Research portfolios of universities: searching for opportunities and collaboration partners

Paulo Morceiro, Ron Boschma and Pierre-Alex Balland

Papers in Evolutionary Economic Geography

25.06

Utrecht University Human Geography and Planning

Research portfolios of universities: searching for opportunities and collaboration partners

Paulo Morceiro[1,2], Ron Boschma[3,4] and Pierre-Alex Balland[5,6]

[1]Instituto Brasileiro de Ensino Desenvolvimento e Pesquisa (IDP)

[2]South African Research Chair in Industrial Development, University of Johannesburg

[3]Department of Human Geography and Planning, Utrecht University

[4]UiS Business School, University of Stavanger

[5]Centre for European Policy Studies

[6]Growth Lab, Harvard University

21 February 2025

Abstract

Universities lack a comprehensive view of their entire research portfolio when looking for opportunities in new research fields and searching for collaboration partners. The paper presents an analytical framework, building on the principle of relatedness, that aims to assess the potential of universities to extend their research portfolios, to identify potentials of collaborations with other research organizations, and to determine the extent to which universities exploit complementarities in their collaborations. We illustrate the framework presenting the case of an university alliance between three Dutch universities that aims to contribute to the circular society. Publication data are used to identify relevant scientific capabilities of the universities to promote the circular society, in what research fields complementarities can be identified between partners, and to what extent partners exploit those complementarities in terms of co-publications.

Key words: scientific portfolio of universities, scientific capabilities, scientific complementarities, inter-university collaborations, circular society

JEL codes: J24, J82, R11, O15

1. Introduction

Universities are research organizations that develop specific research portfolios over time (Van Raan & van Leeuwen 2002; Wagner et al. 2011; Wallace and Rafols, 2015; Katalevsky et al. 2022; Tuesta et al. 2024). They face strategic challenges, like which (new) areas of research to fund, what scientists in what disciplines to hire, and which crossovers to support inside their own organizations and beyond. Opportunities for advancing scientific research and establishing collaborations are constantly monitored and explored (Abramo et al. 2018; Zhang & Leydesdorff 2021; Van de Klippe et al. 2023). Making informed choices requires knowledge about research options and which collaborations to promote (Klavans and Boyack 2017).

However, research organizations often lack a comprehensive view of their entire research portfolio when looking for opportunities in new research fields, when exploring feasible options, and when searching for the right partners (Linton and Vonortas 2015; Vonortas and Ràfols 2019). Universities often go for the same global topics because of funding opportunities, such as addressing global challenges, like the green and the digital transition. While tackling global themes may bring lots of benefits to societies, concerns have been raised that universities may be pushed into research fields in which they have little knowledge and experience, that this may result in massive duplication of research efforts on a global scale, and that it may lead to arbitrary selections of research partners, resulting in, on average, poor scientific output.

At the same time, there is lots of evidence that researchers and organizations are often involved in search processes that are highly localized (Atkinson and Stiglitz 1969; Dosi 1982; Nelson and Winter 1982). This makes them more likely to move into domains that are closely related to their own (Teece et al. 1994; Johnson 2010). This principle of relatedness (Boschma 2017; Hidalgo et al. 2018) has been used to explain the tendency of research organizations to interact and collaborate with adjacent scientific domains (Boyack et al. 2005; Leydesdorff and Rafols 2009; Waltman et al. 2010) and the tendency of regions to develop scientific fields that are closely related to fields in which they already excell (Boschma et al. 2014; Heimeriks and Boschma 2014; Guevarra et al. 2016; Alshamsi et al. 2018). This implies that the possibilities of universities to extend their research portfolio in new fields is depending on their existing set of scientific capabilities which provide opportunities but set also limits to their search process. In other words, their opportunity set might be rather limited (Balland and Boschma 2022).

To our knowledge, few studies have yet applied the relatedness principle to assess the potential of universities to extend their research portfolio's, but also to identify potentials of collaborations with other research organizations (Balland and Boschma 2021). The first objective of the paper is to present this framework and its underlying method. The second objective is to apply it to identify opportunities of universities to move into scientific domains, to assess their ability to exploit complementarities from research partners, and to determine the extent to which there is untapped potential in university collaborations. We analyze the case of the EWUU university alliance which was established in 2019 between Eindhoven University of Technology, Wageningen University and Research, and Utrecht University (including the University Medical Centre Utrecht). The objective of the alliance is to bring together research capabilities of the partners and to exploit complementarities. The paper explores research opportunities across the partners using scientific publication data. The Lens database will be used to identify the scientific capabilities of organizations, to assess the extent to which partners collaborate in terms of co-publications, and in what research fields complementarities can be identified between partners using the relatedness framework. Particular focus will be on the circular society, as this is one of the two focus areas of the EWUU alliance.

The paper is structured as follows. The next section provides a brief literature review on scientific collaborations to show the scientific relevance of our paper. Next, we describe the data sources and the methods used. The subsequent section present the results of our analyses. The last section concludes and discusses the implications for future research and policy.

2. Searching for scientific opportunities and collaborations

Universities are key research organizations in many countries (Perkmann et al. 2013) and regions (Vallance 2016). Studies have investigated their research portfolios, more recently in the context of the need for interdisciplinary research to tackle societal challenges (Van Raan & van Leeuwen 2002; Wagner et al. 2011; Wallace and Rafols, 2015; Tuesta et al. 2024). Opportunities for advancing scientific research are constantly monitored and explored (Abramo et al. 2018; Zhang and Leydesdorff 2021; Van de Klippe et al. 2023). Universities are keen to investing in new research fields that provide funding opportunities. However, research organizations often lack a comprehensive view of their research portfolio when exploring potential new scientific fields (Linton and Vonortas 2015; Vonortas and Ràfols 2019).

There is a large body of literature that has demonstrated that history matters in the production of scientific knowledge: new scientific knowledge production often builds on existing knowledge pieces that are combined in new ways (Dosi 1982). Researchers often work in narrowly defined domains and connect to communities they know well (Guevarra et al. 2016). As a result, researchers and organizations often show myopic behaviour and are engaged in highly localized search processes (Nelson and Winter 1982), or what Johnson (2010) dubbed as the 'adjacent possible'. This makes that opportunities to develop and acquire new knowledge are limited which makes it hard to enter unfamiliar fields (Atkinson and Stiglitz 1969; Heiner 1983). As a consequence, researchers develop new ideas mainly within their own domains.

This is not to say that researchers do not cross scientific boundaries. But when they do, they tend to be active in fields that are close (related) to their own domain (Boyack et al. 2005; Leydesdorff and Rafols 2009; Waltman et al. 2010; Guevarra et al. 2016). This focus on related domains has been used to assess the potential of regions to enter new scientific domains. Boschma et al. (2014) showed that new scientific topics in biotech develop in cities where related scientific topics are locally available. Guevarra et al. (2016) observed that the probability of developing new scientific fields in physics increases when a country shows excellence in scientific fields related to physics. More recently, studies also show that scientific capabilities impact the probability of countries to develop technologies that are closely related to scientific fields (Pugliese et al. 2019; Catalán et al. 2022).

Besides entering new scientific domains, organizations might also have an incentive to develop more complex domains (Balland et al. 2019; Balland et al. 2022). This is because domains that are embedded in complex knowledge are harder to imitate (Kogut and Zander 1993). Hidalgo and Hausmann (2009) defined products as complex when they combine a wide range of capabilities which makes complex products hard to copy. In contrast, simple knowledge fields are more easy to copy and therefore have lower value (Davies and Maré 2020; Pintar and Scherngell 2020; Mewes and Broekel 2022). Studies have made efforts to assess the complexity of scientific knowledge (Wuchty et al. 2007; Heimeriks et al. 2019; Balland et al. 2020). Hidalgo and Hausmann (2009) argued that complexity is associated with a high division of labour between specialized individuals that contribute to knowledge production (Jones

2009). This idea has been applied to scientific fields where a labour division between scientists exists at the level of publications (Wuchty et al. 2007). The complexity of a scientific field is then associated with the average size of a team involved in a publication in a scientific field (Balland et al. 2020), or by the share of publications in a field that involves international co-authorship.

