 54 % corresponds to CSIC (Ministerio de Ciencia e Innovación, 2021).

[13] The literature distinguishes between four types of PROs (Sanz-Menéndez et al., 2011): mission-oriented centres; public research centres and councils; research technology organizations; and independent research institutes. While the first two types are purely public, the latter two comprise a mix of semi-public, private, and non-profit organizations. Given that our main objective is to assess whether public external knowledge from PROs and universities has a differential effect on firm innovativeness, our definition of PROs only includes mission-oriented centres, and public research centres and councils.

[14] The PITEC survey is specifically designed to analyze R&D and other innovating activities following the recommendations of the OSLO Manual on performing innovation surveys (see OECD, 2005). The survey is targeted at manufacturing and services companies whose main economic activity corresponds to sections C, D, and E of NACE 93, except non-industrial companies because of the imprecision of methodological marking in the international context by other branches of activity. Details on the survey and data access guidelines can be obtained at https://icono.fecyt.es/pitec/descarga-la-base-de-datos. The methodology about the construction of the dataset is available here: http://www.ine.es/prodyser/microdatos/metodologia_pitec.pdf. (Access 04/10/2021). From 2014 there has been a change in the survey, such that some firms are not surveyed every year. This generates a change in the sample composition. To ensure the consistency of the composition of the panel, for our analysis, we consider the sample until 2014.

[15] External R&D expenditures are defined in the survey as: "Acquisitions of R&D services through contracts, informal agreements, etc. Funds to finance other companies, research associations, etc., which do not directly imply purchases of R&D services are excluded". R&D services are defined as: "Creative work to increase the volume of knowledge and to create new or improved products and processes (including the development of software)". They specifically exclude licenses and royalties, which are a different question in the survey.

[16] The average internal R&D for firms with only PROs is 1.8 million euros, while for universities only is 1.7 million euros.

[17] This difference is statistically significant at standard levels as shown in Table A1a in the Appendix.

Table 1
Means of main variables.

	External knowledge from			Non-transfers
	PROs only (1)	Universities only (2)	Both PROs & Universities (3)	(4)
Panel A: Volume of R&D external knowledge:				
PROs	61.58	0.00	25.32	0.00
	(38.25)	(0.00)	(23.93)	(0.00)
Universities	0.00	59.76	27.30	0.00
	(0.00)	(38.86)	(23.90)	(0.00)
Panel B: Other firm characteristics:				
Product innovation (0/1)	0.74	0.75	0.79	0.45
	(0.44)	(0.43)	(0.41)	(0.50)
Innovation investment (in logs.)	12.81	12.95	14.34	6.80
	(2.81)	(2.64)	(2.11)	(6.19)
Physical investment (in logs.)	8.45	8.37	8.79	7.88
	(1.74)	(1.80)	(1.72)	(1.94)
Exporter (0/1)	0.80	0.76	0.80	0.47
	(0.40)	(0.43)	(0.40)	(0.50)
Labour productivity (in logs.)	11.98	11.84	12.25	11.67
	(1.05)	(1.14)	(1.18)	(1.10)
Number of employees (in logs.)	4.29	4.33	5.26	4.07
	(1.61)	(1.62)	(1.68)	(1.73)
Internal R&D intensity	1.28	1.42	1.90	0.44
	(2.40)	(2.91)	(4.47)	(2.65)
Absorptive capacity	1.37	1.35	1.46	0.23
	(1.16)	(1.27)	(1.17)	(1.49)
No. observations	846	6036	912	120,626

Notes: Standard deviations in parentheses. The symbol (0/1) means dummy variable. The variables *PROs (Universities*) is the external R&D expenditures coming from PROs (Universities) as proportion of the internal R&D. *Product innovation* is an indicator that equals one if the firm reports having product innovations during the periods t to $t-2$. *Innovation investment* is the natural logarithm of total innovation expenditures; *Physical investment* is the natural logarithm of physical investments per employee; *Exporter* is a dummy variable that take the value one if the firm is an exporter; *Labour productivity* is the natural logarithm of sales over number of employees; *Number of employees* is the natural logarithm of the number of employees. *Internal R&D expenditures* is the spending on internal R&D activities per employee. *Absorptive capacity* is measured as in Escribano et al. (2009) by the principal component of the internal R&D, a dummy if the firm has a fully staffed R&D department, a dummy if the firm provides training for its R&D personnel and the ratio of scientists and researchers to total employees) of firms with external knowledge from universities.

improvements, process innovation or patents.

The mean values of firm characteristics are presented in panel B of Table 1. The evidence in panel B suggests that there are small differences between firms that obtain external knowledge from PROs only and firms that obtain external knowledge from universities only in terms of innovation outputs. For example, the average product innovation for firms with technology transfers from PROs equals 0.74 (with std. = 0.44) versus 0.75 (with std. = 0.43) for firms with technology transfers from universities only. This is corroborated in Table A1b, where the difference of means is statistically equivalent. Comparing columns (1) and (2) with column (3) reveals that firms with both types of external knowledge transfers (column 3) slightly outperform firms with external knowledge transfers from PROs only and firms with external knowledge transfers from universities only.[18] This suggests that there might be some complementarities between external knowledge transfers from PROs and universities. Finally, firms without external knowledge are, on average, less likely to innovate than firms with any type of technology transfer.

We also report averages for the following firm characteristics: the natural logarithm of total innovation investment; physical investment, which is measured as the natural logarithm of physical investments per employee; a dummy variable that takes the value one if the firm is an exporter; labour productivity, which is measured as the natural logarithm of sales per employee; the natural logarithm of the number of employees; the internal R&D intensity, measured as the internal R&D per employee; and the absorptive capacity at the firm level.

Our measure of absorptive capacity follows Escribano et al. (2009), which combines several elements of the internal knowledge capabilities of a firm. Absorptive capacity is constructed as the principal component of the following variables: the internal R&D, a dummy variable that takes the value one if the firm has a fully staffed R&D department, a dummy variable that takes the value one if the firm provides training for its R&D personnel and the ratio of scientists and researchers over total employees.

To avoid that our measure of absorptive capacity is influenced by external knowledge from PROs or universities, we construct the variable at the beginning of the sample period. The advantage of this measure is that it accounts for several firm characteristics that reflect the capabilities of a firm to assimilate external knowledge within the organization. For example, if external knowledge requires some tacit knowledge and personal interactions for processing key information, then different variables that consider distinct

[18] The difference of means is statistically different from zero in both cases.

characteristics of R&D personnel can be an accurate measure of firm absorptive capacities. We also replicate our analysis considering alternative measures of absorptive capacity. First, we use the measure of Escribano et al. (2009) and we construct it at the industry level and at the beginning of the sample period. We do so in order to obtain additional exogeneity in the variable. Second, we consider Escribano et al. (2009), measured at the industry level and at time t, to address the issue that absorptive capacity might vary over time. Third, as in Cohen and Levinthal (1989, 1990), we consider firm R&D intensity.

Firms with external knowledge transfers from PROs only, and from universities only, seem very similar in all different firm observable characteristics of Panel B. Firms with both types of external knowledge are larger, invest relatively more in innovation activities, and are more productive than firms with only one type of provider. On average, firms without external knowledge invest less in total and internal R&D, are smaller, less productive, less likely to be exporters and have less absorptive capacity than firms with external knowledge and these differences are statistically different from zero in all cases.

Overall, the descriptive statistics in Table 1 suggest that firms with external knowledge from PROs only and from universities only are very similar in terms of observable characteristics, while firms with both external knowledge from PROs and universities are very different from firms with only one type of provider.

Fig. 1 shows the distribution of absorptive capacity for firms with external knowledge from PROs only, from universities only, from both PROs and universities and from companies without external knowledge. It is clear from Fig. 1 that for firms with any type of external knowledge, the three distributions largely overlap and are different from firms without external knowledge. This indicates that firms with high levels of absorptive capacity do not select themselves into any specific type of provider. Nevertheless, to avoid that our results are affected by extreme cases, in our robustness check section, we restrict our sample to firms in the common support of absorptive capacity.

Table 2 presents the percentage of firms by sector, differentiating by type of technology transfer. In columns (1) and (2), we show the ratio between the number of firms with external knowledge over the total number of firms in each sector. In column (3) we present the total number of firms in each sector. The descriptive statistics from Table 2 indicate that firms with external knowledge transfers from PROs only are concentrated in the agricultural and pharmaceutical sectors. Firms with external knowledge from universities only are mainly in the pharmaceutical, agricultural, and chemical sector. This reflects the importance of external knowledge for the pharmaceutical sector and the agricultural industry, which is an important sector of activity in the Spanish economy.

4.2. *Characteristics of firms with external knowledge from PROs and universities*

Before studying the effects of transfers of external knowledge from PROs and universities for firm innovation, we explore their determinants. To do this, we estimate probit models where we regress a dummy variable indicator of whether a firm receives external knowledge from PROs only, universities or both PROs and universities during the sample period on firm characteristics with respect to different samples of control groups, explained below, as in Eq. (1).

Formally,

$$External\ Knowledge^{s}_{it} = \begin{cases} 1 \text{ if } \alpha + X^{'}_{it-1}\beta + d_t + \varepsilon_{it} > 0 \\ 0 \text{ if } \alpha + X^{'}_{it-1}\beta + d_t + \varepsilon_{it} \le 0, \end{cases} \tag{1}$$

for s = PROs only, Universities only, Both PROs and universities

In Eq. (1), *External Knowledge* is a dummy variable that takes the value one if the firm receives external knowledge from PROs only and zero otherwise, or from universities only and zero otherwise, or from both PROs and universities and zero otherwise. The vector X_{it-1} reflects pre-treatment firm characteristics that influence the likelihood to obtain external knowledge; d_t denotes time dummies, and ε_{it} is the error term, which we assume is normally distributed with variance σ^2_ε. We include, as pre-treatment characteristics, the following variables: the natural logarithm of the number of employees, which accounts for firm size; the internal R&D intensity, which we include in order to control for existing research capabilities of the firm; labour productivity, which we include to account for firm efficiency; the natural logarithm of the average physical investment, which accounts for the physical assets of the firm; and being an exporter, which accounts for exposure to foreign and highly competitive markets. We also add lagged values of product innovation. Finally, we add geographic, industry and year dummies. In all regressions, we use cluster-robust standard errors. The results are reported in Table 3, where each of the columns corresponds to different samples, explained below.

We consider six different samples. In columns (1), (4) and (5) the treatment is firms with external knowledge from PROs only. We compare firms with external knowledge from PROs only and consider as control group: firms without external knowledge (in column 1), firms with external knowledge from universities only in column (4), and firms with external knowledge from both PROs and universities (column 5). In columns (2) and (6), the treatment is firms with knowledge from universities only and the control groups are firms without knowledge transfers (column 2) and firms with knowledge transfers from both PROs and universities (column 6). In column (3) the treatment is firms with knowledge from both PROs and universities and the control group are firms without knowledge transfers.

In column (1), we show the determinants of firms that obtain external knowledge from PROs only versus firms without transfers (non-transfers). Before obtaining external knowledge from PROs, firms have more internal R&D and more physical investments than firms without external knowledge. They are also more likely to be exporters and larger in terms of number of employees. We also observe that product innovation influences the external knowledge coming from PROs. These results suggest that a firm's globalization exposure and its internal R&D and capital intensity are important determinants to obtain external knowledge from PROs.

