DIRECT AND MODERATING EFFECTS OF PUBLIC R&D SUPPORT ON EXTERNAL KNOWLEDGE ACQUISITION: THE INTERACTION WITH PERFORMANCE FEEDBACK

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Forthcoming in Industry and Innovation. Please cite as:

Martinez-Noya, A., & Garcia-Canal, E. (2024). Direct and moderating effects of public R&D support on external knowledge acquisition: the interaction with performance feedback. Industry and Innovation, forthcoming.
https://doi.org/10.1080/13662716.2024.2340615

Keywords: R&D subsidies; behavioural additionality; cooperation breadth; performance feedback; behavioural theory

Acknowledgments:

We gratefully acknowledge the financial support provided by the Spanish Ministry of Economy, Industry and Competitiveness (project ECO2017-86101-P) and the Spanish Ministry of Science, Innovation and Universities (project PID2023-148063NB-100).

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We argue that public R&D support may not only lead firms to increase their technological cooperation breadth, enhancing knowledge acquisition, but also influence how firms frame and approach R&D alliance decisions in response to their innovation performance feedback. From a behavioural perspective it is firms performing above or below innovation aspirations the ones that are more willing to gain access to new sources of external knowledge. We argue that while public funding of a firm’s R&D activities has a positive direct effect on cooperation breadth, it also exerts a negative moderating influence when firms deviate from their innovation aspirations, because managers’ external knowledge acquisition strategies tend to align with the objectives of subsidised projects. Using a panel of technological-intensive Spanish firms, we find support for our hypotheses, showing the importance of incorporating performance feedback as a key factor when analysing the impact of public R&D instruments on firms’ collaborative behaviour.

Keywords: R&D subsidies; behavioural additionality; cooperation breadth; performance feedback; behavioural theory

1. INTRODUCTION

The deployment of public R&D support instruments by governments aimed at fostering firms' innovativeness and promoting economic development stands as a widely recognised phenomenon that has garnered considerable attention within the innovation literature (Afcha and Lucena, 2022; Becker, 2015; Corsi et al., 2022; David, Hall and Toole, 2000; Greco, Grimaldi and Cricelli, 2017; Huergo, Trenado, and Ubierna, 2016). Most of the innovation policy literature (see Dimos and Pugh, 2016, and Zúñiga-Vicente et al., 2014, for a review) has focused on analysing public R&D support in terms of its effect on firms’ R&D investments (input additionality) or innovation performance levels (output additionality). However, public support, such as in the form of subsidies, does not appear to directly affect firm innovation performance. Instead, it influences firms' behaviour, known as behavioural additionality. This may include increased learning resulting from additional R&D efforts or a higher level of openness to technology markets and new partners, ultimately leading to new knowledge acquisition and thus greater innovativeness, which is the ultimate objective for firms as well as governments (Afcha and Lucena, 2021; Bianchi, Murtinu and Scalera, 2019; Chapman, Lucena and Afcha, 2018; Cano-Kollmann, Friedmann and Pedersen, 2023; Hamilton and Mudambi, 2017; Vasudeva, Spencer and Teegen, 2013). These behavioural changes induced by R&D public support, have been less studied and empirical studies so far lead, in most cases, to inconclusive results (Afcha, 2011; Chapman and Hewitt-Dundas, 2018; Jugend et al., 2020). For this reason, more research on the impact of public support on R&D cooperation and subsequent knowledge acquisition is needed.

One behavioural change that remains understudied is the influence of R&D public support on firms' strategies for acquiring external knowledge through cooperation with new types of technological partners, i.e the breadth of their Technological Alliance Portfolio (TAP). By collaborating with new types of technological partners (such as clients, suppliers, competitors or public institutions), firms can gain access to new sources of knowledge that increase their potential to innovate when combined with their own resources (Cassiman and Veugelers, 2006; Chesbrough, 2006; Belderbos et al., 2004; de Faria, Lima and Santos, 2010; Laursen and Salter, 2006; Perkmann et al., 2013; van Beers and Zand, 2014). However, many firms are still reluctant to increase the breadth of their TAP due to increased complexity and the risks associated in terms of opportunistic behaviour (Harrison and Klein, 2007; Jiang et al., 2010; Laursen, Salter, 2014; Srivastava and Gnyawali, 2011). Cooperating with new types of partners offers significant opportunities for knowledge acquisition, but this expansion also brings about various management costs, stemming from heightened challenges in communication, coordination, and monitoring (Cerulli, Gabriele and Poti, 2016; Goerzen and

Beamish, 2005; Lee et al., 2017). Hence, it becomes crucial to understand whether and how increases in R&D public support translate into enhanced learning opportunities for recipient firms. This question represents a crucial area of inquiry from both public policy and corporate technological strategy perspectives, yet existing literature has not provided a definitive answer. Some studies have reported that public R&D support encourages cooperation with various types of partners, although others have found an impact only with specific types of partners, particularly academic institutions (Jugend et al., 2020; Bianchi et al., 2019). In fact, firm-related factors such as size or experience appear to moderate the relationship. While the positive effect of public support on cooperation appears to be greater for SMEs compared to large firms (Bianchi et al. 2019), or for those firms new to innovation compared to long-time innovators (Cano-Kollmann et al., 2017); other studies show the relevance of firm's collaboration experience to increase its collaboration breadth when receiving public subsidies (Chapman et al., 2018).

Thus, not all organisations are equally predisposed to implement changes, even when presented with the same external stimulus. In this sense, one key internal factor that has not yet been analysed by the previous literature on the effect of public support on external knowledge acquisition is a firm's innovation performance feedback, which is known to influence the firm's propensity to establish new technological alliances (Tyler and Caner, 2016; Lungeanu et al., 2016; Kavusan and Frankort, 2019; Martínez-Noya and García-Canal, 2021). This effect has been explained from the behavioural theory of the firm (Cyert and March, 1963; Greve, 2003a, 2003b; March, 1991, 1994), which posits that firms are more willing to adopt changes when performing above or below their expected innovation performance. Given that both factors, R&D public support and innovation performance feedback, increase the firm's propensity to expand the breadth of their TAP, enhancing learning opportunities, in this paper we analyse the interaction between them. This research question is particularly intriguing because it allows policymakers to analyse the interaction between R&D funding and learning opportunities for recipient firms. A comprehensive understanding of the circumstances and mechanisms through which R&D funding fosters learning holds the potential to empower policymakers in the effective allocation of their R&D policies. This understanding is paramount, as the interaction with performance feedback may yield partnerships that deviate from those originally envisaged by public policies, consequently yielding outcomes that diverge from the initially anticipated ones.

More specifically, to fill this gap, we analyse whether and how the percentage of public funding of a firm's internal R&D activities may influence its TAP breadth. To do so, we do not focus exclusively on the direct effect of R&D public funding, but also on how it moderates the effect of innovation performance feedback (i.e. whether the recipient firm is performing above or below its innovation aspirations). To study this research question, we use panel data from the Spanish Technological Innovation Panel (TIP), Spain's contribution to the European-wide Community Innovation Survey (CIS), for firms operating in technology-intensive sectors for the period 2008-2015.

Overall, our study shows that R&D public funding leads to increases in firm's TAP breadth. This increase can be attributed to the greater allocation of internal resources to R&D, which in turn incentivises firms to seek complementary external resources, as suggested by Cassiman and Veugelers (2006). This dynamic generates ample learning opportunities for firms. We also show that R&D public funding negatively moderates the propensity to increase cooperation breadth when firms perform above or below their innovation aspiration level. We interpret these results as indicating that with increasing R&D public funding, firms prioritise the overall fulfilment of the goals of subsidised projects over addressing performance discrepancies. This shift in attention ensures that new alliances and learning opportunities associated to them are aligned with the objectives of the subsidised projects. Our results are robust to changes in the composition of R&D funding, as well as to changes in our dependent variable, showing the relevance of incorporating performance feedback insights to improve our understanding of how public R&D instruments impact firms' cooperative behaviour.

2. LITERATURE REVIEW

2.1. Breadth of technological collaborations

Alliance research has demonstrated that a key determinant of a firm's innovativeness is the composition of its TAP, especially in technology-intensive industries (Lungeanu et al., 2016; Schroll and Mild, 2011; Van de Vrande, 2013; Veugelers and Cassiman, 1999). For this reason, firms manage their alliances with a portfolio perspective, trying to maximise resource and learning benefits by increasing their TAP breadth while minimising the associated managerial costs (Asgari et al., 2017; Kavusan and Frankort, 2019; Faems et al., 2010). For the purposes of this paper, TAP breadth refers to the range of types of partners with whom the firm is actively engaged for technology acquisition and/or development purposes. These partners may comprehend clients or suppliers (vertical), competitors (horizontal) or public institutions (Chapman et al. 2018; Laursen and Salter, 2006; Love at al., 2014). Indeed, previous research on the effects of external knowledge search on innovation performance has shown that each type of partner differs in terms of the pool of resources and capabilities it can provide to the firm and the ease of accessing this knowledge, which contributes differently to firms' innovativeness (Ashok et al. 2016; Belderbos, et al., 2006; de Faria, et al., 2010; Harrison et al., 2001; Nieto and Santamaría, 2007; Rodríguez et al., 2017; Un et al., 2010). For this reason, a high TAP breadth contributes to creating and sustaining innovation within an organisation; and more especially for firms operating in technology-intensive industries (Chesbrough, 2006; Laursen and Salter, 2014; Giménez-Fernández et al., 2019). Distant search via increasing external collaborative breadth positively impacts innovation (Laursen and Salter, 2006), as it is more likely to contribute to radical innovation or even act as a mechanism to anticipate future environmental changes, increasing firm's innovation opportunities (Rosenkopf and Nerkar, 2001; Tandon and Toh, 2022).