The possibilities of universities and other organizations to extend their research portfolio in new and more complex fields is thus depending on their existing set of scientific capabilities which provide opportunities but set also limits to their search process. In other words, their opportunity set is limited, especially in more complex scientific fields.

Developing a new scientific field may necessitate capabilities that an organization lacks but which are available in other research organizations. This is more likely the case for complex scientific fields that require the combination of a wide range of capabilities (Jones, 2009). In cases where an organization lacks the required capabilities for developing a new scientific field, it can establish connections with other organizations through collaborations and partnerships to gain access to them. Leveraging these capabilities via inter-organizational collaboration may enhance the organization's prospects of diversifying into new scientific fields.

Studies observe persistent growth of collaborative research over time (Wuchty et al. 2007; van der Wouden 2018; van der Wouden and Rigby 2019). A large body of literature has provided insights on the determinants of scientific collaborations, especially when it concerns university-industry linkages (Katz and Martin 1997; Singh 2005; Broekel and Meder 2008; Bruneel et al. 2010; Bodas Freitas et al. 2013; Bozeman et al. 2013; Perkmann et al. 2013; Mascarenhas et al. 2018; Rybnicek and Königsgruber 2019; Olechnicka et al. 2019; Sjöö and Hellström 2019; Figueiredo and Fernandes 2020; Bastos et al. 2021; Rossoni et al. 2024; Romero-Goyeneche et al. 2025). Individual features of researchers and organizations are considered to be important such as absorptive capacity and scientific excellence (Giuliani and Bell 2005; Nooteboom et al. 2007; Hoekman 2012; Lewis et al. 2012). Various proximities between researchers, such as geographical, cognitive and social proximity, also lower search and coordination costs (Boschma 2005). That is, researchers are more inclined to collaborate when sharing the same location, when they share similar knowledge and skills, when they collaborated in the past, when they are socially connected, and when sharing similar norms and values (Nooteboom 2000; Gilsing et al. 2007; Nooteboom et al. 2007; Breschi & Lissoni, 2009; Hoekman et al.

2009; Boschma and Frenken 2010; Vicente et al. 2011; Lewis et al. 2012; D'Este et al. 2013; Muscio and Pozzali 2013; Cassi et al. 2015; Capello and Caragliu 2018; He et al. 2021). Moreover, network positions of researchers also have an impact on who collaborates with whom (Burt 2004; Powell et al. 2005; Gilsing et al. 2007; Tsouri 2018).

This literature has made clear that connecting to external partners to access missing capabilities *per se* is not sufficient. Cohen and Levinthal (1990) talked about the need for absorptive capacity. Boschma (2005) and Torre and Rallet (2005) mentioned the need for proximities to enable learning. Boschma and Iammarino (2009) applied the principle of relatedness to underline that not all interregional connections are beneficial for learning and innovation. Balland & Boschma (2021) developed the concept of complementary inter-regional collaborations and showed that these linkages promote regional diversification, especially in lagging regions. Here, complementary linkages provide access to relevant capabilities in other regions that are absent locally but complement the activity the region aims to develop.

To our knowledge, this concept of complementary linkages has not yet been applied to universities. This study has the objective to apply this concept to assess potential collaborations between universities that have specific scientific portfolios. In particular, our study aims to identify potentials of collaborations of universities with other research organization, and to determine the extent to which universities exploit complementarities in their collaborations.

3. Data

To capture scientific capabilities and collaborations, we make use of data from the Lens database.[1] Lens is a comprehensive database with more than 268 million academic works, consisting of four sources: Microsoft Academic, CrossRef, PubMed and OpenAlex. It covers over 90% of the academic works in Scopus or Web of Sciences, however, it includes more articles from social sciences and humanities (Huang et al., 2020; Visser et al., 2021).

We use scientific articles published in journals between 2016 and 2021 that contain at least one author from a research organization in the Netherlands. Each publication in our dataset contains

[1] Lens: https://www.lens.org/

one or more institutional addresses that enable us to identify the research organizations (universities, academic hospitals, companies) to which authors are affiliated. We adopt a unique identifier for each research organization provided by the Research Organization Registry (ROR) which includes IDs and metadata for more than 106,000 research organizations. ROR makes it easy to disambiguate institution names and connect research organizations to researchers and research outputs. From this organization information, we derive information about collaboration patterns based on co-authorships.

We identified around 300,000 articles published in journals from more than 700 research organizations in the Netherlands. In this study, all scientific articles originating from child research organizations were attributed to their respective parent research organizations. For example, child entities such as the Ministry of Defence and Netherlands Environmental Assessment Agency were included in the Government of Netherlands (non-academic), serving as parent organizations. Besides that, scientific articles from the seven academic hospitals[2] were allocated together with the linked universities because it is challenging to identify whether the author belongs to the university, the academic hospital, or both in many articles.

For the calculations of measures of relatedness between scientific fields, we dropped research organizations and scientific fields with few publications.[3] Our final dataset contains 116 research organizations and 296 ASJC fields (out of 330), responsible for 97% of all articles published by Dutch organizations. Among the 116 research organizations, 45 are affiliated with the healthcare sector, 35 with education, 11 with companies, 10 with facilities, 5 with government entities, 4 with nonprofits, 2 with archives, and 4 with other sectors.[4]

[2] The academic hospitals are: University Medical Center Groningen, Leiden University Medical Center, Amsterdam University Medical Centers, Erasmus MC, Maastricht University Medical Centre, University Medical Center Utrecht, and Radboud University Nijmegen Medical Centre.

[3] We dropped research organizations with under 180 publications (keeping only those with at least 30 per year) and fields with fewer than 120 publications (keeping only those with at least 20 yearly).

[4] It is pertinent to note that research organizations within the health sector (40% of total) typically have a scientific portfolio primarily focused on the domains of life and health sciences, while large universities exhibit diversification across numerous fields spanning various scientific disciplines, encompassing health and life sciences among them. The high specialization in the health fields of healthcare organizations affects the Revealed Comparative Advantage indicator, which will be our specialization criterion. This has implications in terms of specialization in health fields for universities diversified across many fields.

To assess relatedness between scientific capabilities, two steps need to be made. First, we do co-occurrence analysis to determine which scientific fields have much in common in terms of shared capabilities. Second, we use this information to assess the extent to which the scientific capabilities of the university partners within the Alliance are related and complementary to each other. This will reveal the potential of collaboration between the partners. This potential will be compared with the actual collaborations of the Alliance partners in terms of co-publications, especially in preventive health and circular society. This analysis will identify in which potential scientific areas the Alliance partners have complementary capabilities that are not yet fully exploited, because no collaborations yet exist.

Relatedness between scientific fields

As mentioned before, some scientific fields are relevant to each other for knowledge production because they share similar capabilities, while other scientific fields have nothing in common. But how to determine which scientific domains are related to each other? One can identify knowledge flows between scientific fields through co-citation networks that are based on references to different papers associated with disciplines in the same reference list of a paper (Boyack et al. 2005). Direct citation networks link academic fields when a paper from one discipline cites a paper from another. Another way is bibliographic coupling in which pairs of disciplines are connected when papers from different fields cite the same papers.

Inspired by Hidalgo et al. (2007), we adopt the approach outlined by Boschma et al. (2014), wherein two scientific fields, denoted as *i* and *j*, are considered related if they frequently co-occur in journal articles, indicating shared scientific capabilities. To normalize these co-occurrences, we employ the Cosine index, a widely utilized metric in scientometrics (Eck & Waltman, 2009). The relatedness $\varphi_{i,j}$ between each field *i* and *j* is computed as follows:

$$\varphi_{i,j} = \frac{C_{i,j}}{\sqrt{S_i S_j}}$$

Here, $C_{i,j}$ represents the total number of co-occurrences of fields *i* (*i* = 1, 2, …, 296) and *j* (i = 1, 2, …, 296) in the same journal articles, S_i denotes the total number of occurrences of field *i*, and S_j denotes the total occurrences of field *j*. The resulting measure $\varphi_{i,j}$ is symmetric and falls within the range [0, 1], with 0 indicating no co-occurrence, and 1 indicating systematic co-occurrence. In Figure A1 in the Appendix, the so-called Science Space is shown, in which the degree of relatedness between all scientific fields is indicated.

