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Public research organizations' interactions with firms: Factors driving the perceived benefits

Ana García Granero, Jaider Vega Jurado, Liney Manjarrés Henríquez

ABSTRACT: This paper investigates which factors are more effective when taking advantage of benefits perceived by firms in their collaborations with public research organizations (PROs). The empirical study is based on a survey of firms that have collaborated with the Spanish National Research Council (CSIC), the largest PRO in Spain. We performed an ordinal probit regression, where the dependent variables reflect the importance of benefits from the interaction. We add to previous literature by considering benefits beyond innovation results and by studying the firm´s absorptive capacity and knowledge search strategy as determinants of such benefits. Our results show that firms need to have a certain level of absorptive capacity to take advantage of the collaboration with PROs, but that R&D is not the only antecedent that must be considered. Prior collaborative experience with PROs appears as an important factor to exploit these interactions, in particular as a way to develop internal capabilities and obtain long-term benefits. The study also outlined the firm´s external search strategy as a relevant factor in determining the benefits obtained from interactions with PROs.

KEYWORDS: PRO-I interactions, Benefits, Absorptive Capacity, Search strategy, Channels of interactions.

ECONLIT DESCRIPTORS: O31, O32, O36.

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RESUMEN: Este artículo investiga qué características de la empresa son más efectivas para aprovechar los beneficios percibidos de sus colaboraciones con organizaciones públicas de investigación (OPIs). El estudio empírico se basa en una encuesta aplicada a empresas que colaboraron con el Consejo Superior de Investigaciones Científicas (CSIC), el mayor OPI de España. El análisis se basa en una regresión probit ordinal, donde la variable dependiente refleja la importancia que la empresa atribuye a cada tipo de beneficios derivado de la interacción. Contribuimos a la literatura previa considerando diferentes beneficios, no sólo asociados con los resultados de la innovación, sino también beneficios a largo plazo y teniendo en cuenta la capacidad de absorción de la empresa y su estrategia de búsqueda de conocimiento como determinantes de dichos beneficios. Nuestros resultados muestran que las empresas necesitan tener cierto nivel de capacidad de absorción para aprovechar la colaboración con los OPI, pero que la I+D no es el único antecedente que se debe considerar. La experiencia colaborativa previa con los OPI aparece como un factor importante para explotar estas interacciones, en particular como una forma de desarrollar capacidades internas y obtener beneficios a largo plazo. El estudio también señala la estrategia de búsqueda externa de la empresa como un factor relevante para determinar los beneficios que se obtienen de las interacciones con los OPI.

PALABRAS CLAVE: PRO-I interacciones, Beneficios, Capacidad de Absorción, Estrategia de Búsqueda, Canales de Interacción.

Resumen extendido

Interacciones de los organismos públicos de investigación con las empresas: Factores que determinan los beneficios percibidos

Objetivos

La ciencia y la tecnología constituyen un aspecto clave para el desarrollo de las sociedades contemporáneas. Es por ello, que los gobiernos han implementado diversas políticas orientadas a conectar de una manera más eficiente el quehacer de las instituciones científicas con las necesidades sociales y, en particular, con las demandas del sector productivo. En este sentido, se ha desarrollado todo un cuerpo de literatura sobre las interacciones OPI-I (organismos públicos de Investigación-Industria) que aborda los determinantes y efectos de dichas relaciones. No obstante, a pesar de la amplia gama de beneficios que se han señalado, la mayor parte de las investigaciones empíricas han focalizado su atención en el análisis del impacto de dichas relaciones sobre las actividades de innovación empresarial, es decir, sobre el desarrollo e introducción en el mercado de nuevos productos y/o procesos, dejando de lado el análisis de otros tipos de beneficios relacionados con el fortalecimiento a largo plazo de las capacidades empresariales e incluso con la obtención de beneficios a corto plazo asociados con la resolución de problemas concretos.

Este trabajo tiene como objetivo identificar la gama de beneficios que las empresas obtienen de sus interacciones con los OPI, así como sus factores determinantes. En particular, el artículo se orienta a responder dos preguntas: ¿La colaboración de la empresa con los OPI genera múltiples beneficios además de las innovaciones de productos y procesos? De ser así, ¿qué factores influyen en la obtención de los diferentes beneficios percibidos por las empresas?

Diseño y metodología

Este estudio se basa en un conjunto de datos originales recopilados a través de una encuesta aplicada a una muestra de empresas españolas que han establecido una interacción formal con el Consejo Superior de Investigaciones Científicas (CSIC), el OPI más grande de España. Específicamente, el marco muestral se construyó a partir de una lista de empresas que habían establecido al menos un contrato formal con el CSIC durante el período 1999-2010. 1.891 empresas fueron integradas a la base de datos de empresas; de la que se obtuvo una muestra final de 794 empresas españolas que aceptaron participar (una tasa de respuesta cercana al 42%). Se realizó una prueba previa del cuestionario para asegurar la comprensión de las preguntas y entre el 1 de octubre de 2010 y el 31 de enero de 2011 se envió un cuestionario a estas empresas, en concreto a los directores de I+D, directores técnicos o similares. La encuesta se

administró cara a cara con el encuestado (principalmente gerentes técnicos o de I+D) e incluía preguntas generales sobre las características de la firma y preguntas específicas sobre la colaboración de la empresa con el CSIC durante el período mencionado, incluidos los resultados obtenidos después de la colaboración. A través del conjunto de datos del Sistema de Análisis de Balances Ibéricos (SABI) se accedió a información que no estaba totalmente disponible en el cuestionario, como el sector, la edad de la empresa y el tamaño de la empresa. Se analizaron solo las empresas que presentaron información en ambos conjuntos de datos, lo que resultó en una muestra final de 756 empresas.

Las variables dependientes capturan los diferentes beneficios percibidos por las empresas de las interacciones con los OPI. En concreto, se pidió a las empresas que evaluaran la importancia de lograr diferentes resultados a partir de la interacción con el CSIC. Los ítems se evaluaron mediante una escala que va de 1 (resultado inexistente o nada importante) a 4 (los resultados se consideran muy importantes). Los beneficios se agruparon en cuatro categorías. La primera categoría corresponde a los beneficios tradicionales relacionados con los resultados de la innovación (introducción de productos y procesos nuevos o mejorados en el mercado). Las otras dos categorías se denominaron beneficios a largo y corto plazo basándose en los conceptos propuestos por Dutrénit et al (2010). El primer grupo se basa en la idea de que las empresas pueden beneficiarse de los OPI fortaleciendo sus capacidades en el largo plazo mediante la creación de un departamento de I+D o la contratación de nuevo personal dedicado a la I+D. El segundo grupo se basa en el argumento de que las empresas pueden beneficiarse de los OPI de manera más directa al obtener asesoría o asistencia en la resolución de problemas. La última categoría de beneficios considerada en este análisis está relacionada con el papel de intermediario de los OPI (construcción de redes). Como variables explicativas se incluyeron variables relacionadas con la capacidad de absorción de la empresa (desarrollo de actividades internas de I+D, experiencia previa en colaboración con el CSIC y mecanismos de coordinación) así como con la estrategia de búsqueda de conocimiento externo de la empresa. Adicionalmente se incluyeron variables de control asociadas con los canales de relacionamiento con el CSIC (investigación conjunta, investigación contratada, servicios, entrenamiento, difusión) y características de la empresa (tamaño, edad y sector).

Resultados

El análisis descriptivo muestra que los beneficios de corto plazo tienen proporcionalmente más importancia que los otros tipos de beneficios considerados en el análisis, incluso que aquellos beneficios orientados a resultados de innovación. También es importante tener en cuenta que la creación de redes recibe una importancia similar a los resultados de innovación. En este sentido, los OPIs parecen desempeñar un papel importante no solo en la creación de nuevos conocimientos y su transferencia a las empresas, sino también como intermediarios en el sistema de innovación.

