Technological Forecasting & Social Change 180 (2022) 121689

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

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

Boundary spanning R&D collaboration: Key enabling technologies and missions as alleviators of proximity effects?

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ARTICLE INFO

JEL codes:
O31
O38

Keywords:
Innovation policy
Societal challenges
General purpose technologies
Proximity dimensions
Networks

ABSTRACT

Two main targets of contemporary preferential innovation policy support, especially in Europe, are key enabling technologies (KETs) and innovation 'missions' focused on solving societal challenges. Both topics are associated with uniting disparate sets of capabilities, either by driving technology-based innovation into various application domains or by eliciting interdisciplinary and cross-sectoral solutions to urgent societal demands. In this study we assess to what extent pre-commercial R&D collaborations span geographic and cognitive boundaries. We analyze firm-level tie formation in Dutch collaborative R&D projects initiated in the period 2013–2018. Gravity models reveal that, while results for geographic proximity are mixed, some KET types are indeed related to projects in which cognitive proximity is significantly less relevant for tie formation. This contrasts with the findings for projects that retroactively received a mission label. Projects on health and care missions, and especially energy transition and sustainability missions, instead spur collaborations between cognitively proximate firms. The latter suggests that without additional policy intervention, such projects might interconnect similar rather than dissimilar knowledge bases. We conclude by discussing research and policy implications.

1. Introduction

Economic geographers have developed a special interest in knowledge recombination dynamics leading to otherwise unattainable regional development paths (Content and Frenken, 2016; Balland et al., 2019; Grillitsch et al., 2018). A widely propagated policy imperative is to challenge firms' tendencies to draw primarily on knowledge they can easily assimilate, in terms of geographic and cognitive accessibility (Asheim et al., 2011; Grillitsch et al., 2018; Janssen and Frenken, 2019). At the same time, research and innovation policy are gradually moving away from merely boosting knowledge development towards more selectively guiding socioeconomic change (Tödtling and Trippl, 2018; Schot and Steinmueller, 2018; Foray, 2019). This study considers the intersection of two major yet previously unconnected preferential policy developments, both concerned with steering collaborative knowledge development in supposedly promising directions.

First, inspired by the literature on general-purpose technologies ('GPTs'; Bresnahan, 2010), the European Union has been pushing the idea of adopting Key Enabling Technologies (KETs) as springboards for (regional) economic development strategies (European Commission 2012). Due to their wide application potential, KET-oriented R&D is likely to generate knowledge spillovers that may lift the prospects of a broad variety of activities in an economy (Foray et al., 2009). Given the prominent place awarded to KETs in the European Union's 7th and 8th Framework Programme for research and innovation, many European member states have incorporated them into their strategies for building national and regional comparative advantage (Ciffolilli and Muscio, 2018).

Second, there is renewed and increasingly vast interest in innovation policies targeting grand societal challenges (Uyarra et al., 2019). Formulating a mission (Ergas, 1987), as popularized again by Mazzucato (2016; 2018a), represents a prominent way to engage diverse stakeholders in developing and diffusing innovative responses to pressing problems. Imparting clear directions allegedly allows actors to identify unexploited complementarities and overcome the inertia that holds back desirable changes (Hekkert et al., 2020; Janssen et al., 2021). One of the

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https://doi.org/10.1016/j.techfore.2022.121689
Received 20 June 2021; Received in revised form 28 February 2022; Accepted 10 April 2022
Available online 20 April 2022

most advanced mission-oriented policy initiatives today is the European Union's new Framework Programme for research and innovation. Following this example, individual countries and regions in Europe (and beyond) have also begun to prioritize missions (OECD, 2021).

While clearly reflecting different policy traditions and ambitions, both KETs and missions are supposed to present opportunities for uniting geographically and cognitively disparate sets of firm capabilities. The effective exploitation of KETs, to begin with, requires that advanced technologies be coupled to the capabilities of an economy (Antonietti and Montresor, 2019). As KETs are being developed in only a few places, research on new applications usually entails co-development processes also involving distributed actors and capabilities (Montresor and Quatraro, 2017; Wanzenböck et al., 2020a). Mission-based initiatives are no different: successfully aligning complementary capabilities to develop and diffuse solutions has been explicitly linked to achieving collaboration between actors spread across space (Coenen et al., 2015; McCann and Soete, 2020). This imperative is often accompanied with the statement that answers to grand challenges require cross-disciplinary and cross-sectoral innovation (Foray, 2018; Mazzucato, 2018a). Wanzenböck and Frenken (2020, p.57) opine that policies spurring the search for such answers may even be used as 'a basis for regional diversification'. Altogether, both the pushing of new key enabling technologies as well as the pulling demand for new solutions can prompt boundary spanning mechanisms, thereby potentially propelling uncommon knowledge recombination.

What remains unexplored, at least so far, is at which stages of invention and innovation the acclaimed cross-overs come about. The available evidence and arguments discussed above mainly address novel network interactions during the stage of knowledge application. One might nevertheless imagine that, in order to integrate knowledge from various domains and places, distant knowledge search needs to occur long before innovative KET applications or mission solutions are ready for deployment. The purpose of this study, therefore, is to examine to what extent boundaries between places and knowledge bases have already been spanned in R&D projects concerned with early-stage new knowledge development. Of key interest is whether projects on KET and mission themes are capable of bridging geographic and cognitive distances, even in the absence of additional policy incentives. Insights on this matter serve the justification and design of preferential policy strategies aiming to strengthen or bring about such boundary spanning tendencies.

In our empirical analysis, we investigate firm-level tie formation in collaborative R&D projects in the Netherlands. The dataset we study, retrieved from the administration of the Dutch Public-Private Research Allowance scheme, includes the majority of public-private R&D projects taking place between 2013 and 2018. In 2019, existing subsidized projects in the allowance scheme have retroactively been labelled according to the KET and the mission theme they are associated with. By looking at participating firms' location and sectors of activity, we investigate to what extent the R&D projects are alleviating the influences of (respectively) geographic and cognitive proximity – and how that differs if the project is developing a KET or addressing a mission.

The empirical investigation confirms that geographic and cognitive proximity are significant predictors for firm-level tie formation. For some KETs, geographic and especially cognitive proximity are relatively less important (to tie formation) than they are for R&D projects not focused on a KET. This is less the case for projects on mission themes. By showing the geographic and cognitive boundary spanning tendency to be modestly present for some KETs, and mostly absent or even negative in the context of missions, this paper primarily contributes to the current debate on how to drive novel R&D collaboration. As the latter is believed to be a basis for economies to diversify promisingly (Grillitsch et al., 2018), our results highlight an additional reason to target innovation policies at KET research (besides their innate potential to transform sectors). Insofar as mission-oriented innovation policy is legitimized based on its potential to drive cross-overs at the R&D stage, more caution seems to be required.

The remainder of this paper is as follows. In Section 2 we review relevant literature and develop hypotheses on the proximity alleviation effects of KETs and missions. Particular attention is paid to the latter as, due to their recent upsurge, less has been theorized about missions. Section 3 describes the data and methodology deployed to test the hypotheses. After describing regression results in Section 4, we interpret our findings and draw conclusions in Section 5.

2. Theory and hypothesis development

2.1. KETs and overcoming distances

The European Commission (EC) regards investing in research on KETs as a particularly sophisticated strategy for spurring the emergence of new competitive economic activities ((Montresor and Quatraro, 2017); Evangelista et al., 2018). The umbrella term 'KET' covers the latest generation of advanced technologies applicable across vastly different contexts. In research and innovation frameworks, such KETs include industrial biotechnology, nanotechnology, micro- and nanoelectronics, photonics, advanced materials, and advanced manufacturing (European Commission, 2012). The EC's original 2012 Smart specialization strategy heartily advocated increasing accessibility to enabling technologies, so that actors could leverage existing capabilities and diversify in new directions (Foray et al., 2009; Boschma et al., 2014).

As already pointed out by Foray et al. (2009), some regions might lead the development of advanced technologies like KETs, while others might only apply them. Montresor and Quatraro (2017) and Evangelista et al. (2018) situate the leading regions in Western and Central Europe, with high concentrations in only a few places. Applying a new KET means identifying complementarities among local capabilities – a process involving co-invention and possibly the emergence of new technological specialisations (Montresor and Quatraro, 2017; Antonietti and Montresor, 2019). Actual development, instead of the 'plug-and-play' that characterizes typical ICT automation, is needed to transfer KET knowledge and fit it for use in a specific domain. Thus, before any KET-based innovation can be tested for commercialization, resources need to be invested in researching how to make a generic technology usable in a specific context (Bresnahan, 2010). This holds importance for what types of firms are involved in conducting collaborative R&D. Project partners from one place might have specialized knowledge concerning the advanced technology itself, whereas the capabilities of project partners from other places might be more suited to the KET's prospective use (Wanzenböck et al., 2020a). Indeed, in their empirical study on digital KETs, proximity constraints and challenges for industrial policy, Bilbao-Ubillos et al. (2021) state that broad relational networks allow firms to operate at the knowledge frontier (i.e. master KETs) while also exploiting deep industry knowledge obtained via local anchorage.