The portfolio of the research organization is obtained from the institutional affiliation of authors mentioned in journal articles. Scientific articles are fully attributed to each author's research organization, no fractional counting was applied. We follow Balland and Boschma (2022) and utilize Relative Scientific Advantage ($RSA_{r,i}$) index to quantify the degree of scientific specialization of an organization *r* in a scientific field *i*:

$$RSA_{r,i} = \frac{publications_{r,i} / \sum_i publications_{r,i}}{\sum_r publications_{r,i} / \sum_r \sum_i publications_{r,i}}$$

Here, $RSA_{r,i}$ in a scientific field *i* (*i* = 1, 2, …, 296) is equal to the share of publications in field *i* in the scientific portfolio of organization *r* (*r* = 1, 2, …, 116), divided by the share of scientific field *i* in the scientific portfolio of the Netherlands. An organization *r* with $RSA_{r,i} > 1$ signals that it is specialized in scientific field *i*, because it has a higher share of that field within the organization, as compared to the national average.

We combine the relatedness $\varphi_{i,j}$ between scientific fields with organizations' scientific specializations (fields in which they publish) to construct an organization-field level variable indicating the proximity of a new field to an organization's existing scientific portfolio. Following Hidalgo et al. (2007), this variable, termed Relatedness Density ($RD_{i,r,\,t}$), is calculated as:

$$RD_{i,r,\,t} = \frac{\sum_{j \epsilon r, j \neq i} \varphi_{ij}}{\sum_{j \neq i} \varphi_{ij}} \text{ x } 100$$

The RD variable combines the relatedness between fields *i* and *j* with the scientific expertise of organizations, illustrating how cognitively close a potential new field is with the set of current specializations of the organization. This measure is akin to the "density" index introduced by Hidalgo et al. (2007) and the "closeness" index proposed by Neffke et al. (2011). $RD_{i,r,\,t}$ is calculated by summing the scientific relatedness of field *i* to all the scientific fields *j* that are specializations within the scientific portfolio of organization *r*, divided by the sum of relatedness of field *i* to all fields *j*. This value is then multiplied by 100, yielding a variable ranging between 0% and 100%.

The organization-field relatedness signifies the percentage of related fields the organization is specialized in. For example, if a field is scientifically related to 295 other fields and an organization specializes in 100 of these fields, the relatedness between field *i* and organization *r* would be (100/295) × 100 = 33.90%. The higher the value of RD, the higher the likelihood the organization develops or maintains specialization in the field. Table 1 illustrates the scientific RD for a selected number of universities and fields.

Table 1: Scientific relatedness density of Dutch universities in some scientific fields

Universities$_c$	Fields$_i$	Relatedness Density$_{i,c,t}$ (%)
Delft University of Technology	General Chemistry	85.1
University of Amsterdam	General Medicine	68.7
Erasmus University Rotterdam	Preventive health	60.7
Radboud University Nijmegen	Space and Planetary Science	52.5
Utrecht University	Education	52.0
Maastricht University	Sociology and Political Science	38.2
University of Groningen	Computer Science Applications	36.8
Vrije Universiteit Amsterdam	Circular society	29.8
Leiden University	Electrical and Electronic Engineering	12.4
Wageningen University & Research	Cardiology and Cardiovascular Medicine	9.9

Notes: Organization-field relatedness indexes are computed from relatedness between fields and the scientific expertise of organizations from 2016 to 2021.

So, RD reflects the efforts an organization must make when venturing into a new scientific field in which the organization does not have strong expertise. These efforts are minimized when there is significant overlap between the capabilities required for the new field and those fields already existing in the organization. In other words, higher relatedness between current fields and a new scientific field reduces risks and costs when developing the new field.

Relatedness Density Added as an indicator of complementary capabilities

RD captures whether an organization has relevant capabilities to develop a new scientific field. However, developing a new scientific field may necessitate capabilities that an organization lacks but are available in other research organizations. In cases where an organization lacks the required capabilities for developing a new scientific field, it can establish connections with other organizations through partnerships and collaborations to gain access to them. Leveraging these capabilities via inter-organizational collaboration may enhance the home organization's prospects of diversifying into new scientific fields.

Balland & Boschma (2021) introduced the concept of complementary capabilities between regions, which involves searching for capabilities in other regions lacking locally. They introduced a complementary measure termed "relatedness density added" (RD Added) to pinpoint relevant capabilities in other regions that are absent locally but complement the scientific field the region aims to develop. Essentially, it quantifies the relatedness density that each region could contribute to the current relatedness density of the region for a given scientific field. This study adopts a similar approach and methodology, but focusing on inter-complementary capabilities between research organizations.

We employ the "RD Added" indicator to identify the research organizations in the Netherlands with the most complementary capabilities for developing a specific scientific field for a particular research organization. "RD Added" identifies the capabilities present in other research organizations that are lacking locally but are complementary to the scientific field that a particular organization aims to develop. Consequently, for each scientific field, RD Added measures the extent to which each of the other research organizations can augment RD for the particular organization in developing the new field. For instance, Utrecht University exhibits an RD of 47 (out of 100) in preventive health. Eindhoven possesses an RD of 37 in related fields to preventive health that are absent in Utrecht. By collaborating with Eindhoven, Utrecht would augment its RD score by 37, thereby significantly enhancing its potential to further develop the field of preventive health.

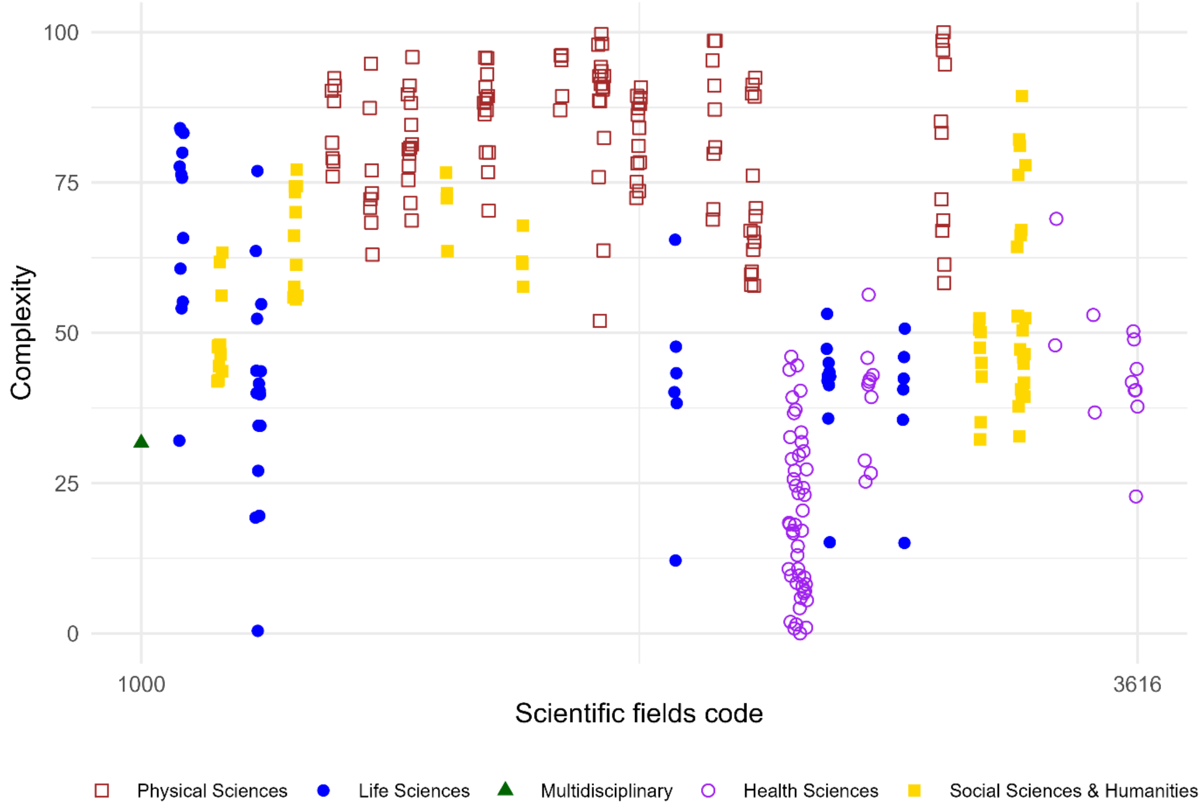
The RD Added indicator enables us to identify and rank research organizations with the highest complementary capabilities for developing a new field by a research organization. An organization may seek to establish research collaborations with other organizations with capabilities more complementary to its own. A fruitful cooperation could be fostered in cases where the capabilities of two research organizations are perfectly complementary in meeting the requirements for developing a scientific field. Such fruitful collaborations are critical in determining success in developing new scientific fields with lower risks and barriers to entry. In sum, the complementary capabilities of other research organizations increase the potential for a given organization to add new scientific fields to its portfolio.