In column (2) and (3), we present results for the determinants of firms that obtain external knowledge from universities only

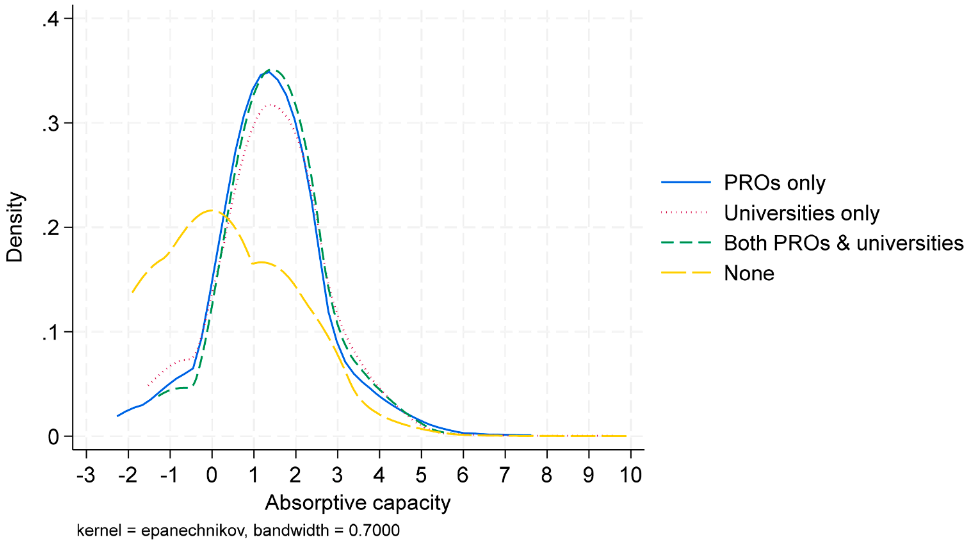

Fig. 1. Distribution of absorptive capacity for firms with different providers of external knowledge.
Note: We show the empirical probability density function (pdf) of absorptive capacity (measured as in Escribano et al. (2009) by the principal component of the natural log of internal R&D, a dummy if the firm has a fully staffed R&D department, a dummy if the firm provides training for its R&D personnel and the ratio of scientists and researchers to total employees) of firms with external knowledge from universities only, with external knowledge from PROs only and of firms for both and firms without external knowledge.

Table 2
Number of observations and percentages by sector of activity.

	Percentage of firms with respect to the number of observations in the sector			Number of observations
Sectors	PROs only (1)	Universities only (2)	Both PROs & Universities (3)	(4)
Agriculture	4.6 %	11.1 %	3.2 %	1391
Mining and extractive industries	0.5 %	7.1 %	1.7 %	5991
Food and tobacco	1.2 %	7.0 %	1.6 %	7036
Textiles, printing and wood	0.6 %	2.1 %	0.3 %	9579
Chemicals	1.4 %	9.3 %	1.8 %	5454
Pharmaceuticals	4.7 %	24.6 %	9.6 %	1485
Manufacturing of non-metallic products	0.8 %	3.8 %	0.7 %	6437
Manufacturing of basic metals	0.7 %	5.1 %	0.5 %	9536
Manufacturing of electrical and optimal equipment	0.8 %	7.9 %	0.5 %	10,040
Manufacturing of transport equipment	0.9 %	4.8 %	0.6 %	3215
Wholesale and retail trade	0.6 %	2.7 %	0.4 %	8328
Transport, storage and communication	0.3 %	4.2 %	0.2 %	7569
Final intermediation	0.2 %	0.7 %	0.0 %	2059
Real estate, renting and business activities	0.4 %	5.1 %	0.3 %	7602
R&D services, software and technical analysis	0.3 %	3.1 %	0.4 %	33,873
Other services	0.2 %	2.4 %	0.2 %	8825
No. observations	846	6036	912	128,420

(column 2) and for firms that obtain external knowledge from both PROs and universities (column 3), as compared to firms without external knowledge. The results are similar in terms of significance to those in column (1), but the coefficients are on average larger. This suggests that there are differences in the determinants of the firms that choose different providers of external knowledge. We explore these differences in the following columns.

In column (4), we compare determinants of external knowledge from PROs only as compared to from universities only. Here, we find some interesting empirical regularities. The estimated coefficient for number of employees is negative and significant at standard statistical levels. This suggests that firms that obtain external knowledge from PROs are smaller than firms that obtain external knowledge from universities. In contrast, firms that obtain external knowledge from PROs are more likely to be exporters than firms that obtain external knowledge from universities.

Once we compare firms with external knowledge from PROs as compared to firms with respect to firms with both PROs and universities (in column 5) and to firms with external knowledge from universities only as compared to firms with both external knowledge from PROs and universities (in column 6), the results suggest that firms with both providers are larger and more R&D

Table 3
Characteristics of firms that obtain external knowledge from PROs and/or Universities. Probit models.

Dependent variable: External knowledge from	PROs only	Universities only	Both PROs & Universities	PROs only	PROs only	Universities only
	(1)	(2)	(3)	(4)	(5)	(6)
Number of employees (in logs.)$_{t-1}$	0.0004*	0.0067***	0.0025***	−0.0080***	−0.0976***	−0.0314***
	(0.000)	(0.001)	(0.000)	(0.003)	(0.010)	(0.003)
Internal R&D intensity$_{t-1}$	0.0002***	0.0022***	0.0002***	0.0002	−0.0164***	−0.0056***
	(0.000)	(0.000)	(0.000)	(0.002)	(0.006)	(0.001)
Labour productivity (in logs.)$_{t-1}$	−0.0001	−0.0012	0.0002	0.0007	0.0199	−0.0008
	(0.000)	(0.001)	(0.000)	(0.005)	(0.016)	(0.005)
Physical investment (in logs.)$_{t-1}$	0.0010***	0.0068***	0.0011***	0.0009	−0.0116	−0.0060**
	(0.000)	(0.001)	(0.000)	(0.003)	(0.008)	(0.002)
Exporter$_{t-1}$	0.0045***	0.0226***	0.0011**	0.0203*	0.0696**	0.0102
	(0.001)	(0.002)	(0.001)	(0.010)	(0.035)	(0.011)
Product innovation$_{t-1}$	0.0071***	0.0444***	0.0057***	0.0138	−0.0038	−0.0228**
	(0.001)	(0.002)	(0.001)	(0.010)	(0.033)	(0.010)
No. observations	64,601	69,113	64,720	5970	1577	6089
Sample:	*PROs only and non-transfers*	*Universities only and non-transfers*	*Both PROs & Universities and non-transfers*	*PROs only and Universities only*	*PROs only and Both PROs and Universities*	*Universities only and Both PROs and Universities*

Note: All regressions include 14 industry dummies, three geographical dummies and year dummies. Explanation of variables in Table 1. We report marginal effects at sample means. Estimated standard errors are in parentheses. * Significant at 10 %, ** significant at 5 %, *** significant at 1 %.

intensive than firms with just one type of knowledge provider. We observe that product innovation is an important determinant for having both providers versus firms that have one provider of knowledge only. These results suggest that there are some differences between firms that acquire external knowledge from PROs only, from universities only and from both that we need to control for to assess the differential effects of types of public external knowledge.

4.3. Methodology

In this sub-section we examine the methodology that we use to study the relative effects of external knowledge from PROs and universities and the moderating effect of absorptive capacity.

4.3.1. The relative effects of external knowledge from PROs and from universities

We estimate the relative effect of PROs and from universities on firm innovation in two different ways. In the first method, we estimate the effect of external knowledge from PROs only, from universities only, from both PROs and universities and we use as a control group firms without external knowledge as in Eq. (2):

$$Y_{it+2} = \alpha + \beta_1 \ External\ Knowledge_{it}^{PRO} + \beta_2 \ External\ Knowledge_{it}^{Uni} + \beta_3 \ External\ Knowledge_{it}^{Both} + \nu \ Absorptive\ Capacity_i + \gamma \ X_{it} + \lambda_{jt} + \phi_t + \varepsilon_{it}, \quad (2)$$

where Y_{it+2} is product innovation output; *External Knowledge*$_{it}^{PRO}$ is a dummy variable that takes the value one if firm *i* has obtained external knowledge from PROs only at time *t*, *External Knowledge*$_{it}^{Uni}$ is a dummy variable that takes the value one if firm *i* has acquired external knowledge from universities only at time *t*, *External Knowledge*$_{it}^{Both}$ is a dummy variable that takes the value one if firm *i* has obtained external knowledge from both PROs and universities at time *t*, and *Absorptive Capacity*$_i$ is measured as in Escribano et al. (2009) at the beginning of our sample period. The variable *product innovation* is included with a two-period lead.

We study the effect on innovation up to two years after receiving external knowledge. The reason for the two-year lead is due to the definition of the variables in the survey. Following the usual definitions in Community Innovation Surveys, in our dataset, innovation output questions are for the current and previous two years, while innovation inputs and accounting variables are for the current period. In the robustness section, we also provide results with a three-year lead of the dependent variable. We consider the initial level of absorptive capacity in order not to confound the effects of external knowledge. Moreover, in the robustness check section, we also consider alternative measures of absorptive capacity, including a time-variant measure, previously explained in Section 4.1. In Eq. (2), X_{it} are firm observable characteristics that may be correlated with both external knowledge and product innovation, λ_{jt} are sector-specific time-fixed effects that absorb shocks in a given year common to all firms within the same industry, ϕ_t are time-fixed effects, and ε_{it} is the error term. In some regressions, we also add firm fixed effects to absorb time invariant firm characteristics. The coefficients of interest are β_1, β_2 and β_3 that capture the effect of the technology transfer from PROs only, universities only and both PROs and universities respectively. The coefficients are identified from time variation in external knowledge within firms, while controlling for shocks hitting all firms in the same industry.

In the second method, we restrict our sample to firms with external knowledge transfers, as in Eq. (3). Initially, we consider as a treated group firms with external knowledge transfers from PROs only, and as a control group firms with external knowledge transfers from universities only. In this way, we can directly determine differences between providers: If the estimated coefficient β in Eq. (3) is small and not statistically significantly different from zero, it would imply that the effect of having external knowledge from PROs only is the same at statistical levels on product innovation than the effect of having external knowledge from universities only. As explained below in detail, in different regressions, we also estimate the differential effects of the providers of external knowledge when we compare them separately with respect to firms without public external knowledge.

$$Y_{it+2} = \alpha + \beta \ External\ Knowledge_{it}^{PRO} + \nu \ Absorptive\ Capacity_i + \gamma \ X_{it} + \lambda_{jt} + \phi_t + \varepsilon_{it}. \tag{3}$$

The advantage of this second methodology is that it allows us to address the potential selection bias generated by the firms being different before treatment using a propensity score reweighting estimator. This technique implies calculating the predicted probability of obtaining external knowledge flows (or propensity score) in terms of observable characteristics and use the propensity scores as weights in Eq. (3). For example, Guadalupe et al. (2012), Haucap et al. (2019), Jabbour et al. (2019), and Javorcik and Poelhekke (2017) use propensity score matching techniques to calculate average treatment effects and control by selection. We calculate the propensity score using a probit estimation for the probability of obtaining external knowledge flows from PROs only as a function of the lagged natural logarithm of employment; lagged natural logarithm of sales, lagged sales growth, lagged natural logarithm of physical investments, lagged indicator of being an exporter and previous product innovations (up to three lags), in order to control for lagged innovation output.[19]

4.3.2. The moderating effect of absorptive capacity

Since a second goal of our analysis is to investigate the relative effect of the external knowledge from PROs and universities on innovation and how this effect is moderated by firm absorptive capacity, we extend Eq. (3) to include the interaction of firm absorptive capacity with external knowledge as in the following equation:

$$Y_{it+2} = \alpha + \theta \ External\ Knowledge_{it}^{PRO} x Absorptive\ Capacity_i + +\beta \ External\ Knowledge_{it}^{PRO} + \nu \ Absorptive\ Capacity_i + \gamma \ X_{it} + \lambda_{jt} + \phi_t + \varepsilon_{it} \tag{4}$$

In Eq. (4) the main variables of interest are the external knowledge transfer and the double interaction. The coefficient β measures the effect of external knowledge transfers from PROs as compared to the impact of external knowledge transfers from universities, and the coefficient θ measures the moderating effect of absorptive capacity for this effect. We exploit the variation of absorptive capacities across firms. In this way, the double interaction accounts whether the effect of external knowledge transfers for PROs is stronger in firms with high absorptive capacity. Conceptually, θ measures the difference between the changes in product innovation driven by external knowledge transfers from PROs in a firm with high absorptive capacity versus a firm with less absorptive capacity. We anticipate that companies with low absorptive capacities benefit relatively more from external knowledge transfers from universities than from PROs. Therefore, we expect that $\theta > 0$ and $\beta < 0$. Note that we include industry time fixed effects, which control for industry-specific time trends, year fixed effects to absorb macroeconomic shocks and, in some specifications, we also include firm fixed effects to control for time-invariant firm characteristics. As in Eq. (3), we use a propensity score reweighting estimator, which essentially absorbs differences between firms' characteristics before obtaining external knowledge. We also use this methodology to estimate the moderating effect of absorptive capacity for each of the providers separately as compared to firms without public external knowledge.