En lo que respecta a los factores que pueden incidir en la obtención de determinados beneficios, los resultados indican que la intensidad en I+D tiene un efecto significativo y positivo en los beneficios a largo y corto plazo, mientras que la experiencia en colaboraciones es significa-

tiva para los beneficios a largo plazo. Estos resultados sugieren que las empresas con un mayor nivel de capacidad de absorción están mejor posicionadas para utilizar las interacciones con los OPI como una estrategia para fortalecer las capacidades internas. Asimismo, los resultados indican que la estrategia de búsqueda de conocimiento implementada por la empresa es otro factor que influye en la obtención de beneficios a partir de la relación con los OPI. En esta línea, los resultados señalan la medida en que la empresa recurre intensamente a diferentes fuentes de información (profundidad de búsqueda externa) está significativa y positivamente relacionada con la obtención de beneficios a largo plazo y la creación de redes, sugiriendo con ello que cuando las empresas recurren intensamente a fuentes externas de conocimiento, desarrollan un conjunto de rutinas para activar la selección y explotación del conocimiento externo, lo que tendrá un impacto en la capacidad de la empresa para beneficiarse de las colaboraciones con organizaciones de investigación.

Conclusiones

Este artículo parte de la tesis que los beneficios que obtienen las empresas de sus interacciones con los OPIs pueden ir más allá de los resultados de innovación y pueden estar determinados por diferentes características de la empresa, en particular, los antecedentes organizacionales de la capacidad de absorción y las estrategias de búsqueda de conocimiento de una empresa. Los resultados obtenidos apoyan en gran medida esta idea. En primer lugar, los resultados indican que las empresas necesitan tener un cierto nivel de capacidad de absorción para aprovechar la colaboración con los OPI, pero que la I+D no es el único antecedente que debe tenerse en cuenta. La experiencia colaborativa previa con los OPI aparece también como un factor importante para explotar estas interacciones, en particular como una forma de desarrollar capacidades internas y obtener beneficios a largo plazo. La colaboración repetida a lo largo del tiempo permite a las empresas institucionalizar mecanismos de aprendizaje que les permitan explotar el conocimiento externo y gestionar de manera más eficaz los acuerdos de colaboración. Este resultado tiene una implicación importante porque pone de relieve que el fortalecimiento de capacidades a largo plazo a través de la colaboración con organizaciones científicas no es un resultado directo, sino que requiere tiempo y contactos previos para desarrollar un proceso de gestión adecuado entre los socios.

Desde la perspectiva de los OPI, este resultado también tiene una implicación importante para fomentar sus impactos sociales: es crucial dedicar más atención a la creación de estructuras alternativas que faciliten espacios de encuentro para construir relaciones entre investigadores y empresas y con el potencial para albergar e impulsar futuras colaboraciones. Las Oficinas de Transferencia de Tecnología (OTT) están desempeñando relativamente bien en la promoción de actividades de transferencia comercial, pero debido a la relevancia de la experiencia colaborativa previa en la explotación de estas relaciones, es importante alentar la participación de los científicos en actividades colaborativas más informales que contribuyan a generar confianza entre las partes.

1. Introduction

The request to demonstrate the societal impact of public policy is increasing everywhere (Ruiz et al., 2017; Sarria-Pedroza and Fernández-Guadaño, 2021). A defining feature in contemporary science policy is connecting science and society (Muhonen et al., 2020). Public research organizations (PROs) stand as key actors in the provision of knowledge and complementary capacity (Saad et al., 2008). Numerous studies support this idea, highlighting the benefits of so-called science-industry (PRO-I) interactions and describing these collaborations as one of the key elements of the National Systems of Innovation (Cowan and Zinovyeva, 2013). Based on this argument, many governments worldwide have launched important initiatives to encourage greater interaction between firms and PROs and the analysis of this kind of interaction has become an outstanding topic of interest for academics and policy makers. As a product, there is increasing literature regarding PRO–I interactions that approaches several relevant issues, including drivers, channels of interaction, and benefits (Dutrénit et al., 2010; Olmos-Peñuela et al., 2017; Vega-Jurado et al., 2021). However, in spite of the wide range of benefits that have been highlighted in the literature, the empirical research about PRO-I interactions has mainly focused on the innovative results, and in particular, the development of new products and processes (Apa et al., 2021; Roud and Vlasova, 2020). Thus, while there is a large body of empirical research that has explored the effect of PRO-I interactions on technological innovation - based on the analysis of innovation surveys-, few efforts have been made to identify empirically those benefits beyond innovation results and the factors influencing them.

Along these lines, Bishop et al., (2011) analyzed the methods through which firms benefit from interactions with research institutions, distinguishing between the enhancement of the firm's explorative capabilities and the exploitative ones. They also suggest that these benefits are contingent on factors such as the firm's R&D commitments, the geographical proximity of partners, and the research quality of universities. In a similar way, De Fuentes and Dutrénit (2012) carried out an analysis of the Mexican case and identified a set of benefits they grouped into three categories: strengthening R&D capabilities, strengthening innovation capabilities other than R&D, and improving quality. They found that these benefits are mainly influenced by the type of channel used to coordinate the interaction. In this vein, Schaeffer et al., (2017) proposed a typology to classify the interactions between universities and industries by taking into account variables like the duration of the interaction, the direction of information flow, the complexity of interaction, and the absorptive capacity of the actors. According to these variables, interactions were categorized into: 1) training-oriented, 2) diffusion-oriented, 3) service- oriented, 4) development-oriented, and 5) research-oriented. The authors point out that only the two last types present a higher quality of interaction, which may provide not only immediate production benefits to the firms but also knowledge to build internal capacities in the long term, enabling them to gain a competitive edge.

Following this line of inquiry, in this paper, we explore the range of potential benefits that firms obtain from interactions with PROs and their determining factors. In particular, we aim to answer two questions: Does the firm's collaboration with PROs generate multiple benefits

other than product and process innovations? If so, which factors are more effective for triggering different benefits perceived by firms?

To disentangle these issues, we take into account some of the factors stated by previous works, but we expand the discussion in several ways. In line with previous studies, we propose that firm´s size and interaction channels influence the type of benefits perceived by firms involved in such interactions, but we also suggest that they are contingent on factors like a) firm's absorptive capacity and b) firm's knowledge search strategy.

Related to the influence of the firm's absorptive capacity we adopt a broad perspective by analyzing not only the firm's R&D efforts but also factors related to the firm experience in interaction activities with scientific agents and the coordination mechanisms used to share knowledge within the organization. Cohen and Levinthal (1990) highlighted in their seminal work that firm's absorptive capacity has organizational antecedents beyond the firm's technological capacity. They emphasized that organizational factors facilitate the sharing and assimilation of external knowledge thereby creating the necessary conditions for its ultimate utilization. However, most of the empirical research has approached the analysis of absorptive capacity taking into account only the firm's commitment to R&D activities, paying little attention to the organizational antecedents. In this sense, we expand on previous research that has analyzed the influence of firm's determinants of absorptive capacity on the exploitation of PRO knowledge (Bishop et al., 2011) by examining the effects of prior collaborative experience and coordination mechanisms.

We also account for the influence of the firm's knowledge search strategy. Laursen and Salter (2004) pointed out that the degree of openness in the external knowledge search strategy of the firm has a significant effect on the probability of using university knowledge in innovation activities. In this sense, we go a step further by analyzing the effect of "openness" on the benefits from interactions with scientific agents beyond innovation results.