Complexity of scientific fields

Some scientific knowledge might be complex while other scientific knowledge might be less so. We adhere to Hidalgo & Hausmann (2009), where complexity signifies the challenge of mastering capabilities necessary for excellence in a scientific field, as demonstrated by its rarity and the diversity of capabilities combined. Essentially, the fields that rank highest are those in which most organizations aspire to leadership, but few can master them due to their complexity. Complex fields entail amalgamating a broad spectrum of challenging capabilities, rendering them difficult to develop and replicate by other organizations. Conversely, less complex fields are comparatively easier to emulate and are more widespread across organizations.

The complexity measurement involves computing a knowledge complexity index for scientific fields using the reflection method from organization-field matrices. This index, initially developed by Hidalgo & Hausmann (2009) for country-product matrices, has been adopted by numerous scholars to gauge the complexity of scientific fields (Balland & Boschma 2022) and technologies (Balland et al. 2019). The reflection method assesses the diversity of scientific fields within an organization and the extent to which other organizations can competitively develop these fields. This method captures the idea that while many organizations can develop simple scientific fields, only a select few can engage in complex ones. Figure 1 shows complexity scores (y-axis) of the ASJC scientific fields (x-axis). Different colours and markers represent distinct subject areas (as used by Scopus), illustrating variations in complexity across disciplines. While fields from Physical Sciences exhibit high complexity, others, like some Life Sciences and Social Sciences & Humanities, display a broader range of complexity levels.

Figure 1: Complexity scores of scientific fields



Source: Authors' elaboration.

Which fields to add and reinforce in scientific portfolio?

Scholars in evolutionary economic geography (Hidalgo et al., 2007; Balland et al., 2019) and economic complexity (Hidalgo & Hausmann, 2009) have utilized the complexity-relatedness diagram, initially introduced by Hausmann et al. (2014), to identify new productive or technological opportunities for regional diversification. This diagram employs a 2-axis graph, with the vertical axis denoting the complexity of activities and the horizontal axis representing the relatedness density of those activities.

We adopt this framework to determine the scientific fields a research organization should consider adding, abandoning, or reinforcing within its current scientific portfolio. The scientific portfolio of a research organization can be categorized into four quadrants: (1) the top-right quadrant showcases fields both desirable (high-complexity) and accessible (high-relatedness), offering significant benefits in terms of complexity; (2) the top-left quadrant exhibits fields that are desirable but less accessible, making their development challenging and risky due to low-relatedness, yet desirable due to the complexity benefits; (3) the bottom-right quadrant displays fields that are accessible (high-relatedness) but less attractive (low-complexity), indicating less risky opportunities but with lower complexity rewards; (4) the bottom-left quadrant features fields that are neither desirable in complexity nor accessible due to low relatedness.

Prior studies have predominantly utilized the complexity-relatedness framework to uncover new diversification opportunities, aligning with the smart specialization approach, which offers a safer route to diversification compared to "pick winners" strategies (Balland et al., 2019). Typically, policymakers are advised that activities without specialization in the top-right quadrant provide a secure route to development due to their high relatedness to the organization's existing portfolio and the significant complexity rewards (case 1 in Figure 2). In this study, we expand the approach of identifying new opportunities beyond case 1. At times, it is prudent to completely abandon a field located in the bottom-left quadrant, irrespective of its consolidated specialization (cases 3 and 4 in Figure 2). The rationale is that such fields have little to do with the organization's portfolio, lack complexity, and reallocating resources to other fields offers better and more rewarding opportunities (cases 1 and 2 in Figure 2). Thus, organizations can optimize their scientific capabilities by rebalancing their portfolios.

Figure 2: Possible paths to improve the scientific portfolio of a research organization

	Field WITHOUT specialization	**Field WITH specialization**
High-relatedness and high-complexity	1.good opportunity to develop new specialization	2. good opportunity to strengthen specialization
Low-relatedness and low-complexity	3. good opportunity to abandon ambition	4. good opportunity to abandon specialization
Low-relatedness and high-complexity	5. nothing to do	6. seek to maintain specialization
High-relatedness and low-complexity	7. it may be an opportunity to develop new specialization if it is a key field	8. maintaining specialization

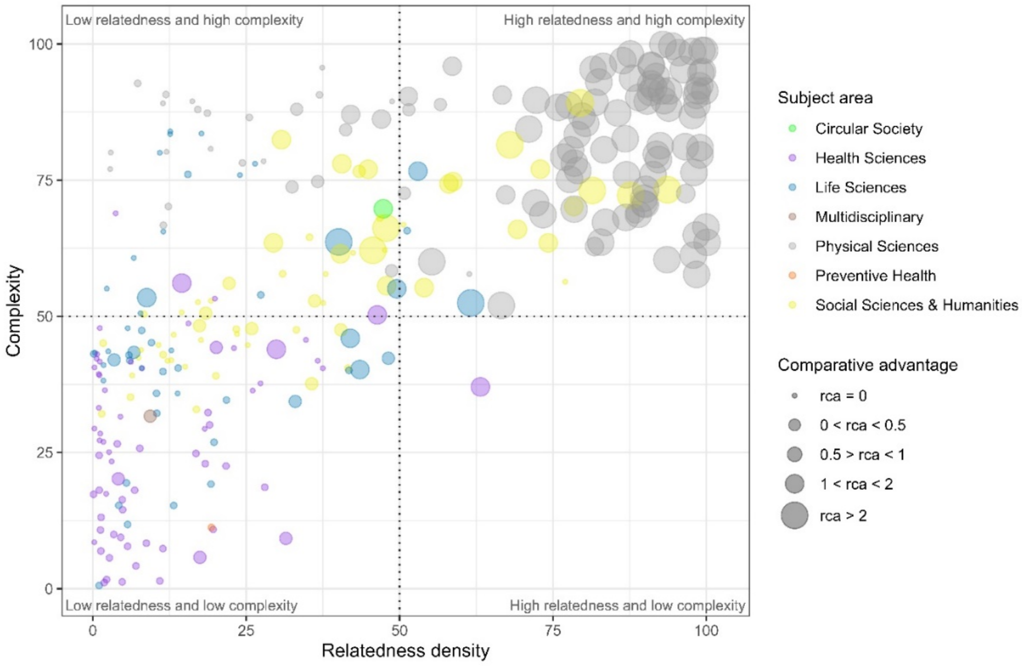
Source: Authors' elaboration.

If the majority of scientific specializations reside in the bottom-left quadrant, the organization is in a position of scientific weakness, akin to a dead-end, making it challenging to promote related diversification and venture into more complex fields. Case 7 in Figure 2 signifies situations where developing a new specialization, albeit with low complexity rewards, is feasible. This becomes compelling if it involves a key field that adds relatedness to several other fields not yet specialized, thereby unlocking other diversification options (Hidalgo, 2023). Case 8 in Figure 2 represents fields that provide related capabilities for other fields and are vital for their development. Hence, retaining existing specializations is advisable.