Nevertheless, many firms may be reluctant to increasing TAP breadth, not only due the natural tendency that firms have towards engaging in local search (Levinthal and March 1993), but also due to the costs involved (Goerzen and Beamish, 2005; Kobarg et al., 2019; Lee et al., 2017). As external technological collaboration breadth increases, communication, coordination and control costs also increase, because each type of partner tends to differ on its strategic orientations, processes, and systems (Estrada et al., 2016; Jiang et al., 2010; Martínez-Noya et al., 2013). In fact, as stated by Laursen and Salter (2006) each of these external knowledge channels has its own norms, habits, and routines thus requiring firms trying to access them to invest significant effort and time to be able to understand and benefit from each knowledge source. In addition, it is also well known that cooperating with new partners also entails appropriability hazards, due to the possibility of the firm's technological knowledge leaking or being misappropriated by the partner (Monteiro et al., 2017; Oxley,1997).

Firms are also heterogeneous in their propensity to expand their TAP. Apart from the technological intensity of the sector the firm operates (Giménez-Fernández et al., 2019), another key determinant of alliance breadth has been demonstrated to be firm's size (Van de Vrande et al., 2009). Research has shown that large firms, due to their greater internal resources and the complementary relationship between internal R&D and external knowledge acquisition (Cassiman and Veugelers, 2006), are more likely to increase their openness. This is also due to the fact that they are better prepared to absorb and exploit a variety of external knowledge sources (Cohen and Levinthal, 1990). Smaller firms, on the other hand, despite their higher need to access complementary external knowledge, seem to face more difficulties when trying to increase their alliance breadth and thus benefit from it (Van de Vrande et al., 2009). In conclusion, research highlights that, despite the benefits associated to increase TAP breadth, there are certain obstacles that can hinder firms from expanding it.

2.2. Public support and breadth of technological collaborations

From an economic policy perspective, one question that arises is whether governments can help firms to mitigate the aforementioned costs and risks through public support and stimulate them to increase the breadth of their collaborations in order to generate opportunities for external knowledge acquisition. Previous research has shown that there are multiples mechanisms through which governments can support innovation at the firm level (Chapman and Hewitt-Dundas, 2018), that can be monetary or non-monetary (Cano-Kollman et al., 2017). Furthermore, these support schemes can operate on the supply side, where they provide funding or other tangible inputs such as public subsidies, grants, or tax breaks; or alternatively, they can operate on the demand side, ensuring a market by facilitating public purchasing of technology or awarding public contracts (Czarnitzki et al., 2020; Slavtchev and Wiederhold, 2016).

As mentioned, previous research has mostly focused on analysing public R&D support effectiveness in terms of input and output additionality, and not so much on behavioural additionality. They have focused on studying how these public measures can stimulate firms' R&D expenditure levels or innovation results (Beck et al., 2016; Czarnitzki and Lopes-Bento, 2013; Dimos and Pugh, 2016; Zúñiga-Vicente et al., 2014), and not so much on how they can impact firms' innovation behaviour, such as their collaboration practices (Bianchi et al., 2019; Jugend et al., 2020) and the efficiency of those collaborations (Greco et al., 2017). Overall, studies on input additionality tend to show a positive effect of R&D subsidies on firms' R&D expenditures. Studies on output additionality, such as innovation performance, show mixed results. Public funding does not seem to have a direct impact on performance; instead, it indirectly influences firms' innovation strategies, particularly their collaborative behaviour (Cerulli et al., 2016; Chapman et al., 2018). These behavioural changes may, in turn, generate new learning opportunities, ultimately contributing to overall innovation outcomes. Despite this, as shown by Jugend et al. (2020) or Bianchi et al. (2019), the existing literature on the relationship between R&D public support and collaboration remains quite limited and offers inconclusive results. In terms of their empirical design, most of these studies utilise cross-sectional data and focus on European countries. They commonly employ binary indicators to capture public support, primarily in the form of subsidies. Upon analysing their main findings, it becomes evident that while most studies generally identify a positive association between public support and technological collaboration (with the exception of works by Colombo et al., 2006, and Hsu, 2006, which find a negative effect), several studies indicate that this relationship is heavily influenced by moderating factors and the specific nature of the collaboration partner being considered. These factors are summarised in the following paragraphs.

Existing research suggests that firm-related factors, such as the availability of internal resources stemming from firm size or experience, moderate the impact of public support on a firm's cooperative behaviour. On the one hand, public support can compensate the lack of such resources, as the positive effects of public R&D support on collaboration seem to be more pronounced for firms with fewer internal resources, such as small and medium-sized enterprises (SMEs), compared to larger firms (Bianchi et al., 2019); as well as for firms that are new to innovation, compared to long-time innovators (Cano-Kollmann et al., 2017). On the other hand, it has also been found that the possession of valuable internal intangible resources also plays a crucial role in leveraging public support to enhance technological collaboration. These resources can include previous experience in cooperative agreements (Chapman et al., 2018; Belderbos et al., 2004), technical and industry-specific expertise of the founding team (Grilli and Murtinu, 2018), an innovative firm's internal climate (Wong and He, 2003), or the ownership of international patents (Busom and Fernandez-Ribas, 2008).

When it comes to the nature of the collaborating partner, many studies analyse the relationship between public support and collaboration differentiating between academic and corporate partners. Indeed, Bianchi et al. (2019) find that academic and corporate partners react differently to the signalling effect of public subsidies. In effect, although most of the studies find that subsidies encourage collaborations with academic partners (Afcha, 2011; Mohnen and Hoareau, 2003; Segarra-Blasco and Arauzo-Carod, 2008), the evidence regarding the effect of public support on the likelihood of collaborating with corporate partners shows mixed results. Some studies find a positive effect of public funding also on corporate collaborations (Arranz and De Arroyabe 2008; Maietta 2015; Grilli and Murtinu, 2018), but there are others that do not find such effect (Afcha, 2011; Miotti and Sachwald 2003; Wong and He, 2003) or even differences between different types of corporate partners (Belderbos et al., 2004).

Only a few studies have focused on examining the effect of public R&D support on collaboration breadth, measured as the number of partner types a firm cooperates with. Their main results are summarised in table 1. As it can be observed, they concur on the positive influence of public support on collaboration breadth, although with some differences. Cano-Kollmann et al. (2017) discovered that public support tends to encourage more collaborative behaviour in firms that are new to innovation compared to long-time innovators. Interestingly, they also found a negative effect of public funding on highly innovative firms. Similarly, Chapman et al. (2018) revealed that while subsidies generally had a positive impact on collaboration breadth, the effects varied significantly at the individual firm level, highlighting the importance of considering moderating factors. Finally, breadth is regarded as a mediator variable between public funding and innovative performance in Cerulli et al. (2016). They demonstrate that the primary driver of improved innovative performance is the additional cooperation stimulated by public support.

------------- Insert Table 1 about here ---------------

In conclusion, while accessing diverse knowledge sources is crucial for firms' innovativeness, previous research indicates that the effect of public support on knowledge acquisition is contingent upon several factors. Drawing on insights from the innovation literature, which underscores that firms often ally with new technological partners to access complementary financial resources and knowledge, our study seeks to contribute by examining the interaction between R&D public support and firm innovation performance feedback. The behavioural theory of the firm (Cyert and March, 1963) suggests that organisational change is primarily driven by discrepancies between performance aspirations and actual performance. Recent research further indicates that such performance discrepancies prompt changes in TAP breadth. However, this factor has been overlooked in studies investigating the impact of public policies on firms' cooperative behaviour. Therefore, analysing their interaction offers a nuanced view of the influence of R&D public support on external knowledge acquisition strategies.

