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# Solver brokerage as an open innovation tool for industrial transfer of mathematical technologies

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ABSTRACT

Mathematical technologies are recognised as a key enabling factor for innovation and competitiveness in the Industry. Although Open Innovation enables innovation processes for companies, there is a lack of studies about the effectiveness of OI mechanisms for mathematical technologies transfer. We fill this gap by exploring Solver Brokerage as a suitable tool for fostering industry-research collaborations based on mathematical technologies. We present a single case study based on a project promoting the industrial transfer of mathematical technologies leveraging a Solver Brokerage approach. We critically discuss the weaknesses and strengths of this approach, sharing valuable contributions for both scholars and practitioners.

## 1. Introduction

It is widely recognised that successful industrial management primarily benefits from the rigour and versatility of quantitative and analytical tools, which offer vast potential for the innovation of society, including public administrations, the research community, enterprises, and citizens. They are fundamental to innovating processes, products, and management, and they are at the centre of a novel industrial interest: challenges faced by companies nowadays show unprecedented complexity, requiring holistic approaches and solution processes.

Industrial transfer is defined as "the process by which firms or institutions transfer technological knowledge, production techniques, or managerial capabilities across organizational boundaries, sectors, or national borders to improve productivity, innovation, and competitiveness" (Arrow, 1962).

Fostering the leading role of industrial transfer of mathematics knowledge for productive and technological innovation is increasingly recognised as a significant strategic development avenue, as reported in many recent studies in economics and business (such as reports by Deloitte (2012, 2014)) and different national prospective studies, including the ones about USA, Spain, and UK (National Research Council, (2012); Spanish Mathematics-Industry Network, (2012); Bond (2018), respectively).

The above-mentioned studies also emphasise how an actionable adoption of mathematical technologies as an innovation driver requires a wide range of management competencies and technical skills, often not concurrently present in a single company, particularly in SMEs. Hence innovation approaches in this field are often based on the Open Innovation paradigm, namely, on 'a strategic inclusion of external stakeholders in the innovation process of an organisation' (Brabham, 2013). In Open Innovation, firms integrate internal Research and Development activities by leveraging various sources for knowledge supplies, including partners,

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competitors, academics, and researchers (Chesbrough, 2006, 2003). Therefore, it represents an effective way to establish contacts and initiate collaborations with external parties in order to acquire expertise, skills, and innovative solutions. This is why nowadays many companies have approached or are approaching the Open Innovation paradigm using different inbound and outbound practices (Chesbrough and Brunswicker, 2014). In particular, OI practices are seen as relevant for SMEs to improve their innovativeness, enabling them to overcome their limited resources, which together with their lack of ties with universities sometimes discourage the implementation of U-I collaborations (Johnston, 2022). Several studies pointed out the positive impact of OI on the performances of organisations and SMEs (Rumanti et al. 2022, Rumanti et al. 2023). OI practices are influenced by both internal and external factors (Popa et al. 2017): for example, interdepartmental connectedness favours OI while Centralization of decision-making does not; the external environmental competitiveness has positive effects on OI climate within enterprises. Kurniawati et al. (2022) showed that OI positively impacts the sustainability performance of SMEs; they showed that some of the main capabilities favouring sustainability-oriented OI practices are: the ability to identify innovation partners, explore external knowledge and build new knowledge from the acquired one. Open Innovation evolves through a path of collective problem-solving, dialogue and exchange between several subjects that accelerate the innovation process. Rau et al. (2012) have described different mechanisms to overcome interpretive differences among heterogeneous partners, especially in University-Industry (U-I) innovation collaborations; for example, the '*engage a translator*' mechanism entails engaging a mediator who transfers knowledge between partners. The translator is 'expected to translate knowledge between actors by complementing a specific piece of knowledge with links from the domain of the partner expected to absorb the knowledge' (Rajalo and Vadi, 2017). In the case of knowledge transfer of mathematical technologies, where industry and academia, in general, speak different languages, and there is a lack of communication between the two, this issue is even more evident. Aziz and Bahar (2016) argued that given the increasingly close link between innovation, science, and mathematics, it might be interesting and fruitful to inquire whether the interface between these three fields works optimally and, in particular, to identify mechanisms for strengthening links between mathematics and industry.

Moreover, given the highly specialised knowledge profile required in the development of mathematical technologies, the contribution of an intermediating actor playing the role of a proper 'translator' seems particularly appropriate. Mathematical technologies can be used in many industries; however, their effective application relies on accurately identifying problems and translating them. This task is often fulfilled in practice by expert facilitators, whom we will refer to in the remainder of this paper as 'Technology Translators', whose specific role is to build relationships between industry and academia. Technology Translators act as intermediaries, bridging the gaps between SMEs and the *knowledge base* of universities and research centres (Iles and Yolles, 2002). In this context, these intermediaries aim to promote the awareness and culture of applying mathematical techniques and methods in industry, at the strategic and technical levels, communicating effectively to both businessmen and academics (OECD, 2008).

However, the extant literature on research and innovation management shows a lack of specific contributions on this topic. We performed a thorough bibliographic search in the SCOPUS database; the fields involved in the search were the title, the abstract, and the keywords (TITLE-ABS-KEY). We performed the search by combining the keywords open innovation, mathematical technologies OR mathematical sciences, technology transfer, two by two, obtaining the following results (up to the year 2023):

| | |
|---|---|
| TITLE-ABS-KEY("open innovation" AND "technology transfer") | 252 |
| TITLE-ABS-KEY("open innovation" AND ("mathematical sciences" OR "mathematical technologies")) | 0 |
| TITLE-ABS-KEY("technology transfer" AND ("mathematical sciences" OR "mathematical technologies")) | 4 |

This paper aims to fill this gap by developing an empirical investigation on real-world research-industry collaborations, based on an Open Innovation governance structure, such as the Solver Brokerage mechanism (Feller et al., 2009), in the context of industrial transfer of mathematical technologies.

Therefore, this work has a practical orientation and utilises the empirical evidence from a vibrant case study to answer the following research questions:

Research question 1: Is Solver Brokerage an appropriate Open Innovation tool to realise the industrial transfer of mathematical technologies? Research question 2: Based on the empirical evidence, what are the strengths and weaknesses of adopting Solver Brokerage as an Open Innovation tool for the industrial transfer of mathematical technologies?

Drawing upon some experiences from a research and innovation project developed by the Institute for Application of Calculus "Mauro Picone" of the National Research Council of Italy in this specific scientific field, our research is conducted through a single case study approach. A qualitative analysis of already accomplished enterprise-research collaborations is performed. In the arising discussion, we highlight distinctive features of this initiative, criticalities, and strengths in order to establish under which conditions the approach turns out to be appropriate and adequate to enhance the quality of the collaborations and increase benefits for the involved stakeholders, thus responding to the proposed research objective.

The remainder of this paper is organised as follows: in the second section, we provide an original definition of mathematical technologies, and we revise the scientific literature on industry-university interaction and the use of mathematical technologies for industrial innovation. In the third section, we explore the notion of Solver Brokerage in the context of Open Innovation. In the fourth section, we undertake an empirical analysis based on a single case study. Findings are presented and discussed in the fifth section. In the sixth section, we develop our theoretical and managerial contributions. In the last section, the conclusions of the study are summarised.