Mapping scientific opportunities of three Dutch universities

Using the relatedness/complexity framework, Figures 3, 4 and 5 show the scientific opportunity sets of Eindhoven University of Technology, Wageningen University and Research, and Utrecht University that are involved in the Alliance Project.[5] The three universities show very different sets of core capabilities. As shown in Figure 3, Eindhoven harbours numerous scientific specializations of high complexity in the coveted top-right quadrant, primarily in physical sciences, with some in the social sciences and humanities. The high relatedness density scores in these fields indicate Eindhoven's internal capacity to maintain or reinforce its privileged position. It is remarkable to see that Eindhoven has few scientific specializations in any of the other quadrants: In both left quadrants, Eindhoven has hardly any scientific specializations, which is in line with the principle of relatedness.

Figure 3: Scientific opportunity set of Eindhoven University of Technology

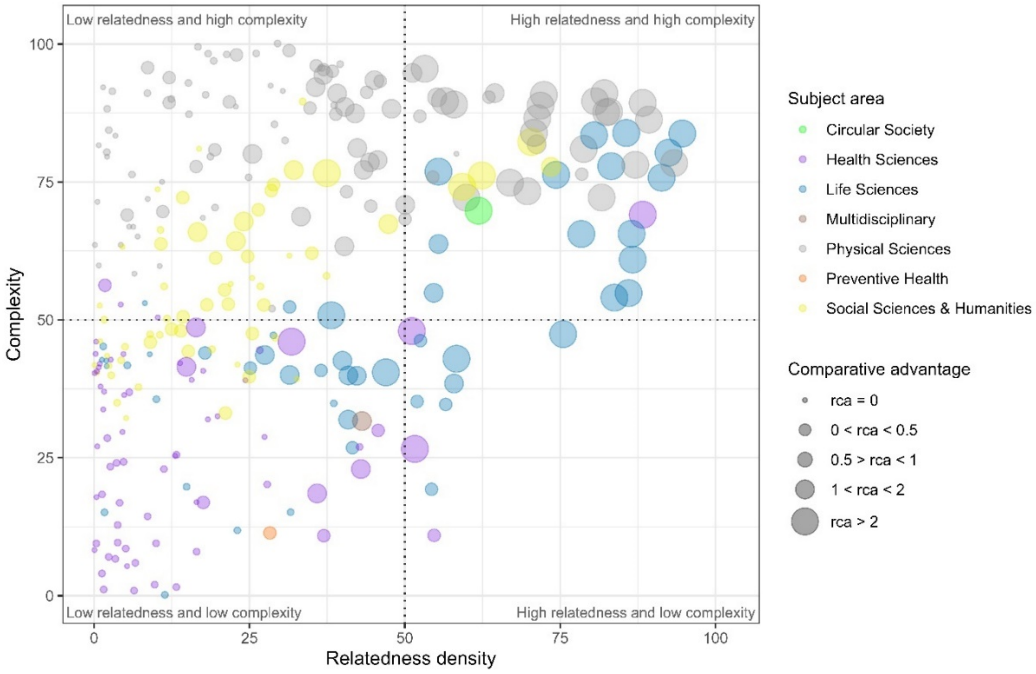


Source: Authors' elaboration.

[5] In 2019 Eindhoven University of Technology, Wageningen University & Research, Utrecht University and University Medical Centre Utrecht decided to form an alliance and to work together. Such universities seek to increase scientific collaborations, especially in two priority fields: circular society and preventive health.

Wageningen University and Research possesses numerous scientific specializations in the top-right quadrant, predominantly in physical and life sciences. A positive correlation between relatedness density and complexity is observed for both Eindhoven and Wageningen, implying that specialization in complex fields increases with relatedness density. However, Wageningen has numerous fields, with or without specialization, situated in low relatedness density quadrants. To internalize some of these fields, Wageningen needs to develop new capabilities distant from its existing specializations, incurring higher costs and risks.

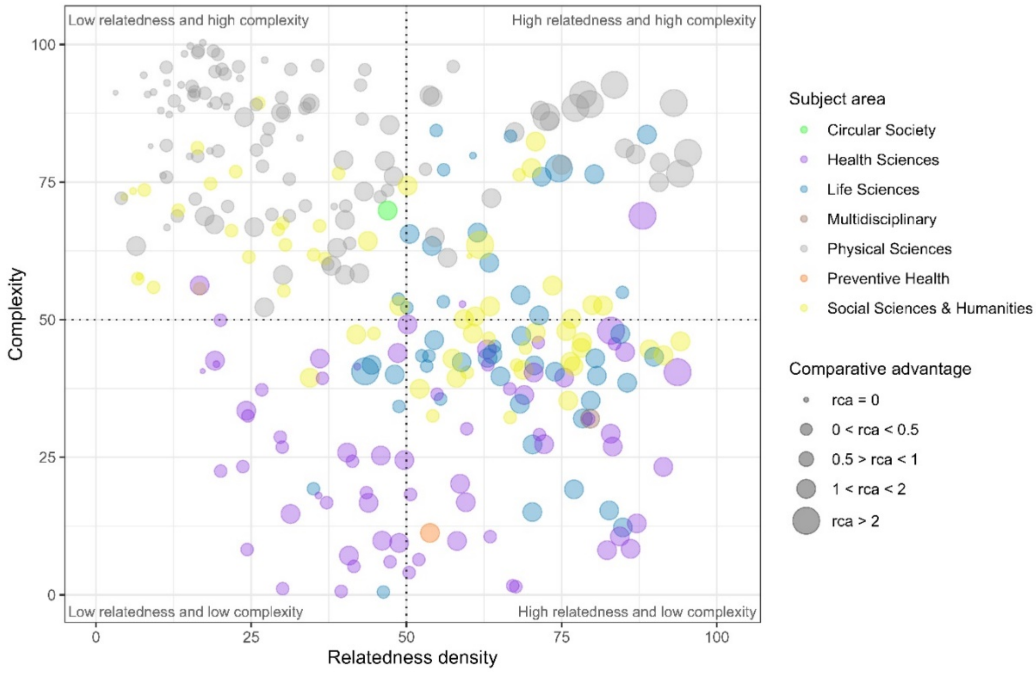
Figure 4: Scientific opportunity set of Wageningen University and Research



Source: Authors' elaboration.

Figure 5 shows that Utrecht University's scientific portfolio lacks a clear association between relatedness density and complexity, although field specialization increases with relatedness density, but not necessarily in more complex fields. As a highly diversified university with fields spanning all four quadrants, Utrecht has ample opportunities to rebalance its scientific portfolio, but increasing its average complexity will prove challenging. As compared to the two universities, the right-bottom quadrant is full of promising fields but of low complexity.

Figure 5: Scientific opportunity set of Utrecht University and University Medical Centre Utrecht



Source: Authors' elaboration.

Table 2 presents 25 opportunities (high RD and complexity scores) for the three universities to develop new scientific specializations. In many of these scientific fields, the universities need not start from scratch, as there is already some activity in these fields, as represented by a relative comparative advantage (RCA) above 0.5 but below 1.0.