3. HYPOTHESES

3.1. Direct effect of R&D public funding on TAP breadth.

As a baseline effect, we expect a positive effect of public R&D funding on the firm's TAP breadth. This relationship is well-documented, as demonstrated in the literature review, and can be theoretically supported by the fact that R&D subsidies increase the total amount of R&D and financial resources available to the firm. Additionally, government preferences to promote cooperative R&D modes further reinforce this association. Receiving R&D subsidies has an immediate consequence of increasing the resources dedicated to R&D. Extensive evidence demonstrates that R&D subsidies lead to input additionality in terms of financial resources and personnel (Chapman et al., 2018). The increase in resources is not solely limited to the size of the subsidy, as R&D subsidies also act as a signal to financial markets, enabling firms to overcome financial constraints by accessing more debt and equity. This effect tends to be persistent over time, as firms learn how to raise funds and apply for grants (Testa et al., 2019; Srhoj et al., 2021). Consequently, the size of the R&D department initially increases quantitatively in terms of the number of employees and later qualitatively in terms of their qualifications (Afcha and García-Quevedo, 2016). It is important to note that these increases in internal R&D and financial resources are not entirely covered by the subsidies themselves (Czarnitzki and Lopes-Bento, 2013). Moreover, the availability of increased internal R&D and financial resources encourages firms to engage in more external R&D collaborations and seek new partners. According to Cassiman and Veugelers (2006), there are synergies between internal and external R&D activities, prompting firms receiving R&D subsidies to complement their internal efforts with external collaborations. Additionally, R&D subsidies play a role in facilitating the search for new partners. The subsidy can also attract other possible corporate partners, helping firms to source external knowledge more easily (Bianchi et al., 2019; Cerulli et al., 2016; Chapman et al., 2018; Kleer, 2010; Meuleman and Maeseneire, 2012). This highlights the importance of R&D subsidies in supporting firms' efforts to leverage external knowledge for their innovation activities.

Governments on the other hand often exhibit a preference for cooperative R&D modes that involve a higher number of partners (Niosi, 1993), as well as public research organizations collaborating with corporate partners (Afcha, 2011; Busom and Fernandez-Ribas, 2008; Lanaham et al., 2021). Government's desire to spread public resources across more firms, connect public R&D agencies with corporate partners, avoid duplication efforts and reaching a critical mass on the financed projects (Niosi, 1993; Browning et al., 1995) favour this type of projects, especially those involving governmental research institutions and knowledge providers (Radicic et al., 2020). In addition, it has been documented that experience with R&D subsidies enhances senior managers' receptiveness to external knowledge and collaborative R&D efforts (Chapman and Hewitt-Dundas, 2018). As a consequence, these subsidies often lead to subsequent R&D alliances that align with the goals of previous subsidized projects, typically executed in sequential stages (Lanahan et al., 2022).

Taking all these pieces of evidence into account, it becomes evident that receiving public R&D support increases the total amount of R&D resources at the firm's disposal and, due to managerial and government preferences, as well as the synergy between internal and external R&D activities, these firms are expected to be more willing to engage with new types of R&D partners. Accordingly, our baseline hypothesis is:

H1: The higher the percentage of public funding of a firm's R&D activities, the higher the breadth of its TAP.

3.2. The effect of innovation performance feedback

As we have seen, public funding serves as an external stimulus for firms, prompting them to expand and modify their TAP breadth. However, according to the behavioural theory of the firm (Cyert and March 1963), the main driver of organisational change is the existence of discrepancies between performance aspirations and actual performance. From a behavioural perspective, in the specific context of technologically intensive sectors, it is firms performing above or below innovative aspirations the ones that are more willing to confront the costs of increasing their TAP breadth. Despite this, to the best of our knowledge, no studies have incorporated how firms' performance feedback discrepancies interact with R&D public policy instruments. Thus, in this section we analyse how public R&D support moderates the impact of innovation performance feedback on TAP breadth. Figure 1 summarises our theoretical framework, which is further developed in the next section.

------------ Insert Figure 1 about here ---------------

3.2.1. The direct effect of innovation performance feedback below and above aspiration levels

Previous studies based on the behavioural theory of the firm have shown that a firm's likelihood of embracing organisational change may depend on how they are performing compared to their aspirations (Cyert and March, 1963; March, 1991, 1994). Behavioural theory states that organisations tend to stick to the status quo unless performance deviates from their aspiration levels (Cyert and March, 1992). On the one hand, when performing below their aspirations, firms are more likely to adopt organisational changes, activating "problemistic search" to find a solution to their performance gap (Greve 2003a, 2003b). This phenomenon refers to the active search for solutions to address the performance gap. The realisation that the firm's current performance is not meeting its aspirations triggers a sense of urgency and the recognition that changes are necessary (Cyert and March, 1992). On the other hand, firms performing above aspirations can also change their patterns of behaviour, but for a different reason. As firms go above aspiration levels, they tend to activate "slack search" to explore more innovation opportunities, triggering organisational change (Greve 2003a, 2003b). In this case, change is primarily driven by the exploration of new innovation opportunities through the utilisation of available slack resources. Cyert and March (1963: 279) state that slack search involves "projects that would not necessarily be approved in a tight budget."

More specifically, and in the context of technology-intensive firms, recent studies have found that the more a firm deviate either below or above from their innovation performance aspirations, the more likely firms are to form new technological collaborations (Kavusan and

Frankort, 2019; Lungeanu et al., 2016; Martínez-Noya and García-Canal, 2021; Tyler and Caner, 2016). Reaching their innovation objectives may be more critical for these firms than even reaching the short-term financial ones. For this reason, when performing below aspirations, problemistic search usually leads to R&D alliances as a viable solution, as they increase the chances of succeeding in new product development and discovering new product opportunities (Gilsing and Nooteboom, 2006; Grant and Baden-Fuller, 2004; Katila and Ahuja, 2002; Teece, 1992). In the case of performance above aspirations, the situation is different, as the firm is not in urgent need to find a solution to an immediate problem, but to take advantage of exploration opportunities. Firms with good track of technological performance can tap into their intellectual capital to identify areas for expansion, potential collaborations, or new market opportunities. This allows them to explore and experiment with new ideas and initiatives, irrespective of their current financial resources. While having a good technological performance may not directly imply having financial resources in excess, it does offer certain advantages in negotiating alliances on favourable terms (Bosse and Alvarez, 2010). For this reason, the firm’s intellectual capital allows it to attract external resources and support by new types of partners offering complementary resources.

Therefore, as firms deviate from their innovation performance aspirations, they are more likely to embrace changes in their innovation strategies by increasing their openness to external knowledge. Building on this behavioural logic, we hypothesise the following two baseline effects related to the effect of technological innovation performance deviations on TAP breadth:

H2a: The more a firm deviate below its innovation performance aspirations, the higher the breadth of its TAP.

H2b: The more a firm deviate above its innovation performance aspirations, the higher the breadth of its TAP.

3.2.2. The interaction effect with R&D public funding

We anticipate that R&D public funding will negatively moderate the impact of innovation performance feedback on TAP breadth, irrespective of whether the firm is performing below or above its aspirations. The primary reason for this lies in the constraints associated with these public funds, which may not align with the type of R&D alliance capable of either promptly reversing performance shortfalls, or undertaking projects associated with slack search. These constraints include the nature of the activities to be developed with partners (Conti, 2018; Conti and Guzman, 2023), a preference for public agencies as partner types (Radicic et al., 2020), and the project scale. Large-scale projects, which condition future research endeavours and potential additional subsidies, are usually favoured by public authorities (Feldman et al., 2022; Lanahan et al., 2022). Due to these constraints, the higher the percentage of public funding for a firm's R&D activities, the greater the limitation on the firm's flexibility to form new alliances that deviate from the purposes and guidelines of subsidised projects. This limitation arises as the firm must prioritise meeting the goals and restrictions of these projects. In addition, the focus of R&D managers shifts from performance discrepancies to fulfilling the goals of the subsidised projects, which are the main bet of the firm for their R&D strategy, progressively channelling larger amounts of resources (Falk, 2007). According to the attention-based view of the firm (Ocasio, 1997), the context and relationships of the firm condition the issues to which decision makers pay attention. Therefore, as the firm's R&D strategy becomes influenced by public support and subsidies, their focus on both problemistic search and slack search is diminished.

For the aforementioned reasons, in the case of performance shortfalls, the potential to enter into alliances with new types of partners aimed at reversing the underperforming situation is not only conditioned by the possible incompatibility of these partners with the various restrictions and guidelines of the subsidies, but also by the pressure that managers face to meet the goals and deadlines of previous subsidised projects. Achieving these goals may be critical for securing additional funding for these or other projects, thereby perpetuating their continuation (Lanahan et al., 2022). As a consequence, due to the shift in managers' attention from problemistic search to the fulfilment of subsidised project goals, and the challenge of accommodating new types of partners different from those in the subsidised projects, we hypothesise that:

H3a: The level of R&D public funding negatively moderates the impact of performing below innovation aspirations on the firm's TAP breadth.

For companies exceeding their innovation goals, we anticipate that R&D public funding will also negatively moderate the impact of performance feedback, mirroring the dynamics observed when performance falls below aspirations. Certainly, over performance may provide the company with flexibility to explore "slack search" projects that would not be approved under less favourable circumstances. However, as the percentage of R&D funding from the public sector increases, the focus of R&D managers tends to shift towards the execution and development of subsidised projects. This strategic shift is driven by the imperative to secure the continuity of funding for subsequent stages. Additionally, it is noteworthy that successful projects backed by public funding may incur refund obligations, as highlighted by Conti (2018). Consequently, R&D managers are inclined to prioritise these subsidised projects to meet financial commitments and maintain a consistent funding stream. Accordingly:

H3b: The level of R&D public funding negatively moderates the impact of performing above innovation aspirations on the firm's TAP breadth.