5. Results

5.1. Main results

In Table 4, we present the results of estimating Eq. (2) by OLS. In column (1), we show results with year fixed effects; in column (2) we add sector-specific time effects; in column (3), we show results where we add lagged firm characteristics to control for firm characteristics that can affect innovation. We consider firm size, labour productivity, average physical investment, being an exporter, internal R&D and product innovation, which are variables that, as shown in Table 3, are determinants of firm external knowledge transfers. We have defined these variables previously in Section 4.1. In column (4), we present the results with firm fixed effects. Here, we use the "pre-sample mean scaling" method of Blundell et al. (1999) to control for fixed effects. We use the pre-sample value of the dependent variable to proxy for unobserved heterogeneity. This methodology has been previously used by Aghion et al. (2013), Bloom et al. (2013), Bloom et al. (2016), Galasso and Simcoe (2011) among others. In column (5), we add regional dummies and finally in

[19] We estimate the propensity score separately for three main sectors of activity (high-tech, medium-tech and low-tech). The classification of industries follows the Eurostat/OECD classification (https://www.oecd.org/sti/ind/48350231.pdf for manufactures and for services https://www.oecd-ilibrary.org/science-and-technology/revision-of-the-high-technology-sector-and-product-classification_134337307632, accessed 04.08.2023). We estimate the probability that a firm "is treated" in a given year. The estimated probability or propensity score can be denoted by $\widetilde{p}$. The weight of each treated firm can be calculated as $1/\widetilde{p}$, while the weight of each control firm can be calculated as $1/(1-\widetilde{p})$. Therefore, the weights change within firm across time.

column (6), we include standard firm fixed effects.

The results from all columns suggest that external knowledge transfers from PROs only, universities only, and both PROs and universities, strongly increases firm innovativeness. For example, the estimates from the most conservative specification in column (6) suggest that external knowledge transfers from PROs only increases product innovation by 7.3 %; external knowledge transfers from universities only increases product innovation by 7.4 %; and external knowledge transfers from both PROs and universities increases product innovation by 4.8 %. In all regressions, the results indicate that initial absorptive capacity increases firm innovation.[20]

To compare the estimated coefficients of external knowledge transfers from PROs only and from universities only, we present at the bottom of the table the *p*-value test for equality of coefficients. In all cases, we cannot reject the null hypothesis that the effects are the same between external knowledge transfers from PROs and universities; from PROs only; and from both. This suggests that, for the average firm, external knowledge transfers from PROs increases firm innovativeness in a similar way as external knowledge obtained from universities.

We further investigate whether there is a differential effect between providers of external knowledge using a propensity score matching and restricting the sample to firms with either external knowledge from PROs only, or from universities only. We estimate Eq. (3) for the reweighted sample. Before presenting the results of the estimations, we show, in Table A2 in the Appendix, the balancing test comparing observable characteristics for the reweighted sample for the treated (firms with external knowledge transfers from PROs only) and control group (firms with external knowledge transfers from universities only). The table indicates that, for the reweighted group, firms that obtain external knowledge from PROs only, and from universities only, have very similar observable characteristics before acquiring external knowledge. This indicates that our matching specification generates a well-balanced weighted sample, which implies that control and treatment group are equivalent in their overall observable characteristics before treatment.

In Table 5, we present the results from the propensity score reweighting estimation for different specifications, where we have combinations of year fixed effects (all columns); sector-specific fixed effects (columns 2 to 6); control variables (column 3); firm fixed effects with the pre-sample mean scaling method (columns 4, 5 and 6); regional dummies (column 5); and including time pre-trends in product innovation (column 6). In all cases, the estimated coefficient for having external knowledge transfers from PROs only (versus the control group of external knowledge from university only) is small and not significant at standard statistical levels. This corroborates the previous results from Table 4 and suggests that the impact of external knowledge transfers on product innovation for the average firm is very similar between the two types of public providers. Moreover, the effect of absorptive capacity is always positive and statistically significant. In column (6), we show that treatment and control groups have similar trends in product innovation before the treatment. The estimated coefficients for the pre-treatment years are small and not significantly different from zero and the rest of the estimates have a similar coefficient and standard errors. Finally, on the bottom of the table, we show the F-test, which indicates that we cannot reject the hypothesis that all the pre-treatment terms are jointly equal to zero.

To study the moderating role of firms' absorptive capacities on external knowledge transfers and innovation, we estimate Eq. (4) for the reweighted sample of firms with external knowledge transfers from either PROs only or universities only. We present the results in Table 6 for different measures of absorptive capacity. We include year fixed effects, sector-specific fixed effects, and firm fixed effects. In columns (1) to (3), we use absorptive capacity as in Escribano et al. (2009). In column (1), this measure is constructed at the firm level and at the beginning of the sample period. In column (2), absorptive capacity is at the industry level and at the beginning of the sample period, and in column (3), absorptive capacity is at the industry level and is time variant. In column (4), we measure absorptive capacity as the natural logarithm of internal R&D over size at the firm level and at the beginning of the sample period. For completeness, in Table A3 in the Appendix, we present the estimation of Eq. (2) using alternative measures of absorptive capacity, without significant changes in the overall results.

In all columns of Table 6, the estimated coefficients for the effect of PROs are negative and the estimated coefficients for the interaction term are positive. In all cases, the estimated coefficients are significant at $p < 0.05$. This suggests that firm absorptive capacity has a positive moderating effect on external knowledge from PROs. As for the magnitude of these effects, for example for column (1), a firm with absorptive capacity equal to 1.25 benefits the same from external knowledge from PROs as from external knowledge from universities to generate innovation.[21] The average absorptive capacity in that sample is equal to 1.37 and the median is equal to 1.31. Therefore, for a firm with average or below average absorptive capacity, the effect of external knowledge transfers from PROs on innovation is smaller than the effect of external knowledge from universities. However, as firm absorptive capacity increases, the relationship is reversed. Firms with external knowledge transfers from PROs have higher innovation than firms with external knowledge transfers from universities provided they also have high levels of absorptive capacities. In Fig. 2, we present this pattern. We plot the differential effect on product innovation of external knowledge from PROs versus universities. To do that, we calculate predicted product innovation. We consider the estimated coefficients of column (1) and we evaluate Eq. (4) for different percentiles of absorptive capacity.

Fig. 2 indicates that firms with very low levels of absorptive capacity (at the 1st percentile of the distribution) that obtain external knowledge from universities only are 15 % more likely to have product innovations than firms with the same level of absorptive capacity and with external knowledge from PROs only. When we look at the other extreme of the distribution of absorptive capacity (at the 99th percentile), we can see that a firm with external knowledge transfers from universities are 23 % less likely to have product innovations than firms with the same level of absorptive capacity and with external knowledge from PROs only. These numbers suggest

[20] In column (6), we cannot estimate the effect of absorptive capacity given that the effect is captured through the firm fixed effect dummies.

[21] This number is the threshold absorptive capacity and it is calculated as 0.060/0.048.

Table 4
Estimated effect of external knowledge from PROs and universities on product innovation.

	(1)	(2)	(3)	(4)	(5)	(6)
PROs only (0/1)	0.151***	0.153***	0.108***	0.106***	0.109***	0.073***
	(0.024)	(0.023)	(0.019)	(0.019)	(0.019)	(0.016)
Universities only (0/1)	0.155***	0.155***	0.094***	0.093***	0.096***	0.074***
	(0.011)	(0.010)	(0.009)	(0.009)	(0.009)	(0.009)
Both PROs & Universities (0/1)	0.186***	0.199***	0.085***	0.084***	0.086***	0.048**
	(0.026)	(0.025)	(0.021)	(0.021)	(0.021)	(0.020)
Absorptive capacity	0.116***	0.102***	0.062***	0.055***	0.046***	
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	
No. observations	78,222	77,558	48,131	48,131	48,131	77,842
p-value equal coefficients						
PROs only vs. Universities only	0.8831	0.9413	0.5046	0.5017	0.5368	0.9577
PROs only vs. Both	0.2851	0.1477	0.3979	0.3969	0.3832	0.2501
Year FEs	Yes	Yes	Yes	Yes	Yes	Yes
Sector specific time FEs	No	Yes	Yes	Yes	Yes	Yes
Control variables	No	No	Yes	Yes	Yes	No
Firm FEs (pre-sample mean scaling)	No	No	No	Yes	Yes	No
Firm FEs	No	No	No	No	No	Yes
Regional dummies	No	No	No	No	Yes	No

Note: Explanation of variables in Table 1. The symbol (0/1) means dummy variable. The standard errors are presented in parentheses and are clustered at the firm-level. We report the *p*-value corresponding to the null hypothesis that the effects of only PRO and only university are the same, as well as the hypothesis that PROs only and both PROs and universities are the same. *** **, * indicate a 1 %, 5 %, and 10 % significance level, respectively.

Table 5
Differential effect of external knowledge from PROs and external knowledge from universities. Reweighted sample.

	(1)	(2)	(3)	(4)	(5)	(6)
PROs only (0/1)	0.003	0.004	0.026	0.007	0.007	0.008
	(0.025)	(0.022)	(0.022)	(0.020)	(0.020)	(0.024)
Absorptive capacity	0.056***	0.060***	0.027***	0.039***	0.038***	0.029**
	(0.010)	(0.011)	(0.009)	(0.011)	(0.011)	(0.012)
PROs only (0/1) [−1]						−0.059
						(0.038)
PROs only (0/1) [−2]						−0.001
						(0.041)
PROs only (0/1) [−3]						0.054
						(0.045)
PROs only (0/1) [−4]						0.003
						(0.069)
PROs only (0/1) [−5]						−0.025
						(0.054)
No. observations	4951	4916	4243	4916	4916	3487
Pre-trends F-statistics						0.81
p-value						0.542
Year FEs	Yes	Yes	Yes	Yes	Yes	Yes
Sector specific time FEs	No	Yes	Yes	Yes	Yes	Yes
Control variables	No	No	Yes	No	No	No
Regional dummies	No	No	No	No	Yes	No
Firm FEs (pre-sample mean scaling)	No	No	No	Yes	Yes	Yes

Note: Explanation of variables in Table 1. Table 5 includes the reweighted sample of firms with external knowledge from PROs only and firms with external knowledge from universities only. The symbol (0/1) means dummy variable. The F statistic tests whether all estimated coefficients before treatment are jointly zero. The standard errors are presented in parentheses and are clustered at the firm-level. ***, **, * indicate a 1 %, 5 %, and 10 % significance level, respectively.

that there is some asymmetry in the extent of the moderating role of absorptive capacity.