The insights gained from this analysis increase our knowledge of the multidimensional nature of benefits derived from PRO-I interactions and show ways in which different firm characteristics influence the exploitation of knowledge and resources coming from PROs.

This study is based on an original data set collected through a survey applied to a sample of Spanish firms that have established a formal interaction with the Spanish National Research Council (CSIC), the largest PRO in Spain. The selection of the sample is relevant since the fact of choosing firms collaborating with CSIC means that we can measure the impact of that collaboration.

The remainder of this paper is divided into four sections. The second section reviews different bodies of literature that addresses the issues discussed here. Section 3 describes the strategy for data gathering and the method used. Section 4 presents and discusses the results, and Section 5 concludes.

2. Theoretical Framework

2.1. Dimensions of potential benefits from PRO interaction

Several studies suggest that firms can benefit from the collaboration with scientific organizations in multiple ways. One of the most highlighted benefits in the literature has been the development of firm's innovation processes. In this sense, interaction with universities and PROs has been stated as an important strategy to create new products and processes. Belderbos et al., (2004) find that firms that cooperate with universities show higher sales growth due to new products than firms that do not cooperate. This result is in line with those in Lööf and Broström (2008), based on the Swedish innovation surveys – CIS-, which find that cooperation with scientific agents has a positive effect on the share of sales of products that are new to the market.

The above studies reinforce the idea that scientific organizations are likely to stimulate innovation results in firms. But this is not the only way in which the firms may gain from their interactions with PROs. In this sense, some researchers have pointed out that interactions with PROs may also contribute to increasing in-house technological competencies by facilitating the qualification of the workforce and the development of internal research skills and capabilities (Santoro and Chakrabarti, 2002).

Other times firms are willing to engage in collaborations with PROs looking for a way to enhance their problem-solving capabilities and even their production capacities (Arza and Vasquez, 2010). These short-term benefits are mainly related to the use of PROs resources to perform tests, quality control, and training programs.

Besides the previous benefits, PROs may act as intermediaries in the frame of the national or regional innovation systems. In many industrialized countries PROs have been created within the context of science and innovation policy in order to perform basic research that often has a long-time horizon and to facilitate the transfer of knowledge to firms. Intarakumnerd (2011) illustrates that PROs play important role not only in creating new knowledge and transfer to firms but also in helping firms to identify, evaluate and acquire technologies that already existed elsewhere. In this sense, PROs also fulfill "hard" intermediary functions, operating particularly between the science base and industry (Van Lente et al., 2003). Thus, collaboration with PROs may be useful not only to access complementary knowledge but also to stimulate future relationships between firms and other scientific and technological actors (universities, R&D labs, and even other firms). In other words, collaboration with PROs may help firms to build networks with other actors and support learning processes (Brekke, 2021; Intarakumnerd and Goto, 2018).

The benefits mentioned above have been grouped in different ways according to the main criteria adopted by researchers. Bellini et al., (2019), for instance, distinguished between tangible benefits that directly affect products and processes, and intangible benefits related to

the firm's learning and knowledge transfer, which enable firms to acquire new skills and capabilities. De Fuentes and Dutrénit (2012) identified three types of benefits from interaction: Strengthening capabilities based on R&D, strengthening capabilities based on innovation activities other than R&D, and improving quality; while Bishop et al., (2011), show that benefits from interactions with universities are multifaceted, including enhancement of the firm's explorative and exploitative capabilities. Independently of the criteria used, what this literature points out is that the benefits from PRO-I interactions are multiple and go beyond the development of new or improved products and processes.

2.2. Determining factors of the types of benefits firms obtain from interactions with PROs

2.2.1. Firm's absorptive capacity

Since Cohen and Levinthal (1990) introduced the concept of absorptive capacity (ACAP), this has been one of the most analyzed factors to explain how firms obtain benefits from interactions with external agents. This concept refers to the firm's ability to identify relevant external knowledge, assimilate it, and apply it to commercial ends (Cohen and Levinthal, 1990). This capacity becomes more important when external knowledge is distant from the firm's knowledge base and when the culture and motivations of the partner are quite different from the firm's organizational culture. On this basis, it has been emphasized that a certain degree of absorptive capacity is required to enable effective learning from inter-organizational collaborations and to develop successful collaboration with research centers (Apa et al., 2021; Pinto et al., 2015).

Along this line of argument, prolific research has emerged to understand how firms could facilitate the development of this dynamic capability. Following Cohen and Leventhal's seminal work, several studies have focused on the analysis of the organizational antecedents of ACAP considering two aspects: a prior knowledge base and the organizational configuration of the firms (Vega-Jurado et al., 2019). The analysis of the firm's knowledge base has mainly relied on measures of the firm's internal R&D activities. Laursen and Salter (2004), for instance, use firm's R&D intensity to explain the use of knowledge created in universities for technological innovation activities, while Monjon and Waelbroeck (2003) found that the benefits derived from collaboration with universities depend on the firm's R&D efforts. Formal collaborations between firms and PROs encourage the production and exploitation of codified scientific and technological knowledge, which requires a minimum threshold of scientific understanding on the part of firms (Apa et al., 2021). Thus, firms must have knowledge codification capabilities, which are sustained by investment in in-house R&D activities and can help them reduce information asymmetry during the collaboration processes, making it possible for them to benefit from scientific organizations.

Based on these previous works we argue that firm's R&D commitment is an important factor in order to obtain benefits from interactions with PROs.

H1. Firms that conduct regular internal R&D activities are more likely to obtain broader benefits as a result of collaborations with PROs

Another factor related to the prior knowledge base is the firm's experience. Cohen and Levinthal (1990) also highlighted the path-dependent nature of absorptive capacity. They pointed out that absorptive capacity is cumulative in the sense that its development in the present will permit its more efficient accumulation in the future. The firm's experience with external knowledge search affects both the locus of the search and the ability to identify and assimilate new knowledge. Thus, a firm may ignore the existence of an important knowledge source if it does not have any related experience of this source; on the other hand, firms will tend to take advantage of sources that have been used before. In the case of interactions with scientific organizations, the prior experience becomes even more relevant. PRO-I relationships must overcome many organizational and bureaucratic rigidities to succeed (Siegel et al., 2003). Additionally, the level of trust increases because of the consecutive interaction between parties. This means that prior experience may generate trust, which limits the cost of future partnerships from the point of view of the transaction cost theory and can turn the collaboration more effective. In addition, firms involved in regular collaborations with types of partners can refine their organizational routines and increase their experience of managing cooperation, and therefore obtain greater benefits from such agents. Along this line, Bellini et al. (2019) found evidence that past collaborative experience increases the benefits drawn from university-industry cooperation and that this relationship is mediated by trust. Thus, to benefit fully from collaboration with universities, firms have to build their collaborative know-how, drawing on previous cooperation relationships. This will allow them to maximize the benefits related to knowledge transfer.

This set of arguments leads to the formulation of the following hypothesis.