4. DATA

The empirical analysis of this study uses data from the Spanish Technological Innovation Panel (TIP) (PITEC, is its Spanish acronym). This panel is built upon the annual Spanish responses to the European-wide Community Innovation Survey (CIS) and it has been extensively used by previous innovation studies. The survey is carried out repeatedly on a yearly basis since 2003 applying the methodological guidelines defined by OECD´s Oslo

Manual, and thus offers highly representative and detailed data on the innovation activities of Spanish firms from all industries. We believe that the longitudinal character of this database makes it very suitable for analysing our research question on the evolution of firms' TAP breadth, because we can account for both cross-sectional differences between firms and temporal changes within each firm. Furthermore, it should be acknowledged that Spain occupies a middling technological position and has an industrial structure similar to the one of other countries in the EU, which makes this country a good setting to test our hypotheses (e.g. Afcha and Lucena, 2022; Busom and Fernández-Ribas, 2008; Chapman et al., 2018; Cuervo-Cazurra et al., 2018; Tamayo and Huergo, 2017).

We decided to restrict our panel to Spanish non-state-owned firms operating in medium to high technologically intensive industries, as defined in OECD (2011), for the following reasons. First, because different sectors have different propensities to innovate and to patent. Second, in technology-intensive industries, unlike low-tech sectors, alliances are anticipated to play a more critical role in innovation, and there is a higher propensity for patenting (Arora et al., 2008). As a result, our data comprises an unbalanced panel with more than 6,500 firms for the period 2008-2015. Table 2 shows our sample distribution.

------------- Insert Table 2 about here ---------------

4.1. Dependent variable

In line with previous literature on innovation openness (Chapman et al., 2018; Laursen and Salter, 2006; Love, 2014), to account for the degree of external collaboration breadth of a firm's TAP we considered the different types of partners with whom the firm indicated in the survey that it actively engaged in cooperation for technological innovation within the period from *t* to *t-2*[1]: (1) other companies in the same firm's business group, (2) suppliers, (3) clients, (4)

[1] Note that firms are told to only indicate those partners with whom the firm "actively cooperated for technological innovation" so that outsourcing agreements without active R&D cooperation are not considered.

competitors, (5) commercial labs, (6) universities, and (7) research centres. We use firm's binary responses to the question above to define our dependent variable TAP BREADTH, which takes values 0–7 depending on the number of different types of technological partners with which each firm was collaborating. Therefore, our unit of observation is the firm-year and we obtained 27,563 observations (see table 2).

4.2. Main explanatory variables

To analyse how R&D public funding impacts firm's TAP breadth decisions, we accounted for the firm's declared percentage of its internal R&D expenses that were publicly founded (either by national or international entities) for each period *t*. Building upon Falk's (2007) suggestion that a single policy intervention is insufficient to stimulate collaborative behaviour, our study considers public R&D support measures aimed at reducing costs or increasing resources allocated to R&D activities. More specifically, in the questionnaire public funding comprehends the following sources of funding: subsidies from local and national public institutions, contracts with local and national public institutions, as well as international funding from EU programs, and other international public institutions. Although previous research on the effect of public funding on R&D collaboration used to measure public support using a binary variable (see Bianchi et al., 2019 for a review), we believe that our continuous measure PUBLIC FUNDING (that ranges from 0 to 100) can offer more accurate information to address our longitudinal research question. Thus, our definition of public support not only considers the supply side but also some of the demand side of public technology policies (Czarnitzki et al., 2020; Slavtchev and Wiederhold, 2016).

To compute our variables related to innovation performance compared to aspirations, we followed previous research on the behavioural theory of the firm (Cyert and March, 1963; Greve, 2003; 2008; Yang et al., 2017). We measured the firms' actual technological innovation performance for a given year (P) as the number of patent applications made by the firm over a three-year window (i.e. from *t* to *t-2*). We use patents as a measure of innovation performance, because a firm's patenting activity has been demonstrated to be a good indicator of its innovative success, particularly within technology-intensive industries (Ahuja, 2000; Hagedoorn and Cloodt, 2003). In fact, within these sectors, patents have found to be highly related to new product introductions and inventions, sales growth, and expert ratings of technological strength (Ahuja and Katila, 2001). Thus, firms patenting more than their peers are in the innovation frontier of their field (Rothaermel and Boeker, 2008). Indeed, the scarce literature that exists analysing how innovation performance feedback influences alliance decisions within technology-intensive sectors have used patents to build their performance aspiration measures, as innovation goals may precede financial ones when making strategic decisions in these industries (Gaba and Bhattacharya, 2012; Kavusan and Frankort, 2019; Lungeanu et al., 2016; Martínez-Noya and García-Canal, 2021; Tyler and Caner, 2016). We computed the firm's innovation aspiration levels (A), considering both its social aspiration (SA) and its historical performance aspiration (HA), as well as the firm's distance to the aspiration level (DA), where *t* is time and *i* indicates the firm[2], as follows:

$A_{ti} = a_1 \, SA_{ti} + (1-a_1) \, HA_{ti}$

$HA_{ti} = a_2 \, HA_{t-1,i} + (1-a_2) \, P_{t-1}$

$DA_{ti} = P_{ti} - A_{ti}$

In the equations, SA captures the performance of the social reference group that the focal firm attempts to anchor, and it is computed as the average of the patenting activity of the other firms in the same sector for the same period *t*. HA reflects the focal firm's past technological innovation performance as an indicator of how well it should perform. Aligned with behavioural literature (Baum et al., 2005; Greene, 1993; Greve, 2003a, 2003b), we implemented a spline function for innovation performance, and we entered separate variables for performance below

[2] Following Greve (2003a) we estimated the weights by searching all parameters values by increments of 0.1 and we selected the combination offering the best fit of the models to the data (0.5 for a_1 and 0.4 for a_2). In line with previous research, the most recent performance (P) is weighed higher than HA in *t-1* (Chen, 2008; Tyler and Caner, 2016).

and above aspiration level, so that our variable INNOVATION PERFORMANCE BELOW ASPIRATIONS (PBA) equals 0 for all observations in which DA>0, and the distance to the aspiration level otherwise. While our variable INNOVATION PERFORMANCE ABOVE ASPIRATIONS (PAA) equals 0 for all observations in which DA<0, and the distance to the aspiration level otherwise. In our estimations, we reverse-coded PBA for an easier interpretation of our interaction effects.

4.3. Control variables

We control for a range of factors that may influence our estimations. First, based on Cohen and Levinthal (1989, 1990), we control for the firm's level of R&D INTENSITY (measured as a firm's R&D expenditures in year *t* divided by its sales in *t*) to account for a firm's technological absorptive capacity and its ability to handle external technological knowledge (Hagedoorn and Cloodt, 2003; Laursen and Salter, 2006; Martínez-Noya and García-Canal, 2021). Following previous studies focusing on the effect of this variable on technological alliance formation, we operationalized this variable as the three-year moving average of R&D intensity (Shin, Kim and Park, 2016)[3]. According to the behavioural theory, the lack of financial resources can influence the impact of R&D public funding on alliance decisions, as well as on the firm's response to innovation performance deviations (Greve, 2003a; Kotiloglu et al., 2021; Zhang and Greve, 2019), therefore we introduced the dummy variable SLACK FINANCIAL RESOURCES that takes a value of 1 if the firm indicated in the survey that that the lack of funds within the company was perceived as a problem of low or none importance when pursuing innovation in the period *t* to *t-2*. Similarly, because the firms' competitive position within their technological market can influence their need, or even possibility, to modify their alliance portfolio (Kim and Rhee, 2017), we introduced the dummy variable MARKET DOMINATED BY OTHER FIRMS that takes a value of 1 if the firm considered an obstacle for innovation of medium or high

[3] We opt to pursue this approach due to the potential influence of two key independent variables on firms' R&D intensity levels. There are studies that use performance feedback models to explain firms' R&D intensity levels (Chen, 2008; Greve 2003a). In addition, existing literature focusing on the input additionality effects of public R&D funding has highlighted the direct impact of public support on firms' private R&D investments and, consequently, their R&D intensity (Carboni, 2017; Jugend et al., 2020).

importance for the company the existence of dominant firms in its market within the period t to t-2. It is known that the international dimension of a firm influences its need to access more diverse external knowledge, and that governments appear to prefer to support domestic firms, as well as those that export (Chapman et al., 2008; González and Pazó, 2008). For this reason, we included the dummy FOREIGN that equals 1 if the firm has a capital structure with at least 50% of foreign capital; and the dummy INTERNATIONAL SALES capturing whether the firm sells products outside of the domestic country. To control for resource endowments that can influence decision makers' risk tolerance (Audia and Greve, 2006), and given that firm size has been found to be a key determinant of collaboration breadth (Van de Vrande et al., 2009), we introduced FIRM SIZE measured as log of the firm's total sales in *t* (in euros), as well as the dummy BUSINESS GROUP to capture whether the firm belongs to a business group. In the same vein, we included the dummy STP LOCATION to control whether the firm is located within a science and technology park (STP) as this fact has been found to influence the intensity of the effect of spillovers on innovation and on R&D alliance activity (Martín-de Castro et al., 2011). We also introduced FIRM AGE, measured as the number of years since the company's foundation, as it has been found that age is an important factor influencing both innovation practices as well as the effectiveness of R&D subsidies (Coad, Segarra-Blasco and Teruel, 2016; Segarra-Blasco and Teruel, 2016). To account for the fact that firms allocating more R&D resources to basic research may have a higher propensity to collaborate with research organisations, we introduce RESEARCH ACTIVITIES to control for the percentage of the firms' internal R&D spending allocated to basic research activities, as opposed to applied or development ones. Finally, to control for possible common shocks at the industrial level, we introduced 16 sectoral dummies for our medium to high technological industries according to the OECD classification, and year fixed effects. All our main explanatory variables as well as control variables were lagged one year in our analyses, as it is known that alliances take time to be formed (Baum et al., 2005). As the survey is replied on a yearly basis, to run our regressions, we lag all our independent and control variables by one year.