## 2. Background on the transfer of mathematical technologies

### 2.1. Mathematical technologies for industrial innovation

Digital Transformation is a comprehensive concept which refers to “the changes digital technologies can bring about in a company’s business model, which result in changed products or organizational structures or in the automation of processes” (Hess et al., 2016). Digital Transformation, which is also defined in (Westerman et al., 2011) as “the use of technology to radically improve the performance or reach of enterprises.", is having a considerable impact involving several dimensions, including customer, technology, strategy, ecosystem, people, organisation, and innovation (Ivančić et al., 2019). Also, for this reason, the industry is experiencing years of significant organisational and technological changes. Digitalization is advancing at all levels, enabled by a series of technologies, such as IoT, Big Data, and Cloud (Calabrò et al., 2022). In a digitalised world, from the industry’s point of view, mathematics turns out to be an enabling technology in the meaning given by Teece (2016), as it ‘allows the creation or improvement of products and services across a wide product scope’. It constitutes a universal language for the optimization, simulation, and control of industrial processes, and it provides a logically consistent framework for analysis and problem-solving. For this reason, although its contributions are almost invisible in the final product, the economic impact of mathematics is concrete and substantial, and many companies have gained a competitive edge through the well-advised use of math-based technologies, as shown by many success stories such as those collected in the book by Lery et al. (2011).

We provide here our formal definition of mathematical technologies as *the comprehensive set of all quantitative based tools, methods and techniques enabling an actionable use of results from Mathematical Sciences, with an aim of making a tangible impact while coping with real-world problems in industry, governments, organisations and society at large*.

Accordingly, mathematical technologies embrace Modelling, Simulation and Optimization methods in a fully inclusive manner, thus covering applications ranging from Artificial Intelligence to Machine and Deep Learning, from Business and Decisional Analytics to Operational Research, and from Statistics to Data Science methods, among others.

Mathematical technologies are pivotal in economic development and cut across many high-technology and high-value-added industries, including aerospace, finance, defence and security, life sciences, and even entertainment and agriculture. There is a clear need across multiple areas in business, industry, and government for problems to be defined mathematically and to be solved through innovative mathematical techniques to derive economic and social benefits. Mathematical technologies are currently responding to the uncertain data-rich world the industry is facing since they make it possible to extract information and knowledge from the data collected (Calabrò et al., 2022). All the while, industry-driven problem-solving is constantly expanding from day to day, leading to ever-increasing challenges for the whole mathematics community, as several concrete applications demonstrate (see, for example, the report by EU-MATHS-IN (2018)).

Different studies and reports described the impact of Mathematical Science on a nation’s economy. The first study was carried out in 2012 in the UK (EPSRC[1] commissioned Deloitte to realise it). It provided a snapshot of how mathematics broadly impacts the UK economy and quantitative insights into the value across all sectors in terms of the employment it supports - a positive influence on the economy of the UK to the extent of ca. 2.8 mln jobs - and is also the first to indicate the GAV of maths to the UK economy (ca. £ 208 mln in GNP) (Deloitte, 2012). Two years later, the same consulting company published a report (see Deloitte (2014)) on the economic impact of Mathematics on the Dutch economy. Furthermore, the study by CMI (2015) is related to the socio-economic impact of mathematics in France. Finally, the most recent study analysed the socio-economic impact of mathematical research and mathematical technology in Spain (REM, 2019). Albeit with lower numbers compared to other European countries, due to the economic structure of Spain, this study also emphasised the role of mathematics in productive activities and its impact on several industries, including IT, telecommunication services, energy, and finance.

Many industrial sectors are changing their production systems and/or services provided thanks to the application of advanced mathematical technologies. The challenges for future innovation in industry and society are characterised by rising complexity and shorter innovation cycles. The process of developing new products/processes increasingly requires a holistic approach that considers the complete life cycle, including the impact and risks for society, the environment, and sustainability (EU-MATHS-IN, 2018). To realise this goal, it is necessary to assist the development and design phases with appropriate virtual products/processes that allow long-term risk analysis, improvements or even optimization in an early innovation phase. Interesting examples are the innovative statistical techniques of data analysis and simulation applied to Agrifood (crop pattern optimization, scheduling seeding and harvest activities, water and soil management) or to the Smart Factory (predictive maintenance and Digital Twins in Industry 4.0). Moreover, Operational Research impacts the logistics and transport sectors and Energy and Waste management. Finally, the latest lines of research on Cybersecurity, Artificial Intelligence and Big Data Analytics have important repercussions on services and their security. These key technologies are highly complex and require skilled experts, which often are not available, especially in SMEs. Hence, fostering contacts and collaborations with academia can greatly benefit businesses. The specialised knowledge held by knowledge institutions, most often universities and research centres, can benefit business professionals in need to develop more competitive products, services, and technologies or to improve internal processes (Rajalo and Vadi, 2017). In the following section, we will deepen this aspect in the context of mathematical technologies.

[1] Engineering and Physical Sciences Research Council https://www.epsrc.ac.uk/

### 2.2. Industry-academia collaboration for industrial transfer of mathematical technologies

University-Industry (U-I) collaboration is now considered an important economic driver, and as a result, knowledge and technology transfer between universities and industry should stimulate innovation, because of the combination of heterogeneous partners and heterogeneous knowledge (Rajalo and Vadi, 2017). As seen above, mathematical technologies are known to be key enabling factors for industrial innovation since they are highly reliable yet flexible and affordable. Thus, the past twenty years have witnessed increased efforts to introduce mathematical research into private industry, mainly emanating from the activities of governmental research centres, Universities and applied mathematics societies, such as SIAM[2] in the United States and ECMI[3] in Europe. Since the interface between mathematics and industry is much more than a medium for technology transfer, its successful development can bring tangible rewards for both parties (O'Brien, Charpin, 2013). Hence, one of the main challenges is how to effectively improve the infrastructure to increase interactions and collaborations in academia and the industry. The worldwide mathematical community has often debated this issue. Already on the occasion of an international workshop[4] a few years ago, the participants identified several mechanisms that can improve the partnership between mathematics and industry, including Interdisciplinary Research Centres, Faculty Positions for Industrial Mathematics, Research Internships, Special Interest Groups (SIG), Direct Research Collaborations, Student Activities, Consultancy, Translation of Technology (OECD, 2008). As reported by Bertsch et al. (2014), while in North America there is evidence of strong cooperation between the applied mathematics research community and the private sector, the European landscape is still fragmented; therefore, the European Science Foundation (ESF) set up a common strategy for European industrial mathematics, see EMS (2011), to increase the competitiveness of Europe, based on the idea of building a community of Industrial Mathematicians that can work with the industrial sector for R&D. Recently, Bond (2018) has highlighted the need to make the existing mechanisms for knowledge exchange more robust and expanded in scope and capacity to enable both industry and academia to find appropriate expertise.

As discussed above, some studies carried out by renowned consulting firms assess the economic impact and benefits of mathematical sciences research. Similar conclusions and findings emerged from other studies on related topics, resulting in several initiatives being implemented to boost mathematics in industry. Math-in is a Spanish Network that pursues a proactive role in establishing industry/academia cooperation creating contacts between Spanish Enterprises and research groups. In France, the *Agence pour les Mathematique en Interaction avec l'Enterprise et la Societé* (AMIES) through its facilitators – responsible for different French geographical regions - aims to forge connections between industry and academia through multiple actions such as financially supported projects, summer schools for doctoral students in math, career days for math students. Beyond European boundaries, we can mention the Canadian Network of Centers of Excellence (MITACS) established to facilitate connections between Canadian Enterprises and Canada's Mathematical Community. Other examples of collaborations based on international networks are IMA (USA), Matheon (Germany) and the Smith Institute for Industrial Mathematics and System Engineering (UK).

Collaborations between applied mathematics and industry have generally been fostered by actions such as Master's degrees and Ph.D. degrees, modelling weeks, internships, or study groups. The latter format consists of a week-long workshop during which industrialists and academic mathematicians work together on industrially relevant problems. Under the sponsorship of the European Consortium of Mathematics in Industry (ECMI) annually several European Study Groups with Industry are organised.

Alongside these consolidated modes, there is room for more innovative practices such as the Math AIMday, a thematic declination of AIMday, the proactive approach developed at Uppsala University, Sweden, consisting of a workshop dedicated to specific questions submitted by companies and discussed by researchers, in this case researchers in industrial mathematics (Baraldi et al. 2016), mathematical hackathons and crowdsourcing platforms specialised in solving scientific problems shared by companies.