H2. Firms with previous experience in collaboration with PROs are more likely to obtain broader benefits as a result of collaborations with PROs

Regarding the organizational configuration of the firms, several authors (Jansen et al., 2005; Vega-Jurado et al., 2019) have turned their attention to the analysis of organizational antecedents of ACAP, such as mechanisms promoting the acquisition and application of knowledge. The underlying rationale rests on the argument that prior knowledge resources, although important, are not sufficient to ensure that a firm will internalize external information successfully. In addition to a firm's knowledge base, companies need to develop coordination mechanisms which enable them to synthesize and apply current and newly acquired external knowledge. These mechanisms can be formal or informal, depending on their degree of systematization, but they are associated with practices such as job rotation, decentralized decision-making, the creation of inter- departmental teams, and practices aimed at promoting communication among the employees (Van den Bosch et al., 1999; Jansen et al. 2005). These mechanisms promote group interaction and reduce barriers to knowledge exchange within an organization. Jansen et al., (2005) provide empirical evidence about the effect of coordination on innovation results. They found that connectedness within units appears to be an important antecedent of

both exploratory and exploitative innovation. Coordination is a characteristic that streamlines decision-making processes, synthesizes different points of view, and allows correcting errors in a timely manner to achieve the objectives set (Daspit et al., 2014). Eisenhardt and Martin (2000) highlight coordination as an important factor for the effective exchange of knowledge and experiences, both internally and externally.

Taking into account the above mentioned, we propose that coordination mechanisms are likely to play an important role in explaining how well-positioned the firms are to obtain benefits from their interactions with PROs. The transfer and exploitation of scientific knowledge require higher efforts by the firm for it to be incorporated into its products and processes and even to leverage its in-house technological capacities. Knowledge coming from PROs mainly extends the existing knowledge base within firms. Therefore, to gain benefits from this type of interaction the firm must establish coordination mechanisms that allow managing the relationship among its units sufficiently well.

H3. Firms with internal coordination mechanisms are more likely to obtain broader benefits as a result of collaborations with PROs

2.2.2. External knowledge search strategy

Another factor that may influence the benefits obtained from PRO-I interactions is the firm's knowledge search strategy. Katila and Ahuja (2002) defined the search strategy as the "problem-solving activities that involve the creation and recombination of technological ideas" (Katila and Ahuja, 2002: 1184). These activities are related to the firm's efforts to scan the environment to identify and process information and knowledge for innovation. Building on this concept Laursen and Salter (2004) argue that the extent to which firms rely on different types of information sources is an important driver of collaboration with universities. Specifically, these authors proposed a proxy variable for the openness of a firm's knowledge search strategy and found that this variable strongly influences the probability of using university knowledge in innovation activities. In other words, firms that have adopted an "open" approach to innovative search are more likely to use universities as a source of information for innovation.

Based on the above results, we propose that the higher the openness of knowledge search strategy, the higher the benefits perceived by the firm from its interactions with PROs. This is so because learning from a wide range of external sources helps to develop a broader knowledge base and increases the firm's flexibility and adaptation (Bierly and Daly, 2007). Also, an external knowledge search strategy implies that the firm is capable of activating the complementarities between the information and knowledge obtained from different actors to enhance its capacity to benefit from interactions with research organizations.

H4. Firms with an active external knowledge search strategy are more likely to obtain broader benefits as a result of collaborations with PROs.

3. Data Sources, description of measurements and empirical strategy

3.1. Context and data sources

This study focuses on the Spanish case, a country that according to the Innovation Union Scoreboard classification is within the moderate innovator group, that is below the European Union average (European Commission, 2021). The Spanish national innovation system depends highly on public sector organizations and displays relatively low levels of firm's R&D expenditure (OECD, 2021). This makes the system especially vulnerable to events like the 2008–2009 global crisis or the pandemic, which significantly affected private investment in Research and Development (R&D) influencing the ability of firms to innovate. According to OECD (2021) partnerships between firms and PROs can be an effective tool to spur innovation by sharing risks and rewards of innovation. Following this suggestion, the Spanish Strategy of Science, Technology and Innovation 2021-2027 includes support to PROs as key institutions in enabling knowledge transfer to firms.

Moreover, given the maturity and efficiency of the national innovation systems there may be differences in collaboration patterns. Thus, in under-developed national innovation systems, such as the spanish case, previous work has pointed out that the role of PROs is evolving from the generation of knowledge and the strengthening of research capabilities to a more operational focus like problem-solving via consulting activities or access to facilities (Dutrénit et al., 2010; Schaeffer et al., 2017; Vega-Jurado et al. 2009).

The context of the study were spanish firms collaborating with the largest PRO in Spain (CSIC). In 2011, CSIC counted with 126 research institutes, which employed 14,050 employees. Nowadays, it counts with 120 research institutes and 11,000 employees. The CSIC is multidisciplinary, carrying out research in almost all fields of knowledge. Its activities encompass basic research all the way through to technological development.

Specifically, the sampling frame was constructed from a list of firms that had established at least one (among 5334) formal contract with CSIC during the period 1999–2010. 1,891 firms were integrated into the database of firms; of which we obtained a final sample of 794 Spanish firms who agreed to participate (a response rate of nearly 42%). We conducted a pre-test of the questionnaire in order to assure understandable questions, and between 1 October 2010 and 31 January 2011, a questionnaire was sent to these companies, specifically to the R&D managers, technical managers, or similar. The survey was administered face to face with the firm respondent (mostly R&D or technical managers). To test for the existence of common method bias in our data we performed Harman's one-factor test; the results suggested that our data did not suffer from this problem (Podsakoff and Organ, 1986).

The survey asked general questions on the firm's characteristics and specific questions in relation to the firm's collaboration with CSIC during the period mentioned, including the results obtained after the partnership. Information not fully available by the questionnaire such

as the sector, firm's age and firm's size, was accessed through the Iberian balance sheet analysis system (SABI) dataset. We analyzed only the firms that presented information in both datasets, resulting in a final sample of 756 firms.

3.2. Dependent variables

Our dependent variables capture the different benefits perceived by firms from interactions with PROs. Specifically, firms were asked to evaluate the importance of achieving different outcomes from the interaction with CSIC. The items were assessed using a scale ranging from 1 (result is nonexistent or none important) to 4 (results are considered as highly important).

Benefits were grouped into four categories taking into account previous literature which has identified types of benefits obtained by firms from I-PRO interaction (Dutrénit et al., 2010; Bishop et al., 2011; Fuentes and Dutrénit 2012; Olmos-Peñuela et al., 2017). The first category corresponds to the traditional benefits related to innovation results. Following the definition of Oslo Manual (OECD, 2003), respondents were asked if as a result of their interactions with CSIC, the firm introduced a new product (good or service), new process or accessed to a new market.

The other two categories were referred to as long-term and short-term benefits drawing on the concepts proposed by Dutrénit et al (2010). The first group is based on the idea that firms may benefit from PROs by nurturing their ability to become innovative in the long-term by, for instance, strengthening their innovative capabilities via creation of R&D department or hiring new R&D personnel. The second group is based on the argument that firms may benefit from PROs more directly by obtaining consulting advice or assistance in problem resolution. The last category of benefits considered in this analysis is related to the intermediary role of PROs (network building). Along this line, we ask respondents to evaluate if as a consequence of the interaction with CSIC, the firm established new contacts with universities, R&D labs, or other firms.

We conducted principal component analyses for the four dependent variables. First, we followed Kaiser criterion that suggests retaining factors with eigenvalues equal or higher to 1. Second, we run Barlett's test of spherity and results were satisfactory. Finally, we used the factor loadings from the factor analysis in order to measure the dependent variables. Table 1 reports the results and the total variance explained by the factor.

Since the principal component analyses for the four dependent variables were satisfactory, we created constructs for each type of benefit. For instance, in the case of long-term benefits we first calculated the average of the three items referenced in Table 1: (1) if the firm has created a new R&D department (2) if the firm has increased R&D investment (3) if the firm has hired new R&D personnel. Second, we transformed the variable into an ordinal scale as follows: if the value of the variable was between 1 and 1.4, the converted variable took value 1; if the value of the variable ranged between 1.5 and 2.4, the converted variable took value 2; if the value of the variable was between 2.5 and 3.4, the converted variable took value 3; and if the value of the variable ranged between 3.5 and 4 the converted variable took value 4.