5.2. Robustness checks

We perform several robustness checks to the baseline results. In these robustness checks, we compare the effect of each type of provider of external knowledge separately to firms not acquiring external knowledge, and we determine the moderating effect of absorptive capacity. We control for heterogeneity in treatment timing by presenting results by cohort and by using a dynamic model; for treatment intensity; for pre-innovation output; and for persistence of treatment. We perform a placebo test by randomly assigning treatment to non-treated firms; we eliminate extreme values of absorptive capacity by estimating within the common support of

Table 6
Moderating role of absorptive capacity PROs only versus universities only. Reweighted sample.

	(1)	(2)	(3)	(4)
Absorptive capacity as in Escribano et al. (2009)				
At the firm level and beginning of the sample period				
PROs only (0/1)	−0.060*			
	(0.034)			
PROs only (0/1) x Absorptive capacity	0.048***			
	(0.017)			
No. observations	4916			
At the industry level and beginning of sample period				
PROs only (0/1)		−0.067*		
		(0.036)		
PROs only (0/1) x Absorptive capacity 2		0.063***		
		(0.024)		
No. observations		4916		
At the industry level and time variant				
PROs only (0/1)			−0.061**	
			(0.030)	
PROs only (0/1) x Absorptive capacity3			0.094***	
			(0.024)	
No. observations			4916	
Absorptive capacity as internal R&D over sales				
At the firm level and beginning of sample period				
PROs only (0/1)				−0.322**
				(0.134)
PROs only (0/1) x Absorptive capacity1				0.039***
				(0.015)
No. observations				4492

Note: Explanation of variables in Table 1. Table 6 includes the reweighted sample of firms with external knowledge from PROs only and firms with external knowledge from universities only. The symbol (0/1) means dummy variable. The standard errors are presented in parentheses and are clustered at the firm-level. Columns (1), (2) and (4) include industry times year dummies, year and firm fixed effects. Column (3) includes industry dummies, year and firm fixed effects. All regressions include industry times year dummies, year and firm fixed effects. ***, **, * indicate a 1 %, 5 %, and 10 % significance level, respectively.

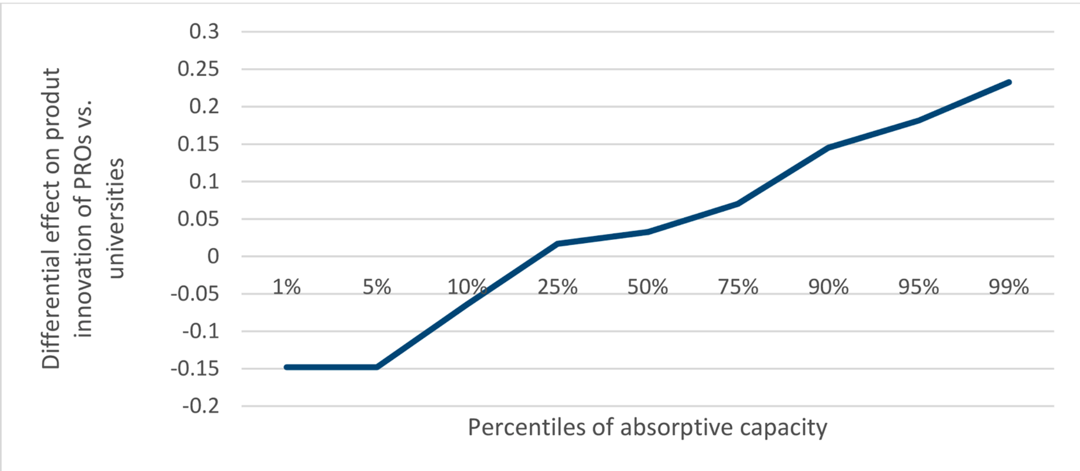

Fig. 2. Differential effect on product innovation of PROs only vs. universities only by firm absorptive capacity.

absorptive capacity and only for firms with positive internal R&D; and, finally, we tackle the issue of external validity by estimating the differential effect on innovation of external knowledge from foreign PROs and foreign universities.

5.2.1. *Comparing separately the effect of each type of public provider vs. firms without transfers of technology*

In this section, we estimate separately the effect on innovation of each type of treatment (PROs only, universities only and both PROs and universities) as compared to firms without transfers of technology. For each estimation, we use a different propensity score matching to control for the potential selection bias of each of the treatments, in order to guaranty the balancing properties, in the propensity score matching procedure, we include the initial value of the dependent variable as an additional control.

We present the results from the propensity score reweighting estimation in Table 7. In column (1), we estimate the effects of PROs

Table 7
Differential effect of different provided of external knowledge with respect to firms without external knowledge. Reweighted samples.

	(1)	(2)	(3)	(4)	(5)	(6)
PROs only (0/1)	0.100***			0.156***		
	(0.037)			(0.052)		
Universities only (0/1)		0.126***			0.099***	
		(0.018)			(0.030)	
Both PROs & Universities (0/1)			0.185***			0.191**
			(0.062)			(0.083)
Treatment (0/1) [−1]				−0.092	0.038	−0.110
				(0.116)	(0.034)	(0.150)
Treatment (0/1) [−2]				0.100	0.030	0.033
				(0.074)	(0.041)	(0.106)
Treatment (0/1) [−3]				−0.035	−0.014	0.100
				(0.079)	(0.036)	(0.172)
Treatment (0/1) [−4]				0.048	0.053	−0.049
				(0.096)	(0.033)	(0.170)
Treatment (0/1) [−5]				−0.127	−0.006	−0.196
				(0.132)	(0.039)	(0.156)
Absorptive capacity	0.095***	0.043***	0.044	0.065***	0.044***	0.032
	(0.015)	(0.008)	(0.027)	(0.019)	(0.010)	(0.028)
No. observations	34,070	36,644	41,777	18,851	20,253	26,429
Pre-trends F-stat				0.87	1.46	0.79
p-value				0.498	0.198	0.556
Year FEs	Yes	Yes	Yes	Yes	Yes	Yes
Sector specific time FEs	Yes	Yes	Yes	Yes	Yes	Yes
Sample (reweighted)	*PROs only vs. non-transfers*	*Universities only vs. non-transfers*	*Both PROs & Universities vs. non-transfers*	*PROs only vs. non-transfers*	*Universities only vs. non-transfers*	*Both PROs & Universities vs. non-transfers*

Note: Explanation of variables in Table 1. Table 7 includes the reweighted sample of firms. The symbol (0/1) means dummy variable. The F statistic tests whether all estimated coefficients before treatment are jointly zero. The standard errors are presented in parentheses and are clustered at the firm-level. ***, **, * indicate a 1 %, 5 %, and 10 % significance level, respectively.

Table 8
Moderating role of absorptive capacity for different provided of external knowledge with respect to firms without external knowledge. Reweighted samples.

	(1)	(2)	(3)
Sample: PROs only vs. none			
PROs only (0/1)	0.076*		
	(0.044)		
PROs only (0/1) x Absorptive capacity	0.040*		
	(0.023)		
No. observations	34,065		
Sample: Universities only vs. none			
Universities only (0/1)		0.168***	
		(0.023)	
Universities only (0/1) x Absorptive capacity		−0.058***	
		(0.014)	
No. observations		36,644	
Sample: Both PROs and universities vs. none			
Both PROs and universities (0/1)			0.270***
			(0.071)
Both PROs and universities (0/1) x Absorptive capacity			−0.114***
			(0.044)
No. observations			41,777

Note: Explanation of variables in Table 1. Table 8 includes the reweighted sample of firms. The symbol (0/1) means dummy variable. The standard errors are presented in parentheses and are clustered at the firm-level. All regressions include industry times year dummies, year and firm fixed effects. ***, **, * indicate a 1 %, 5 %, and 10 % significance level, respectively.

only versus non-transfers. In column (2), we compare universities only versus non-transfers. In column (3), we show both PROs and universities versus non-transfers. In columns (4) to (6), we include the time pre-trends in product innovation for all the different cases. In all cases, the effects of the different providers of external knowledge are positive and significantly different from zero. The estimated coefficients are in line with these previously estimated in Table 4. The estimations in columns (4) to (6) indicate that there is no differential trend between the treatment and control groups, which supports the causality of the positive impact of the different types of external knowledge on innovation. The *F*-test at the bottom of the table also indicates that we cannot reject the hypothesis that all the pre-treatment terms are jointly equal to zero.

Next, in Table 8, we assess the moderating effect of absorptive capacity of each treatment with respect to firms without external knowledge. As in the previous table, in column (1), we present the effects of PROs only, in column (2) of universities only, and in column (3) of both PROs and universities. In all cases, the estimated direct effect of the treatment is positive and significantly different from zero. In column (1), the interaction effect for PROs only is positive. This suggests that firms with higher absorptive capacity profit relatively more from the external knowledge coming from PROs than from firms with low absorptive capacity. This is consistent with our previous results and suggests that to fully benefit from the knowledge from PROs, companies need to have a certain degree of internal knowledge capabilities. In columns (2) and (3), the coefficients of the interaction term for universities only or for both PROs and universities is negative, which suggests that the external knowledge transfer from universities is relatively more beneficial for firms with low levels of absorptive capacity than to firms with high levels of absorptive capacity.

5.2.2. Heterogeneity in the treatment timing: results by cohort and a dynamic model

To check the robustness of the previous evidence, we consider variations in the timing of treatment. First, we estimate differences between cohorts of treatment and, second, we estimate a dynamic model using an event-study specification. Our sample period includes data from 2005 to 2014. A potential concern about the baseline specification is that the estimates might change over time and thus that they may differ across time. For example, our sample period includes a non-recession period (from 2005 to 2007) and the global financial crisis and the Great Recession of the late 2000s (which in Spain lasted from 2008 to 2013). It is possible that, during the recession period, severe financial constraints might have affected the way universities and PROs transfer their knowledge. Moreover, the recent literature in staggered treatments have shown that under time-varying treatment effects, two-way fixed effects might not be robust to OLS estimation due to the potential negative weights if earlier-treated groups are used as controls in the estimations (Sun and Abraham, 2021; Callaway and Sant'Anna, 2021; Goodman-Bacon, 2021).

To assess potential bias due to time heterogeneity of our treatments, we follow Wooldridge (2021) and estimate the effect of external knowledge transfers, distinguishing by different cohorts of treatment. The Wooldridge (2021) approach proposes a set of saturated interaction effects by adding cohort/year interactions to overcome the potential bias problem of the two-way fixed effects in difference-in-differences designs. This methodology allows the consistent estimations of ATTs without abandon simple regression approaches. We define different cohorts of treatment at the time of the first treatment and the comparison group are never treated units.[22] We consider three sets of regressions, which we estimate separately corresponding to the three possible cases. The treatment dummies in the first regression indicate when a firm obtained external knowledge for the first time from PROs only; in the second

[22] We implement the difference-in-difference (DID) estimator proposed by Wooldridge (2021) using the command jwdid in Stata.