Based on the above, we might expect that most R&D projects involving KETs would be relatively diverse in terms of the firm capabilities and locations they unite. The positive influence of geographic and cognitive proximity (on tie formation) would be lower, then, than for R&D projects concerned with an innovation *not* based on a KET.

Hypothesis 1a. Tie formation in collaborative R&D projects for KETs is less positively influenced by geographical proximity than in projects not involving KETs.

Hypothesis 1b. Tie formation in collaborative R&D projects for KETs is less positively influenced by cognitive proximity than in projects not involving a KET.

2.2. Missions and overcoming distances

Drafting a mission statement that expresses a clear direction and level of ambition allows policy makers to engage stakeholders in developing and diffusing innovative solutions for complex societal problems (Kattel and Mazzucato, 2018). The notion of a 'mission' dates back to Ergas' (1987) edict to use 'big science for big problems' (Mazzucato and Semieniuk, 2017). Hence, one aspect of the vibrant debate surrounding mission-based innovation concerns questions on what research, development and innovation policies to devote to mobilizing and steering a nation's, region's or organization's innovation capacities (Mazzucato, 2016; Fisher et al., 2018; Mazzucato and Robinson, 2018). While some have noted that not all solutions rely on knowledge-based novelty (Wanzenböck et al., 2020b), and that user involvement and institutional change may be crucial elements (Von Hippel, 1978; Hekkert et al., 2020; Uyarra et al., 2020), mission-oriented research policies continue to be associated with R&D policy. The European Union's Horizon Europe Framework Programme for research and innovation, operational as of 2021, is a case in point. The mission areas it focuses on are climate change; cancer; climate-neutral and smart cities; healthy oceans, seas, costal and inland waters; and soil health and food (European Commission 2021). Other well-known examples at the national level are the revised German High-Tech Strategy, featuring 12 missions, and the Dutch Mission-oriented Topsector and Innovation Policy, which encompasses 25 missions distributed among four mission themes (OECD, 2021).

2.2.1. Geographical proximity

As mission-oriented research and innovation policies are back on the policy agenda only recently, the spatial perspective on missions is still emerging (Cappellano and Kurowska-Pysz, 2020; Bugge et al., 2021; Flanagan et al., 2022). Available studies generally point at the importance of place-specificity when it comes to searching and adopting innovative solutions for societal problems, as both problems and innovative capacities tend to be marked by regional contextual factors (Coenen et al., 2015; Wanzenböck and Frenken, 2020).

For collaborative R&D in the pre-commercial stage of knowledge development, however, it does not automatically follow that mission-focused research projects draw mostly on regionally proximate firms. A starting point for many studies and strategies dealing with mission-oriented research policy is that addressing widespread societal problems (Europe's 'grand challenges', the UN's Sustainable Development Goals) will require input from world-class innovators with dissimilar knowledge bases (Mazzucato, 2018b; European Commission, 2018). The rationale here is that if individual societies are unable to tackle persistent societal problems themselves, and if the complexity of these problems makes it hard to even know which solution or direction to follow, perhaps there are answers to be found by mobilizing diverse actors at the global technology and knowledge frontier. As stated by (Foray et al., 1700), "Mission-oriented R&D programs for future societal challenges must support the development and deployment of many different technologies that will be employed in a diverse array of sectors throughout the world."

Following this science and technology based perspective, highly visible missions can help solve quasi-universal problems by involving geographically diffuse researchers in ground-breaking research, which then opens the way to local tweaking of emerging solution directions. Missions may accordingly be regarded as the 'global pipelines' through which distant actors are united, with the resulting knowledge the input for further experimentation and diffusion through 'local buzz' in regional innovation systems (Bathelt et al., 2004). This implies that R&D project teams working on possible solutions can be expected to have relatively mixed geographical backgrounds, given that knowledge-based innovations may need adjusting to local capabilities and contextual factors. After all, R&D project teams involving parties affected by a societal problem (or at least having knowledge about the conditions within which the problem arises) do not need to be located in the same place as actors helping to develop suitable solutions (Mazzucato, 2018b). An agricultural mission dedicated to sustainable food security, for instance, might benefit from expertise on tractors and crop yielding techniques developed in a technology cluster located elsewhere.

In sum, missions have the potential to link frontier knowledge from one place with firms in other places who are not able to solve a problem with the capabilities they have available locally. Long distance knowledge exchange may also occur in 'regular' R&D projects, of course, but the question is whether missions on societal challenges can build on some inherent (not policy-induced) characteristic of problem-oriented R&D projects to unite geographically remote capabilities. If it is true that teams working on such projects tend to be made up of remote partners, this could be leveraged by innovation policy that promotes problem-based directionalities. Here, we put this to the test by hypothesizing that collaboration in R&D projects with a mission-related theme is relatively less affected by geographical proximity's customary positive influence on tie formation.

Hypothesis 2a. Tie formation in collaborative R&D projects on missions is less positively influenced by geographical proximity than in projects not involving a mission.

2.2.2. Cognitive proximity

In their discussion of the nature and design of mission-oriented R&D programs, Foray et al. (2012) stress the importance of support for knowledge development in the basic research stage. They also make the point that while private funding might increase when (technological) solutions are ready for commercialization and dissemination, firms already have a role to play in the early stages of research and development as well. In a more recent article, Foray (2018) explains how mission-oriented R&D policy can drive the search for solutions emerging from complementarities between different sets of actors and their capacities. As opposed to individual industries as the target of selective policies, missions are special because of their potential to spur research activities at the interface of parts of different industries (which can also help to transform these industries).

A similar claim is found in Mazzucato and Penna (2016) and Mazzucato (2018a). Setting a concrete direction can enable the alignment of different types of capabilities, which in turn may yield innovative responses to grand societal challenges. The innovation process, especially when it comes to wicked societal problems, ought to bridge industries, disciplines, and types of actors in the early stages of solution development (Kuhlmann and Rip, 2018). Mazzucato (2018a) therefore stresses the importance of interaction among scholars from quite distinct scientific disciplines (spanning natural sciences, formal sciences, social sciences and humanities) when conducting R&D activities related to addressing wicked problems. In the case of healthcare, for example, suitable outcomes would not only require codesign and cocreation to investigate new pharmaceuticals, but also innovations from domains such as "nutrition, artificial intelligence, mobility and new forms of digitally enhanced public service provision" (Mazzucato, 2018a, p. 811).

Compared to 'vertical' research priorities (specific technologies, predefined sectors) problem-based missions appear as 'diagonal' in the sense that they may act as natural interfaces between various 'horizontally' unrelated sectors (Janssen and Frenken, 2019). While much of the current debate surrounding mission-based initiatives is devoted to how to govern them, there appears to be a resurgence of optimism that innovation efforts focused on solutions for societal challenges are *de facto* more cross-sectoral than regular innovation efforts. To test this assumption, we hypothesize the following:

Hypothesis 2b. Tie formation in collaborative R&D projects on missions is less positively influenced by cognitive proximity than in projects not involving a mission.

3. Data and methodology

3.1. Case description: collaborative R&D in the Netherlands

In 2012, the Dutch ministry of Economic Affairs and the ministry of Education, Culture and Science implemented a new strategy to increase the competitiveness of the Dutch economy. Fundamental to this strategy was the creation of nine Topsectors: a set of triple-helix coordination structures designed to strengthen the Dutch innovation system (for more detail, see Janssen, 2019). Given that one of the Topsector's main goals is to increase business investments in public-private research, policy support is largely geared towards facilitating collaborative R&D. Through Topconsortia for Knowledge and Innovation (TKIs), the Topsectors organize events and fund R&D activities in line with the Knowledge and Innovation Agendas they publish every two years. The Dutch Public Private Research Allowance scheme provides funding for public-private R&D projects by adding 30% (previously 25%) to the privately funded share of earlier public-private R&D projects.

For our empirical analysis, we use data sets provided by the Netherlands Enterprise Agency (RVO.nl) on all collaborative R&D projects that received support from the allowance scheme in the period 2013–2018. The data sets include information about project titles, starting years, participants and budgets. By merging the data, it is possible to map the evolution of the collaborative network for the period 2013–2018. The total network includes 1884 Dutch firms and 105 publicly-funded organizations. Given our focus on recombining firm capabilities, our analyses concentrate on the 1884 firms only.

The continuation of the Topsector approach, announced in 2019, attaches primary importance to missions and KETs (EZK, 2019). For monitoring and evaluation purposes, RVO.nl has retroactively labelled existing R&D projects according to the mission and KET themes they would correspond to – even though they were not subject to policy actively promoting these themes when they began. The ex-post labeling (which we exploit here) ensures that projects retroactively allocated to a theme have not received different formal treatment. The original allowance scheme did not require or select projects based on team diversity (in terms of geographic and cognitive proximity), nor did granters seek to ascertain whether a project was relevant to a KET or a mission. We can exclude the influence of informal treatment due to e.g. biases from either the project team members (inserting KET- and mission-related tags in their proposals to increase the likelihood of getting funded) or the policy agency funding the projects. The fact that not all granted projects could be associated with either a KET or a mission allows us to benchmark KET and mission projects against 'regular' R&D collaboration projects.