Table 1. Factor principal component analyses

	Items: As a consequence of the collaboration with CSIC…	**Factor 1**
Innovation results	The firm introduced a new product (good or service)	0.81
	The firm accessed a new market	0.80
	The firm introduced a new process (good or service)	0.61
Eigenvalue: 1.67; Barlett's test of sphericity: $\chi 2$: 254.73 ; p= 0.000; 56% of total variance explained; Cronbach alpha (0,60)		
	Items: As a consequence of the collaboration with CSIC…	**Factor 1**
Network building	The firm established new contacts with universities and other PROs	0.82
	The firm established new contacts with private R&D labs, technological centers or consultants	0.86
	The firm established new contacts with other firms (competitors, potential clients, potential suppliers…)	0.78
Eigenvalue: 2.02; Barlett's test of sphericity: $\chi 2$: 542.89 ; p= 0.000; 67% of total variance explained; Cronbach alpha (0,75)		
	Items: As a consequence of the collaboration with CSIC…	**Factor 1**
Long-term benefits	The firm has created or increased the R&D department	0.86
	The firm has hired new personnel	0.78
	The firm has increased R&D investment	0.77
Eigenvalue: 1.94; Barlett's test of sphericity: $\chi 2$: 458.67 ; p= 0.000; 65% of total variance explained; Cronbach alpha (0,70)		
	Items: As a consequence of the collaboration with CSIC…	**Factor 1**
Short-term benefits	The firm has obtained assistance in problem resolution	0.67
	The firm has reduced the risk and costs associated to R&D	0.69
	The firm has obtained consulting advice	0.65
	The firm has acquired scientific and technical resources	0.77
Eigenvalue: 1.93; Barlett's test of sphericity: $\chi 2$: 342.67 ; p= 0.000; 48% of total variance explained; Cronbach alpha (0,63)		

Source: Author's elaboration.

3.3. Independent variables

3.3.1. Antecedents of firm's absorptive capacity

Our set of independent variables includes different factors related to the antecedents of a firm's absorptive capacity, such as coordination mechanisms, internal R&D, and previous experience in collaboration with research institutions. To measure coordination mechanisms, we used a construct composed of four questions related to the extent to which firms implement the following practices on a scale ranging from 1 (never) to 4 (always): inter-departmental teams are created, employees rotate between different functional areas or departments, employees are encouraged towards decision- making, and communication between employees at different hierarchical levels in the organization is promoted (Jansen et al., 2005). The resulting variable was calculated as an arithmetic mean and takes values ranging from 1 to 4. We measure internal R&D on a scale from 1 to 3 (the firm does not develop internal R&D, the firm pursues R&D occasionally and the firm develops internal R&D yearly). We chose this measure rather than a dummy variable as we consider it to be a better proxy for the firm's R&D stock and, therefore, a better indicator of technological capabilities. The last antecedent of absorptive capacity introduced is experience in collaborations. This variable takes value 1 in the case in which the firm considers CSIC to be the most frequent external partner used in their collaborations, and 0 otherwise.

3.3.2. External knowledge search strategy

General knowledge sourcing patterns can also influence firms-PROs partnering. We focus on the firm's search strategy by capturing the extent to which the firm looks towards multiple sources beyond its organizational boundaries for ideas. To build this variable, we draw on the concepts from Laursen and Salter (2004) related to the breadth and depth search strategy, reflecting the extent to which firms draw from different external sources. Specifically, we ask firms about the importance (on a scale of 1-4 ranging from non- important to highly important) of a number of external knowledge sources in order to improve their innovation processes. The sources include suppliers; clients; competitors; consultants, laboratories or R&D private institutes; universities and PROs; technology centers; conferences, congresses, fairs, and professional meetings; regional and national governments and professional and industry associations. Thus, we created the following two independent variables for search strategy:

- External search breadth, as the variety of external sources used by the firm to innovate, constructed by combining the nine external sources identified. The first step was coding each external source (ranging initially from 1 to 4) into a binary variable, which takes the value 1 if the firm relies on a particular source for innovation and 0 otherwise. The second step was adding up the nine variables, which takes the value 9 if the firm relies on every external source and 0 if it does not rely on any of them.

- External search depth, relates to the importance to the firm on external knowledge sources. It was constructed by coding each external source (initially ranging from 1 to 4) into a binary variable, which takes the value 1 if the firm reports the external source as very important for innovation and 0 otherwise. We added the nine binary variables obtained to construct our independent variable external search depth, which takes the value 0 if the firm does not consider any external sources to be very important, and 9 if it considers all nine external sources of information to be very important.

3.4. Control variables

In this study, we control for specificities related to the collaboration of the firms with CSIC and also different firm's characteristics. First, following previous studies showing that the benefits from PRO-I are contingent on the channel used to coordinate the relationship (De Fuentes and Dutrénit, 2012; Dutrénit et al., 2010; Schaeffer et al., 2017; Vega-Jurado et al., 2017), we include six binary variables that measure distinct channels the firm has used to interact with CSIC, which are, joint research, contract research, services, training, diffusion and nonformalized. Joint research represents whether the project was part of a public program financed by the Spanish national research plan, other regional programs or EU programs. Contract research measures whether the research was contracted out to CSIC. Services captures if the firm has been involved in consultancy activities and whether the firm has used CSIC's installations and equipment. Training measures whether the firm has allowed employees to pursue training stays at CSIC or specialized training with CSIC's researchers. Diffusion represents if there has been joint participation in dissemination activities. Lastly, nonformalized stands for non-formalized enquiries or collaborations that have been established between the partners without being channeled through the institution.

We also control for three main firm's characteristics, size, sector and age. Age is measured through a continuous variable that counts the number of years since the firm's foundation. Firm size is captured by a continuous variable for the number of firm employees. We use a logarithmic transformation to match this variable with a normal distribution. We control for industrial sector through a binary variable which takes the value 1 if the firm belongs to that sector and 0 otherwise. The sectors considered are: construction, energy and water supply, mining, services, agriculture, forestry and fishing, high technology manufacturing, low technology manufacturing and medium-high technology manufacturing industries.

Finally, considering that some knowledge could also be non-formalized we also ask for the degree of importance of firm's internal sources of information (i.e. from other employees, firm's procedures…) and create a variable named Internal search depth ranging from 1 (not important) to 4 (highly important). This variable captures the importance to the firm of drawing on internal sources of information for innovation, meaning the extent to which the firm relies on information and knowledge from firms' employees and internal R&D activities.