Since industry and academia, in general, speak different languages, there is a need to facilitate communications between the academic and the industrial world. This is especially important for SMEs that are the main producers of innovative technologies but have relatively little contact with academia. Although the industrial transfer of mathematical technologies offers huge potential for innovation in society at large, also addressing the world's most pressing challenges (Unesco, 2022), the realisation of this potential is hindered by a series of barriers: legal, e.g., concerning IPR management; technical, concerning the access to specific technologies; human, due to a lack of trained facilitators. We argued that the intermediation of professional facilitators can favour this process. In this context, the training of 'Technology Translators' becomes increasingly important. According to the description provided by the Report on Mathematics in Industry (OECD, 2008), Technology Translators 'identify industrial opportunities for mathematics, understand the detailed requirements of each firm, translate business challenges into the language of mathematics, identify the best mechanisms to involve the academics with relevant expertise, facilitate the relationships to ensure successful collaborations, and assist with the implementation and exploitation of the results.'(page.15).

### 2.3. The role of intermediary organisations in innovation and knowledge transfer

As seen before, Open Innovation brings different stakeholders together – large firms, SMEs, public institutions, universities, start-ups, and individuals – to discover and develop new ideas for products and services. Working in these types of open ecosystems allows firms and organisations to expand both the search breadth and the search depth. Moreover, they can share the risks of innovation and,

[2] Society for Industrial Mathematics http://www.siam.org/

[3] European Consortium for Mathematics in Industry https://ecmiindmath.org/

[4] Workshop on 'Mathematics in Industry' held in Heidelberg, Germany, on March 22–24, 2007

in some cases, increase the speed at which new products are brought to the market while reducing costs (Christensen and Karlsson, 2019; Secundo et al., 2019). An important step, therefore, is exploration for recognising external opportunities for innovation. This can be done by analysing the external environment, examining emerging research trends, attending conferences and trade fairs, or joining professional associations. Also, insights can be gained by establishing connections with universities and research institutions or contacting third-party Open Innovation intermediaries that offer mediated crowdsourcing services (Bhatti et al., 2020; Cricelli et al., 2022; Massa et al.,2022).

Looking outside an organisation's boundaries can lead to new resources and ideas for internal R&D, but several barriers and hurdles exist, especially for SMEs that often are poorly informed about new technologies and ill-prepared to assimilate them (Brunswicker and Vanhaverbeke, 2015; Doppio et al., 2020; Yusuf, 2008). However, as found by Bruneel et al. (2010), both SMEs and large companies indicate *transaction-related barriers* – regarding possible conflicts over IPRs and administrative procedures - more often than *orientation-related* ones – differences in orientation and incentives. Barriers and obstacles are also perceived by universities. As reported by several authors, obstacles of a different nature exist to collaborations between universities and industry. Villani (2013) pinpoints cultural (mindset and motivation), institutional (bureaucracy and incentive systems) and operational (the perception of time) barriers. Muscio and Vallanti (2014) found that academia sees as the main barrier to interaction with industry the difficulty of finding innovative companies to collaborate with. According to the authors, it is difficult to get in contact with industrialists, especially for those departments with little or no previous collaboration with companies.

The intermediation of specific figures can help companies but also universities overcome these barriers, for example, by managing to reconcile the different needs of the two parties (Ankrah et al., 2013) and more easily identifying the partner able to solve the proposed challenge by gaining access to the most suitable solution community. This is true for many areas of R&D, and product and process innovation. For this reason, many dedicated platforms (such as InnoCentive,[5] Ennomotive,[6] NineSigma,[7] etc.) have emerged in recent years, offering companies and organisations a comprehensive suite of services, such as technology scouting, specialised innovation consulting, and access to global networks to crowdsource solutions to their problems. Yusuf (2008) uses the term ‘midwifery’ to describe the intermediaries that assist in the exchange of knowledge between universities and the business community by creating links and interfaces, diagnosing needs, and articulating the demand for certain types of innovation. Villani et al. (2017) show that intermediary organisations can facilitate U-I relationships, ‘purposefully reducing cognitive, organisational, geographic and/or social distance according to the experience of the actors involved and the type of knowledge exchanged’. Howells and Thomas (2022) identify the stages of the innovation search process and describe the role of the intermediaries within each phase. In particular, the innovation search phases are the following: *Search Articulation* (i.e. the shaping of what outcome a company wants from a search process); *Scanning* (i.e. looking for particular technology or market opportunity); *Signalling* (a company provides the description of its problem to third parties in order to find possible co-operators); *Core Searching* (the actual search for partners with the competencies to deal with the proposed industrial problem); *Screening* (filtering options and selecting the best solution); *Feedback* (evaluating the outcome). Al-Tabbaa and Ankrah (2019) investigated the impact of social capital on the technology transfer process that takes place in the University-Industry collaborations (UICs), focusing on initiatives triggered by a third-party (‘Engineered’ UICs), and conceptualised technology translation, defined by Ankrah et al. (2013) “the process of promoting interactions between partners”, as an essential component of UIC for technology transfer. In the Open Innovation context, Baban et al. (2021) investigated the determinants of U-I collaborations, while Feller et al. (2009) discussed direct and mediated models to supply and acquire innovation capabilities and intellectual property from external sources. In particular, the authors identified four potential Open Innovation governance structures differentiated along two axes: *configuration*: whether the structure is direct (e.g., a hierarchy or decentralised market) or mediated (e.g., a brokerage), and *focus*: whether the structure enables the sale/purchase of existing Intellectual Property (IP) or innovation capability (access to experts capable of creating new IP). For the purposes of this study, in the next section, we will delve into one of these governance structures.

## 3. Solver brokerage

Theory on Solver Brokerage draws on crowdsourcing, innovation networks, and intermediaries. We addressed the latter in the previous section; before proceeding with Solver Brokerage, we briefly introduce crowdsourcing. According to the definition provided by Estellés-Arolas and González-Ladrón-de-Guevara (2012),

‘Crowdsourcing is a type of participative online activity in which an individual, an institution, a non-profit organization, or company proposes to a group of individuals of varying knowledge, heterogeneity, and number, via a flexible open call, the voluntary undertaking of a task. The undertaking of the task, of variable complexity and modularity, and in which the crowd should participate bringing their work, money, knowledge and/or experience, always entails mutual benefit. The user will receive the satisfaction of a given type of need, be it economic, social recognition, self-esteem, or the development of individual skills, while the crowdsourcer will obtain and utilise to their advantage that what the user has brought to the venture, whose form will depend on the type of activity undertaken.’ (page 197).

This definition embraces a broad set of initiatives and approaches that fall within the concept of crowdsourcing. Every crowdsourcing organisation relies on a specific process to achieve an explicit goal, with many different applications (Afuah and Tucci, 2012;

[5] https://www.innocentive.com/

[6] https://www.ennomotive.com

[7] https://www.ninesigma.com/

Ghezzi et al. 2018; Vermicelli et al. 2020; Zahay et al. 2018). The mechanisms that impact this process were evaluated and classified by Geiger et al. (2011), resulting in the identification of the following four dimensions (see Fig. 1) that describe how crowdsourcing processes differ:

- *preselection of contributors* (the organisation have to decide which restrictions on the group of potential contributors to apply in order to pre-select contributors to the process),
- *accessibility of peer contributions* (the organisation have to decide the degree of access to peer contributions),
- *aggregation of contribution* (the organisation have to decide how to aggregate and use the contributions received),
- *remuneration for contributors* (at the end of the campaign, the organisation may need to pay or compensate the contributors for their work).