Our data contains information on the six KETs identified by the European Commission (mentioned in Section 2.1) plus two additional categories: chemical and quantum technologies. The last category in our data includes projects that are not classified as a KET (hereafter 'Not a KET'). Labels were assigned by starting with a list of keywords, followed by a manual inspection of all matches. Table 1 provides the descriptive statistics of projects across the nine KET categories. 'Not a KET' is the largest category. It contains about 40% of all projects. These projects are technologically heterogeneous, covering a wide range of topics and knowledge bases. Except for the distribution of the number of projects across categories, it seems KETs are similar in terms of their statistics. The only exception is the category Quantum Tech, with only 11 projects having no involvement of SMEs (measured as firms with maximum 250 employees). Given the relatively small number of observations, we exclude this category in our inferential analyses. The geographical distribution of involved organizations shows that most activities are concentrated in large cities (see Fig. 1). Interestingly, more than half of collaborative ties (between 52% and 75%) cross regional boundaries, and collaborative ties identified as 'Not a KET' have the second lowest value of the share of interregional ties. This might imply that joint research and innovation activities in KETs are being largely conducted by expert organisations located in knowledge hubs spread across the country.

Table 1
Descriptive statistics of projects.

Technologies	Project number	Average number of participants	Share of SMEs	Share of Dutch participants
KET category				
Advanced material	54	4.09	0.62	0.95
Chemical technologies	105	4	0.61	0.93
Digital technologies	52	3.69	0.63	0.99
Engineering and fabrication technologies	89	3.52	0.58	0.95
Life sciences technologies	67	4.18	0.68	0.97
Nanotechnologies	15	2.8	0.5	0.9
Photonics and light technologies	24	4.25	0.68	0.94
Not a KET	310	4.61	0.64	0.97
Mission category				
Agriculture, water and food	49	5.06	0.66	0.97
Energy transition and sustainability	75	4	0.69	0.96
Health and care	91	3.67	0.7	0.98
No mission	572	4.33	0.67	0.96

The so-called 'Mission-oriented Topsector and Innovation Policy' approach announced in 2017 and introduced at the end of 2019 focuses on 25 missions categorized under 4 central themes. The TKIs that collected projects before administering them with RVO.nl initially attempted linking the projects to mission themes themselves. RVO.nl enriched this classification by following a combination of keyword and manual matching, assigning them to four mission themes. These are: Energy Transition and Sustainability (share: 0.09); Agriculture, Water and Food (0.06); Health and Care (0.12); and Safety (0.01). 72% of projects are not associated with a mission ('No Mission'), and therefore can serve as our reference group. Only 4 projects belong to the Safety mission theme. Given the small number of observations for this theme, we exclude this category from our inferential analysis. Table 1 provides additional descriptive statistics. The total number of projects with a mission theme label (including 'No Mission') is higher than the total number of projects with a KET label (including 'Not a KET'), as the latter variable includes more projects with missing data.

As discussed, given the structure of our dataset, each project can potentially fall into a KET category and a mission category. Fig. 2 illustrates the distribution of projects across KET types and mission themes. This meets our intuitive expectation, as it shows that a relatively large share of projects in the KETs Advanced Material and Chemical Tech are part of the Energy Transition and Sustainability mission theme, and projects in the KETs Life Sciences Tech and Engineering and Fabrication Tech tend to address the Health and Care mission theme. Again, these KET-Mission relationships are not affected by a top-down design to integrate KETs and missions into a cohesive framework, because this has been of major policy concern only since 2019 and was not a dominant policy aim in the time period for which we retrieved the data.

3.2. Variable construction

3.2.1. Dependent variable

In this study, we seek to provide a better understanding of how proximity dimensions facilitate or hamper the formation of collaborative R&D ties across KET and mission categories. To construct the dependent variable, we created a set of all possible pairwise combinations of firms, each of which takes the value of one if, for a particular category, there is a collaborative tie between the given two firms, and

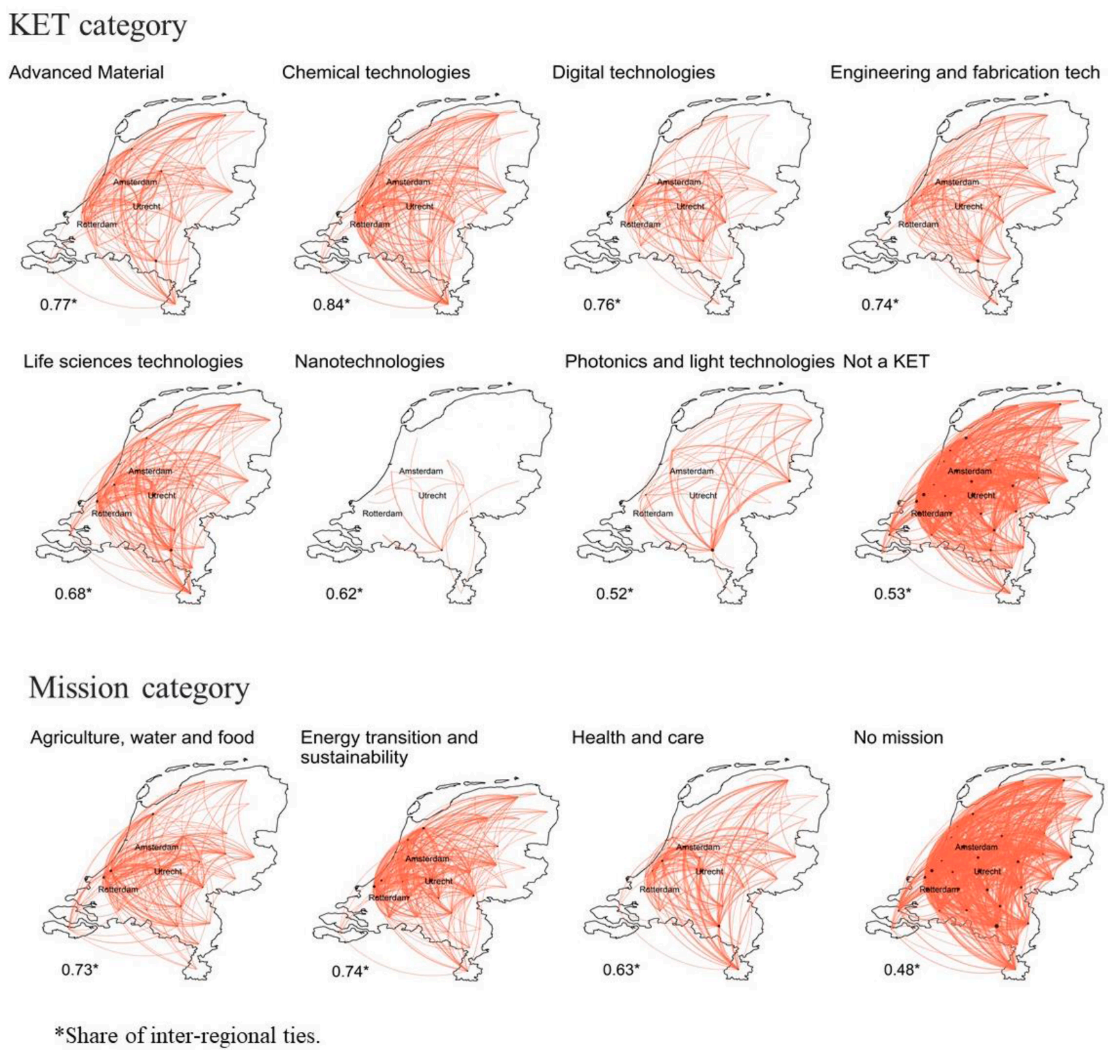

Fig. 1. The geographic distribution of collaborative R&D ties.