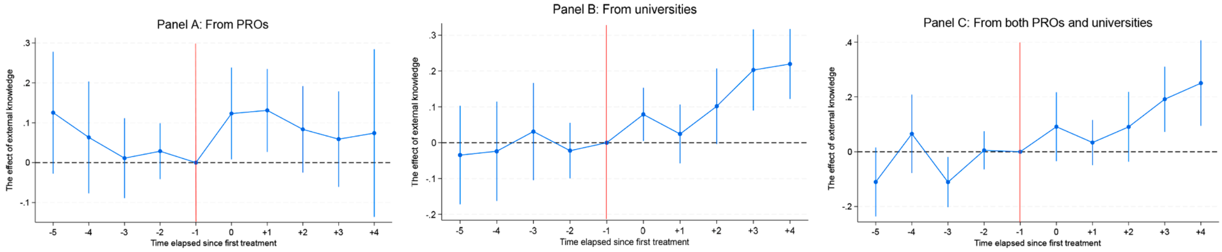

Fig. 3. Dynamic effect.

regression from universities only; and in the third regression from both PROs and universities. Each cohort is interacted with each time specific effects. The effects are aggregated to obtain the average treatment effect, the cohort effects, and the dynamic effect.

We show our results from the cohort effect in Table A4 in the Appendix, and we present the average treatment effect at the bottom of the table. The results in Table A4 indicate that the large majority of the estimated coefficients for all the different cohorts of external knowledge from universities only, from PROs only or form both are positive. On average the coefficients are estimated with less precision than in previous estimations. The estimated average effects are positive and significant in all cases and of similar magnitude than in the previous specifications.

Next, in Table A5, we present the dynamic effect results where we show the number of years after and before firms obtained for the first-time external knowledge from public providers (denoted as zero). We do not find evidence for a pre-trend on innovation before obtaining external knowledge. The effects on innovation are positive and significantly different from zero after the treatment. For example, product innovation increases by 12.3 % in the year of obtaining external knowledge from PROs only and by 13.1 % the year after, while the increases of innovation for firms that obtained external knowledge from universities is equal to 7.9 % on the year of the first treatment. The dynamic effects for external knowledge from both PROs and universities are positive and significantly different from zero and they materialized four years after the treatment. These findings are consistent with the idea that while the average treatment effects are very similar between PROs and universities, the effect from universities might be slightly more persistent over time than the effect from PROs. We present these results graphically in Fig. 3.

5.2.3. *Intensity of external knowledge*

We explore the effect of the *intensity* of the external knowledge. In the survey, companies report the expenditure of the acquisition of external knowledge by type of provider. With this information, we construct the ratio of the expenditures of external knowledge from PROs and from universities over the internal R&D expenditures. We replicate the estimation of Eqs. (2)–(4) using these variables instead of the dummy variables acquiring external knowledge from PROs only and from universities only. We present the results from the estimations in Panel A of Table A6. The estimated coefficients are precisely estimated and corroborate previous findings: the effects on product innovation of the external knowledge from PROs is very similar to the effect of acquiring external knowledge from universities and from the effect from both PROs and universities for the average firm. However, firms with high levels of absorptive capacities benefit relatively more from external knowledge from PROs than from universities. Furthermore, the opposite pattern happens for firms with low absorptive capacity.

5.2.4. *Controlling for the persistence of innovation output*

A possible concern is that our estimations do not control for the persistence of innovation output. Although when we construct our reweighted sample, we include lagged innovation output variables and, therefore, we control for the innovation status before the treatment, in the next robustness check, we explicitly include innovation output variables as control variables. We present the results from these estimations in Panel B of Table A6. The key messages remain unchanged and confirm our previous results.

5.2.5. *Controlling for persistence of treatment and longer lead of the dependent variable*

In the next set of robustness checks, we control for the potential persistence of the treatment (acquired external knowledge). It is possible that some treated firms received the treatment over several years. To address potential concerns regarding the effect of previous external knowledge transfers, we estimate Eqs. (2)–(4) including controls for having received external knowledge from any provider in the previous year and two years before. We show results from these estimations in Panel C of Table A6. The results are, again, consistent with the idea that both external knowledge transfers from PROs and universities increase innovation and that absorptive capacities play a fundamental moderating role for product innovation. Furthermore, in Panel D of Table A6, we modify our dependent variable and consider three leads in the innovation output variable. Again, the results corroborate previous estimations.

5.2.6. *Placebo test: random assignment of treatment*

To further assess the robustness of the results, we estimate a placebo regression where, within the sample of firms without external knowledge, we randomly assign the treatment status to half the sample and the control status to the other half.[23] We present these

[23] The placebo treatment should be understood as companies receiving knowledge either from universities or from PROs.

results in Table A7. The results from these placebo regressions are very different from previous estimations. Using a propensity score reweighting estimator, in column (1) we find no significant difference between the randomly assigned treatment and the control group in terms of the probability of introducing a product innovation. This result suggests that our baseline results are not biased due to some unobservable confounders. In column (2), we introduce the interaction between the *placebo treatment* and absorptive capacity. Differently from our results, the estimated coefficient for the interaction term is not significant, meaning that when the treatment is randomly assigned, the moderating effects of absorptive capacity do not arise. Interestingly, in columns (1) and (2) the absorptive capacity variable continues to be significant, confirming our previous results on the importance of internal knowledge in improving innovation performance.

5.2.7. Firms within common support of absorptive capacity and with positive R&D

In this section, we drop observations that are extreme outliers. First, we drop firms that are not in the common support of absorptive capacity. Second, we drop firms without positive R&D expenditures. As we have shown in Fig. 1, firms with external knowledge from PROs have a slightly more skewed distribution of absorptive capacity than firms with external knowledge transfers from universities. To avoid our results being biased by a potential confound between absorptive capacity and external knowledge transfers, we estimate our regressions for firms in the common support of absorptive capacity. Next, we limit the sample to firms with positive R&D expenditures. We show the results in Panels A and B of Table A8. The estimated results confirm the positive effect of external knowledge transfers from PROs and universities, the indistinguishable effect for the average firm, and the moderating role of the absorptive capacity.

5.2.8. Generalisability of the results

A potential concern is that the results we find are due to the specific institutional framework of Spain and that, consequently, the findings might be different for non-Spanish PROs or universities. Here, we assess the external validity of our results. In the survey, firms report whether they obtain public external knowledge from non-Spanish PROs or universities. We construct a dummy variable that takes the value one if a firm obtains external knowledge from non-Spanish PROs only and zero otherwise (denoted as foreign PROs only), and a dummy variable that takes the value one if a firm reports obtaining external knowledge from non-Spanish universities only and zero otherwise (denoted as foreign universities only). We drop firms with external knowledge from either Spanish PROs or Spanish universities from the sample. Note that we do not have enough observations to study the case of firms that obtain external knowledge from both foreign PROs and foreign universities.[24] In column (1) of Table A9, we show the results for the effects of foreign PROs and foreign universities on product innovation. The results indicate that both foreign PROs and foreign universities increase innovation. The *p*-value indicates that we cannot reject the hypothesis of equality of coefficients, which suggests that the effects are similar at standard statistical levels. Next, we construct a reweighted sample of firms with external knowledge transfers from foreign PROs and foreign universities and we report the balancing test in Table A10. In columns (2) and (3), we report the results for the reweighted sample of firms. The results suggest, again, that for the average firm the effects from external knowledge from foreign PROs and foreign universities on product innovation are very similar and that firms with low levels of absorptive capacity benefit relatively more from foreign universities than from foreign PROs, while we observe the opposite pattern for firms with high levels of absorptive capacity.

To conclude, the analysis in this section suggests that, after comparing the effect of each type of provider of technology separately with respect to firms without transfers of technology, controlling for heterogeneity in treatment timing, treatment intensity, pre-innovation output, persistence of treatment, performing a placebo test, dropping outliers, and assessing external validity, there is evidence that public external knowledge from PROs and universities increases innovation. The effect between PROs and universities is very similar for the average firm. We find, again, evidence that for firms with low levels of absorptive capacity, external knowledge from universities increases firm innovation more than external knowledge from PROs, although this differential effect declines as absorptive capacities increase.

5.2.9. Spillover effects

A possible concern is that there are spillover effects from firms that obtain external knowledge from public providers to firms without public external knowledge. In that case, there might be a bias in our estimations. In this section, we study the possibility of spillover effects. As in Griliches (1992), we assume that spillovers are regional and industry concentrated. We construct different clusters of regions and industries where there is a high concentration of firms with external knowledge transfers from PROs only, from universities only, and from both PROs and universities. Then we estimate the difference in product innovation for firms without any type of public external knowledge that are located in clusters with high concentration of firms with public external knowledge, versus firms without any type of public external knowledge that are located in clusters with low concentration of firms with public external knowledge. In our analysis, we establish 32 industry-region clusters, and we consider clusters with high concentration of public external knowledge as those clusters with external knowledge above the 90th percentile of the distribution of public external knowledge.

We present our estimations in Table A11. In column (1), we show results for the whole sample, (with the exception of firms that obtain external knowledge from public providers). We find a positive and statistically significant spillover effect from universities only and from both PROs and universities. The spillover effects from PROs only are positive but the estimated coefficient is very small and

[24] There is only one observation in our sample of firms with external knowledge from both foreign universities and foreign PROs and without external knowledge from domestic PROs or universities.

Table 9
Effect of external knowledge from PROs and universities on other firms' outputs.

Dependent variable:	% Products new to the market	Quality improvements	Process innovation	Sales	Patents
Panel A	(1a)	(2a)	(3a)	(4a)	(5a)
PROs only (0/1)	0.139***	0.132***	0.077***	0.103***	0.004
	(0.049)	(0.027)	(0.024)	(0.039)	(0.003)
Universities only (0/1)	0.125***	0.110***	0.047***	0.076***	0.005***
	(0.023)	(0.013)	(0.011)	(0.020)	(0.002)
Both PROs & Universities (0/1)	0.177***	0.084***	0.026	0.101**	0.009**
	(0.054)	(0.029)	(0.025)	(0.042)	(0.003)
No. observations	48,131	46,321	48,131	40,998	41,045
p-value equal coefficients					
PROs only vs. Universities only	0.7842	0.4619	0.2420	0.5052	0.8037
PROs only vs. Both	0.5760	0.2079	0.1292	0.9691	0.3179
Panel B	(1b)	(2b)	(3b)	(4b)	(5b)
PROs only (0/1)	0.001	0.000	0.034	0.028	0.001
	(0.048)	(0.027)	(0.024)	(0.055)	(0.003)
No. observations	4916	4726	4916	4372	4409
Panel C	(1c)	(2c)	(3c)	(4c)	(5c)
PROs only (0/1)	−0.156**	−0.082*	0.033	−0.139*	−0.008**
	(0.069)	(0.042)	(0.037)	(0.083)	(0.004)
PROs only (0/1) x Absorptive capacity	0.062***	0.058***	0.001	0.114*	0.007*
	(0.020)	(0.021)	(0.021)	(0.063)	(0.004)
No. observations	4916	4726	4916	4372	4409

Note: Explanation of variables in Table 1. Panels B and C include the reweighted sample of firms with external knowledge from PROs only and firms with external knowledge from universities only. The symbol (0/1) means dummy variable. The standard errors are presented in parentheses and are clustered at the firm-level. All regressions include industry times year dummies, year and firm fixed effects. In Panel A, we also report the *p*-value corresponding to the null hypothesis that the effects of only PRO and only university are the same and the effects of PROs only and both PROs and university are the same. ***, **, * indicate a 1 %, 5 %, and 10 % significance level, respectively.

not statistically significantly different from zero. Since the spillovers are positive, our results suggests that our previous estimates might be a lower bound of the effect of the public external knowledge transfers. The *t*-test of equality of coefficients at the bottom of the table suggests that there are differences in the extent of the spillovers. In columns (2) and (3), we explore this difference of coefficients, and we restrict the sample to firms without external knowledge from public providers that are located in clusters with a high concentration of external knowledge transfers from either PROs only or from universities only. The results indicate that universities create a 5.7 % higher spillover than PROs. In column (3), we estimate this difference for a reweighted sample of firms. The results corroborate the previous findings that spillover effects from universities are higher than spillovers from PROs.