The first dimension deals with restrictions concerning the crowd, i.e. the group of potential contributors. After that, an 'open call' is spread among the selected group of contributors, who then decide if they want to contribute to the process. It is interesting to point out that to ensure a minimum quality level, some processes require a *qualification-based preselection*: the potential contributors have to demonstrate certain knowledge or skills before being allowed to contribute, to meet the minimum required quality threshold. In addition, another form of preselection is based on *context-specific* reasons; some processes apply both kinds of preselection.

Accessibility indicates to what extent contributors can access each other's contributions, based on the following four degrees of access:

- *none* (contributors cannot see each other's contributions),
- *view* (all contributions are visible to any other potential contributor),
- *assess* (there is a mean for a rating or commenting on other contributions),
- *modify* (the highest level of accessibility that implies the possibility to alter, correct, or delete other contributions).

The third dimension describes how the contributions are used to achieve the desired outcome. In the *integrative* processes all the contributions are reused unless they failed to respect certain requisites; on the other hand, *selective* processes, commonly adopted in contests, follow a more competitive approach, choosing the best one among a set of contributions. Finally, the remuneration for contribution is the dimension that concerns the payment or compensation for the work of contributors; here Geiger et al. (2011) distinguish between *fixed, success-based and no remuneration*.

Crowdsourcing enables the acquisition of innovation capability in terms of knowledge and skills. Solver Brokerages can help firms and organisations implement the crowdsourcing process. In line with Feller et al. (2012), we use the term Solver Brokerages to indicate those subjects that act as intermediaries to facilitate innovation exchanges between organisations and crowds. Solver Brokerages seek to match innovation problem owners (*innovation seekers*) with potential solution providers (*innovation providers*) to foster knowledge transfer and establish cooperative relationships with external partners. Solver Brokerages' critical functions include helping firms identify potential solvers, specify problems, and manage legal and logistical issues (Feller et al., 2009). Compared to proceeding directly on their own, using an intermediary such as the Solver Brokerage enables the seekers to reduce uncertainty by facilitating knowledge exchange among participants and giving them access to the appropriate solution community (Feller et al., 2010, 2012; Massa et al. 2022). Feller et al. (2009) characterised the Solver Brokerages as an intermediary that knows the availability of potential solvers, helps solution seekers in the problem specification, provides value-added services for both parties, but without the guarantee of a solution, vets solvers, and can exploit economies of scale.

The problem articulation (*problem decomposition and framing*) is a key element, as well as the specification of the challenge. Feller et al. (2010) demonstrated that the Solver Brokerage seeks to maximise the ease with which 'knowledge is shared, acquired and deployed' by:

- aggregating a significant mass of innovation seekers,
- aggregating a sufficient mass of solution providers (a specific community or a large, anonymous solution community),
- implementing mechanisms and processes to facilitate exchanges between the two.

The success of this whole process is 'affected by the ability of brokerages to enable access to an appropriate solution community, facilitate the specification challenges, and ensuring that all parties in the innovation exchange are able to appropriate value from interaction' (Feller et al., 2010).

As seen before, mathematical technologies offer huge potential for innovation of companies and organisations, and some relevant European experiences have been initiated to promote mathematical knowledge transfer towards the industry by proposing new means and mechanisms for cooperation, in which the role of Technology Translators is critical. However, to our knowledge, the scientific literature still lacks an accurate research activity investigating the most appropriate innovation practices and policies to realise an effective industrial transfer of mathematical technologies. In the next section, we examine a specific case study focused on a knowledge transfer project in this field where it is possible to draw a parallel with the Solver Brokerage governance structure.

## 4. Methodology and study context

This section describes the case study context. Given the lack of empirical research on intermediaries for mathematical technologies

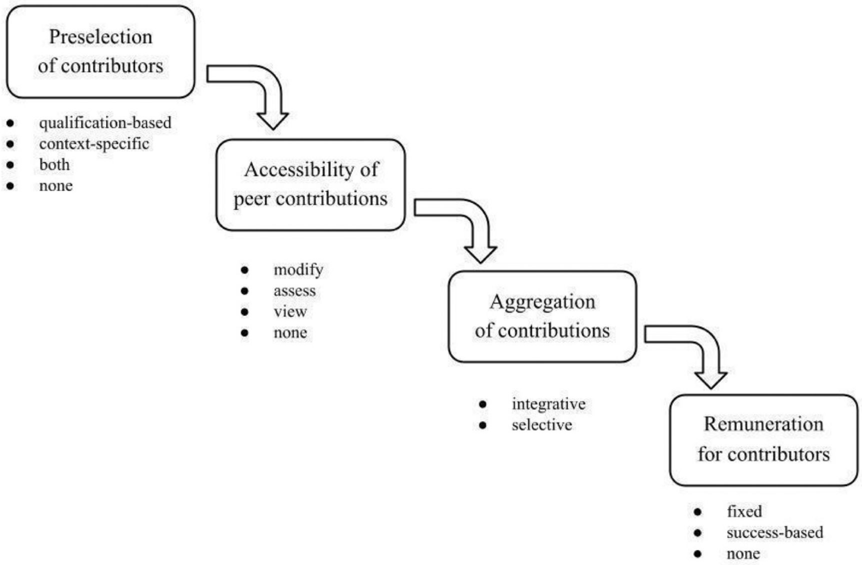


**Fig. 1.** Characteristics of crowdsourcing processes – source: adapted from Geiger et al# (2011).

transfer and the exploratory nature of this work, we adopted the case study approach (Yin, 2003). An in-depth case examination of an Italian intermediary was taken. Following Eisenhardt and Graebner (2007), we chose this single case because it is unusually revelatory and offers the possibility to conduct a rich analysis with many details. This allows us to highlight the strengths and weaknesses of the process described and share the lessons we learned.

Sportello Matematico per l'Innovazione e le Imprese[8] (hereinafter referred to as 'Sportello Matematico') is a research and innovation project developed at the Institute for Application of Calculus "Mauro Picone" of the National Research Council of Italy. The project is co-funded by the Italian Ministry for University and Research (MIUR) to enhance the impact of Mathematical Sciences and Technologies on companies and organisations. Specific objectives of the projects are:

- Promoting and fostering the industrial adoption of mathematical technologies, increasing the number, quality, and impact of industry-academia research and innovation collaborations;
- Providing the industry and, in particular, small and medium enterprises, with a highly qualified access point for consulting needs in the field of mathematical technologies;
- Creating an Italian network for excellence in mathematical technologies, to be integrated into the European context and initiatives in this field;
- Supporting and orienting early career experts in mathematical technologies looking for jobs in the industry.

Sportello Matematico draws upon the work of a team of collaborators acting as consultants with a solid background in mathematical technologies. As seen above, these consultants, also referred to as Technology Translators, play the role of 'facilitators' in the relationships between research institutions and companies, highlighting the competitive advantages arising from a knowledgeable adoption of mathematical technologies. Bond (2018) declared that 'mathematics is a powerful engine for innovation,' but engines need transmission belts. This key transmission role is secured by the professional figure of the Technology Translator that, along with mathematical competencies and the knowledge of the technical jargon, also possesses the so-called 'soft skills' such as communication abilities, flexibility, teamwork, business experience and the ability to meet time constraints. A Technology Translator must have a solid mathematical background and a wide knowledge of industrial processes in order to perform different tasks: consulting activities to support companies and organisations in identifying possibilities for innovation that can be developed by means of a mathematical contribution, translation activities to reformulate the industrial problem in scientific terms, intermediation activities to manage and supervise all interactions between industries and research centres, dissemination and promotion activities. These facilitators seek to connect industry and research in order to generate a growing number of collaborations, using strategic activities such as cold calling,[9] social media marketing, participation at conferences and workshops, and participation at matchmaking events (b2b meetings) to make contact with firms. They also offer companies a specialised and customised support model that resembles the 'door-to-door' approach

[8] https://www.sportellomatematico.it/

[9] According to the definition given by Investopedia (available at https://www.investopedia.com/terms/c/coldcalling.asp, last access 3rd May, 2023), cold calling is 'the solicitation of a potential customer who had no prior interaction with a salesperson. A form of telemarketing, cold calling is one of the oldest and most common forms of marketing for salespeople.'

employed by other Technology Transfer Services (see Cattapan et al. (2012)). It consists of *visits to the SMEs* in order to perform a 'technological audit' of the company, which is essential to understand the detailed requirements of each company, and *technology translation,* the process that makes the interaction between research centres and companies and their mutual understanding possible.