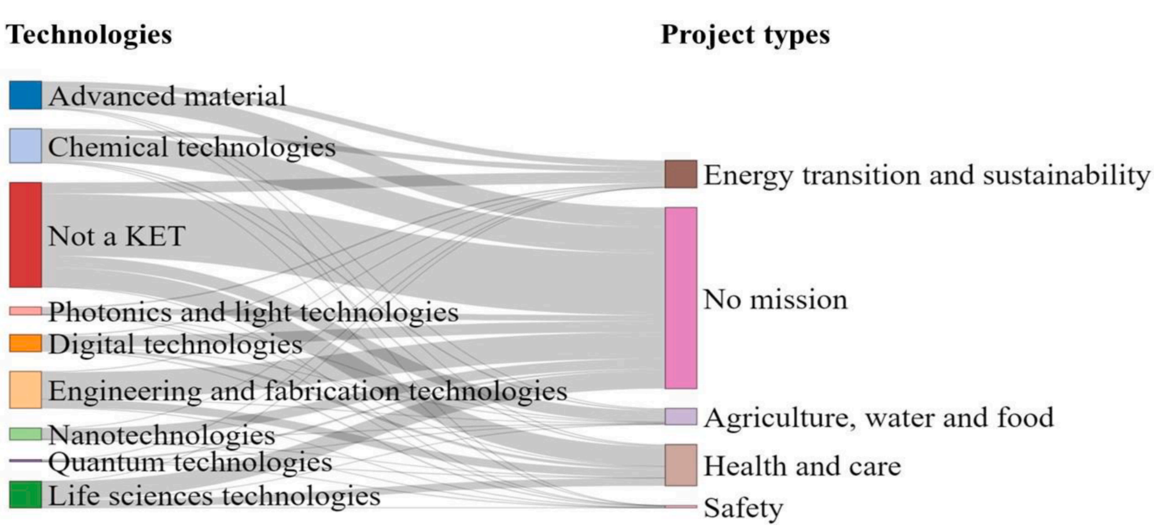

Fig. 2. Distribution of projects across KET types and Mission themes.

takes the value of zero otherwise. The dependent variable thus varies across models that focus on investigating the relationship between collaborative tie formation and proximity dimensions in specific KETs or missions. Also, constructed dependent variables are not necessarily mutually exclusive because two given firms can be involved in more than one project associated with different KETs and missions.

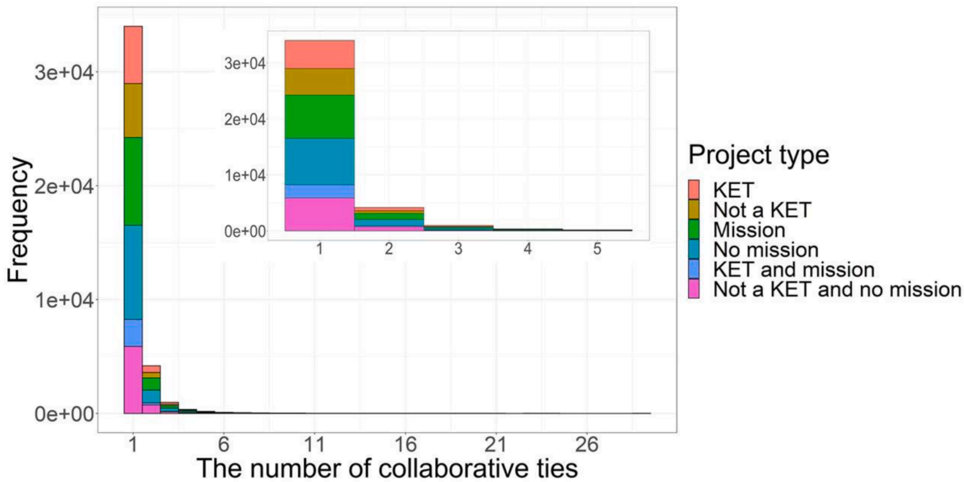

Fig. 3. Frequency of single and multiple collaborative R&D ties.

3.2.2. Independent variables

The association of geographical and cognitive proximities with the formation of collaborative ties of different nature (i.e. KETs and missions) is of interest in this study. After Boschma's (2005) paper, there has been a rise of studies empirically using various methods to operationalize proximity dimensions. Scholars use colocation in a geographic area or the geographic distance between organizations to create geographical proximity variables (for a review, see Micek 2018). We opted for the latter because this measure is not biased by the modifiable areal unit problem (Scholl and Brenner, 2014) and provides more granular information compared to a binary variable based on the former alternative. Thus, we retrieved the information regarding the position of firms based on their postal codes (4-digit level). Next, we calculated the distance (in kilometres and log-transformed) between each two firms. The variable regarding geographical proximity (*GEO*) is the opposite of the calculated distance.

Cognitive proximity is the second independent variable of interest. We follow similar studies, like the one by e.g. Janssen et al. (2020), using the method proposed by Neffke et al. (2017) based on the skill relatedness measure. This method estimates inter-industry skill relatedness by the observed volume of labor flows between industries normalized by the theoretical expectation of such flows. To estimate the inter-industry skill relatedness in the Netherlands, we used inter-industry labor mobility data in 2009 and 2010 (NACE codes at the 4-digit level). Industries are assumed to be cognitively more proximate if there is a more intense labor mobility between them, implying that they require similar skills and knowledge. To create the cognitive proximity variable (*COG*), we assigned the estimated values for inter-industry skill relatedness to firms based on their NACE codes. This implies that two firms that share the same NACE code have the highest degree of cognitive proximity, otherwise the cognitive proximity between these two firms corresponds to the normalized value for inter-industry skill relatedness of their NACE codes. While empirical studies more often utilize patent or publication data to operationalize the cognitive proximity variable (Messeni Petruzzelli et al. 2009), such methods might be biased by underestimating the cognitive proximity between smaller firms with a relatively small number of patents and publications. Our method however treats all firms equally because all firms are assigned to a NACE code.

3.2.3. Controls

We constructed three control variables to ensure the robustness of our empirical analysis. Since firms vary in knowledge sourcing based on their absorptive capacity and access to resources, we made a distinction between large enterprises and small and medium-sized enterprises (SMEs). The information on firm size is included in the retrieved dataset. *SME* is a dummy variable that takes the value of one if a given firm is identified as SME, and it takes the value of zero otherwise.

The second size-related control variable is concerned with the amount of project funding each firm received. To estimate this amount (*BUDGET*) we assigned the normalized funding value (project budget divided by the number of involving firms) to involved firms (log-transformed). *BUDGET* increases if a given firm is involved in more R&D projects.

The third set of control variables reflects the extent to which academic intermediaries (PROs) are involved in collaborative R&D projects. One may argue that the involvement of such actors enhances a firm's ability to tap into cognitively or geographically distant knowledge pools – and thereby engage in boundary spanning collaborative ties. In the R&D dataset, we identified the five Open Innovation Network research organisations that facilitate and undertake cross-sectoral research in the Netherlands (also known as the TO2 institutes).[1] By retrieving information on the TO2 institutes involved in each project, we created two dummy variables for firms in each possible firm pair (i.e., *PRO origin* and *PRO destination*). The dummy takes the value of one if the firm was involved in at least one project with one or multiple TO2 institutes, and it takes the value of zero otherwise. By interacting the two dummy variables for each firm pair, we also control for the effect of the involvement of both firms in at least one project that includes one or multiple TO2 institutes (*PRO origin* × *destination*).

3.3. Empirical model specification

The gravity model is an analytical tool to model the formation of R&D collaborative ties. The model is derived from Newtonian physics and implies that the intensity of interaction (e.g. R&D collaboration) between two actors is proportional to their size and proximity (inversely proportional to their distance) (Brodzicki and Uminski, 2017; Broekel et al., 2014). The gravity model has been widely used to empirically analyze co-inventorship, co-publishing, citation and R&D networks (Maggioni et al., 2007; Hoekman et al., 2009; Peri, 2005; Scherngell and Barber, 2009).

Given the skewed distribution of the frequency of the number of collaborative ties, one may operationalize gravity models by negative binomial regressions. Yet, the descriptive statistics shown in Fig. 3 suggest that only a small share of inter-firm relations (15%) includes R&D collaborative ties more than once. The number of multiple ties is

[1] For more information, see: https://www.euraxess.nl/netherlands/information-researchers/research-landscape.

Table 2
Descriptive statistics (of regression variables) and correlation matrix.

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
GEO (z-score)	1773,786	0.000	1.000	-1.727	-0.622	0.375	12.202
COG (z-score)	1773,786	0.000	1.000	-1.411	-0.884	0.765	2.175
SME (origin)	1773,786	0.693	0.461	0	0	1	1
SME (destination)	1773,786	0.692	0.462	0	0	1	1
BUDGET (origin)	1773,786	11.882	1.480	0.000	10.952	12.698	17.488
BUDGET (destination)	1773,786	11.944	1.458	0.000	10.949	12.794	17.488
PRO (origin)	1773,786	0.541	0.498	0	0	1	1
PRO (destination)	1773,786	0.547	0.498	0	0	1	1
PRO (origin × destination)	1773,786	0.296	0.456	0	0	1	1

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1) GEO (z-score)	1.00								
(2) COG (z-score)	0.02	1							
(3) SME (origin)	-0.03	0.056	1						
(4) SME (destination)	-0.01	0.031	-0.001	1					
(5) BUDGET (origin)	0.05	0.004	-0.151	0	1				
(6) BUDGET (destination)	-0.01	0.032	0	-0.198	0	1			
(7) PRO (origin)	0.03	-0.013	0	-0.17	0.001	0.066	1		
(8) PRO (destination)	0.00	-0.03	-0.141	0.001	0.07	-0.001	0	1	
(9) PRO (origin × destination)	0.02	-0.019	-0.083	-0.101	0.041	0.039	0.597	0.59	1

Table 3
Regression results for KETs and missions (aggregate level).