Table 2. Description of the variables

Variable	Question	Measurement scale and reference studies
Innovation results	As a consequence of the collaboration with CSIC: • The firm introduced a new product (good or service) • The firm accessed a new market • The firm introduced a new process	From 1 (result is non-existent or none-important) to 4 (results are considered as highly important). **Reference studies:** Dutrénit et al. (2010); Bishop et al. (2011); Fuentes and Dutrénit (2012)
Network building	As a consequence of the collaboration with CSIC: • The firm established new contacts with universities and other PROs • The firm established new contacts with private R&D labs, technological centers or consultants • The firm established new contacts with other firms (competitors, potential clients, potential suppliers…)	
Long-term benefits	As a consequence of the collaboration with CSIC: • The firm has created or increased the R&D department • The firm has hired new R&D personnel • The firm has increased R&D investment	
Short-term benefits	As a consequence of the collaboration with CSIC: • The firm has obtained assistance in problem resolution • The firm has reduced the risk and costs associated to R&D • The firm has obtained consulting advice • The firm has acquired scientific and technical resources	
Coordination mechanisms	Indicate, the extent to which firms implement the following practices: • Inter-departmental teams are created • Employees rotate between different functional areas or departments • Employees are encouraged towards decision-making • Communication between employees at different hierarchical levels in the organization is promoted	From 1 (never) to 4 (always) **Reference studies:** Jansen et al (2005)
Internal R&D	Did your enterprise perform in-house R&D during the three years?	From 1 to 3 (1: the firm does not develop 'internal R&D', 2: the firm pursues R&D occasionally and 3: the firm develops internal R&D yearly) **Reference studies:** Vega-Jurado et al (2009)

Variable	Question	Measurement scale and reference studies
Experience in collaborations	For the development of R&D and innovation activities in your company, indicate with which of these organizations you have maintained more relations: a) Universities; b) Other firms; c) CSIC; d) Technological centers	This variable takes value 1 in the case in which the firm considers CSIC to be the most frequent external partner used in their collaborations, and 0 otherwise. **Reference studies:** Olmos-Peñuela et al. (2017)
Channels of interaction	Indicate the activity or activities through which your firm interacted with CSIC: • Joint research • Contract research • Services • Training • Diffusion • Nonformalized	Binary variables that take value 1 if the firm used the channel to interact with CSIC and 0 in another case **Reference studies:** De Fuentes and Dutrénit (2012); Dutrénit et al. (2010)
External search breadth	Please, indicate if the firm uses the following external sources of information for your innovation processes. If so, indicate the level of importance: 1) suppliers; 2) clients; 3) competitors; 4) consultants, laboratories or R&D private institutes; 5) universities and PROs; 6) technology centers; 7) conferences, congresses, fairs, and professional meetings; 8) regional and national governments, and 9) professional and industry associations	This variable takes value from 0 to 9, considering the number of external sources of knowledge or information used by the firm in its innovative activities. Reference studies: Laursen and Salter (2004)
External search depth		This variable takes values from 0 to 9, considering the number of external sources of knowledge or information that the firm considers to be of great importance **Reference studies:** Laursen and Salter (2004)
Internal search depth	Please, indicate if the firm uses the following external sources of information for your innovation processes. If so, indicate the level of importance: Internal knowledge (employees, internal processes)	Degree of importance of firm's internal sources of information (i.e. from other employees, firm's procedures…) This variable takes value from 1 (not important) to 4 (highly important).
Firm's age	In which year was your enterprise established?	Number of years since the firm's foundation
Firm's size (ln)	Indicate the number of employees	Natural logarithm of the number of firm´s employees

Source: Author's elaboration.

3.5. Empirical strategy

In order to understand the multiple outcomes obtained through the interaction with CSIC we performed an ordinal probit regression.

Attention should be paid to the tight connections between the potential benefits derived from firms-PRO interactions. For instance, the establishment of linkages with PROs with the objective of obtaining consulting advice or assistance in problem resolution could be tightly connected with the ultimate strategy of introducing new products and processes into the market. Also, the generation of capabilities can also be intimately related to firm's ultimate development of technological innovations. The non-independency of the different results could generate estimation problems due to cross-correlations. To control for this issue, we corroborated results by using seemingly unrelated regressions models, which account for dependency between the explained variables and potential correlations in the error terms, and results did not change.

4. Results and Discussions

Table 3 reports the descriptive statistics and bivariate correlations of the variables in our study. Low correlations inform us that multicollinearity is not a problem in our data. The highest VIF is of 6 and the overall mean VIF is of 1.85 well below the recommended value of 10 (Neter et al., 1996).

Descriptive figures show that short–term benefits are proportionally given more importance than the other type of benefits considered in the analysis, even than those benefits-oriented towards innovation results. In other words, the results show that in the analyzed context, the role of PROs as business partners has a more operational focus in which problem-solving and consulting advice is strategic. It is also important to note that network building is given similar importance to innovation results. This result shows that PROs can play important roles not only in creating new knowledge and transfer to firms, but also acting as intermediaries in the innovation system (Intarakumnerd and Goto, 2018).

The results of the regressions are presented in table 4 and show that the impact of the factors analyzed on specific benefits differ. Starting with the analysis of the organizational antecedents of the firm's absorptive capacity, the results show that R&D intensity has a significant and positive effect on long-term and short-term benefits, while experience in collaborations is significant for long-term benefits, which partially supports hypotheses 1 and 2. These results show that firms with a higher level of absorptive capacity are better positioned to use interactions with PROs as a strategy to strengthen internal capabilities. Being "able to do" new things often involves parties' interaction and participation in a process of mutual learning, which requires an understanding from both sides. This can be nurtured through previous experiences and the development of similar knowledge bases. In addition, the results also show that even for those firms who perceived more short-term benefits a strong knowledge base resulting from R&D is necessary to recognize and assimilate knowledge coming from PROs.

Table 3. Descriptive statistics and correlations

	Mean	S.D.	Min	Max	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
(1) Innovation results	1.76	0.81	1.00	4.00	1.00																	
(2) Network building	1.70	0.89	1.00	4.00	0.35	1.00																
(3) Long-term benefits	1.58	0.85	1.00	4.00	0.43	0.47	1.00															
(4) Short-term benefits	2.17	0.86	1.00	4.00	0.42	0.51	0.49	1.00														
(5) Coordination mechanism	2.75	0.56	1.00	4.00	0.04	0.09	0.13	0.14	1.00													
(6) Internal R&D	2.65	0.62	1.00	3.00	0.03	0.09	0.15	0.17	0.37	1.00												
(7) Experience in collaborations	0.13	0.34	0.00	1.00	0.11	0.02	0.17	0.10	-0.04	-0.11	1.00											
(8) Joint research	0.48	0.50	0.00	1.00	-0.08	0.19	0.16	0.22	0.18	0.22	-0.00	1.00										
(9) Contract research	0.55	0.50	0.00	1.00	0.00	-0.04	0.00	0.11	0.07	0.11	-0.00	-0.04	1.00									
(10) Services	0.75	0.43	0.00	1.00	0.19	0.08	0.11	0.20	0.04	0.04	0.10	0.01	0.10	1.00								
(11) Training	0.24	0.43	0.00	1.00	0.12	0.09	0.18	0.20	0.08	0.08	0.22	0.15	0.12	0.24	1.00							
(12) Diffusion	0.31	0.46	0.00	1.00	0.09	0.23	0.18	0.24	0.10	0.12	0.15	0.27	0.12	0.09	0.25	1.00						
(13) Nonformalized	0.51	0.50	0.00	1.00	0.10	0.17	0.16	0.23	0.12	0.11	0.04	0.22	0.13	0.28	0.27	0.32	1.00					
(14) Internal search depth	3.57	0.60	1.00	4.00	0.08	0.09	0.13	0.13	0.31	0.17	-0.03	0.13	0.05	0.00	0.11	0.07	0.09	1.00				
(15) External search depth	2.12	1.98	0.00	9.00	0.06	0.11	0.12	0.12	0.20	0.14	-0.04	0.09	0.05	0.07	0.04	0.07	0.04	0.36	1.00			
(16) External search breadth	8.33	1.32	0.00	9.00	0.07	0.14	0.13	0.14	0.11	0.12	-0.10	0.11	0.06	0.05	0.08	0.09	0.07	0.20	0.27	1.00		
(17) Firm's age	27.46	21.29	2.00	209.00	0.04	0.06	-0.05	0.03	-0.01	0.12	-0.06	-0.02	0.11	0.01	-0.01	0.03	-0.01	0.03	0.09	0.10	1.00	
(18) Firm's size (ln)	3.96	1.69	0.69	10.13	-0.07	0.03	-0.04	0.00	0.10	0.25	-0.14	0.05	0.10	0.01	-0.01	0.05	0.04	0.08	0.05	0.16	0.44	1.00

Notes: the table displays the means, standard deviations (SD) and correlations among the variables of study. Correlations above 0.08 are statistically significant at the $p < 0.05$ level (two tailed). Correlations above 0.13 are statistically significant at the $p < 0.01$ level (two tailed). Sector dummies not included in descriptive statistics.