The industrial transfer of mathematical technologies is characterised by some specific issues and features. Companies, particularly SMEs, are often unaware of the opportunity to benefit from mathematical technologies and, therefore, lack the competencies and expertise to formulate their industrial problems in mathematical terms. As we have already observed, searching for the right partner can be tricky, and sometimes companies do not have any connections to research facilities. On the other hand, sometimes research on real-world problems is overlooked at the academic level when it can lead to new avenues for academic research, and developing networks with the private sector for new partnerships can bring added value to both sides. In this context, engaging in a project like Sportello Matematico can benefit and provide considerable support to all the involved stakeholders.

### *4.1. Managing the process: The mechanism for governing interaction between the solution seekers and providers*

In this paragraph, we describe how the process conducted by Sportello Matematico works. It all begins with a connection between a company and Sportello Matematico (see Fig. 2). Contacts can be inbound, in case a company approaches Sportello Matematico as it considers that mathematical technologies could be of help to address its business challenges. Contacts may be also outbound as the result of the various activities carried out by Sportello Matematico to reach businesses. Every time contact is made between an enterprise and Sportello Matematico, possible areas of intervention are explored collaboratively, working together to identify specific problems considered relevant by the involved company or organisation. Then, the Sportello Matematico's team takes care of the scientific translation process, preparing a brief summary of the company's needs to be submitted to the network of scientific partners for their evaluation. The activation of the request for service is formalised by an agreement to ensure mutual commitment and regulate the rights and obligations of the parties (company and Sportello Matematico).

The challenge is spread throughout the network; the interested research groups have the opportunity to take part in a technical meeting with the company, upon the signature of a non-disclosure agreement (NDA). The technical meetings are conducted in virtual mode, using video conferencing tools, and each research partner is represented at the meeting by one researcher. Sportello Matematico moderates the meeting, and each group gets one or more chances to interact directly with the company's representative in order to further clarify their needs and detail their requests.

After the meeting, each research group has the chance to send a collaboration proposal following a specific template developed by Sportello Matematico by a deadline agreed upon with the company. This document covers several sections: the description of the research group itself, the technical offer, the working plan, the timeline, and the economic request. The collaboration proposals are then submitted to the company to enable it to single out those most suitable for its business. Each interested scientific partner sends its proposal directly to the company, without previous or concurrent transmission to Sportello Matematico in order to allow for a fully confidential process, and exclude asymmetric information. After that, if required by the company, Sportello Matematico might arrange one-to-one follow-up meetings to help the company analyse the proposals and discuss details with the proposing centres.

In the end, if the company manages to select one or more suitable project proposals, a related contract of collaboration is signed with the selected research group. Sportello Matematico also follows and monitors the development of collaboration and supports ex-post analyses in order to improve the service and, where authorised, disseminate the details of the resulting collaboration in the form of a success story.

### *4.2. Empirical evidence: qualitative analysis of mediated collaborations*

This section is devoted to describing and analysing data and pieces of evidence drawn from Sportello Matematico's actual experience of providing Technology Translation and Brokerage services. The data presented here are primary data collected and made available by the project team during the management of the project. For each request for service (referred to as '*calls*'), data on the size of companies, industrial sectors and industrial applications and the average budget allocated were made available for the purpose of this research by the [anonymised institution B]. The data were then anonymised.

Analysing a set of thirty calls received by Sportello Matematico between 2014 and 2022, a prevalence of calls triggered by small businesses can be observed (Fig. 3).

Among industrial sectors, the highest number of calls is in the Mechanics and Mechatronics sector (30 %), followed by ICT (26.7 %) and Materials (16.7 %), as illustrated in Fig. 4. The list of industrial sectors is based on the statistical classification of economic activities in the European Community (Nomenclature statistique des Activités économiques dans la Communauté Européenne) NACE Rev. 2[10] used by the Statistical Office EUROSTAT. Table 1 containing the NACE classification and the corresponding classification adopted internally by Sportello Matematico can be found in the Appendix.

It is also worth observing the prevalence of requests for services against a classification including some of the industrial applications of mathematical technologies (Fig. 5).

Regarding the budget, on average (in the cases where it was explicitly stated - 19 out of 30) it is about 21400 euros; as for the timescale, in the 22 out of 30 calls where this information is available, the average duration is about 5 months. We can also observe that