Table 3 presents the summary statistics and the correlation matrix. As it can be observed, given the low correlation that exists between our variables, as well as the variance inflation factors (VIFs) that are well below the commonly accepted threshold of 10, collinearity does not appear to be a problem within our study.

------------ Insert Table 3 about here --------------

5. METHODS AND RESULTS

We used the negative binomial model as our estimation method because our dependent variable is over-dispersed and takes discrete non-negative integer values. This method is a generalisation of the Poisson model in which the assumption of equal mean and variance is relaxed, and thus it is more suitable because it helps to adjust for over-dispersion (Cameron and Trivedi, 1998; Hausman et al., 1984; Haynes et al., 2003)[4]. In particular, because the Generalised Estimating Equation (GEE) offers inherent advantages compared to fixed and random effects specifications, both in terms of efficiency and to account for unobserved heterogeneity (Hardin and Hilbe, 2003; Katila and Ahuja, 2002; Liang and Zeger, 1986), we used a GEE negative binomial estimator with an independent correlation structure and heteroscedasticity consistent standard errors (Fernández-Méndez et al., 2018; Krishnan and Kozhikode, 2015).

Table 4 reports the estimated coefficients of our GEE negative binomial estimations, where Model 1 represents the baseline model with only the control variables; Model 2 adds the main effect of public funding; Model 3 adds the main effect of our innovation performance feedback variables; and Model 4 includes the interaction effects of public funding with innovation performance variables. The results are consistent across models, and the Wald Chi-square test ($p<0.01$) shows that all models are statistically significant.

[4] Furthermore, a model comparison analysis in STATA (with the user-written *count* function) showed that the negative binomial regression was the best fitting model (Tyler and Caner, 2016).

------------- Insert Table 4 about here ---------------

In terms of the effect of the percentage of public funding of a firm's internal R&D activities on its decision to modify its TAP breadth, aligned with our first hypothesis, the results show that the baseline effect of R&D public funding is positive and highly significant across models ($p<0.01$). Similarly, supporting our baseline hypotheses 2a and 2b stating that the more a firm deviate either below or above its aspiration levels, the higher the breadth of its TAP, the effects of our performance feedback variables PBA and PAA are also positive and highly significant across models ($p<0.01$).

In relation to the interaction effects of public funding with performance feedback, our results show in Model 4 that when a firm deviate from its innovation aspirations, receiving a higher percentage of R&D public funding moderates negatively the breadth of its TAP, as demonstrated by the negative and significant coefficients of both interaction effects in model 4. This negative effect of public funding is significant for firms performing below aspirations (PUBLIC FUNDING*PBA, $p<0.05$), which supports our hypothesis 3a; and highly significant for those performing above (PUBLIC FUNDING*PAA, $p<0.01$), supporting our hypothesis 3b. Indeed, when computing the size of these effects, we observe that while a one standard deviation increase in public funding would lead to a 37.86% increase in the breadth of the firm's TAP, this effect becomes negative as the performance deviate from firms' aspirations. More specifically, when considering different percentile values (10th, 50th, and 90th) of firms' performance deviations below aspirations, a one standard deviation increase in public funding would result in a decrease in the number of types of knowledge sources accessed by 0.03%, 0.12%, and 0.50%, respectively. This demonstrates that the negative effect of public funding becomes more pronounced as performance deviates further below aspirations. For firms performing above aspirations, we observe that for different percentile values (10^{th}, 50^{th} and 90^{th}) of firms' performance deviations above aspirations, a one standard deviation increase in its public funding would lead to a decrease in the number of types of knowledge sources accessed by 0.09%, 0.41% and 2.8% respectively. Thus, we find that the negative effect of public funding on TAP breadth is higher for firms over performing, and becomes larger as the firm deviates from aspirations. For a better understanding of these interaction effects, we also display them for different values of both firm's R&D public funding (its minimum value, i.e., 0; its mean; its mean plus 1 standard deviation; and its maximum value, i.e., 100) as well as for different percentile values (10^{th}, 50^{th} and 90^{th}) of firms' performance deviations both below (PBA) and above (PAA) aspirations (see figure 2). In this figure it can be clearly observed how as the percentage of public funding of the firms' R&D activities increases, TAP breadth becomes lower. The negative effect of public funding on breadth becomes stronger for firms performing above aspirations. Indeed, the graph indicates that when firms perform far above aspirations, those having their R&D activities totally publicly funded, opt for even reducing the breadth of their TAP, showing a much more conservative behaviour compared to those receiving less public funding. Therefore, these results support our hypotheses 3a and 3b.

------------- Insert Figure 2 here ---------------

As regards the control variables, our results show that firm variables related to the firm's ability to handle external knowledge such as its R&D intensity levels, or the firm's resource availability such as slack of financial resources, firm size, the fact of belonging to a business group or being in a STP, all of them contribute positively to increase the breadth of its TAP as expected. Similarly, in relation to firm's international dimension, results indicate that while having foreign ownership does not contribute to increase alliance breadth, the fact of selling abroad does foster the access to more diverse external knowledge. Finally, it seems that those firms that perceive innovation difficulties because the market is dominated by other firms, are the ones that feel a greater need of increasing the breadth of their TAP.

5.1. Robustness analyses

To test the robustness of our results, we carried out several robustness tests. Considering that our variable PUBLIC FUNDING encompasses the percentage of firms' internal R&D activities that are publicly funded by various sources (including regional, national, and international subsidies, contracts, or participation in EU programs), we conducted our analyses using different operationalisations for this variable, and our results remained consistent. For instance, because there exist differences among the collaboration requisites to benefit from R&D support from national as compared to international programs, such as those of the EU (for a detailed description of the differences between programs see Busom and Fernández-Rivas, 2008); we repeated our analyses only considering the percentage of R&D public funding received by national entities, discarding public funding from international institutions and the EU, and we obtained fully consistent results (see column 1 in table 5). We also defined our variable considering both national and international public support, but discarding the funding from EU programs, and our results hold (see column 2 in table 5). Finally, to separate the supply-side from the demand-side public support instruments, we also repeated our analyses discarding from our public funding measure the percentage of funding received from public contracts, and our results were consistent (see column 3 in table 5).

------------- Insert Table 5 about here -----------

We also carried out our analyses using alternative measures for our dependent variable TAP BREADTH. Firstly, recognising that not all types of partners entail the same level of risks and that public support has been shown to significantly promote collaboration with research centres (which are expected to pose lower appropriability hazards and are typically engaged in more basic research), we conducted all previous analyses using an alternative dependent variable for TAP BREADTH, excluding this type of partners, i.e., research organisations. Remarkably, we obtained exactly the same results (see column 1 in table 6) even when incorporating all aforementioned variations of our public funding variable[5]. Similarly, because some previous literature on firms' innovation openness not only paid attention to the breadth of the external sources used, but also their depth (Cerulli et al., 2016; Laursen and Salter, 2006); i.e. "the extent to which firms draw intensively from different search channels or sources of innovative

[5] These additional analyses are available upon request.

ideas" (Laursen and Salter, 2006: 140), we also constructed a dependent variable adding this dimension. More specifically, we multiplied each partner type by its normalised weighted relevance as knowledge source for the firms' innovation activities, and the same results were obtained (see column 2 in table 6). Finally, because the diversity of external knowledge sources also increases when sourcing from additional geographical locations, we also carried out our analyses with a new dependent variable considering not only the types of partners with whom the firm cooperates, but also their locations. This information was taken from the questionnaire, as firms had to indicate in which of the following geographical locations they were cooperating with each type of partner: (1) its country of origin (in this case, Spain), (2) other EU country, (3) the US, (4) China or India, and (5) other countries. Based on this information, we calculated a new dependent variable as the count of the different partner-location combinations that a firm had each year, being the maximum number of possible combinations 35 and the minimum 0. After running our models with this new measure for TAP breadth, our results also hold (see column 3 in table 6).