Table 2: Opportunities for Alliance partners to develop new specializations with high complexity

	University	Fields	Area	RD	Complexity	RCA
1	Utrecht	Insect Science	Life Sciences	84.9	55.2	0.68
2	Wageningen	Paleontology	Physical Sciences	78.6	76.7	0.59
3	Eindhoven	Industrial Relations	Social & Humanities	77.0	56.2	0
4	Utrecht	Development	Social & Humanities	68.3	76.3	0.93
5	Utrecht	Soil Science	Life Sciences	66.5	83.2	0.87
6	Wageningen	Ocean Engineering	Physical Sciences	63.6	90.5	0.99
7	Eindhoven	Logic	Physical Sciences	61.1	57.9	0
8	Utrecht	Horticulture	Life Sciences	60.8	80.0	0.48
9	Utrecht	Conservation	Social & Humanities	60.1	61.8	0
10	Utrecht	General Dentistry	Health Sciences	58.7	53.0	0.35
11	Wageningen	Economic Geology	Physical Sciences	58.4	80.0	0
12	Utrecht	Computers in Earth Sciences	Physical Sciences	57.8	95.8	0.68
13	Eindhoven	Waste Management and Disposal	Physical Sciences	56.9	89.1	0.56
14	Utrecht	Neuroscience (miscellaneous)	Life Sciences	56.1	53.2	0.71
15	Utrecht	Biotechnology	Life Sciences	55.7	76.9	0.93
16	Utrecht	Agronomy and Crop Science	Life Sciences	55.1	84.1	0.55
17	Wageningen	Catalysis	Physical Sciences	54.3	76.0	0.65
18	Utrecht	Organic Chemistry	Physical Sciences	53.4	77.0	0.79
19	Wageningen	Geology	Physical Sciences	52.3	87.0	0.75
20	Eindhoven	Pollution	Physical Sciences	51.6	88.1	0.65
21	Eindhoven	General Environmental Science	Physical Sciences	51.1	72.4	0.92
22	Eindhoven	Applied Microbiology and Biotechnology	Life Sciences	51.0	65.5	0.29
23	Eindhoven	Safety Research	Social & Humanities	50.5	67.1	0

24	Wageningen	Inorganic Chemistry	Physical Sciences	50.2	68.4	0.89
25	Utrecht	Biophysics	Life Sciences	50.0	52.3	0.85

Note: Ranking is organized from highest relatedness density (RD) to lower RD.

With whom to connect and why?

Diversification hinges on internal capabilities to add or reinforce new scientific fields to portfolios. Increasing the relatedness density (RD) of a specific field can be both time-consuming and costly for organizations. Moreover, societal pressures may necessitate the development of new fields without organizations possessing all the necessary capabilities in-house. Consequently, seeking complementary scientific capabilities in other research organizations can enhance the prospects of field development, even in situations of lower RD, while also saving time and resources (Balland & Boschma, 2021). This section aims to address the question: with whom should research organizations connect, and why?

For illustrative purpose, we utilize the case study of the circular society field which Utrecht University aims to further develop within the Alliance Project involving Utrecht University, Eindhoven University of Technology, and Wageningen University. Circular society stands for a transformative socio-economic and sustainable model that addresses resource scarcity and a climate-neutral society with greater health and social well-being (Alliance Project, 2021; Friant et al., 2024; Jaeger-Erben et al., 2021; Leipold et al., 2021; Melles, 2021). The circular society concept emphasizes that circular economy transitions require commitment and participation from all societal actors (Jaeger-Erben et al., 2021), including consumer awareness and education, policy and regulation, and individual actions to reduce the carbon footprint. Its main objective is to reduce greenhouse gases and other emissions, promote sustainability, maximize the efficient use of resources, deal with resource scarcity, and improve social well-being.

There is no predefined field of circular society in scientific publication databases. To our knowledge, despite its strong connection to circular economy, circular society is a concept that has not yet been measured. We identified and quantified this emerging field through a three-step approach: (i) selecting ASJC categories associated with circular society; (ii) identifying relevant Lens fields of study[6]; and (iii) mapping scientific journals linked to the topic. Our

[6] The Lens fields of study are generated using machine learning and the parsing of all accessible text within an article. There are over 700,000 unique fields of study covering publications worldwide.

initial screening involved analyzing key scientific fields, terms, and keywords related with circular society, drawing on the Alliance Project agenda (Alliance Project, 2021), a comprehensive literature research (Friant et al., 2024; Geissdoerfer et al., 2017; Jaeger-Erben et al., 2021; Kirchherr et al., 2017; Korhonen et al., 2018; Leipold et al., 2021; Melles, 2021; Murray et al., 2017; Prieto-Sandoval et al., 2018; Stahel, 2016), and additional keywords provided by ChatGPT. Generally, each scientific article receives an average of three ASJC codes or nine Lens fields of study, while each journal is assigned to one or multiple ASJC codes. We initially selected 21 ASJC categories (out of 330) and extended this selection using text mining, identifying 730 Lens fields of study (out of over 116,000 available for Dutch publications) and approximately 150 journals belonging to the ASJC categories that were not initially selected. Each of these three steps —ASJC categories, Lens fields of study, and journals— provides a high level of granularity and complementarity, allowing us to identify the most relevant scientific articles directly linked to circular society. This selection approach ensures broad coverage while minimizing the risk of omitting essential topics. Figure A.2 in the Appendix presents word clouds illustrating our selection process based on the three criteria, encompassing the main fields and terms typically associated with circular in both academic literature and public debate. Based on this methodology, we assigned a new field called circular society to selected articles in our database, thereby establishing it as a distinct field of study.

Circular society covers a wide variety of scientific fields mainly linked to environmental sciences, exhibiting high complexity (69.9). We applied the principle of relatedness to identify the scientific fields that are related to scientific fields in circular society. Appendix 1 shows the position of the domain of circular society in the science space at a more aggregate level. Figure 5 shows that Utrecht University has scientific capabilities in fields around circular society: it holds an intermediate RD score of 47.1 out of 100, but this figure is higher for Wageningen University (61.6) and Eindhoven University (47.6). Utrecht University is also slightly specialized in circular society: it has a relative comparative advantage (RCA) just above 1, which is considerably lower than Wageningen (2.8) and Eindhoven (1.7).

Table 3 depicts the ranking of the top 100 scientific fields most related to the circular society field, along with indications of whether the universities participating in the Alliance Project specialize in these fields. Besides General Environmental Science, we have on top of the rank fields such as Renewable Energy, Sustainability and the Environment, Environmental Chemistry, Environmental Engineering, Pollution, and Waste Management and Disposal.

Collaboration potential arises when one university possesses expertise in a field that another university lacks. For instance, while Utrecht University lacks specialization in Environmental Chemistry (field #3), both Eindhoven University of Technology and Wageningen University have expertise in this area that would add to the Relatedness Density that Utrecht University already has. Utrecht could establish partnerships with these organizations to bolster its specialization in Environmental Chemistry.

Table 3: Specializations in scientific fields most related to circular society (Ranking 1 to 100) for Eindhoven (Eind), Utrecht (Utre) and Wageningen (Wag)