[10] https://ec.europa.eu/eurostat/documents/3859598/5902521/KS-RA-07–015-EN.PDF

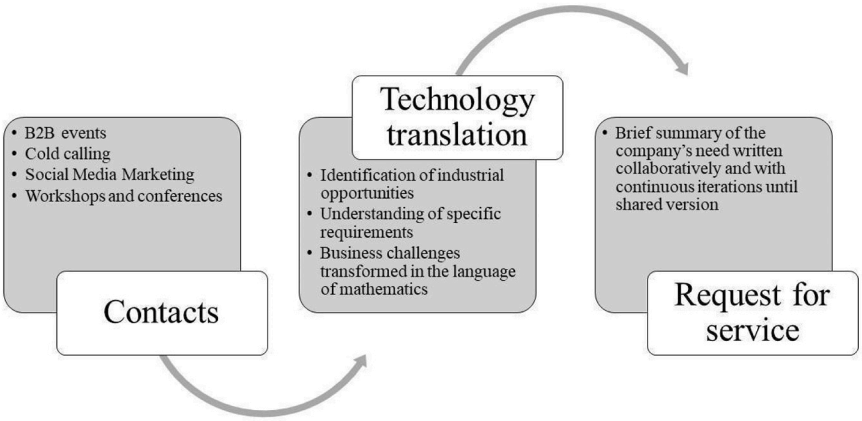


**Fig. 2.** From initial contacts to the request for service.

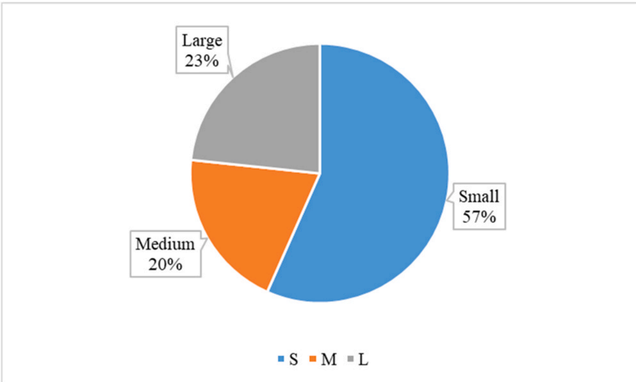


**Fig. 3.** Calls vs enterprise size.

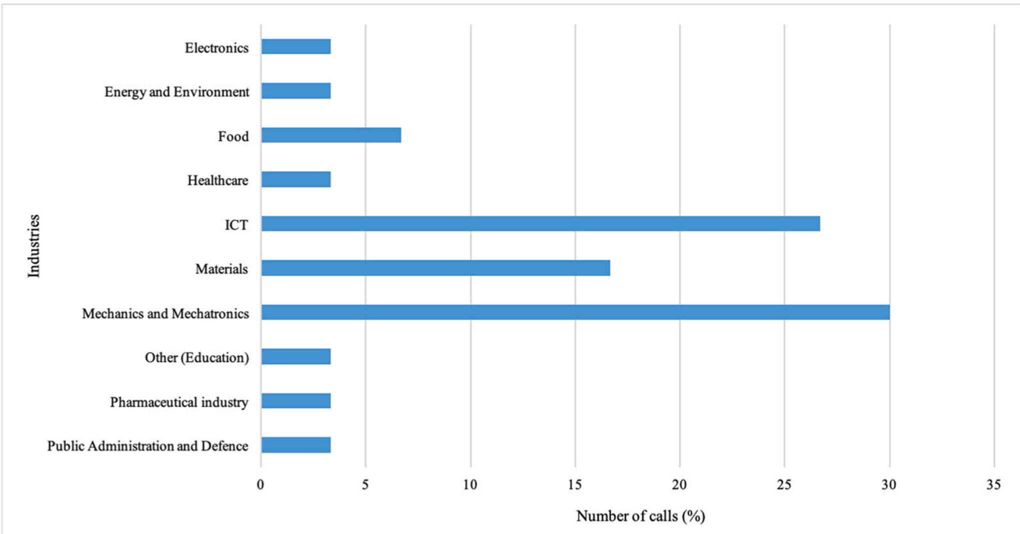


**Fig. 4.** Number of calls vs industrial sectors.

on average large companies allocated budgets of about 33000 euros which corresponds to a longer duration of about 6 months, on average.

## 5. Discussion and findings

Based on the case reported above, we start now to discuss the research findings of our study against the original research questions and objectives. Namely, we aim to assess the impact of adopting an Open Innovation approach to foster an effective industrial transfer of mathematical technologies and to identify the strengths and weaknesses of the latter approach based on the observations and insights revealed by a real-world project. One major analysis underpinning the answer to the first research question is analysing how the project considered in our empirical investigation meets with the definition of Solver Brokerage mechanism (Feller et al., 2009).

In the previous section, we illustrated the mechanism underlying the process realised by Sportello Matematico. We can recognise the four dimensions identified by Geiger et al. (2011). The selection of partners based on their scientific and mathematical competencies addresses the need for a pre-validated solution community, and pre-filtering of network members based on specific skills and backgrounds. We can see that the *preselection of contributions* is both qualification-based and context-specific to ensure that all participants have a background judged pertinent to the type of problem proposed and that the community represents a diverse range of skills. This aspect is closely linked with the initial selection of the right solution community and is relevant to foster the matching between seekers and solvers.

In the process set by Sportello Matematico, there is no accessibility to peer contributions. Research groups cannot see each other's proposals; moreover, the aggregation of contributions is selective. There is a competitive approach in which the contributions presented by the research groups are compared to each other. The rationale is to allow the company to have a range of options from which to choose the 'best' one, after evaluating the proposals. Finally, the remuneration for contributors is success-based: only the selected research group signs the contract of collaboration.

From this analysis, it emerges that the definition of Solver Brokerage (Feller et al., 2012) as the 'intermediary that facilitates innovation exchanges between organisations and crowds' fits Sportello Matematico. Through the 'door-to-door' approach and other outbound marketing activities, Sportello Matematico reaches out to companies and organisations, fostering the aggregation of a critical mass of potential seekers interested in finding innovative solutions. At the same time, by forming a network of research centres, it realises the aggregation of the population of expert solution providers, i.e. the solution community (Fig. 6).

To join the network, these partners are examined by Sportello Matematico's scientific advisory board, and the scientific partnerships are governed by an agreement between each research institution and Sportello Matematico. Sportello Matematico has developed a network of excellence involving more than 45 Italian research institutions with expertise in mathematical technologies. In this way, Sportello Matematico ensures a high-quality network of potential solvers by acting as an upstream regulator.

This proactive two-pronged approach appears to be effective and appropriate for overcoming some of the difficulties occurring in the transfer of mathematical technologies, as discussed in Section 2. Also, following Feller et al. (2009), we claim that the effort made by Technology Translators to provide a clear definition and communication of the problem is essential for the resolution of the challenge proposed and for the knowledge transfer. As shown by Hossain (2018), the most frequent challenge for solvers is the unclear

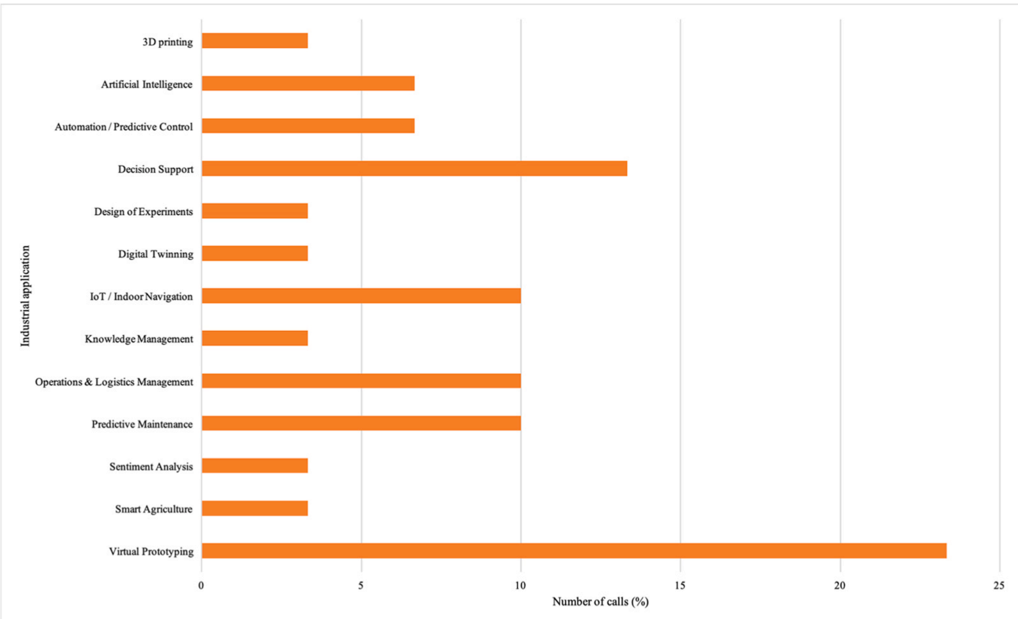


**Fig. 5.** Number of calls vs industrial applications.

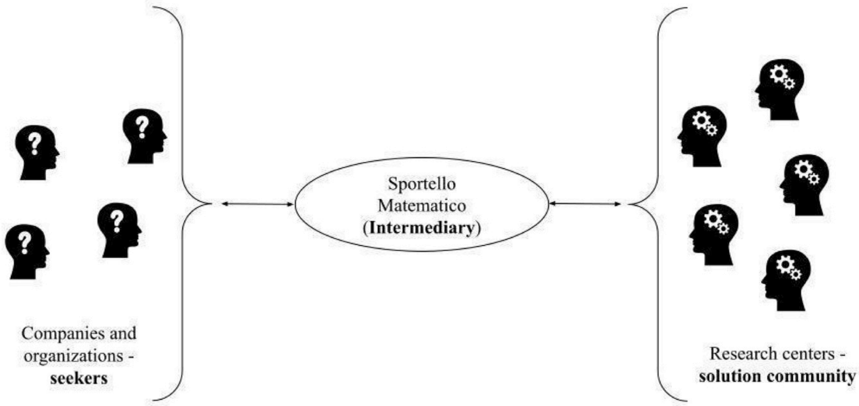


**Fig. 6.** Aggregation of a population of seekers and solvers.

or insufficient problem description provided by the seekers. The translation of the industrial challenge has a critical role in the success of the process, and the intervention of the intermediary helps to overcome this obstacle by facilitating the articulation and presentation of the problem.

The diagram below (Fig. 7) illustrates the different phases of the procedure implemented by Sportello Matematico. We can identify the elements of the crowdsourcing process managed by a Solver Brokerage. The process begins with an open call that is disseminated throughout the solution community (*request diffusion*). This is followed by the implementation of mechanisms designed to connect the seeker - typically a firm - with the solver, a research group, facilitating both the knowledge mobility and appropriability. The process concludes with a final reward in the form of a contract.