------------- Insert Table 6 about here -----------

6. DISCUSSION AND CONCLUSION

In this paper we find that R&D public funding has an ambivalent effect on the way in which firms frame the decision to increase or not their TAP breadth and gain access to external knowledge. On the one hand, we find that this funding has a direct positive effect on the breadth of the firm's TAP. This finding is aligned with the scarce literature analysing the role that public support may have on alliance breadth, that, overall, also finds a positive effect (Bianchi et al., 2019; Cerulli et al., 2016; Chapman et al., 2018). But, on the other hand, we also find that as firms receive higher levels of R&D public funding, they become less inclined to increase TAP breadth to implement slack search, or as a solution to problemistic search, when they deviate from their innovation aspirations. This finding contributes to the recent and also scarce literature on the impact of innovation performance feedback on R&D alliance portfolio decisions (Tyler and Caner, 2016; Lungeanu et al., 2016; Kavusan and Frankort, 2019; Martínez-Noya and García-Canal, 2021) by showing a new type of behavioural additionality effect: receiving R&D public funding reduces the changes in TAP breadth associated to performance feedback deviations.

This result also contributes to the innovation literature, particularly to research focused on analysing the effect of public support on collaboration practices. Besides providing one additional confirmation of the direct impact of R&D public funding on TAP breadth, we highlight its moderating effect on the impact of innovation performance feedback deviations. Our research setting allowed us to collect information regarding different types of R&D public funding schemes, contemplating not only the supply side, but also the demand side (Czarnitzki et al., 2020; Slavtchev and Wiederhold, 2016). We were also able to use a continuous measure accounting for the percentage of a firms' internal R&D expenses that are publicly funded, which is a more accurate measure than the binary variable used to account for public support in most of the previous research (for a review see Bianchi et al., 2019). Considering that our results are also robust to different changes in the definition of the dependent and independent variables, our study shows the importance of considering the interaction with innovation performance feedback when analysing firms' reactions to R&D public funding in future empirical research. Our interpretation of these findings suggests that public support not only impacts changes in alliance portfolios but also plays a significant role in shaping the characteristics of the partners engaged and the substance of alliance activities. This phenomenon is driven by the prioritization of R&D managers towards monitoring the progression of ongoing publicly funded projects, rather than focusing on resolving performance discrepancies. Consequently, this shift in managerial attention from performance feedback to ensuring the continuity of subsidized projects fosters the formation of a network of partners where learning opportunities are aligned with the domains of these projects.

Our study aligns with the research conducted by Busom and Vélez-Ospina (2021), who observed that the effects of receiving public support vary between periods of recession and expansion. This pattern can be explained taking a behavioural perspective grounded in performance feedback theory. This theoretical framework allows us to gain a better understanding of how public support can influence the potential cognitive biases related to the risk-return trade-off when making decisions regarding collaboration with new types of partners. In this sense, from a behavioural perspective, it is known that firms performing above or below innovation performance aspirations are the ones that should be more willing to take the costs and risks of increasing alliance portfolio breadth (Kavusan and Frankort, 2019; Lungeanu et al., 2016; Tyler and Caner, 2016). The interest of the moderating role found in our study lies in the fact that R&D public support alters the way in which firms frame the decision to expand or not the number of external sources of knowledge. Starting to cooperate with new types of partners is a costly and risky choice and our results show that in the absence of R&D public support, the companies more willing to embrace this risk are those performing above and below innovative aspirations. This is consistent with traditional behavioural theory of the firm (Greve 2003b; Baum et al, 2005), because firms performing at their aspiration level are more willing to avoid any source of uncertainty (Cyert and March, 1963; Greve, 2003b). As a result, they are less likely to engage in distant search activities, such as expanding their alliance portfolio breadth. Nevertheless, over and underperformers have different reasons to undertake this distant search. For firms performing below aspirations, the incorporation of new types of partners can be a way to deal with the problemistic search to restore performance, despite the additional coordination costs. For firms performing above aspirations, new types of partners can help to develop slack search projects, despite both appropriability hazards and coordination costs (Martínez-Noya and García-Canal, 2021). Our results suggest that the increasing significance of public support within the total R&D budget reshapes how firms address performance discrepancies. This shift is not primarily driven by a substantial alteration of the risk-return balance in response to performance discrepancies, but rather by a strategic reorientation towards prioritizing the continuity of subsidized projects. Consequently, the firm's focus transitions from short-term concerns to the long-term trajectory defined by these projects. While this prioritisation enhances consistency within the firm's alliance portfolio in line with the objectives of the subsidised projects, it also results in fewer adjustments made in response to performance discrepancies. Whether this alignment with the overarching objectives of subsidised projects translates into enhancements in cooperative R&D performance and learning opportunities is beyond the scope of this paper. However, it raises a research question warranting further investigation.

Public policy implications can be derived from our paper. From an economic policy perspective, it is claimed that one of the main objectives of public funding should be to be able to change firms' attitudes to innovation, such as reduce managers' risk perceptions to encourage external collaboration and distant search oriented to external knowledge acquisition. However, there is still limited knowledge about the specific variables that condition the effect of public subsidies on R&D strategy (Afcha, 2011; Busom and Vélez-Ospina, 2021; Chapman and Hewitt-Dundas, 2018). For this reason, given the lack of conclusive results on this topic and the importance of identifying criteria to allocate effectively R&D public interventions, we believe that our study has demonstrated the relevance of investigating not only the direct effect of public funding but also its interaction effect with performance feedback. Specifically, our results demonstrate that R&D public funding discourages firms from responding to performance discrepancies through distant search strategies. While this reaction may not necessarily be detrimental for the firm, it hinges on the assumption that the long-term strategy defined by subsidised projects is sound and that the selected alliance partners within these projects possess the necessary external knowledge. Although accessing external knowledge is generally advantageous for firms, in line with Greco et al. (2017), we argue that public policies should prioritise securing cooperation with appropriate partners, rather than pursuing partnerships indiscriminately. Given that distant search primarily occurs within subsidised projects, it is imperative for public policies to ensure the coherence of these projects. Additionally, complementing public subsidies with other policies aimed at assisting firms in identifying and attracting competent partners would enhance the effectiveness of these public instruments.

Several managerial implications can be drawn from our findings. Firms equipped with strong alliance management capabilities are better positioned to identify suitable partners and maximise learning opportunities. Investing in alliance management capabilities, as suggested by Dyer and Singh (1998) and Kale and Singh (2007), can enable firms to select partners and design projects that attract competent collaborators within the restrictions established by the conditions of subsidies and grants. Moreover, the shift in managerial focus from performance feedback to the long-term success of subsidised projects may not necessarily be detrimental to firms. Managers should prioritise ensuring alignment between subsidised projects and the firm's long-term strategy. In the case of underperforming firms, refraining from overreacting to performance discrepancies may be advantageous if the underlying R&D strategy is sound. Similarly, for over performing firms, abstaining from engaging in slack-search projects solely driven by the interests of R&D scientists, as suggested by the behavioural theory of the firm (Cyert and March, 1963), may not have catastrophic consequences. Instead, projects should be aligned with the firm's interests to maintain strategic coherence.

6.1. Limitations and future research agenda.

Although we found robust evidence consistent with our view on the influence of public R&D funding on TAP breadth, the research reported in this paper suffers from some limitations. First, we have relied only on data from a single country, Spain; therefore, some peculiarities of the Spanish institutional environment for R&D activities may have introduced some biases in our results. This is a limitation because firms can react to performance feedback in different ways depending on their cultural and institutional context (Lewellyn and Bao, 2015; O'Brien and David, 2014). Indeed, it should be considered that our study period covers years of growing public budget constraints due to the financial economic crisis of 2008 that impacted firms worldwide. Nevertheless, it is also during these periods of uncertainty in which it becomes more relevant for governments to learn how to be able to allocate the scarce public resources available in a more effective way to support firms' innovativeness (Antonioli and Montresor, 2021; Cano-Kollmann et al. 2017; Jugend et al., 2020). Second, another potential limitation is the impossibility to quantify two sources of public support for R&D: tax benefits and subsidised loans. These two forms of support are challenging to identify and quantify, which may have resulted in incomplete information in our study. Third, our data on TAP breadth could be neglecting other forms of portfolio reconfigurations like forming or reinforcing new alliances with the same types of partners, or even by terminating some of them (Kavusan and Frankort, 2019). Indeed, as shown by knowledge recombination studies, it would be also important to acknowledge how the pool of alliance partners are tied to each other because these linkages will influence the recombinant potential for the focal firm (Kok, Faems, and de Faria, 2020). Fourth, not all types of alliances entail the same degree of costs and risks. Although we proved the robustness of our results by excluding some of the forms with lower risks, our research setting did not allow us to quantify the costs and risk level of the different types of partnerships, nor the number of alliances that the firm held with each partner type. Finally, we acknowledge that although patents are considered as a valid indicator of innovation performance and technological competence within R&D intensive sectors (Hagedoorn and Cloodt, 2003; Tyler and Caner, 2016), its use presents some limitations. For instance, there are patents that are not commercialised, or innovations that cannot be patented or are not worth patenting (Arora et al., 2008). In addition, the nature of our survey data prevents us from directly measuring knowledge acquisition by examining the characteristics of patented technologies, as seen in previous works such as those by Friedmann and Pedersen (2023) or Vasudeva et al. (2013).