5.3. Effect of external knowledge from PROs and/or from universities on other firms' outputs

The previous sections show a positive effect of external knowledge from PROs and universities on firms' innovation and the moderating role of absorptive capacities. In this section, we consider other firm outputs that can also be influenced by external knowledge.

We present these results in Table 9. We estimate Eq. (2) in Panel A. In panel B, we show our results for the estimation of Eq. (3), and finally in Panel C, we estimate Eq. (4). We present the effect of external knowledge transfers from PROs and universities on percentage of products that are new to the market (column 1); quality improvements of the products measured in the survey as the innovations having an important effect on improving the quality of the products (column 2); process innovation (column 3); sales (column 4); and patents (column 5). In all the different columns of Panel A, the estimated coefficients of both external knowledge from PROs and universities are positive and of similar magnitude. However, the estimated coefficient for the effect of external knowledge transfers from PROs on patents is estimated with low precision. Similar to previous regressions, we cannot reject the hypothesis of equality of coefficients. This is corroborated by the estimated results in panel B for the reweighted sample of firms with public external knowledge transfers. Regarding the moderating effect of absorptive capacity, in all columns, the estimated coefficient for external knowledge transfers from PROs is negative and the interaction term with absorptive capacity is positive. For all cases, these effects are significant at standard statistical levels, with the exception of process innovation, where we do estimate the effects with precision. The results suggest that firms with low levels of absorptive capacity that obtain external knowledge from universities increase the percentage of products new to the market, the quality of their products innovation and their patents and also their sales more than firms that obtain their external knowledge from PROs. However, this effect declines with the firm's absorptive capacities.

6. Summary and concluding remarks

Some of the main technological innovations of the last century have emerged thanks to the fundamental role of the public sector in the production and transmission of knowledge (Link et al., 2021; Mazzucato, 2011). As Bozeman (2000) argues "universities and government laboratories make, industry takes" (p. 633). In this paper, we study the effect of external knowledge on firm innovativeness from the two main organizations that receive large amounts of public funds: PROs and universities. Our results suggest that external knowledge transfers from these organizations increase firm innovativeness, highlighting the relevance of public funds for promoting private innovation activities. We find that external knowledge transfers from PROs increase firm product innovation by 7.3 %, and external knowledge transfers from universities by 7.4 %. We then take one step further and compare the importance of external knowledge from PROs and universities on firms' innovativeness. In this case, we do not find any significant difference at standard statistical levels.

Although these findings suggest that external knowledge transfers from PROs increase firm innovativeness in a similar way to external knowledge transfers from universities, we posit that firm absorptive capacity may play an important role in the relative effect of PROs versus universities. The rationale behind the consideration of the moderating effects of absorptive capacity stems from the fact that firms, to fully exploit external knowledge flows, should maintain a minimal level of in-house technological capacity (Veugelers, 1997; Paoli and Prencipe, 1999) that will enable them to "recognize the value of new, external information, assimilate it, and apply it to commercial ends" (Cohen and Levinthal, 1990, p. 128). Once we include the interaction of firm absorptive capacity with external knowledge, we find that, for a firm with a low level of absorptive capacity, external knowledge from universities increases firm innovativeness more than external knowledge from PROs. However, as absorptive capacity increases, the differential effect declines. Indeed, firms with high levels of absorptive capacities benefit relatively more from external knowledge transfers from PROs than that from universities.

Our study contributes to the open innovation literature (Chesbrough, 2003) and the role played by public research centres to generate and disseminate their knowledge (Añón, 2016; Vega-Jurado et al., 2017; García-Vega and Vicente-Chirivella, 2020; Link et al., 2019, 2021; Robin and Schubert, 2013). We add to this strand of literature the first evidence on the comparative importance of external knowledge transfers from PROs and universities on firms' innovativeness, which is important for firms to design their optimal R&D strategies. We also contribute to this literature by showing the increasing importance of absorptive capacity to use and absorb the external scientific public knowledge (Arora et al., 2016, 2018). Our contribution consists of disentangling the different impact of absorptive capacity depending on the external knowledge public provider.

All in all, the empirical analysis carried out in this study has important policy implications for policy makers and managers. Our results suggest that economic policies that encourage, facilitate and fund research projects between firms and publicly funded research centres are beneficial for the innovativeness of the private sector. Moreover, our results emphasize the interdependence between absorptive capacities and external knowledge from PROs. Therefore, public policies to finance PROs' external knowledge transfers might simultaneously consider R&D policy instruments to influence R&D firm capabilities. From the companies' side, firms' managers might design their internal R&D strategies considering the differences between the public providers of knowledge. Given that the knowledge transfers from public providers are sometimes persistent relationships, the effects can be long-term.

Our study provides relevant insights into the design of efficient innovation policies and strategy advice. However, we would like to point out some caveats and limitations of our study that we believe merit future research. First, there is some heterogeneity across universities and PROs in terms of their research intensity and management of R&D. Therefore, it is important to explore this variability to understand the specific characteristics of the organizations that lead to an increase in firm innovativeness. Second, "science parks" (special areas devoted to scientific and development research) are another important agent within the national and regional R&D system. The impact of science parks on firm innovation is beyond the scope of our study, but we think it is an important channel for external knowledge transfers, because of the potential knowledge spillovers due to agglomeration effects. Finally, our measure of external knowledge transfers comprises R&D industry contracts. However, PROs and universities might have other ways of transferring knowledge such as licensing technologies or through spin-offs. The analysis of the effects of other types of external knowledge between PROs and universities and the private sector is an important avenue for future research.

CRediT authorship contribution statement

María García-Vega: Conceptualization, Methodology, Software, Funding acquisition, Validation, Formal analysis, Writing – original draft, Writing – review & editing. **Óscar Vicente-Chirivella:** Conceptualization, Methodology, Software, Funding acquisition, Validation, Formal analysis, Writing – original draft, Writing – review & editing.

Data availability

Details on the survey and data access guidelines can be obtained at https://icono.fecyt.es/pitec/descarga-la-base-de-datos.

Appendix A

Table A1a
Difference of means of external knowledge volumes.

External knowledge for firms from PROs only vs. for firms with external knowledge from universities only	1.817
	(1.424)
External knowledge from firms with both PROs & universities: Knowledge from PROs vs. Knowledge from universities	−1.977*
	(1.140)

Table A1b
Differences of means for the main variables.

	PROs only vs. universities only (1)	PROs only vs. Both PROs and universities (2)	Universities only vs. Both PROs and universities (4)	PROs only vs. none (5)	Universities only vs. none (6)	Both PROs and universities vs. none (7)
Product innovation (0/1)	−0.005	−0.044**	−0.039**	−0.295***	−0.301***	−0.339***
	(0.016)	(0.020)	(0.015)	(0.017)	(0.007)	(0.017)
Innovation investment (in logs.)	0.083	−0.332***	−0.415***	−0.579***	−0.495***	−0.910***
	(0.070)	(0.087)	(0.065)	(0.071)	(0.027)	(0.066)
Physical investment (in logs.)	0.047***	0.006	−0.042***	−0.338***	−0.291***	−0.332***
	(0.016)	(0.019)	(0.015)	(0.017)	(0.007)	(0.017)
Exporter (0/1)	0.140***	−0.265***	−0.405***	−0.313***	−0.173***	−0.578***
	(0.041)	(0.053)	(0.041)	(0.038)	(0.015)	(0.037)
Labour productivity (in logs.)	−0.039	−0.971***	−0.932***	−0.220***	−0.259***	−1.191***
	(0.059)	(0.078)	(0.058)	(0.060)	(0.023)	(0.057)
Number of employees (in logs.)	−0.139	−0.617***	−0.479***	−0.841***	−0.979***	−1.458***
	(0.105)	(0.173)	(0.112)	(0.091)	(0.035)	(0.089)
Internal R&D intensity	0.018	−0.091	−0.109***	−1.138***	−1.120***	−1.229***
	(0.047)	(0.056)	(0.045)	(0.052)	(0.020)	(0.049)
Absorptive capacity	−0.005	−0.044	−0.039**	−0.295***	−0.301***	−0.339***
	(0.016)	(0.020)	(0.015)	(0.017)	(0.007)	(0.017)

Table A2
Covariate means for the weighted sample.

	Mean		
	Treated firms with external knowledge from PROs only	Control firms with external knowledge from universities only	$p > \|t\|$
Product innovation$_{t-1}$	0.761	0.760	0.954
Product innovation$_{t-2}$	0.757	0.756	0.968
Product innovation$_{t-3}$	0.752	0.747	0.831
Ln(size)$_{t-1}$	4.291	4.386	0.142
Ln(sales)$_{t-1}$	16.255	16.238	0.850
Sales growth$_t$	0.074	0.068	0.798
Ln(physical investment)$_{t-1}$	8.559	8.498	0.403
Being an exporter$_{t-1}$	0.755	0.759	0.805

Note: For exact definitions and sources of all variables see Table 1 and main text. This table presents mean values of the variables used for the matching procedure. The *t*-test indicates the balancing of the variables.

Table A3
Alternative measures of absorptive capacity.

	(1)	(2)	(3)
Escribano et al. (2009)			
At the industry level and beginning of sample period			
PROs only (0/1)	0.092***		
	(0.020)		
Universities only (0/1)	0.073***		
	(0.009)		
Both PROs & Universities (0/1)	0.049**		
	(0.021)		
No. observations	31,749		
p-value equal coefficients			
PROs only vs. Universities only	0.3553		
PROs only vs. Both	0.1044		
At the industry level and time-variant			
PROs only (0/1)		0.129***	
		(0.019)	
Universities only (0/1)		0.112***	
		(0.009)	
Both PROs & Universities (0/1)		0.110***	
		(0.020)	
No. observations		48,131	
p-value equal coefficients			
PROs only vs. Universities only		0.3891	
PROs only vs. Both		0.4554	
Internal R&D over sales			
PROs only (0/1)			0.125***
			(0.019)
Universities only (0/1)			0.105***
			(0.009)
Both PROs & Universities (0/1)			0.101***
			(0.021)
No. observations			48,131
p-value equal coefficients			
PROs only vs. Universities only			0.3415
PROs only vs. Both			0.3617

Note: Explanation of variables in Table 1. This table includes the sample of firms with external knowledge from PROs only, firms with external knowledge from universities only, and firms without external knowledge (non-transfers). The symbol (0/1) means dummy variable. The standard errors are presented in parentheses and are clustered at the firm-level. Columns (1) and (3) include industry times year dummies, year and firm fixed effects. Column (2) include industry dummies, year and firm fixed effects. We also report the *p*-value corresponding to the null hypothesis that the effects of PRO only and university only are the same, as well as the hypothesis that PROs only and both PROs and universities are the same. ***, **, * indicate a 1 %, 5 %, and 10 % significance level, respectively.