Moreover, the entire procedure managed by Sportello Matematico can be framed within the broader innovation process described by Howells and Thomas (2022) as outlined in Section 2. Specifically, the translation activity aligns with both the articulation and

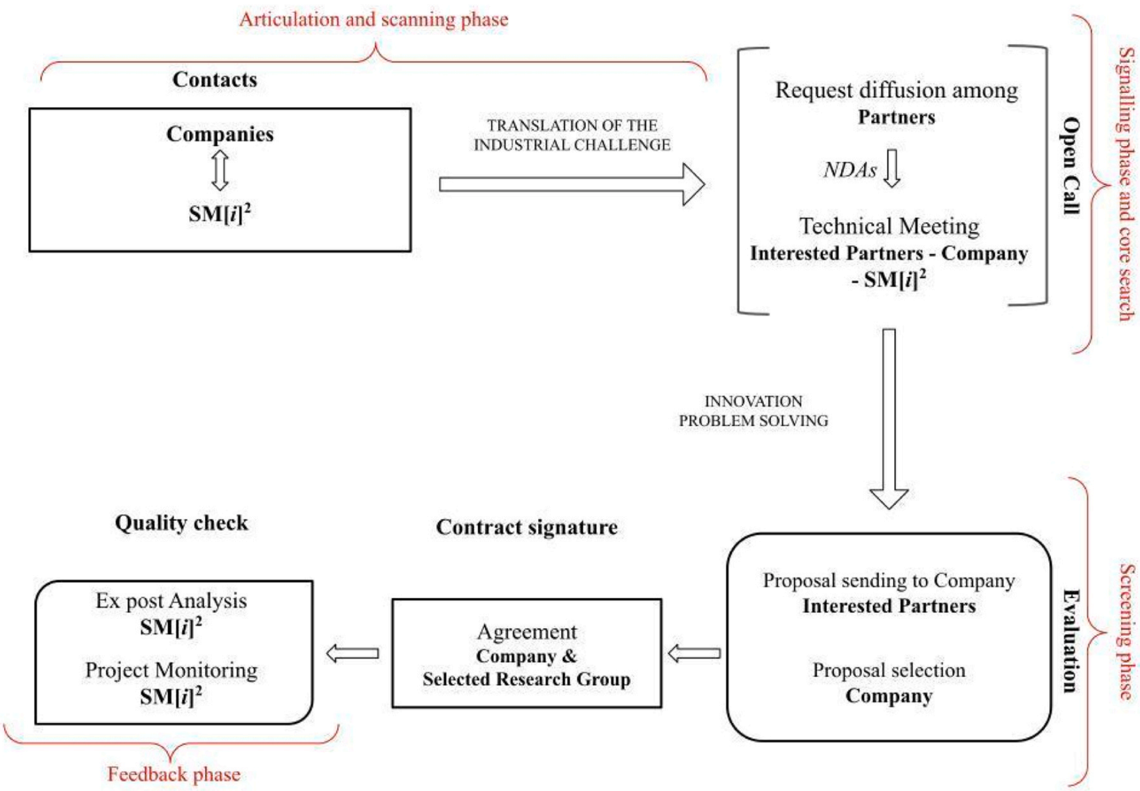


**Fig. 7.** The intermediation process implemented by Sportello Matematico with innovation search phases, as described by Howells and Thomas (2022), in red.

scanning phases, while the diffusion of the request corresponds to the signalling phase. The technical meeting represents the core search, and the subsequent evaluation and selection of the proposals reflect the screening phase. Finally, the quality check conducted at the end mirrors the final feedback stage of the innovation process.

The correspondence with the innovation search phases is highlighted in red in Fig. 7.

Moreover, Sportello Matematico provides a qualified environment in which companies can seek external knowledge, collaborates in framing and defining problems, and facilitates the process of identifying their solution, encouraging the capture of the value associated with such solutions. Feller et al. (2009) showed that 'the ability of all parties involved in the innovation process to capture value improves mobility, increasing the likelihood of future participation'. In line with this proposition, we recognise some aspects related to *appropriability*, i.e. the 'ability of seekers and solvers to capture value from the innovation process' (Feller et al., 2010). Therefore, all parties involved must derive value from the brokerage process, even when it does not end with signing a contract. For companies that fail to find the right partner, value can still be gained from a better understanding of their problems.

Similarly, solution providers who are not selected can have a return in the form of visibility, improved reputation, and personal learning. In this sense, the evaluation phase is crucial because it enhances the value of the work done to present the project proposal and helps solvers understand which aspects to improve. Sportello Matematico also enables risk mitigation for both seekers and solvers. On the one hand, despite not having the certainty of obtaining a solution, companies have access to a qualified solution community, minimising the risk of failure in the search. Conversely, the various activation procedures throughout the process assure the seeker's commitment and collaboration.

Finally, the ex-post analysis consists of a quality check of the whole process, based on continuous monitoring and supervision of the collaboration, with interactions with both sides. It goes in the same direction of providing added value and a positive experience to all, thus incentivising future participation.

According to the characterization of open innovation governance structure proposed by Feller et al. (2009), the Solver Broker can favour either seekers, solvers, or both, depending on the business model implemented. Sportello Matematico stays neutral, as the processes and mechanisms implemented facilitate both seekers and solvers, enhancing the process's fairness and transparency. Moreover, none of the solvers involved is favoured over the others as the competitive bidding mechanism naturally pushes scientific partners to submit their best offer.

From the fact that we have highlighted, it follows that Sportello Matematico is an intermediary that facilitates Open Innovation practices, both Inbound and Outbound: in fact, Sportello Matematico favours the Inbound OI for the seekers and the Outbound OI for the solvers. Concerning the actions that Sportello Matematico favours, we can mention (see Rumanti et al. 2021): for Inbound OI, technology scouting, purchasing of scientific service, joint R&D, external technology acquisition, research collaboration; concerning Outbound OI, supply of scientific services and research collaborations.

Moreover, we can also see (Flor et al. 2019) that the Inbound OI service provided by Sportello Matematico is of pecuniary type since it requires the seeker to pay the solver for the provided services (Pecuniary Inbound practice - Acquiring). The mechanisms involved are innovation intermediaries, R&D outsourcing, R&D cooperation.

The empirical analysis presented in Section 4.2 suggests that some industrial sectors, such as Mechanics and Mechatronics and ICT, have proven to be more receptive and responsive. These are industries where the economic impact of digital twin and virtual prototyping is significant, and there is a greater awareness of the role of quantitative techniques. Think, for example, of the use of CAD/CAM software and CNC programming in manufacturing and of the role of algorithms in software development.

We also noticed that the budget aspect is to be handled with care. During the *translation* of their business needs, firms are usually invited to provide indicative budgets and timescales that may be useful in giving the research centres an order of magnitude for the project, and improving the quality of the collaboration proposals. However, companies often prefer to be guided by research centres on these issues and conduct a time and cost assessment once project proposals are received. Also, micro-small businesses, although often interested, e.g., start-ups, present many innovative issues, show financial limitations, and often require as an ancillary service help in accessing funding through regional, national, or European funding and tenders. Whereas large companies have money to invest in R&D, small companies often lack the financial resources to invest in this in the short run.

The totality of companies that have activated the call service are private companies; in interacting with public entities, there are difficulties on the one hand related to the need for public entities to be subject to the procurement code, and on the other hand for the existence of ad hoc agencies that play this role as broker for public entities.

## 6. Theoretical and managerial implications

By analysing the single case study presented in the previous sections, we were able to draw a range of contributions which can be valuable for both academics and practitioners.