	KETs and Missions KETs	Not a KET	Missions	No mission	KETs and missions	Not a KET and no mission
GEO (z-score)	0.0669***	0.1219***	0.0763***	0.0854***	0.0537**	0.1333***
	(0.0144)	(0.0106)	(0.0140)	(0.0105)	(0.0211)	(0.0124)
COG (z-score)	0.2819***	0.3425***	0.4911***	0.2204***	0.2959***	0.2200***
	(0.0192)	(0.0165)	(0.0206)	(0.0140)	(0.0282)	(0.0196)
SME (origin)	-0.4105***	-0.5870***	-0.3214***	-0.4828***	-0.2477***	-0.6652***
	(0.0413)	(0.0330)	(0.0418)	(0.0293)	(0.0626)	(0.0400)
SME (destination)	-0.4764***	-0.5523***	-0.2722***	-0.5017***	-0.1730***	-0.6458***
	(0.0420)	(0.0334)	(0.0423)	(0.0298)	(0.0636)	(0.0405)
BUDGET (origin)	0.3684***	0.0211**	0.2424***	0.1819***	0.5281***	0.0577***
	(0.0122)	(0.0106)	(0.0133)	(0.0090)	(0.0184)	(0.0126)
BUDGET (destination)	0.4095***	0.0060	0.2157***	0.2011***	0.5354***	0.0625***
	(0.0120)	(0.0107)	(0.0132)	(0.0088)	(0.0186)	(0.0125)
PRO (origin)	-1.2029***	-1.4086***	-1.5730***	-1.0101***	-1.7479***	-1.4008***
	(0.0677)	(0.0648)	(0.0653)	(0.0587)	(0.0975)	(0.0902)
PRO (destination)	-1.4070***	-1.2639***	-1.6087***	-1.0202***	-2.1429***	-1.2380***
	(0.0741)	(0.0613)	(0.0657)	(0.0592)	(0.1138)	(0.0851)
PRO (origin × destination)	2.4524***	2.9599***	2.4098***	2.7423***	2.9122***	3.3416***
	(0.0953)	(0.0857)	(0.0927)	(0.0776)	(0.1469)	(0.1175)
Constant	-15.1291***	-5.4842***	-10.9995***	-9.9541***	-19.3918***	-7.1473***
	(0.2310)	(0.1895)	(0.2411)	(0.1653)	(0.3595)	(0.2271)
Observations	1773,786	1773,786	1773,786	1773,786	1773,786	1773,786
Log Likelihood	-18,206.9400	-26,482.8800	-18,724.6400	-32,321.4400	-8979.2720	-18,621.5500
Akaike Inf. Crit.	36,433.8900	52,985.7500	37,469.2700	64,662.8700	17,978.5400	37,263.1000

Note: $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.

negligible if we exclude inter-firm relations that are created based on the involvement of firms in two common projects. Thus, we opted for a set of binary logit models with maximum likelihood estimation. Using the gravity model, one can include two-way fixed effects with reference to firm level variables at origin and destination as well as effects associated with firm pairs (e.g. proximity dimensions).[2]

Our empirical setting includes 1884 firms and 8037 (out of 1773,786 possible) collaborative ties.[3] The estimating equation takes the following form:

$$\ln\left(y_{ij} / 1 - y_{ij}\right) = \alpha + \beta 1 GEO_{ij} + \beta 2 COG_{ij} + \beta 3 Node_i + \beta 4 Node_j + u_{ij} \quad (1)$$

where y_{ij} denotes the probability of the presence of at least one collaborative tie, andGEO_{ij} and COG_{ij} correspond to the geographical and cognitive proximities between firms *i* and *j* respectively. *Node* denotes control variables at the firm level (i.e. *SME, BUDGET,* and *PRO*) with reference to firms *i* and *j* (origin and destination). It is important to note that we standardized[4] the variables *GEO* and *COG*. Since the number of observations and included variables remain constant across models, including the main variables of interests (i.e. *GEO* and *COG*) in models as

[2] Alternatively, one can use Exponential Random Graph Models (ERGMs) or Stochastic Actor Oriented Models (SAOMs). However, such models normally encounter convergence problems when the number of nodes (i.e. firms) is greater than 1000.

[3] The number of potential collaborative ties corresponds to (n (n-1))/2, where n is the number of firms.

[4] In doing so, we calculated the z-score for the two variables. z-score = (x-$\bar{x}$)/sd(x) where $\bar{x}$ and sd(x) are the mean and standard deviation of x, respectively.

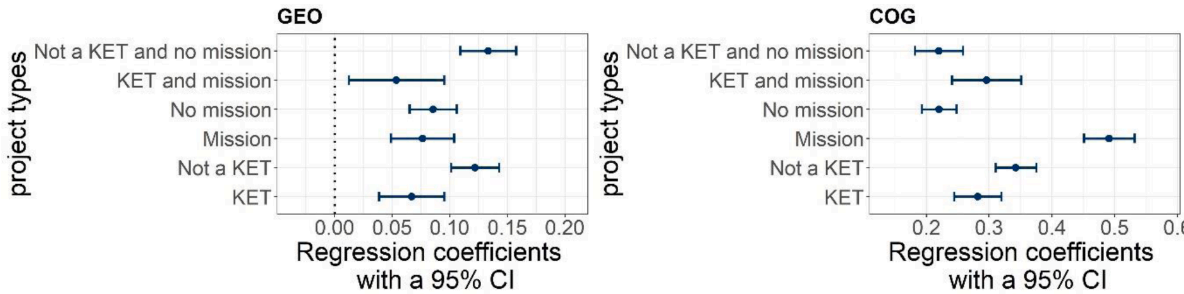

Fig. 4. Coefficients of GEO (left panel) and COG (right panel) with a 95% confidence interval.

z-scores enables us to compare and more easily interpret the magnitude of their effects. We visualize the calculated coefficients and the corresponding 95% confidence intervals, in order to examine their sign and significance and to investigate whether the effect sizes of the variables of interest are meaningfully different from one another. Table 2 provides descriptive statistics and the correlation matrix for the constructed variables.

4. Results

To obtain an overall impression of the respective influences of proximities on KETs and missions, we first report aggregate results based on the 'KET' and 'Mission' categories as such. Subsequently, in Section 4.2 and 4.3 we unpack the observed patterns by providing detailed results for specific KET types and mission themes.

4.1. Regressions for KETs and missions

The results for regressions at the aggregate KETs and missions level are included in Table 3. Fig. 4 shows coefficients and 95% confidence intervals for the dependent variables. Given that all intervals lie above zero, geographical proximity is consistently a positive predictor for tie formation. The independent variable 'Not a KET and No mission' has the highest coefficient (suggesting that reversely, KETs and missions might indeed be associated with geographic boundary spanning), but to draw conclusions on the relative importance of each regression variable we compare the confidence intervals. As it turns out, for geographical proximity only the relatively high estimates and intervals for 'Not a KET and No mission' and – to a lesser extent – 'Not a KET' are significantly above the estimates for projects focused on a KET. This suggests that conducting a project on KETs might alleviate the influence of GEO, while from Fig. 4 this does not seem to be the case for missions.

In the results for cognitive proximity, the 'Mission' category particularly stands out. Projects focused on a mission generally exhibit a stronger positive correlation with cognitive proximity (also in comparison to the reference category of 'No mission'), which goes against the expectations captured by Hypothesis 2b. The contrast for key enabling technologies is less prominent, as the KETs confidence interval overlaps with the one for 'Not a KET'-projects.

Table 3 also reports on the control variables. SMEs are less likely to form ties, while (unsurprisingly) participating in projects with larger budgets increases the chance of tie formation. Moreover, if only one of the firms in a possible pair participates in projects with a PRO this reduces the chance of tie formation, while the reverse holds if both firms are active in projects involving such boundary-spanning research organisations. The last effect is strongest for 'Not a KET and no mission' projects, suggesting that PROs make more of a difference in projects not concerned with our key variables of interest.

Since younger companies may lack accumulated knowledge and have sparser networks, the age of the company may also impact their knowledge sourcing behavior. To ensure the robustness of our findings, we retrieved establishment dates from Chamber of Commerce files and created a categorical age variable (*AGE*).[5] The results of the models including *AGE* are in line with the models presented earlier (see Appendix A). We refrain from including this variable in other models because missing age values decrease the number of observations by about 10 percent, which for models at more disaggregated levels increases the chance of biases.

4.2. Regression results for KET types

To better grasp how proximity alleviation plays out, we also compare findings per KET type. According to Table 4 and Fig. 5, GEO is significantly positive in the reference category of 'Not a KET', but also for the categories Engineering and Fabrication, Digital Tech, Nanotech, and Photonics and Light Tech. Tie formation in R&D projects in the other three KETs is less subjected to the influence of geographical proximity. Only in the Life Sciences Tech category, however, did we observe the hypothesized significant difference from the 'Not a KET' category.