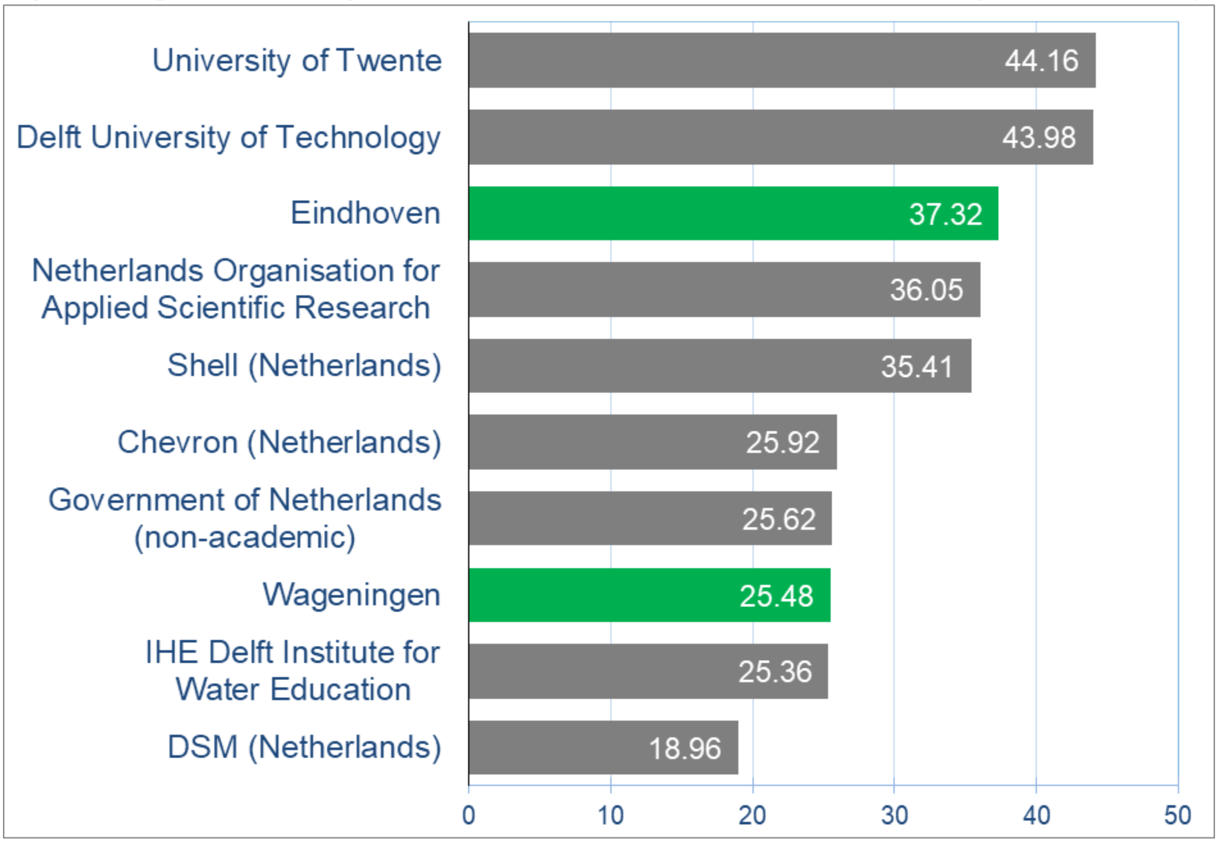
Rank	Fields	Eind	Utre	Wag	Rank	Fields	Eind	Utre	Wag
1	General Environmental Science		■	■	51	Economics and Econometrics			■
2	Renewable Energy, Sustainability and the Environment	■	■	■	52	General Medicine			
3	Environmental Chemistry	■		■	53	Electrochemistry	■		■
4	Management, Monitoring, Policy and Law		■	■	54	Geology		■	
5	Environmental Engineering	■		■	55	Biomaterials	■		
6	Pollution			■	56	Automotive Engineering	■		
7	Waste Management and Disposal			■	57	Safety, Risk, Reliability and Quality	■		■
8	Ecology		■	■	58	Electronic, Optical and Magnetic Materials	■		
9	Energy Engineering and Power Technology	■			59	Biotechnology	■		■
10	Water Science and Technology		■	■	60	Plant Science		■	■
11	Geography, Planning and Development	■	■	■	61	Geotechnical Engineering and Engineering Geology	■		
12	Global and Planetary Change		■	■	62	Computers in Earth Sciences			■
13	Nature and Landscape Conservation		■	■	63	Surfaces, Coatings and Films	■		
14	Health, Toxicology and Mutagenesis		■	■	64	Bioengineering	■		■
15	Civil and Structural Engineering	■			65	Applied Microbiology and Biotechnology		■	■
16	Atmospheric Science		■	■	66	Animal Science and Zoology		■	■
17	General Earth and Planetary Sciences		■	■	67	Organic Chemistry	■		■
18	Fuel Technology	■			68	Process Chemistry and Technology	■		■
19	Ecology, Evolution, Behavior and Systematics		■	■	69	Multidisciplinary		■	■
20	Industrial and Manufacturing Engineering	■		■	70	Agricultural and Biological Sciences (miscellaneous)		■	■
21	Environmental Science (miscellaneous)		■	■	71	Geophysics		■	
22	General Chemical Engineering	■		■	72	Paleontology		■	
23	Public Health, Environmental and Occupational Health				73	Microbiology		■	■
24	Mechanical Engineering	■			74	Chemical Engineering (miscellaneous)	■		■
25	Building and Construction	■			75	General Social Sciences		■	■
26	General Materials Science	■			76	Computer Science Applications	■		
27	Ecological Modeling			■	77	General Agricultural and Biological Sciences		■	■
28	Soil Science			■	78	Social Sciences (miscellaneous)		■	
29	General Energy	■	■		79	Sociology and Political Science		■	
30	preventive health		■		80	Geochemistry and Petrology		■	
31	Aquatic Science		■	■	81	Biochemistry	■	■	■
32	Agronomy and Crop Science			■	82	General Biochemistry, Genetics and Molecular Biology		■	
33	General Chemistry	■	■	■	83	Management Science and Operations Research	■		
34	Forestry		■	■	84	General Physics and Astronomy	■		
35	Mechanics of Materials	■			85	Toxicology		■	■
36	Oceanography		■	■	86	General Engineering	■		
37	Earth-Surface Processes		■	■	87	Surfaces and Interfaces	■		■
38	Earth and Planetary Sciences (miscellaneous)		■	■	88	Tourism, Leisure and Hospitality Management	■	■	■
39	Materials Chemistry	■			89	Catalysis	■	■	
40	Transportation	■			90	General Decision Sciences	■		■
41	Urban Studies	■	■	■	91	Metals and Alloys	■		
42	Polymers and Plastics	■		■	92	Chemistry (miscellaneous)	■		■
43	Ceramics and Composites	■			93	Law		■	
44	Ocean Engineering	■	■		94	Analytical Chemistry	■		■
45	Food Science			■	95	Physical and Theoretical Chemistry	■		
46	Condensed Matter Physics	■			96	Aerospace Engineering	■		
47	Strategy and Management	■		■	97	Materials Science (miscellaneous)	■		■
48	Electrical and Electronic Engineering	■			98	Fluid Flow and Transfer Processes	■		■
49	Nuclear Energy and Engineering	■			99	Nutrition and Dietetics			■
50	Development			■	100	Modeling and Simulation	■		

Note: Black-filled (blank) cells mean that the university has (does not have) a specialization in the field.
Source: Authors' elaboration.

Because Utrecht University has the weakest scientific capabilities of the three universities in fields around circular society, it has most to gain from connecting to research organizations that can offer the highest complementarities. However, are Eindhoven University of Technology and Wageningen University the most suitable partners for Utrecht University to strengthen its circular society specialization? To answer this, we employ the RD Added index discussed earlier. Specifically, we identify the Dutch research organizations with the most complementary capabilities to Utrecht University for strengthening its circular society field.

Figure 6 presents the top 10 research organizations in the Netherlands (out of 116) capable of adding the most RD to Utrecht University. Numerous organizations can contribute to fortifying Utrecht's position in the circular society field. Each of the top 10 organizations can add between 19 and 44 RD points to Utrecht. Notably, the University of Twente and Delft University of Technology stand out, each capable of adding approximately 44 RD points to Utrecht. Moreover, two Alliance members, Eindhoven and Wageningen, rank among the top 10 organizations capable of providing complementary capabilities to Utrecht. Thus, Utrecht can leverage scientific collaborations and partnerships with these institutions to exploit lacking complementary capabilities in order to develop further the circular society field.

Figure 6: Top 10 research organizations that can add most RD to Utrecht University in circular society



Source: Authors' elaboration.

Additionally, we identify ongoing scientific collaborations between Utrecht and the top 10 organizations in the most crucial fields for circular society, where Utrecht lacks specialization but in which the top 10 organizations excel. In other words, does Utrecht University collaborate with other research organizations that provide the best complementarities, or is there still untapped potential in the research collaborations that Utrecht University has established?

The second column in Figure 7 displays the top 30 critical fields for circular society relatedness that Utrecht University is not specialized in. Cells in green indicate the organization (column) has specialization in the field (row) and Utrecht University has collaboration in publications <u>above</u> the average collaboration in this field. Cells in red indicate that the organization (column) has specialization in the field (row) and Utrecht has collaboration in publications <u>below</u> the average collaboration in this field. So, Utrecht does not have specialization in this field and collaborates little with organizations that have specialization in this field. Cells in white indicate that the organization (column) does not have specialization in this field.