Source: Authors elaboration.

Table 4. Ordered probit results

	Innovation results	Network building	Long-term benefits	Short-term benefits
Internal R&D	0.07	0.06	0.44***	0.25***
	(0.08)	(0.09)	(0.10)	(0.08)
Experience in collaborations	0.19	-0.00	0.57***	0.14
	(0.14)	(0.15)	(0.15)	(0.14)
Coordination mechanism	0.10	0.04	-0.07	0.02
	(0.09)	(0.10)	(0.11)	(0.09)
External search breadth	0.01	0.10**	0.09**	0.04
	(0.04)	(0.04)	(0.05)	(0.04)
External search depth	0.03	0.05*	0.10***	0.03
	(0.03)	(0.03)	(0.03)	(0.02)
Joint research	-0.15	0.37***	0.42***	0.40***
	(0.10)	(0.11)	(0.11)	(0.10)
Contract research	0.09	-0.10	0.05	0.21**
	(0.10)	(0.10)	(0.11)	(0.09)
Services	0.36***	0.16	0.19	0.44***
	(0.12)	(0.12)	(0.13)	(0.11)
Training	0.12	-0.08	0.15	0.09
	(0.12)	(0.12)	(0.13)	(0.11)
Diffusion	0.26**	0.42***	0.23**	0.30***
	(0.11)	(0.11)	(0.11)	(0.11)
Nonformalized	0.01	0.38***	0.25**	0.35***
	(0.11)	(0.11)	(0.12)	(0.10)
Firm's size (ln)	-0.15***	-0.07**	-0.10***	-0.06**
	(0.03)	(0.03)	(0.03)	(0.03)
Firm's age	0.00	0.00*	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)
Internal search depth	0.13	0.06	0.06	0.14*
	(0.09)	(0.09)	(0.10)	(0.09)
Energy and water supply industry	-1.69***	0.08	-0.09	0.03
	(0.59)	(0.38)	(0.40)	(0.38)
Mining industry	-0.15	-0.74*	-0.87*	-0.45
	(0.38)	(0.43)	(0.47)	(0.38)
Services industry	-0.36	-0.38*	-0.41*	-0.12
	(0.23)	(0.23)	(0.24)	(0.22)

	Innovation results	Network building	Long-term benefits	Short-term benefits
Agriculture, forestry and fishing industry	-0.57*	-0.06	-0.48	0.13
	(0.31)	(0.31)	(0.34)	(0.30)
High technology industries	-0.47	-0.30	-0.28	0.13
	(0.29)	(0.29)	(0.31)	(0.28)
Low technology industries	-0.24	-0.50**	-0.60**	-0.26
	(0.23)	(0.23)	(0.24)	(0.22)
Medium-high technology industries	-0.22	-0.44*	-0.50*	-0.38
	(0.25)	(0.25)	(0.27)	(0.24)
cut1	0.58	1.56***	2.36***	1.40***
	(0.49)	(0.53)	(0.57)	(0.48)
cut2	1.69***	2.61***	3.58***	2.85***
	(0.49)	(0.54)	(0.58)	(0.49)
cut3	2.65***	3.68***	4.54***	4.34***
	(0.50)	(0.55)	(0.60)	(0.50)
N	616	612	608	611
Log likelihood	75.24***	115.69***	150.26***	164.00***

Note: We conceptualized one equation for each type of benefit perceived by the firms from their interactions with CSIC. As we identified four types of benefits for firms we have a set of four equations. Standard errors are reported in parentheses. Significance levels are based on a two-tailed test: *p<.10; **p<0.05; ***p<0.01.

Source: Author's elaboration.

Contrary to our expectations coordination mechanisms were not significant for none of the types of benefits analyzed. Thus, the data does not support hypothesis 3. Even though previous literature has pointed out coordination mechanisms as an important antecedent of a firm's absorptive capacity, our results show that they are not relevant to obtain benefits from PRO-I interactions. A possible explanation for this result is that coordination mechanisms could be relevant to promote the acquisition and assimilation of new external knowledge (the first two dimensions of absorptive capacity) but they are not directly related to its effective exploitation. In order to transform the knowledge acquired through interaction with PROs, firms require more stable knowledge structures. Thus, the temporal nature of job rotation and inter-departmental teams indeed may foster acquisition of new external knowledge, but this augmentation may be insufficient to embed new external knowledge into systems and structures (Jansen et al., 2005).

The results also show that the firm's external knowledge search strategy matters for obtaining benefits from PRO-interactions, which supports hypothesis 4. On the one hand, external search breadth, has a significant and positive effect on two of the four benefits considered in the analysis: network building and long-term benefits. The drawing of knowledge from a

variety of external sources is likely to develop a broader knowledge base extending the firm's current expertise, allowing it to exploit efficiently the collaboration with PROs. Besides, the experience of using a broader set of external sources, and managing a portfolio of collaborations implies that the firm is capable of activating the synergies between internal and external knowledge.

On the other hand, the results also show that the extent to which the firm draws intensively on different information sources (external search depth) is significantly and positively related to the strengthening of the firm's internal capabilities (long-term benefits) and network building from collaboration with PRO. The relevance and non-superficiality of external sources suggest the existence of learning capabilities between the firm and external agents and thus, explains the prediction involving the strengthening of capabilities and network building. In other words, when firms draw intensively on external sources of knowledge, they develop set of routines to activate the screening and exploitation of external knowledge, which will have an impact in the firm's capacity to benefit from collaborations with research organizations.

Regarding the control variables, the results indicate that the channels of interactions are important ways in order to determine the benefits perceived by firms from their interactions with PRO, but they have different impacts on each type of benefit. In this sense, joint research, diffusion, and nonformalized are the most important channels by affecting most of benefits analyzed. Services are positively related to innovation results and short-term benefits, while contract research positively affects short-term benefits. The results of joint research are similar to those of De Fuentes and Dutrénit (2012), who found that PRO–I interactions through R&D projects have a positive impact on the strengthening of internal capacities but also show, in line with other studies carried out in the Spanish context (Vega-Jurado et al., 2009), that collaboration with research organizations through R&D projects are not a relevant strategy to obtain innovation results. However, the collaboration channeled through consultancy activities or the use of installations and equipment (services), seems to be relevant to introduce innovation into the market.

The firm's size shows a significant and negative association with all of the benefits analyzed. This result suggests that small firms benefit more from cooperation with research organizations than large firms. In line with previous studies, our results show that smaller firms are more motivated to access external resources and use the collaboration with external agents as a relevant strategy to innovate and acquire complementary assets that otherwise would have been difficult for them to develop internally (Barge Gil, 2010). In this sense, when smaller firms collaborate with PROs, they use external knowledge strategically because they do not have the critical mass to be able to cope on their own with the uncertainty and complexity of innovation projects.

Finally, the firm's age is overall not predicting results from PRO-I collaborations. Start- ups are generally in a phase of development and, just as we argued for small firms, their need for resources usually is higher. However, it could be the case that their youngness, and the difficulty to find complementarities, restricts them to capitalize on these resources and thus, end up not being relevant results for these types of companies.