These limitations present opportunities for future research to explore further. It would be useful to replicate this study in a different national setting or in an international comparative study. Future studies could also analyse the impact of R&D public support on other types of technological alliance reconfigurations not addressed in our research, utilising more precise measures of knowledge acquisition and exploring additional outcomes of cooperative R&D. In addition, given that firms may face ambiguity due to conflicts between financial and non-financial performance feedback, which can result in varied organisational responses (Joseph and Gaba, 2015), future research could also benefit from studying the effect of public support when this ambiguity arises. Finally, our research could also be extended to the field of the governance of R&D alliances (Lioukas and Reuer, 2020). This literature focuses on the role played by coordination costs and apppropiability hazards and the different governance choices and contractual provisions to avoid these costs and risks (Keller et al., 2021). Whereas this literature pays special attention to the incentives firms have to comply with the spirit of the agreement, due to the governance structure (Oxley and Sampson, 2004), learning opportunities (Kale and Singh, 2009), or concurrent projects with the same partner (García-Canal et al., 2014), our research suggest that the way in which potential partners frame the decision to enter into costly and risky cooperative agreements needs to be taken into account. In this way, aligned with Walrave, and Gilsing (2023) we call for further research to analyse how managerial cognition can influence firm decisions on their distant search activities.

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Table 1. Studies on the relationship between public R&D support and collaboration breadth.

Authors	Sample	Variable for R&D public support	Variable for alliance breadth	Effect of public support on collaboration breadth	Main findings of the study
Cerulli et al. (2016)	Italian CIS Survey Panel data 1090 observations (CIS waves:1998-2000 and 2022-2004)	R&D subsidy binary variable (supported vs non-supported) including all regional, national and European support	Number of partner types (from 0 to 6) weighted by their relevance for the company. (Mediator variable)	Public support positively encourages breadth	The main driver of higher innovative performance is the additional cooperation activated by the public support
Cano-Kollmann et al. (2017)	Innobarometer survey 2007 5133 observations (29 European countries)	Total monetary support variable counting different types of support schemes (from 0 to 6) Total non-monetary support variable counting other types of public support (from 0 to 4)	Number of partner types with whom the firm collaborates (0-4). (Dependent variable)	Overall positive effect of public support schemes on cooperation breadth	The positive effect of public support on firms' openness is more significant for less innovative firms. Non-financial support more strongly linked to openness than monetary support.
Chapman et al. (2018)	Spanish CIS Survey 5371 observations (2002-2010 and 2007-2013 waves)	Binary variable that equals 1 if firm receives a R&D subsidy from Spanish national programs, and 0 otherwise.	Number of partner types with whom the firm collaborates (from 0 to 6) (Dependent variable)	Public support positively encourages breadth	Significant average positive effect of R&D subsidies on breadth, although the firm effect is heterogeneous (56% of the firms experience positive effect, 31% experience a negative effect, 13% no impact).

Table 2. Composition of the sample.

TAP BREADTH	N	Percent
0	19,625	71.20
1	2,806	10.18
2	1,661	6.03
3	1,343	4.87
4	871	3.16
5	573	2.08
6	378	1.37
7	306	1.11
Total	27,563	100

INDUSTRIES	N	Percent
Machinery and equipment	4,668	16.94
Chemicals	4,003	14.52
Fabricated metal products	3,906	14.17
Rubber and plastics products	2,491	9.04
Other non-metallic mineral products	2,094	7.6
Computing machinery, precision and optical instruments	1,907	6.92
Motor vehicles	1,851	6.72
Electrical machinery and apparatus	1,835	6.66
Other transportation	1,476	5.36
Pharmaceuticals	1,102	4
Basic metals	1,087	3.94
Installation and repairing of machinery and equipment	605	2.19
Other transport equipment	211	0.77
Building of ships and boats	157	0.57
Aircraft and spacecraft	149	0.54
Petroleum	21	0.08
Total	27,563	100

Table 3. Summary statistics, correlation matrix and VIFs.

		Mean	S.D.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	VIF
1	TAP BREADTH	0.8	1.5															
2	PUBLIC FUNDING	4.99	15.4	0.2488*														1.03
3	TECHNOLOGICAL INNOVATION PERFORMANCE BELOW ASPIRATIONS (PBA)	0.45	3.01	0.0459*	0.0297*													1.01
4	TECHNOLOGICAL INNOVATION PERFORMANCE ABOVE ASPIRATIONS (PAA)	0.43	6.4	0.1166*	0.0168*	-0.0102												1.01
5	LACK OF MARKET KNOWLEDGE	0.46	0.5	0.0156*	0.0605*	0.0006	-0.0077											1.09
6	RDINTENSITY	0.04	0.08	-0.0194*	0.0534*	0.0210*	-0.0196*	0.0499*										1.24
7	SLACK FINANCIAL RESOURCES	1.85	1.08	0.0443*	0.0560*	-0.0087	-0.0100	0.1445*	0.0998*									1.14
8	MARKET DOMINATED BY OTHER FIRMS	0.5	0.5	0.0650*	0.0470*	0.0078	-0.0037	0.1873*	0.0707*	0.2738*								1.13
9	FOREIGN OWNERSHIP	0.16	0.37	0.1042*	-0.0464*	0.0275*	0.0420*	-0.0859*	-0.1540*	-0.1161*	-0.0742*							1.3
10	FIRM AGE	35.1	18.04	0.1087*	0.0204*	0.0055	0.0322*	-0.0274*	-0.1460*	-0.0447*	0.0006	0.1350*						1.11
11	INTERNATIONAL SALES	0.81	0.38	0.1466*	0.0772*	0.0217*	0.0286*	-0.0158*	-0.0782*	0.0369*	0.0643*	0.1451*	0.1365*					1.13
12	FIRM SIZE (log)	16.01	1.88	0.2886*	0.0533*	0.0301*	0.0879*	-0.0948*	-0.4150*	-0.1831*	-0.0799*	0.3864*	0.3031*	0.3039*				2.09
13	BUSINESS GROUP	0.45	0.49	0.2435*	0.0273*	0.0294*	0.0504*	-0.1036*	-0.2295*	-0.1619*	-0.0749*	0.4488*	0.1292*	0.1513*	0.5778*			1.69
14	STP LOCATION	0.02	0.17	0.1182*	0.0785*	0.0139*	0.0140*	-0.0084	0.1005*	0.0084	-0.0033	-0.0174*	-0.0736*	0.0219*	0.0238*	0.0402*		1.03
15	RESEARCH ACTIVITIES	1.28	6.32	0.0653	0.0512	0.0151	0.0088	0.0030	0.0054	-0.0018	0.0108	0.0061	0.0298	0.0495	0.0338	0.0057	0.013	1.01

*$p<0.05$

Table 4. GEE negative binomial regressions predicting TAP breadth

	Model 1	Model 2	Model 3	Model 4
PUBLIC FUNDING		0.020	0.020	0.021
		(23.17)***	(23.07)***	(23.39)***
TECHNOLOGICAL INNOVATION PERFORMANCE BELOW ASPIRATIONS (PBA)			0.009	0.021
			(2.63)***	(2.72)***
TECHNOLOGICAL INNOVATION PERFORMANCE ABOVE ASPIRATIONS (PAA)			0.007	0.010
			(5.23)***	(4.51)***
PUBLIC FUNDING*PBA				-0.028 [a]
				(2.00)**
PUBLIC FUNDING*PAA				-0.027 [a]
				(2.67)***
LACK OF MARKET KNOWLEDGE	0.188	0.173	0.174	0.174
	(3.91)***	(3.65)***	(3.67)***	(3.68)***
RDINTENSITY	1.783	1.356	1.338	1.334
	(32.70)***	(25.24)***	(24.93)***	(24.85)***
SLACK FINANCIAL RESOURCES	0.115	0.106	0.107	0.106
	(4.83)***	(4.41)***	(4.41)***	(4.40)***
MARKET DOMINATED BY OTHER FIRMS	0.181	0.172	0.174	0.174
	(3.68)***	(3.52)***	(3.55)***	(3.55)***
FOREIGN OWNERSHIP	-0.269	-0.198	-0.198	-0.198
	(3.87)***	(2.87)***	(2.86)***	(2.86)***
FIRM AGE	0.002	0.002	0.002	0.002
	(1.60)	(1.23)	(1.28)	(1.29)
INTERNATIONAL SALES	0.453	0.426	0.426	0.426
	(4.54)***	(4.38)***	(4.38)***	(4.37)***
FIRM SIZE (log)	0.326	0.312	0.306	0.305
	(15.94)***	(15.50)***	(15.26)***	(15.22)***
BUSINESS GROUP	0.552	0.569	0.572	0.574
	(7.76)***	(8.26)***	(8.29)***	(8.32)***
STP LOCATION	0.561	0.442	0.446	0.445
	(5.03)***	(3.83)***	(3.86)***	(3.85)***
RESEARCH ACTIVITIES	0.012	0.010	0.010	0.010
	(4.84)***	(4.00)***	(4.00)***	(3.98)***
INTERCEPT	(1.18)	(1.17)	(1.15)	(1.15)
	(2.13)**	(3.13)***	(3.19)***	(3.14)***
Industry effects	*Included*	*Included*	*Included*	*Included*
Year effects	*Included*	*Included*	*Included*	*Included*
Wald chi-square	2576.2***	2961.5***	3037.2***	2964.1***
N	14,824	14,824	14,824	14,824

*z-statistics in parentheses: *** p<0.01, ** p<0.05, * p<0.1*

[a] Coefficient multiplied by 100

Table 5. GEE negative binomial regressions predicting TAP breadth for different specifications of our public funding variable.