For cognitive proximity, the patterns look markedly different. Besides the significantly positive finding for 'Not a KET', the KETs that exhibit a positive correlation with cognitive proximity are Engineering and Fabrication Tech, Photonics, Life Sciences Tech, and Chemical Tech. Nanotech and Advanced Material are not statistically significant, while the results for Digital Tech depend on which control variables we include in our model. With respect to Hypothesis 1b, it turns out that tie formation in three KETs is less correlated with COG than in the reference category of 'Not a KET': Advanced Material, Digital Tech and Chemical Tech (the latter still being significantly positive but with a relatively smaller effect size). At the same time, compared to the reference group, tie formation in Life Sciences Tech correlates *more* with cognitive proximity. This is remarkable, as for geographical proximity it was the only one demonstrating the acclaimed proximity alleviating effects of KETs. Apparently, Life Sciences Tech projects unite cognitively similar firms from dissimilar places.

4.3. Regression results for mission themes

Turning towards the second type of possible proximity alleviator, 'No mission' projects are found to be positively correlated with both types of proximity (see Table 5 and Fig. 6). We do not observe sharp contrasts between 'No mission' and the various mission themes regarding the effects of geographical proximity. At first sight, tie formation in projects associated with the Agriculture, Water and Food mission theme seems to exhibit a less positive influence of cognitive proximity. This partial confirmation of hypothesis 2a/b is only weak, however, given that the confidence intervals for this mission theme still have a slight overlap with the intervals for the 'No mission' category. Instead, given that the COG estimates and intervals for the Health and Care and especially Energy Transition and Sustainability theme are clearly above the 'No

[5] Number of firms per age category: 82 (5>), 307 (6-10), 502 (11-20), 627 (21-50), 286 (50<). 80 missing values.

Table 4
Regression results for KETs.

	KETs Advanced material	Chemical tech	Digital tech	Engineering	Life sciences	Nanotech	Photonics	Not a KET
GEO (z-score)	0.0367	0.0523*	0.1537***	0.1217***	-0.0176	0.1992***	0.0981**	0.1219***
	(0.0428)	(0.0296)	(0.0291)	(0.0290)	(0.0304)	(0.0670)	(0.0391)	(0.0106)
COG (z-score)	0.0757	0.2029***	0.0992**	0.3445***	0.4464***	0.2913*	0.3507***	0.3425***
	(0.0476)	(0.0373)	(0.0485)	(0.0491)	(0.0359)	(0.1559)	(0.0646)	(0.0165)
SME (origin)	0.0111	-0.7064***	-0.4861***	-0.6840***	-0.2073***	-0.4485	0.3708**	-0.5870***
	(0.1057)	(0.0817)	(0.1008)	(0.1037)	(0.0788)	(0.3476)	(0.1560)	(0.0330)
SME (destination)	-0.3611***	-0.9644***	-0.1592	-0.7346***	-0.2285***	-0.8729**	0.2646*	-0.5523***
	(0.1048)	(0.0849)	(0.1034)	(0.1081)	(0.0791)	(0.4427)	(0.1538)	(0.0334)
BUDGET (origin)	0.2222***	0.3914***	0.0804**	0.3231***	0.6967***	0.4562***	0.6928***	0.0211**
	(0.0317)	(0.0229)	(0.0313)	(0.0304)	(0.0235)	(0.1034)	(0.0439)	(0.0106)
BUDGET (destination)	0.3274***	0.3895***	0.1479***	0.4204***	0.6598***	0.9792***	0.8272***	0.0060
	(0.0296)	(0.0228)	(0.0306)	(0.0293)	(0.0244)	(0.1113)	(0.0471)	(0.0107)
PRO (origin)	-0.5681***	-0.3444**	-0.5784**	-1.0699***	-2.2273***	-0.5165	-1.5089***	-1.4086***
	(0.2009)	(0.1423)	(0.2674)	(0.1729)	(0.1223)	(0.5289)	(0.1958)	(0.0648)
PRO (destination)	-0.6297***	-0.1889	-1.7156***	-1.8177***	-2.3663***	-2.2293**	-1.1444***	-1.2639***
	(0.2111)	(0.1400)	(0.3934)	(0.2340)	(0.1291)	(1.0849)	(0.1834)	(0.0613)
PRO (origin × destination)	2.1983***	0.8578***	4.1321***	2.8950***	2.6810***	2.0147*	0.7706***	2.9599***
	(0.2636)	(0.1748)	(0.4460)	(0.2762)	(0.1772)	(1.1368)	(0.2721)	(0.0857)
Constant	-15.1695***	-16.6974***	-11.5735***	-16.4163***	-23.3708***	-28.2679***	-27.7511***	-5.4842***
	(0.5860)	(0.4400)	(0.5855)	(0.5650)	(0.4700)	(2.1416)	(0.9157)	(0.1895)
Observations	1773,786	1773,786	1773,786	1773,786	1773,786	1773,786	1773,786	1773,786
Log Likelihood	-3706.7800	-5522.3820	-3611.0420	-3516.5750	-5856.5870	-361.9901	-2012.8730	-26,482.8800
Akaike Inf. Crit.	7433.5610	11,064.7600	7242.0840	7053.1510	11,733.1700	743.9802	4045.7460	52,985.7500

Note: $*p < 0.1$; $**p < 0.05$; $***p < 0.01$.

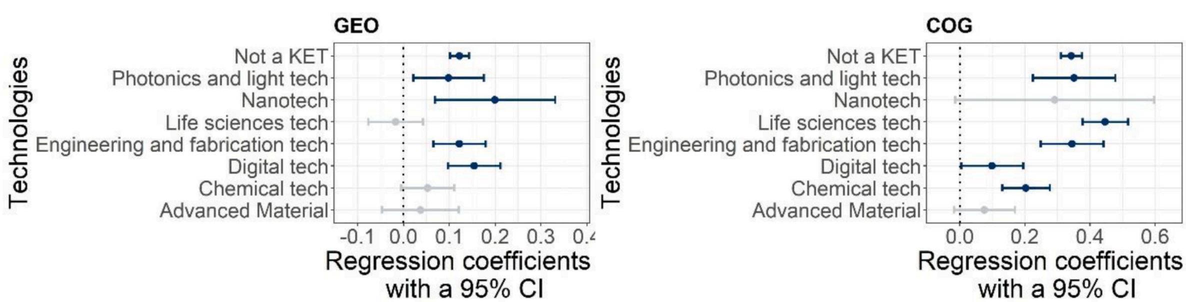

Fig. 5. Coefficients of GEO (left panel) and COG (right panel) across key enabling technologies, with a 95% confidence interval. Results not significantly different from zero are shaded in light gray.

mission' benchmark, projects in these mission themes rather seem to be associated with cognitively proximate R&D collaborations.[6]

5. Conclusion

5.1. Discussion

This study sets out to assess the acclaimed boundary spanning potential of R&D projects that have ex-post been associated with KETs and mission themes, but were not already influenced by any policy strategy providing preferential support. Evidence that these topics spur geographically and cognitive distant search would, from a knowledge recombination perspective, imply an additional policy rationale for targeting them through non-neutral collaborative R&D policies.

While aggregate results showed that, indeed, geographical proximity has relatively little (positive) influence on tie formation in KET projects – compared to the 'Not a KET' category – detailed inspection of particular KET types revealed this finding only holds for Life Sciences Tech. In the case of cognitive proximity, we noticed the opposite: at the aggregate level, there did not seem to be a substantial difference, but looking at individual KETs there are three types (Digital Tech, Chemical Tech, Advanced Materials) that exhibit significantly less positive influence of COG than 'Not a KET' projects. This hypothesized relation is thus obscured at the aggregate level, partially due to Life Sciences Tech projects being in fact extremely sensitive to cognitive proximity. Projects from the life science KET domain seem to unite cognitively similar firms from geographically dissimilar places, which could reflect the relative importance of science-input and codified knowledge for this particular KET (Wanzenböck et al., 2020a).

The overall finding that several KETs are associated with uniting cognitively disparate knowledge bases is consistent with their acclaimed potential to drive unrelated recombination, but we find fewer indications that they also facilitate cross-overs in space compared to the reference group ('Not a KET'-projects). Besides the extent to which KETs differ in how much they rely on scientific research and codified knowledge, one other potential explanation can be found in how developers and users of certain technologies are geographically distributed. Our assumption was that tie formation in R&D projects is only weakly influenced by geographical proximity if KETs are created by specialized firms located in a few places, who then co-develop KET applications together with clients from a broad range of sectors and places (Montresor and Quatraro, 2017). An example would be the commercial

[6] A robustness check focusing on only the years 2017-2018 indicates that the 'No mission' benchmark exhibits a stronger positive relation with cognitive proximity, compared to the results from the full 2013-2018 period. The coefficient and confidence interval are now above those for Agriculture, Water and Food, but still significantly below those for the Energy Transition and Sustainability mission theme.