5. Conclusions and implications

Science-industry interactions have become particularly relevant in recent decades, from both an academic and a political perspective. Approaches, such as innovation systems and the triple helix, suggest that research organizations can make very important contributions to development. These contributions are mainly associated with the emergence of patterns of interactions between these actors and the business sector. Thus, connecting science and society have become a defining feature in contemporary science policy (de Jong, 2022) and have conducted to the design and implementation of instruments aimed at fostering these relations directly and, in particular, promoting the knowledge transfer of research organizations to industry.

The rationale behind these policies is based primarily on the expectation that PRO-I interactions have a positive effect on the development of new products and processes, benefiting the dynamics of territorial development and innovation. However, it is reasonable to assume that the effects PRO-I interactions may not be homogeneous; rather, they may be contingent on the capabilities of different actors. Along these lines, this paper started by observing that the benefits firms gain from their interactions with PROs may go beyond innovation results and may be determined by different firm characteristics, in particular, organizational antecedents of a firm's absorptive capacity and knowledge search strategies. The results obtained largely support this idea.

First, the results indicate that firms need to have a certain level of absorptive capacity to take advantage of the collaboration with PROs, but that R&D is not the only antecedent that must be considered. Prior collaborative experience with PRO appears also as an important factor to exploit these interactions, in particular as a way to develop internal capabilities and obtain long-term benefits. Repeated collaboration over time allows firms to institutionalize learning mechanisms that enable them to exploit external knowledge and to manage more effectively the collaboration agreements. This result has an important implication because it highlights that the strengthening of capabilities in the long-term through collaboration with scientific organizations is not a direct result, but it requires time and previous contacts to develop an appropriate management process between the partners. The management of interactions with scientific actors is a critical activity to firms because of the complexity and uncertainty of projects and the differences in terms of organizational culture, objectives, and knowledge bases between the partners.

Therefore, firms should develop strategic competencies to fully benefit from collaborations with PROs, which can be built through iterated collaborative relationships.

From the perspective of PROs, this result has also an important implication in order to foster their societal impacts: it is crucial to devote more attention to the creation of alternative structures that facilitate meeting spaces to build relationships between researchers and companies and with the potential to house and boost future collaborations. Technology Transfer Offices (TTO) are performing relatively well in promoting commercial transfer activities, but because of the relevance of prior collaborative experience in exploiting these relationships, it is important to encourage the scientists' engagement in more informal collaborative activities

that contribute to build trust between the parties. This is even more relevant in countries or regions where formal interactions between PROs and the business sector are not a common practice.

This study also outlined the firm's search strategy as a relevant factor in determining the benefits obtained from interactions with PROs. The sourcing of knowledge from a variety of external sources has been associated with the development of a broader knowledge base extending the firm's current expertise. Moreover, the extent to which firms draws intensively on different external sources suggest the existence of learning between both parties and thus, a more intense development of the firm's knowledge base and the possibility of tapping into many new ideas. Following this idea, we argue that firms were going to perceive the benefits of interacting with PROs in a more positive way when pursuing an open search strategy because of their possibility of creating and maintaining large networks. The results confirm this idea particularly in the case of firms that achieve long-term benefits and establish new contacts with other actors of their innovation ecosystem.

Besides, it is clear from our results that different channels of interaction lead to different benefits. In this sense, it is striking that most of the channels used to manage the relationship with PRO are not associated with the introduction of innovations into the market. This fact may be explained by considering the characteristics of the context analyzed in the present study. In regions characterized by a productive structure comprised mainly of small companies in traditional sectors and low levels of R&D investment, demand for scientific and technological knowledge is low. Therefore, PRO- I interactions are probably not a regular practice or take the form of the provision by the research organization of technical services rather than collaborative R&D (Pinto et al., 2015). This pattern of collaboration may reduce the effectiveness of PRO-I interactions as a strategy to promote the development of new products and processes, but may be effective to achieve other short and long-term benefits and network building.

Related to the firm`s structural characteristics, the results show that size has a strong influence on the type of benefits derived from the interaction with PROs. In particular, smaller firms tend to obtain more benefits from their interaction with PRO than larger firms. Even though several studies suggest that collaboration with scientific agents is easier for large firms because they have abundant resources that complement PROs knowledge and ease the management of collaboration agreements (Vivas-Augier and Barge-Gil, 2015), our results highlight that for small firms this strategy is more relevant to improve their performance. Thus, collaboration with PROs represent to SMEs a more important strategy to achieve innovation results, strengthen internal capacities, or access to consulting advice or technical facilities compared to large firms. In other words, although large firms tend to cooperate more with external agents, small firms benefit more from cooperation compared to large firms.

The results mentioned above contribute with insights for science and innovation policy and for debate on the role of PROs in regional development, particularly in contexts with a low absorptive capacity or characterized by a weak innovation system. First, policymakers should be more creative in order to design programs that consider a wide spectrum of benefits and the degree to which the benefits of PRO-I interactions differ according to the firm's characteristics.

In this sense, the promotion of "one size fits all" mechanisms, focused on specific channels does not seem to be the best strategy. Likewise, it is important to consider that the benefits of this type of interaction go beyond technological innovation, therefore from a policy perspective a broader set of indicators should be taken account to evaluate the effectiveness of public instruments aimed to promote PRO-I interactions.

In this sense, it is important to note that the implementation of policies designed without considering the characteristics and limitations of the local context may be not effective. Recent research on science-industry linkages has pointed out that the channels of interactions between research organizations and firms change as the country or region develops (Vega-Jurado et al., 2021). The relationship between these two key components of an innovation system reflects the coevolution of factors such as the research capabilities of research organizations on the one hand and the absorptive capacity of firms on the other. These factors define different modes of interaction and different benefits coming from these relationships. Understanding the dynamic and evolutionary nature of these relationships as well as their results is important in order to implement instruments that promote the contribution of scientific organizations to regional development.

In the context analyzed, for instance, the results show that interactions between firms and PROs allows firms to obtain assistance in problem resolution or acquire technical resources aiming to solve production problems in the short-term. Likewise, the results also show that network building is given similar importance to innovation results, in other words, PROs are performing activities bridging firms and other actors of the innovation system (universities, consultants, R&D labs, etc.). In this sense, due to the open nature of innovation today, the roles of PROs as intermediaries can be more important in the long- term, by helping to solve "systemic failures" that might slow down interactive learning in innovation systems.

These findings are also important for management practice. Managers draw increasingly upon scientific sources in order to find opportunities for technological innovation and to acquire external resources, and the general message that arises from this study is that the effectiveness of such processes is to some degree a matter of strategic needs and having in place an open search strategy. In order to exploit this type of collaboration firms should have a broader base of internal knowledge and expertise, which can be built through the development of in-house R&D activities, but also could be nurtured by previous experience in collaboration or the adoption of an active external search strategy. These last aspects are useful to extend the firm's expertise, develop similar knowledge frameworks and institutionalize learning mechanisms that ease the management of collaboration between partners and the exploitation of shared knowledge.

Limitations of the study need to be mentioned. First, the study uses cross-sectional survey data, which does not allow conclusions to be made about causal relationships and avoids taking into account the counterfactual effect, that is, comparing the situation of presence versus absence of collaboration. Also, analyzing data at one point in time implies a need for careful interpretation of results since our dependent variables deals with short- and long-term benefits but we are not able to include time variation in our empirics. Second, we capture firm's percep-

tion of the benefits obtained from their collaborations with PROs, including perception biases to our results. Third, we rely on data from only one country (Spain), which does not allow for generalization to other countries or contexts. Fourth, the study was conducted on firms that have collaborated with CSIC, thus generally intensive in R&D, which reduces the generalization of our results to other settings. Finally, the explanatory power of our model could be improved by including information about academics, thus allowing us to fully understand both sides of the collaboration.

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