The considered case study can be framed within the existing literature in the field of Solver Brokerage for U-I collaboration. For example, we recognise that there exists a correspondence between the intermediation mechanism described in Section 5 and the six stages defined in Howells and Thomas (2022). Moreover, the case study can be characterised by the four dimensions of Geiger et al. (2011). Also, Sportello Matematico satisfies the definition of Solver Brokerage set by Feller et al. (2012).

The findings of our paper add to the extant literature on university-industry interaction in multiple ways. First, to the best of our knowledge, this is one of the first studies providing a test and assessment on the field for the practical applicability of Solver Brokerage as an Open Innovation approach to foster and realise university-industry collaborations, with outcomes of this application that can be overall deemed as positive.

Second, this is also the first study where an Open Innovation intermediation mechanism is designed and applied to foster collaborations centred in the field of mathematical technologies. The competitive bidding procedure implemented within the analysed case study shows how Solver Brokerage can be adopted as a valid governance tool to promote and unleash the potential of mathematical technologies for companies and organisations.

Furthermore, it can be observed how the specific intermediation process described in this case study allowed for mitigating some of the main barriers and obstacles discussed in section 3.2. For example, the difficulty for companies, especially SMEs, to get in touch with universities and research, turns out to be ameliorated by the *door-to-door* approach and by the specialised technology translation activity. Universities, according to Muscio and Vallanti (2014), often suffer from difficulty in finding innovative companies to partner with. From our study, it is apparent how being part of a network allows them to have greater visibility and recognisability. This turns out to be also particularly relevant for those research centres that present strong expertise in mathematical technologies, and hence great potential for impact, but little or no previous experience in consultancy projects, thus making any cooperation with the industry less likely to occur in lack of the supportive role played by the intermediary officers. Similarly, the transaction-related barriers are smoothed by the governance mechanisms put in place by the intermediary and by its support in the negotiation phase.

This study also has implications for practitioners. Although there is great potential for technology transfer toward SMEs, there appear to be obstacles in the adoption of mathematical technologies, as compared to large companies, due to financial, organisational and managerial issues. Indeed, the need for initial investment often becomes an obstacle for micro and small enterprises, and the limited workforce might limit the chance for SMEs to get in touch with research centres in mathematical technologies. The above-described gaps seem to be partially filled by promoting support activities such as awareness-raising and dissemination, which can improve the absorptive capacity of SMEs with positive impacts on OI in SMEs and their ability to engage with external parties (Doppio et al., 2020). More importantly, playing an active role in reaching out to companies can increase the possibility of matching seekers and solvers, while the competitive bidding mechanism naturally pushes scientific partners to increase flexibility in their economic requests.

Moreover, in the evaluation phase, while respecting its role as an impartial third party, and drawing upon the support of its team of technology translators, the Sportello Matematico strives to put the seeker (for instance, a company) in a more comfortable position, thus gathering more insight into the differences among proposals, and orienting their decisions among the ones which are considered most profitable.

Confirming findings from previous works (e.g., OECD - Organisation for Economic Co-operation and Development Global Science Forum, 2008), our study shows that, in this field, among the ingredients of a successful collaboration are the skills and expertise of the partners involved, the alignment on the timescales and economic aspects, and the shared expectation that the problem is solvable through the development and application of mathematical technologies. The latter aspect can be facilitated by the technology translation activity operated by the intermediary. The presence of technology translators provided with soft skills, scientific background, and industrial experience represents, indeed, a strength of the analysed project as it enables the realisation of the 'midwifery' role already emphasised in the literature.

## 7. Conclusions and future directions

There is huge potential for the knowledge transfer of mathematical technologies towards companies and organisations. Several international studies and reports substantiate the economic impact of mathematical technologies, and many countries established dedicated entities for enabling technology transfer based on the application of mathematical techniques. The degree of penetration of mathematical technologies into the industry is generally quite satisfactory for large companies, whereas it turns out to be still limited for SMEs. Furthermore, there are differences in the resources that large and small-medium companies can allocate for innovative projects.

This paper aimed to find out how to implement appropriate mechanisms to stimulate the interaction of the mathematical and industrial communities and maximise the impact of their collaborations.

First, we analysed the expert literature around industry-academia collaborations; we provided an original definition for the concept of mathematical technologies while reviewing their role in industrial innovation, and the role of intermediary organisations in knowledge transfer. Then, we recalled the concepts of crowdsourcing and Solver Brokerage as a governance structure in the context of Open Innovation. In the second part, we analysed a real-world case study, the project Sportello Matematico per l'Innovazione e le Imprese. We explored the application of the Solver Brokerage as a model for knowledge transfer in the field of mathematical technologies. Based on this analysis, we can affirm that this approach, combined with the technology translation process, can foster the realisation of new collaborations and partnerships between companies and research centres specialised in mathematical technologies. We could also notice a higher incidence of collaborations activated within some sectors, such as Mechanics and Mechatronics, and ICT. Also, this study provides some initial answers to new avenues Hossain (2018) opened to the mediating role of intermediaries between solvers and seekers in terms of problem formulation and support to solvers. Finally, we provided useful contributions for managers, practitioners and scholars.

### *7.1. Further lines of research*

This study is not without limitations that may set the stage for some future research in the innovation management area. One first important aspect is around the adopted research method and the arising generalizability of these research findings. Indeed, our study is based on a single case study, therefore, in order to increase its generalizability, future research could conduct comparative studies in other geographical and economic contexts. It might also be interesting to carry out a survey on a designed sample of companies to evaluate the impact of the Technology Translator's role in realizing the processes described above. An action research activity, involving researchers and practitioners to make changes to the implemented mechanism, could also be very promising. For instance, it might be interesting to consider including more stringent and contractually binding mechanisms for all parties involved. Moreover, as this is one of the first applications of the Solver Brokerage model in a specific scenario, it would be beneficial to explore if and under which circumstances it can be adopted in other contexts. Lastly, in this work, we focused our attention on Solver Brokerage as an Open Innovation tool to foster fruitful collaborations in the specific area of mathematical technologies. Given the promising outcomes of our analysis, it might be worth it and interesting to investigate whether other Open Innovation governance structures, such as the ones proposed by Feller et al. (2009) and illustrated in Section 2.3, namely Solution Hierarchy, Solver Market, Solution Brokerage, Solver Brokerage, may prove to be more or less suitable and effective in the context of industrial transfer of mathematical technologies.

## CRediT authorship contribution statement

**Maurizio Ceseri:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Data curation. **Silvia Vermicelli:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Data curation, Conceptualization. **SGALAMBRO Antonino:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Conceptualization.

## Ethic statement

Not applicable.

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## Appendix

**Table 1**
The NACE classification and the corresponding classification adopted internally by Sportello Matematico

| SMII Category Names | NACE N° |
|---|---|
| **Agriculture** | Section: A Division: 1–3 |
| **Construction** | Section: F Division: 41–43 |
| **Economy and finance** | Section: K Division: 64–66 |
| **Electronics** | Section: C Division: 26, 27 |
| **Energy and Environment** | Section:B Division: 5–9 |
| | Section: D Division: 35 |
| | Section: E Division: 36–39 |
| **Food** | Section: C Division: 10–12 |
| **Healthcare** | Section: Q Division: 86–88 |
| **ICT** | Section: J Division: 58–63 |
| **Logistics and Transports** | Section: G Division: 45–47 |
| | Section: H Division: 49–53 |
| **Materials** | Section: C Division: 16–20 |
| | Section: C Division: 22–25 |
| **Mechanics and Mechatronics** | Section: C Division: 28–33 |
| **Pharmaceutical industry** | Section: C Division: 21 |
| **Public Administration and Defence** | Section: O Division: 84 |
| **Services Management** | Section: I Division: 55, 56 |
| | Section: N Division: 77–82 |
| | Section: R Division: 90–93 |
| | Section: S Division: 94–96 |
| **Textiles and wearing apparel** | Section: C Division: 13–15 |

## Data Availability

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy restrictions.

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