Table 5
Regression results for missions.

	Missions Agriculture, water, and food	Energy transition and sustainability	Health and care	No mission
GEO (z-score)	0.0588**	0.0476**	0.0823***	0.0854***
	(0.0288)	(0.0228)	(0.0215)	(0.0105)
COG (z-score)	0.1573***	0.6884***	0.3685***	0.2204***
	(0.0355)	(0.0311)	(0.0355)	(0.0140)
SME (origin)	-0.5901***	0.0083	-0.4942***	-0.4828***
	(0.0755)	(0.0631)	(0.0763)	(0.0293)
SME (destination)	-0.4582***	-0.2109***	-0.1879**	-0.5017***
	(0.0762)	(0.0609)	(0.0793)	(0.0298)
BUDGET (origin)	0.2508***	-0.0471***	0.7765***	0.1819***
	(0.0222)	(0.0182)	(0.0244)	(0.0090)
BUDGET (destination)	0.2036***	-0.0743***	0.7660***	0.2011***
	(0.0223)	(0.0193)	(0.0260)	(0.0088)
PRO (origin)	-0.7745***	-1.3313***	-2.3127***	-1.0101***
	(0.1594)	(0.0872)	(0.1114)	(0.0587)
PRO (destination)	-0.9690***	-1.2160***	-2.5876***	-1.0202***
	(0.1669)	(0.0839)	(0.1203)	(0.0592)
PRO (origin × destination)	2.7409***	1.8455***	1.6046***	2.7423***
	(0.2116)	(0.1238)	(0.1785)	(0.0776)
Constant	-12.9148***	-5.1502***	-25.4028***	-9.9541***
	(0.4190)	(0.3269)	(0.4975)	(0.1653)
Observations	1773,786	1773,786	1773,786	1773,786
Log Likelihood	-6266.4070	-10,364.2200	-5614.0940	-32,321.4400
Akaike Inf. Crit.	12,552.8100	20,748.4400	11,248.1900	64,662.8700

Note: $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.

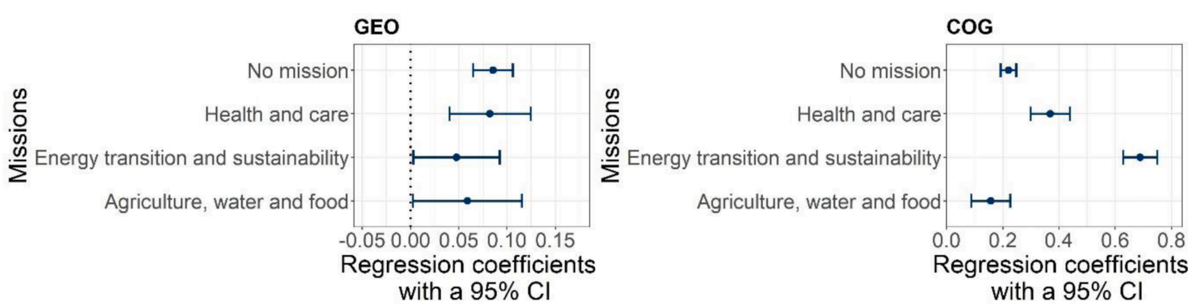

Fig. 6. Coefficients of GEO (left panel) and COG (right panel) across missions themes, with a 95% confidence interval.

labs in the Life Science Technology hubs around Amsterdam, Utrecht or Leiden, who partner with medical equipment manufacturers, food producers and hospitals from across the country. Alleviation of geographical proximity constraints can also occur when the users are concentrated in (a remote place in) space, like the chemical industry in the south of the Netherlands, but still distant from distributed KET developers. On the other hand, a positive relation between geographical proximity and tie formation exists when all parties involved in joint R&D co-locate in the same clusters. This might hold for e.g. the nanotech developers and users in the Twente and Eindhoven regions, or the digital technology firms in and around the Greater Amsterdam area. This tentative interpretation would thus suggest that the potential influence of R&D on KETs to unite spatially disparate parties is likely to depend on how broadly a KET is applied – which in practice can be much narrower than their theoretical potential – and on where (possible) technology developers and users are located in the first place.

For the missions, projects under the three investigated mission themes turned out not to be statistically different from the reference group (i.e. projects that ex-post received the label ‘No Mission’) regarding the influence of geographical proximity. Moreover, and directly against our expectations, tie formation is more subject to cognitive proximity in Health and Care themed projects, and even more so in Energy Transition and Sustainability themed projects. With effect sizes for COG being two to seven times higher than for GEO, R&D projects in these two mission themes unite relatively very uniform sets of capabilities. These results seem to contradict the notion that projects focused on societal challenges are *de facto* more likely to entail spatial and cognitive cross-overs. The latter result is only found for the mission theme Agriculture, Water and Food, in the robustness check specifically focusing on the years 2017 and 2018.

One factor that could give rise to the contrasting cognitive proximity findings for the Agriculture, Water and Food mission theme and the other two themes, is the historical presence of actors and structures that support knowledge creation and diffusion. Teaming up for an R&D project requires that firms have a sufficient degree of absorptive capacity to effectively make use of complementary pieces of knowledge (Cohen and Levinthal, 1989). Historically, the Dutch agricultural and horticultural sectors have been very organized, with branch organisations and research institutes strongly driving the development and application of new knowledge (Klerkx and Leeuwis, 2009). A tradition of exposing a wide variety of industry players to each other’s developments might explain why firms from these sectors find it relatively easy to combine their knowledge, unhindered as they are by the hurdle of cognitive distance. In the ‘newer’ domains of Health and Care and especially Energy Transition and Sustainability, institutionalized coordination was established more recently (EZK, 2019), which is possibly why there firms (still) collaborate with cognitively similar counterparts.

5.2. Theoretical and policy implications

Our analysis of boundary spanning in collaborative R&D projects aims to advance the debate on overcoming proximity constraints and – ultimately – facilitating unrelated diversification (Grillitsch et al., 2018). While the links between KETs and diversification trajectories have been examined before ((Montresor and Quatraro, 2017); Antonietti and Montresor, 2019), we are the first to study KETs alongside currently emerging and still under-investigated missions. By exploiting a dataset containing ex-post assigned labels on both these policy topics, we provide rare empirical insights into their natural tendency to alleviate proximity effects.

In terms of research implications, our results probably serve more as a supplemental form of legitimization for policies focused on KETs, and less as a starting point for designing policy criteria. Given that explicitly requiring project teams to be diverse might have perverse effects, our findings suggest that supporting research directed at KETs (which in itself can already drive competitiveness) presents an alternative way of using collaborative R&D policies to connect cognitively distant partners. Depending on how important this secondary objective is, more preference might be given to the selection of KETs demonstrating a higher attenuation of proximity effects. Alternatively, in response to KETs' unequal tendency to unite dissimilar capabilities, policy makers might also opt for different policies per KET domain and per proximity constraint (instead of using one single instrument like the PPP R&D allowance scheme investigated here). For instance, the scope of e.g. networking events designed to overcome cognitive proximity constraints in a domain like Life Sciences Tech would probably need to differ substantially from policy measures mediating the geographic concentration of nanotechnology projects. The type of policies suitable to such boundary spanning is likely to depend on the technological idiosyncrasies of the domain they target, as for example the use of (and therefore support for) capital-intensive infrastructures like R&D laboratories has a profound influence on collaboration dynamics (Neuländtner and Scherngell, 2020).

For missions, the observations resulting from our analyses contribute to the ongoing debate on why to deploy and what to expect from mission-oriented research and innovation policies (Mazzucato, 2018a; Brown, 2020; (McCann and Soete, 2020)). There appears to be a consensus that finding solutions for societal challenges calls for interdisciplinary collaborations that build on a wide range of expertise. As Coenen et al. (2015) point out, challenge-based innovation policies can play a major role in overcoming the transformational failures (including coordination and network failures) preventing geographically distributed actors from complementing each other's capabilities. A particularly prominent feature of the mission approach in this respect is the belief that directionality in the form of clearly recognizable goals, i.e. a mission statement, offers a basis for different actors to seek each other out in their attempts to develop novel solutions (Hekkert et al., 2020). Missions can act as a 'focusing device' for inviting different actors and sectors to devote their innovation capacities to the same cause (Mazzucato, 2018a). However, there are also worries that mission-oriented innovation and research strategies do little more than appoint priority areas, without providing detailed views and complementary support measures for developing particular solution directions (Brown, 2020; OECD, 2021; Janssen et al., 2021). In light of this, it is striking that R&D projects concerned with topics associated with the Dutch missions have (so far) yet to show unusual collaboration patterns. Our findings indicate that if left to actors in the Dutch innovation system themselves, R&D projects that can be linked to the Energy Transition and Sustainability mission theme in particular are often collaborations among relatively similar and geographically proximate organizations.