Table A4
Estimated effects by cohort.

	PROs only (0/1)	Universities only (0/1)	Both PROs & Universities (0/1)
Cohort for the year 2007	0.089	0.046	−0.131**
	(0.106)	(0.081)	(0.050)
Cohort for the year 2008	0.036	−0.017	0.003
	(0.105)	(0.061)	(0.082)
Cohort for the year 2009	0.113	0.200**	0.075
	(0.080)	(0.074)	(0.072)
Cohort for the year 2010	0.131*	0.155**	0.185**
	(0.071)	(0.062)	(0.078)
Cohort for the year 2011	0.157*	0.043	0.135**
	(0.083)	(0.059)	(0.058)
Cohort for the year 2012	0.051	0.075	0.043
	(0.067)	(0.075)	(0.066)
Average effect	0.103**	0.093**	0.098*
	(0.051)	(0.039)	(0.049)

Note: Explanation of variables in Table 1. The standard errors are presented in parentheses and are clustered at the firm-level. ***, **, * indicate a 1 %, 5 %, and 10 % significance level, respectively.

Table A5
Dynamic model.

Time elapsed since first treatment	PROs only (0/1)	Universities only (0/1)	Both PROs & Universities (0/1)
[−5]	0.125	−0.034	−0.111
	(0.093)	(0.084)	(0.077)
[−4]	0.063	−0.024	0.066
	(0.085)	(0.084)	(0.087)
[−3]	0.011	0.031	−0.111**
	(0.061)	(0.082)	(0.056)
[−2]	0.029	−0.022	0.005
	(0.043)	(0.047)	(0.042)
[0]	0.123*	0.079*	0.091
	(0.070)	(0.045)	(0.077)
[1]	0.131**	0.024	0.034
	(0.063)	(0.050)	(0.050)
[2]	0.084	0.102	0.091
	(0.066)	(0.064)	(0.078)
[3]	0.059	0.203***	0.192***
	(0.073)	(0.069)	(0.072)
[4]	0.074	0.220***	0.251***
	(0.128)	(0.059)	(0.095)
[5]	−0.058	0.183*	0.033
	(0.304)	(0.099)	(0.130)

Note: Explanation of variables in Table 1. ***, **, * indicate a 1 %, 5 %, and 10 % significance level, respectively.

Table A6
Additional robustness checks.

Panel A: Treatment intensity	(1a)	(2a)	(3a)
PROs expenditures intensity	0.001***	−0.000	−0.0009**
	(0.000)	(0.000)	(0.000)
University expenditures intensity	0.001***		
	(0.000)		
Both PROs & Universities intensity	0.001***		
	(0.000)		
PROs expenditures intensity x Absorptive capacity			0.0005**
			(0.000)
No. observations	48,131	4916	4916
p-value equal coefficients			
PROs only vs. Universities only	0.9346		
PROs only vs. Both	0.5161		
Panel B: Controlling by pre-innovation output	(1b)	(2b)	(3b)
PROs only (0/1)	0.086***	0.014	−0.048*
	(0.016)	(0.018)	(0.029)
Universities only (0/1)	0.067***		
	(0.008)		
Both PROs & Universities (0/1)	0.060***		
	(0.018)		
PROs only (0/1) x Absorptive capacity			0.004***
			(0.001)
No. observations	48,131	4916	4916
p-value equal coefficients			
PROs only vs. Universities only	0.2909		
PROs only vs. Both	0.2495		
Panel C: Controlling for previous techno transfers	(1c)	(2c)	(3c)
PROs only (0/1)	0.091***	−0.008	−0.079**
	(0.021)	(0.024)	(0.035)
Universities only (0/1)	0.091***		
	(0.009)		
Both PROs & Universities (0/1)	0.084***		
	(0.021)		
PROs only (0/1) x Absorptive capacity			0.005***
			(0.002)
No. observations	47,978	4761	4761
p-value equal coefficients			
PROs only vs. Universities only	0.9870		
PROs only vs. Both	0.8094		
Panel D: For longer lead of dependent variable	(1d)	(2d)	3d)

(*continued on next page*)

Table A6 (*continued*)

PROs only (0/1)	0.123***	0.021	−0.071**
	(0.020)	(0.021)	(0.032)
Universities only (0/1)	0.092***		
	(0.010)		
Both PROs & Universities (0/1)	0.106***		
	(0.024)		
PROs only (0/1) x Absorptive capacity			0.006***
			(0.001)
No. observations	41,045	4379	4379
p-value equal coefficients			
PROs only vs. Universities only	0.1564		
PROs only vs. Both	0.5639		

Note: Explanation of variables in Table 1. Columns (2) and (3) include the reweighted sample of firms with external knowledge from PROs only and firms with external knowledge from universities only. The symbol (0/1) means dummy variable. The standard errors are presented in parentheses and are clustered at the firm-level. All regressions include industry times year dummies, year and firm fixed effects. In Column (1), we also report the *p*-value corresponding to the null hypothesis that the effects of only PRO and only university and both PROs and universities are the same. ***, **, * indicate a 1 %, 5 %, and 10 % significance level, respectively.

Table A7
Placebo test.

	(1)	(2)
Random PROs only (0/1)	−0.044	0.002
	(0.045)	(0.046)
Absorptive capacity	0.117***	0.117***
	(0.002)	(0.002)
Random PROs only (0/1) x Absorptive capacity		−0.021
		(0.022)
No. observations	71,794	71,794

Note: Explanation of absorptive capacity variable in Table 1. Random PROs only is a randomly assigned dummy variable, within the group of firms with no external knowledge, that takes the value one for half of the sample. In column (1) and (2), the sample includes firms without external knowledge (non-transfers). The symbol (0/1) means dummy variable. The standard errors are presented in parentheses and are clustered at the firm-level. All regressions include industry times year dummies and year fixed effects. ***, **, * indicate a 1 %, 5 %, and 10 % significance level, respectively.

Table A8
Estimations without outliers.

Panel A: Firms at the common support	(1a)	(2a)	(3a)
PROs only (0/1)	0.106***	0.009	−0.054*
	(0.019)	(0.021)	(0.032)
Universities only (0/1)	0.092***		
	(0.009)		
Both PROs & Universities (0/1)	0.084***		
	(0.021)		
PROs only (0/1) x Absorptive capacity			0.004***
			(0.002)
No. observations	47,640	4901	4901
p-value equal coefficients			
PROs only vs. Universities only	0.4824		
PROs only vs. Both	0.3938		
Panel B: Firms with internal R&D expenditures	(1b)	(2b)	(3b)
PROs only (0/1)	0.098***	0.010	−0.056*
	(0.020)	(0.021)	(0.034)
Universities only (0/1)	0.082***		
	(0.009)		
Both PROs & Universities (0/1)	0.071***		
	(0.021)		
PROs only (0/1) x Absorptive capacity			0.004***
			(0.002)
No. observations	37,530	4838	4838
p-value equal coefficients			
PROs only vs. Universities only	0.4463		
PROs only vs. Both	0.3016		

Note: Explanation of variables in Table 1. In column (1), the sample includes firms with external knowledge from PROs only, firms with external knowledge from universities only and firms without external knowledge (non-transfers). Columns (2) and (3) include the reweighted sample of firms with external knowledge from PROs only and firms with external knowledge from universities only. The symbol (0/1) means dummy variable. The standard errors are presented in parentheses and are clustered at the firm-level. All regressions include industry times year dummies, year and firm fixed effects. In column (1), we also report the *p*-value corresponding to the null hypothesis that the effects of only PRO and only university are the same. ***, **, * indicate a 1 %, 5 %, and 10 % significance level, respectively.

Table A9
External validity. Effect of foreign PROs and foreign universities for a reweighted sample.

	(1)	(2)	(3)
Foreign PROs only (0/1)	0.138**	0.039	−0.571**
	(0.064)	(0.175)	(0.220)
Foreign universities only (0/1)	0.093*		
	(0.056)		
Foreign PROs only (0/1) x Absorptive capacity			0.428***
			(0.095)
No. observations	48,131	128	128
p-value equal coefficients	0.5923		

Note: Explanation of variables in Table 1. In column (1), the sample includes firms with external knowledge from foreign PROs only, firms with external knowledge from foreign universities only and firms without external knowledge (non-transfers). We drop from the sample firms with external knowledge firms with external knowledge from Spanish PROs or from Spanish universities. Columns (2) and (3) include the reweighted sample of firms with external knowledge from foreign PROs only and firms with external knowledge from foreign universities only. In these columns, we also eliminate from the sample firms with external knowledge from Spanish PROs or Spanish universities. The symbol (0/1) means dummy variable. The standard errors are presented in parentheses and are clustered at the firm-level. All regressions include industry times year dummies, year and firm fixed effects. In Column (1), we also report the *p*-value corresponding to the null hypothesis that the effects of only PRO and only university are the same. ***, **, * indicate a 1 %, 5 %, and 10 % significance level, respectively.

Table A10
Covariate means for the weighted sample corresponding to Table A9.

	Mean		
	Treated	Control	$p > \|t\|$
Product innovation$_{t-1}$	0.784	0.803	0.817
Product innovation$_{t-2}$	0.769	0.806	0.697
Product innovation$_{t-3}$	0.684	0.780	0.405
Ln(size)$_{t-1}$	4.149	4.258	0.680
Ln(sales)$_{t-1}$	16.20	16.05	0.685
Sales growth$_t$	0.120	0.088	0.606
Ln(physical investment)$_{t-1}$	8.223	8.662	0.171
Being an exporter$_{t-1}$	0.757	0.803	0.579

Note: For exact definitions and sources of all variables see Table 1 and main text. This table presents mean values of the variables used for the matching procedure. The *t*-test indicates the balancing of the variables.

Table A11
Spillover effect.

	(1)	(2)	(3)
Spillover from universities only	0.064***	0.057***	0.059**
	(0.012)	(0.022)	(0.024)
Spillover from PROs only	0.003		
	(0.014)		
Spillover from both PROs and universities	0.080***		
	(0.017)		
No. observations	77,558	15,004	10,795
p-value equal coefficients			
PROs only vs. Universities only	0.0007		
PROs only vs. Both	0.0043		
Sample (reweighted)	No	No	Yes

Notes: The treated groups are companies without technology transfers from universities or PROs located in regions and sectors with *high* external knowledge from PROs only (spillover from PROs only), from universities only (spillover from universities only) and from both PROs and universities (spillover from PROs and universities). The control groups are companies without technology transfers located in regions and sectors with low external knowledge. . * Significant at 10 %; ** Significant at 5 %; *** significant at 1 %.