	1	2	3
	Only national funding	**EU programs excluded**	**Contracts excluded**
PUBLIC FUNDING	0.020	0.020	0.022
	(21.89)***	(22.03)***	(24.60)***
TECHNOLOGICAL INNOVATION PERFORMANCE BELOW ASPIRATIONS (PBA)	0.019	0.019	0.020
	(2.43)**	(2.44)**	(2.64)***
TECHNOLOGICAL INNOVATION PERFORMANCE ABOVE ASPIRATIONS (PAA)	0.010	0.010	0.010
	(4.41)***	(4.50)***	(4.39)***
PUBLIC FUNDING*PBA	-0.025 [a]	-0.025 [a]	-0.028 [a]
	(1.75)*	(1.77)*	(2.02)**
PUBLIC FUNDING*PAA	-0.024 [a]	-0.028 [a]	-0.024 [a]
	(2.21)**	(2.74)***	(2.12)**
LACK OF MARKET KNOWLEDGE	0.173	0.173	0.176
	(3.65)***	(3.65)***	(3.72)***
RDINTENSITY	1.388	1.379	1.313
	(25.84)***	(25.72)***	(24.52)***
SLACK FINANCIAL RESOURCES	0.111	0.111	0.107
	(4.61)***	(4.60)***	(4.45)***
MARKET DOMINATED BY OTHER FIRMS	0.174	0.173	0.170
	(3.55)***	(3.54)***	(3.46)***
FOREIGN OWNERSHIP	-0.209	-0.209	-0.201
	(3.01)***	(3.02)***	(2.90)***
FIRM AGE	0.002	0.002	0.002
	(1.44)	(1.42)	(1.32)
INTERNATIONAL SALES	0.434	0.434	0.423
	(4.42)***	(4.41)***	(4.35)***
FIRM SIZE (log)	0.307	0.307	0.305
	(15.32)***	(15.32)***	(15.25)***
BUSINESS GROUP	0.565	0.566	0.577
	(8.17)***	(8.18)***	(8.35)***
STP LOCATION	0.459	0.461	0.430
	(4.06)***	(4.08)***	(3.67)***
RESEARCH ACTIVITIES	0.010	0.010	0.010
	(4.12)***	(4.12)***	(3.93)***
INTERCEPT	-6.696	-6.692	-6.658
	(20.32)***	(20.33)***	(20.31)***
Industry effects	*Included*	*Included*	*Included*
Year effects	*Included*	*Included*	*Included*
Wald chi-square	2929.7***	2935.1***	3008.3***
N	14,824	14,824	14,824

*z-statistics in parentheses: *** p<0.01, ** p<0.05, * p<0.1*

[a] Coefficient multiplied by 100

Table 6. GEE negative binomial regressions predicting TAP breadth for different specifications of our dependent variable: (1) without research centres (2) breadth weighted by depth; (3) breadth considering also location diversity.

	1	2	3
	No research centres	**Breadth & depth**	**Breadth & location**
PUBLIC FUNDING	0.018	0.012	0.016
	(19.78)***	(15.99)***	(18.17)***
TECHNOLOGICAL INNOVATION PERFORMANCE BELOW ASPIRATIONS (PBA)	0.020	0.012	0.027
	(2.64)***	(1.69)*	(2.67)***
TECHNOLOGICAL INNOVATION PERFORMANCE ABOVE ASPIRATIONS (PAA)	0.009	0.006	0.015
	(4.42)***	(4.32)***	(5.29)***
PUBLIC FUNDING*PBA	-0.026 [a]	-0.015 [a]	-0.034 [a]
	(1.86)*	(1.13)	(1.92)*
PUBLIC FUNDING*PAA	-0.022 [a]	-0.016 [a]	-0.021 [a]
	(2.31)**	(1.89)*	(2.20)**
LACK OF MARKET KNOWLEDGE	0.174	0.118	0.097
	(3.53)***	(2.82)***	(1.95)*
RDINTENSITY	1.179	0.234	1.163
	(21.87)***	(4.52)***	(21.03)***
SLACK FINANCIAL RESOURCES	0.096	0.045	0.061
	(3.81)***	(1.99)**	(2.27)**
MARKET DOMINATED BY OTHER FIRMS	0.168	0.085	0.153
	(3.29)***	(2.02)**	(2.97)***
FOREIGN OWNERSHIP	-0.181	-0.045	-0.127
	(2.60)***	(0.78)	(1.71)*
FIRM AGE	0.002	0.002	0.001
	(1.04)	(1.74)*	(0.78)
INTERNATIONAL SALES	0.371	0.130	0.223
	(3.55)***	(1.34)	(2.21)**
FIRM SIZE (log)	0.300	0.175	0.291
	(14.51)***	(9.53)***	(12.99)***
BUSINESS GROUP	0.665	0.695	0.600
	(9.14)***	(10.98)***	(8.69)***
STP LOCATION	0.446	0.338	0.400
	(3.53)***	(3.52)***	(3.45)***
RESEARCH ACTIVITIES	0.010	0.003	0.006
	(3.92)***	(1.17)	(2.26)**
INTERCEPT	-6.749	-5.697	-5.726
	(19.68)***	(18.28)***	(14.99)***
Industry effects	*Included*	*Included*	*Included*
Year effects	*Included*	*Included*	*Included*
Wald chi-square	2548.5***	1226.7***	1782.3***
N	14,824	11,138	11,163

*z-statistics in parentheses: *** p<0.01, ** p<0.05, * p<0.1*

[a] Coefficient multiplied by 100

Figure 1. Theoretical framework

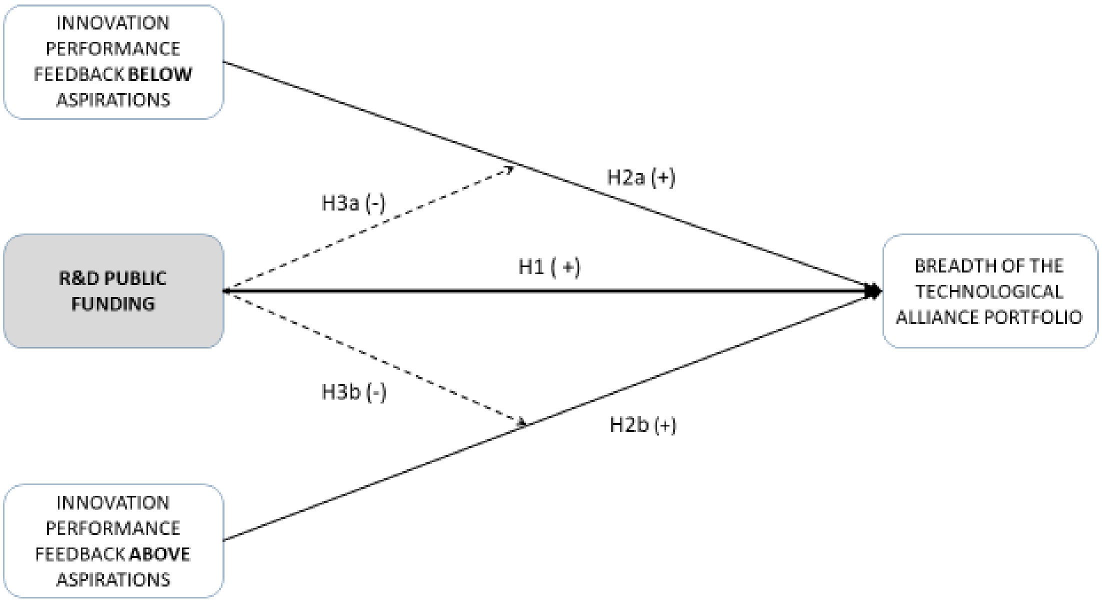

Figure 2. TAP breadth depending on level of R&D public funding received and firm's innovation performance feedback below (PBA) or above aspirations (PAA).