In all fairness, mission-oriented research and innovation policies will seldomly be deployed merely to stir up innovation systems. If the main goal is to develop innovative solutions for pressing societal problems, it might be understandable or even desirable that similar and nearby actors team up in their efforts to come up with a solution (McCann and Soete, 2020). However, as Coenen et al. (2015) argue, the question is always to what extent the results of local experimentation will yield innovations that can also be applied beyond the particular regional context from which they emerge. For mission-oriented innovation policies also motivated by the ambition to obtain economic gains from either the solutions themselves (Mazzucato, 2016), or from the side-effects such policies might have on innovation system dynamics, our results urge for prudence. The finding that uncommon knowledge recombination is far from guaranteed does not necessarily discredit the belief that missions can engender otherwise unattainable collaborations, but rather suggests that complementary policy efforts are essential here.

Although the current study hasn't touched upon this empirically, it is to be expected that the performativity of a shared goal benefits from a clear narrative around what is being prioritized. The notion of incantatory governance, focusing on ritualisation and repetition, might offer inspiration on how to manage the symbolic and discursive dimensions of collectively tyring to tackle societal problems (Aykut et al., 2020). Also forecasting and planning activities likely have an important role to play here: for missions to be performative, it is helpful if they invoke coordination activities allowing various stakeholders to agree on solution directions viable for addressing the technological as well as socioeconomic challenges arising when trying to complete the mission goal (Wanzenböck et al., 2020). Moreover, as missions do not rely on static or closed-off policy instruments (Janssen et al., 2021), there is a continuous need for alignment and adaptation of the set of policy initiatives supporting the search for solutions (OECD, 2021). Relevant policies may include supply-side innovation instruments for developing the absorptive capacity required to engage in inter-disciplinary innovation (Mazzucato, 2018a), demand-side innovation instruments inviting unusual solutions and collaborations (Boon and Edler, 2018), and softer policy efforts like joint agenda writing, networking events or support for bodies providing advisory and brokerage services (Van Lente et al., 2020). Again, the scope of such policies can be refined by taking into account the respective influences of geographical and cognitive proximity on tie formation in a given mission's R&D projects – the Energy Transition and Sustainability domain arguably requires more attention than the Agriculture, Water and Food domain. As missions continue to spread, it will become possible to assess to what extent complementary policy interventions (alone or jointly) can help unleash the cross-over potential that missions allegedly present. Future evaluations can take findings like ours as the ex ante situation when examining to what extent mission policies have altered collaboration patterns.

5.3. Shortcomings and further research

This study presents some initial empirical evidence on the potential that KETs and missions have to unite disparate actors. A potential weakness in the deployed type of analysis is the possibility that societally desirable behavior led project teams to write their proposals towards KETs and missions. However, the data used here stems from before the renewed (mission-oriented) focus in the Topsector policy, and independent administrators assigned the KETs and mission labels to projects retroactively.

Moving forward, more research is needed to uncover why boundary spanning results vary per KET and mission type. For KETs, it may also be useful to relate proximity dynamics to attributes associated with industry and technology lifecycle dynamics (Klepper, 1997). The extant literature on technological complexity may provide an alternative analytical framework to provide a better understanding of how and why the formation of collaborative ties varies across technologies (Broekel, 2019). Also, while the focus of the current study was at the dyad level (proximity dimensions), future studies can extend it by taking into consideration place-specific characteristics as well as micro-determinants of a given R&D network (Abbasiharofteh and Broekel, 2020). After all, recent scholarly debate on proximities suggests that the relevance of proximity dimensions should be investigated hand in hand with the structural properties of a given collaborative network (Balland et al., 2020). For missions, frameworks are emerging that foster analysis of proximity sensitivities related not only to different mission types and mission ambitions (Fisher et al., 2018), but also relative to currently deployed policy initiatives designed to spur creativity and engage actors (OECD, 2021). Acknowledging the rising interest for Europe's 'twin transition' based on digital and green transformations, finally, it seems worthwhile to examine boundary spanning dynamics at the crossroads of these two particular KET and mission domains (Andersen et al., 2021; Santoalha et al., 2021).

A rare feature of our study is that it concerns findings on pre-commercial R&D projects, as this stage is often neglected in arguments on how KETs and missions might affect innovation processes. Follow-up research could study the influence of KETs and missions along the entire spectrum from knowledge development to deployment. For the selection of domains that engage in technological innovation, such research could rely on patent analyses to measure both technological relatedness (instead of taking skill-relatedness as a proxy for cognitive proximity) as well as the results of R&D projects. Furthermore, the mechanisms behind the demonstrated boundary spanning potential of some KETs and missions should be studied in more depth. Due to data limitations, this study did not allow for examining the precise project contributions made by different firms involved in an R&D project. While firms from distinct areas and sectors may seek each other out because of technological complementarities on the one hand, and particular demands in application areas on the other, additional research is needed to uncover the specificities in, for instance, the roles, capabilities and marketing possibilities brought in by various project partners.

CRediT authorship contribution statement

Matthijs J. Janssen: Conceptualization, Writing – original draft. **Milad Abbasiharofteh:** Methodology, Formal analysis, Visualization, Writing – original draft.

Declaration of Competing Interest

The authors declare they have no conflict of interests.

Acknowledgments

The authors would like to thank participants at the UU-CWTS workshop 2020 and Eu-SPRI Annual Conference 2021 as well as two anonymous reviewers for their valuable suggestions. Our gratitude also goes out to Koen Frenken and Iris Wanzenböck for commenting on earlier versions of the paper. We thank RVO.nl for the provision of the data.

Appendix A

This appendix presents the results for regressions at the aggregate KETs and missions levels, based on models containing age variables for the two firms that can form a tie (AGE_1 and AGE_2). The number of observations in this model is 8% lower than in the original empirical setting.

	KETs and Missions KETs	Not a KET	Missions	No mission	KETs and missions	Not a KET and no mission
GEO (z-score)	0.0681***	0.1271***	0.0884***	0.0855***	0.0689***	0.1384***
	(0.0150)	(0.0107)	(0.0142)	(0.0108)	(0.0212)	(0.0124)
COG (z-score)	0.2911***	0.3541***	0.5146***	0.2362***	0.3062***	0.2310***
	(0.0198)	(0.0165)	(0.0211)	(0.0143)	(0.0295)	(0.0196)
SME (origin)	-0.4190***	-0.4812***	-0.2491***	-0.4182***	-0.3168***	-0.5599***
	(0.0448)	(0.0350)	(0.0450)	(0.0315)	(0.0686)	(0.0424)
SME (destination)	-0.4044***	-0.3878***	-0.0898*	-0.3831***	-0.1084	-0.4959***
	(0.0462)	(0.0358)	(0.0462)	(0.0323)	(0.0709)	(0.0434)
BUDGET (origin)	0.3382***	0.0095	0.2063***	0.1671***	0.4820***	0.0453***
	(0.0126)	(0.0106)	(0.0134)	(0.0091)	(0.0191)	(0.0126)
BUDGET (destination)	0.3778***	-0.0004	0.1897***	0.1827***	0.5007***	0.0511***
	(0.0123)	(0.0106)	(0.0133)	(0.0089)	(0.0193)	(0.0124)
PRO (origin)	-1.1510***	-1.4752***	-1.6031***	-1.0341***	-1.6723***	-1.4623***
	(0.0705)	(0.0656)	(0.0667)	(0.0609)	(0.1012)	(0.0918)
PRO (destination)	-1.3594***	-1.3431***	-1.6502***	-1.0280***	-2.0552***	-1.2863***
	(0.0771)	(0.0622)	(0.0672)	(0.0612)	(0.1167)	(0.0862)
PRO (origin × destination)	2.3629***	2.9572***	2.3516***	2.7162***	2.7707***	3.3216***
	(0.0983)	(0.0866)	(0.0943)	(0.0800)	(0.1501)	(0.1190)
AGE_1	**0.0935*** **	**0.2390*** **	**0.2393*** **	**0.1506*** **	**0.0937*** **	**0.2300*** **
	(0.0205)	**(0.0166)**	**(0.0206)**	**(0.0147)**	**(0.0307)**	**(0.0203)**
AGE_2	**0.1551*** **	**0.3062*** **	**0.3021*** **	**0.2305*** **	**0.1297*** **	**0.2956*** **
	(0.0216)	**(0.0174)**	**(0.0213)**	**(0.0155)**	**(0.0320)**	**(0.0214)**
Constant	-15.2652***	-7.2429***	-12.2360***	-10.9526***	-19.1588***	-8.7701***
	(0.2579)	(0.2102)	(0.2707)	(0.1843)	(0.4014)	(0.2519)
Observations	1626,306	1626,306	1626,306	1626,306	1626,306	1626,306
Log Likelihood	-17,012.4800	-25,337.7700	-17,547.9600	-30,481.7400	-8284.4840	-17,823.7900
Akaike Inf. Crit.	34,048.9500	50,699.5400	35,119.9100	60,987.4700	16,592.9700	35,671.5800

Note: $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.

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