References

Aghion, P., Van Reenen, J., Zingales, L., 2013. Innovation and institutional ownership. Am. Econ. Rev. 103 (1), 277–304.
Añón Higón, D.A., 2016. In-house versus external basic research and first-to-market innovations. Res. Policy 45 (4), 816–829.
Apa, R., De Marchi, V., Grandinetti, R., Sedita, S.R., 2021. University-SME collaboration and innovation performance: the role of informal relationships and absorptive capacity. J. Technol. Transf. 46 (4), 961–988.
Arora, A., Belenzon, S., Patacconi, A., 2018. The decline of science in corporate R&D. Strateg. Manag. J. 39 (1), 3–32.
Arora, A., Cohen, W.M., Walsh, J.P., 2016. The acquisition and commercialization of invention in American manufacturing: incidence and impact. Res. Policy 45 (6), 1113–1128.
Arvanitis, S., Kubli, U., Woerter, M., 2008. University-industry knowledge and technology transfer in Switzerland: what university scientists think about co-operation with private enterprises. Res. Policy 37 (10), 1865–1883.
Barge-Gil, A., Vivas-Augier, C., 2019. Does Cooperation with Universities and KIBS Matter? Firm-level Evidence from Spain, 96949. University Library of Munich, Germany.
Beise, M., Stahl, H., 1999. Public research and industrial innovations in Germany. Res. Policy 28 (4), 397–422.
Bentley, P.J., Gulbrandsen, M., Kyvik, S., 2015. The relationship between basic and applied research in universities. Higher Educ. 70 (4), 689–709.
Bloedon, R.V., Stokes, D.R., 1994. Making university/industry collaborative research succeed. Research-Technology Manag. 37 (2), 44–48.
Bloom, N., Draca, M., Van Reenen, J., 2016. Trade induced technical change? The impact of Chinese imports on innovation, IT and productivity. Rev. Econ. Stud. 83 (1), 87–117.
Bloom, N., Schankerman, M., Van Reenen, J., 2013. Identifying technology spillovers and product market rivalry. Econometrica 81 (4), 1347–1393.
Blundell, R., Griffith, R., Van Reenen, J., 1999. Market share, market value and innovation in a panel of British manufacturing firms. Rev. Econ. Stud. 66 (3), 529–554.
Bozeman, B., 2000. Technology transfer and public policy: a review of research and theory. Res. Policy 29 (4–5), 627–655.
Callaway, B., Sant'Anna, P.H, 2021. Difference-in-differences with multiple time periods. J. Econom. 225 (2), 200–230.
Caloghirou, Y., Giotopoulos, I., Kontolaimou, A., Korra, E., Tsakanikas, A., 2021. Industry-university knowledge flows and product innovation: how do knowledge stocks and crisis matter? Res. Policy 50 (3), 104195.
Capron, H., Cincera, M., 2004. Industry/university S&T transfers: what can we learn from Belgian CIS-2 data? Brussels Econ. Rev. 46 (3), 59–86. Available at SSRN 637185.
Chesbrough, H.W., 2003. Open Innovation: The New Imperative for Creating and Profiting from Technology. Harvard Business Press.
Cohen, W.M., Levinthal, D.A., 1989. Innovation and learning: the two faces of R&D. Econ. J. 99 (397), 569–596.
Cohen, W.M., Levinthal, D.A., 1990. Absorptive capacity: a new perspective on learning and innovation. Adm. Sci. Q. 35 (1), 128–152.
Cohen, W.M., Nelson, R.R., Walsh, J.P., 2002. Links and impacts: the influence of public research on industrial R&D. Manag. Sci. 48 (1), 1–23.
Cruz-Castro, L., Martínez, C., Peñasco, C., Sanz-Menéndez, L., 2020. The classification of public research organizations: taxonomical explorations. Res. Eval. 29 (4), 377–391.
Cruz-Castro, L., Sanz-Menéndez, L., Martínez, C., 2012. Research centers in transition: patterns of convergence and diversity. J. Technol. Transf. 37 (1), 18–42.
Debackere, K., Veugelers, R., 2005. The role of academic technology transfer organizations in improving industry science links. Res. Policy 34 (3), 321–342.
D'Este, P., Patel, P., 2007. University–industry linkages in the UK: what are the factors underlying the variety of interactions with industry? Res. Policy 36 (9), 1295–1313.
Eom, B.Y., Lee, K, 2010. Determinants of industry–academy linkages and, their impact on firm performance: the case of Korea as a latecomer in knowledge industrialization. Res. Policy 39 (5), 625–639.
Escribano, A., Fosfuri, A., Tribó, J.A., 2009. Managing external knowledge flows: the moderating role of absorptive capacity. Res. Policy 38 (1), 96–105.
Fontana, R., Geuna, A., Matt, M., 2006. Factors affecting university–industry R&D projects: the importance of searching, screening and signalling. Res. Policy 35 (2), 309–323.
Fudickar, R., Hottenrott, H., 2019. Public research and the innovation performance of new technology based firms. J. Technol. Transf. 44 (2), 326–358.
Galasso, A., Simcoe, T.S., 2011. CEO overconfidence and innovation. Manag. Sci. 57 (8), 1469–1484.
García-Vega, M., Vicente-Chirivella, Ó., 2020. Do university technology transfers increase firms' innovation? Eur. Econ. Rev. 123, 103388.
González-Pernía, J.L., Parrilli, M.D., Peña-Legazkue, I., 2015. STI–DUI learning modes, firm–university collaboration and innovation. J. Technol. Transf. 40 (3), 475–492.
Goodman-Bacon, A., 2021. Difference-in-differences with variation in treatment timing. J. Econom. 225 (2), 254–277.
Griliches, Z., 1992. The search for R&D spillovers. Scand. J. Econ. 94, 29–47.
Guadalupe, M., Kuzmina, O., Thomas, C, 2012. Innovation and foreign ownership. Am. Econ. Rev. 102 (7), 3594–3627.
Haucap, J., Rasch, A., Stiebale, J., 2019. How mergers affect innovation: theory and evidence. Int. J. Ind. Organ. 63, 283–325.
Intarakumnerd, P., Goto, A, 2018. Role of public research institutes in national innovation systems in industrialized countries: the cases of Fraunhofer, NIST, CSIRO, AIST, and ITRI. Res. Policy 47 (7), 1309–1320.
ITRI, (2021). Annual Report 2021. Retrieved from https://www.itri.org.tw/english/ListStyle.aspx?DisplayStyle=18&SiteID=1&MmmID=1037333564136616055 on July 24 2023,.
Jabbour, L., Tao, Z., Vanino, E., Zhang, Y., 2019. The good, the bad and the ugly: Chinese imports, European Union anti-dumping measures and firm performance. J. Int. Econ. 117, 1–20.
Jaffe, A.B., Lerner, J., 2001. Reinventing public R&D: patent policy and the commercialization of national laboratory technologies. RAND J. Econ. Apr 1, 167–198.
Jaffe, A.B., Trajtenberg, M., 1996. Flows of knowledge from universities and federal laboratories: modeling the flow of patent citations over time and across institutional and geographic boundaries. Proc. Natl. Acad. Sci. 93 (23), 12671–12677.
Javorcik, B., Poelhekke, S., 2017. Former foreign affiliates: cast out and outperformed? J. Eur. Econ. Assoc. 15 (3), 501–539.
Kafouros, M., Wang, C., Piperopoulos, P., Zhang, M., 2015. Academic collaborations and firm innovation performance in China: the role of region-specific institutions. Res. Policy 44 (3), 803–817.
Kobarg, S., Stumpf-Wollersheim, J., Welpe, I.M., 2018. University-industry collaborations and product innovation performance: the moderating effects of absorptive capacity and innovation competencies. J. Technol. Transf. 43 (6), 1696–1724.
Kunttu, L., 2017. Educational involvement in innovative university–industry collaboration. Technol. Innov. Manag. Rev. 7 (12), 14–22.
Lane, P.J., Lubatkin, M., 1998. Relative absorptive capacity and interorganizational learning. Strateg. Manag. J. 19 (5), 461–477.
Link, A.N., Morris, C.A., van Hasselt, M., 2019. The impact of public R&D investments on patenting activity: technology transfer at the US Environmental Protection Agency. Econ. Innov. New Technol. 28 (5), 536–546.
Link, A.N., Morris, C.A., van Hasselt, M., 2021. The impact of the third sector of R&D on the innovative performance of entrepreneurial firms. Small Bus. Econ. 57, 1413–1418.
Mazzucato, M., 2011. The entrepreneurial state. Soundings 49 (49), 131–142.
Medda, G., Piga, C., Siegel, D., 2005. University R&D and firm productivity: evidence from Italy. J. Technol. Transf. 30 (1–2), 199–205.
Min, J.W., Kim, Y., Vonortas, N.S., 2020. Public technology transfer, commercialization and business growth. Eur. Econ. Rev. 124, 103407.
Ministerio de Ciencia e Innovación. Presupuesto 2021.
OECD, 2021. Improving knowledge transfer and collaboration between science and business in Spain. In: OECD Science, Technology and Industry Policy Papers, 122. OECD Publishing, Paris. https://doi.org/10.1787/4d787b35-en.
OECD, 2005. Oslo Manual. Guidelines for Collecting and Interpreting Innovation Data. OECD Publishing, Paris.
OECD, 2002. Benchmarking Industry-Science Relationships. OECD Publishing, Paris. https://doi.org/10.1787/9789264175105-en.

Paoli, M., Prencipe, A., 1999. The role of knowledge bases in complex product systems: some empirical evidence from the aero engine industry. J. Manag. Gov. 3 (2), 137–160.
Perkmann, M., Salandra, R., Tartari, V., McKelvey, M., Hughes, A., 2021. Academic engagement: a review of the literature 2011–2019. Res. Policy 50 (1), 104114.
Perkmann, M., Tartari, V., McKelvey, M., Autio, E., Broström, A., D'Este, P., Sobrero, M., 2013. Academic engagement and commercialisation: a review of the literature on university–industry relations. Res. Policy 42 (2), 423–442.
Perkmann, M., Walsh, K., 2007. University–industry relationships and open innovation: towards a research agenda. Int. J. Manag. Rev. 9 (4), 259–280.
Robin, S., Schubert, T., 2013. Cooperation with public research institutions and success in innovation: evidence from France and Germany. Res. Policy 42 (1), 149–166.
Sanz-Menéndez, L., Cruz-Castro, L., Jonkers, K., Derrick, G.E., Bleda, M., Martínez, C., 2011. Public research organisations. Policy Brief, The Innovation Policy Platform. OECD.
Senker, J., 2006. Reflections on the transformation of European public-sector research. Innovation 19 (1), 67–77.
Siegel, D.S., Waldman, D.A., Atwater, L.E., Link, A.N., 2004. Toward a model of the effective transfer of scientific knowledge from academicians to practitioners: qualitative evidence from the commercialization of university technologies. J. Eng. Technol. Manag. 21 (1–2), 115–142.
Sun, L., Abraham, S, 2021. Estimating dynamic treatment effects in event studies with heterogeneous treatment effects. J. Econom. 225 (2), 175–199.
Szücs, F., 2018. Research subsidies, industry–university cooperation and innovation. Res. Policy 47 (7), 1256–1266.
Tether, B.S., Tajar, A., 2008. Beyond industry–university links: sourcing knowledge for innovation from consultants, private research organisations and the public science-base. Res. Policy 37 (6–7), 1079–1095.
Vega-Jurado, J., Kask, S., Manjarrés-Henriquez, L., 2017. University industry links and product innovation: cooperate or contract. J. Technol. Manag. Innov. 12 (3), 1–8.
Veugelers, R., 1997. Internal R & D expenditures and external technology sourcing. Res. Policy 26 (3), 303–315.
Wooldridge, J.M. (2021). Two-way fixed effects, the two-way Mundlak regression, and difference-in-differences estimators. *Available at SSRN 3906345*.
Yu, G.J., Lee, J., 2017. When should a firm collaborate with research organizations for innovation performance? The moderating role of innovation orientation, size, and age. J. Technol. Transf. 42 (6), 1451–1465.