Figure 7: Top 10 organizations for Utrecht University to collaborate in critical fields to circular society that are lacking internally

Rank	Top-30 most important fields for **circular society** that Utrecht has no specialization in	Top 10 organizations that can add the most RD to Utrecht (from highest to lowest score)									
		Univ. of Twente	Delft Univ. of Tech.	Eindhoven	NL Org. for Applied Scientific Research	Shell (NL)	Chevron (NL)	Government of Netherlands (non-academic)	Wageningen	IHE Delft Institute for Water Education	DSM (NL)
3	Environmental Chemistry	100	100	100	100	0	0	100	100	0	0
5	Environmental Engineering	0	0	100	100	0	0	100	100	0	
6	Pollution	0	0		100	100	0	100	100	0	
7	Waste Management and Disposal	0	0		100	0	0	100	100	0	
9	Energy Engineering and Power Technology	0	0	0	100	0	0	100		0	
15	Civil and Structural Engineering	0	0	0	100	0	0	100		0	
18	Fuel Technology	0	100	100	100	0	0			0	
20	Industrial and Manufacturing Engineering	0	0	0	100	100	0	100	0	0	100
22	General Chemical Engineering	100	100	100	100	0	0		100	0	0
23	Public Health, Environmental and Occupational Health				100			100		100	
24	Mechanical Engineering	0	0	100	100	0	0	100			0
25	Building and Construction	0	0	0	100	100		100			
26	General Materials Science	100	100	100	100	100	0				0
27	Ecological Modeling	0	0			0			100	0	
28	Soil Science	100				0		100	0	0	
32	Agronomy and Crop Science					100		100	0	0	0
35	Mechanics of Materials	100	0	100	100	100	0				0
39	Materials Chemistry	100	0	100	0	0	0				0
40	Transportation	0	0	0	0			100			
42	Polymers and Plastics	100	0	100					100		0
43	Ceramics and Composites	100	0	100							
45	Food Science				100			100	100		0
46	Condensed Matter Physics	0	0	100	0	100	0				0
47	Strategy and Management	100	100	100	0	0		100	0		
48	Electrical and Electronic Engineering	100	0	0	100	0	0	100			
49	Nuclear Energy and Engineering	0	0	0							
50	Development		0					100	100	0	
51	Economics and Econometrics				100			100	100	0	
52	General Medicine										0
53	Electrochemistry	0	0	100		100			0		

Note: Rank is organized in order of importance for the circular society relatedness.
Source: Authors' elaboration.

Utrecht collaborates well above average in numerous fields (cells in green), particularly with research organizations such as the Netherlands Organization for Applied Scientific Research, the Dutch government, Eindhoven University of Technology, and Wageningen University. However, there is a mismatch in some fields in red, that is, where Utrecht has no specialization and collaborates little, indicating room for improvement in scientific collaboration between Utrecht and organizations like the University of Twente, Delft University of Technology, Shell, Chevron, IHE Delft Institute for Water Education, and DSM.

Conclusion

This paper introduced a relatedness-based framework for universities to strategically evaluate research portfolio expansion and identify valuable collaboration partners. We illustrated the framework by analysing an university alliance between three Dutch universities that aims to extend scientific knowledge production around the concept of the circular society and to exploit research complementarities between the universities in the alliance and beyond.

The universities show markedly different research strengths: Eindhoven excels in complex physical sciences deeply embedded in its capabilities, Wageningen demonstrates similar patterns in life sciences, while Utrecht maintains a diverse portfolio across health sciences, physical sciences, and humanities. Their opportunity sets also differ - both Eindhoven and Wageningen show strong potential in complex fields closely related to their existing work, while Utrecht's broader portfolio offers opportunities across both complex and less complex scientific domains. Our analysis of three Dutch universities focused on circular society research also revealed distinct portfolio characteristics and opportunities.

In examining research complementarities around circular society, we found Utrecht University could benefit most from external partnerships, having the weakest capabilities in this area. Our study showed that many organizations, like the University of Twente and Delft University of Technology, but also the two Alliance members can fortify Utrecht's position in the field of circular society. Utrecht seems to exploit those complementarities: it collaborates in numerous fields with other research organizations including Eindhoven University of Technology and Wageningen University that provide access to complementary capabilities in fields in which Utrecht University is not specialized. We also identified untapped potential, as indicated by little collaboration by Utrecht University with other organizations such as University of Twente, Delft University of Technology and Shell in fields that are underdeveloped in Utrecht.

Future research could extend this framework to all research organizations and examine how it complements other factors in university decision-making, such as funding opportunities in specific scientific themes. In this respect, our framework might help or assist university leadership to assess the potential of these scientific themes fully, and with whom to collaborate to develop them. The framework could also help evaluate collaborative research funding applications, by looking at the extent to which the partners in a proposed consortium bring in relevant and complementary capabilities. Moreover, our framework can be useful to explain the evolution of scientific fields within university portfolios, particularly whether loosely connected fields are more likely to disappear over time. Finally, our approach relied on scientific articles. Future studies could use patent records to map technological opportunities and seek more effective partnerships between private companies and research organizations.

Bibliography

Abramo, G., D'Angelo, C. A., & Zhang, L. (2018). A comparison of two approaches for measuring interdisciplinary research output: The disciplinary diversity of authors vs the disciplinary diversity of the reference list. *Journal of Informetrics* 12 (4), 1182–1193.

Alliance Project. (2021). Alliance Agenda 2021-2025. Utrecht: Alliance TU/e, WUR, UU, UMC Utrecht. 1-20. https://ewuu.nl/wp-content/uploads/sites/370/2021/11/Alliantie-agenda_EN-_Def.pdf

Alshamsi, A., Pinheiro, F. L., & Hidalgo, C. A. (2018) Optimal diversification strategies in the networks of related products and of related research areas. *Nature Communications* 9 (1), 1328.

Atkinson A. B. and Stiglitz J. E. (1969) A new view of technological change, *Economic Journal* 79, 573–578.

Balland, P.-A., & Boschma, R. (2021). Complementary interregional linkages and Smart Specialisation: an empirical study on European regions. *Regional Studies* 55 (6), 1059–1070. https://doi.org/10.1080/00343404.2020.1861240

Balland, P.-A., & Boschma, R. (2022). Do scientific capabilities in specific domains matter for technological diversification in European regions? *Research Policy*, 51(10), 104594. https://doi.org/10.1016/j.respol.2022.104594

Balland, P.-A., Boschma, R., Crespo, J., & Rigby, D. L. (2019). Smart specialization policy in the European Union: relatedness, knowledge complexity and regional diversification. *Regional Studies*, *53*(9), 1252–1268. https://doi.org/10.1080/00343404.2018.1437900

Balland, P.A., Broekel, T., Diodato, D., Giuliani, E., Hausmann, R., O'Clery, N. and Rigby, D. (2022) The new paradigm of economic complexity, *Research Policy* 51 (3), 1-11.

Balland, P.A., Jara-Figueroa, C., Petralia, S., Steijn, M., Rigby, D., and Hidalgo, C. (2020) Complex Economic Activities Concentrate in Large Cities, *Nature Human Behavior* 4, 248–254.

Bastos E.C., Sengik A.R., Tello-Gamarra J. (2021) Fifty years of university-industry collaboration: a global bibliometrics overview. *Science and Public Policy* 48 (2), 177–199. https://doi.org/10.1093/scipol/scaa077

Bodas Freitas I.M., Geuna A., Rossi F. (2013) Finding the right partners: institutional and personal modes of governance of university-industry interactions. *Research Policy* 42 (1), 50–62. https://doi.org/10.1016/j.respol.2012.06.007

Boschma, R.A. (2005) Proximity and innovation. A critical assessment. *Regional Studies* 39 (1), 61–74.

Boschma, R. (2017) Relatedness as driver behind regional diversification: a research agenda, *Regional Studies* 51 (3), 351-364.

Boschma, R. A. and K. Frenken (2010) The spatial evolution of innovation networks: A proximity perspective. In R. Boschma and R. Martin (Eds.), *The handbook of evolutionary economic geography*, Cheltenham: Edward Elgar, pp. 120-135.

Boschma, R., Heimeriks, G., & Balland, P.-A. (2014). Scientific knowledge dynamics and relatedness in biotech cities. *Research Policy*, *43*(1), 107–114. https://doi.org/10.1016/j.respol.2013.07.009

Boschma, R. A., & Iammarino, S. (2009). Related variety, trade linkages and regional growth. *Economic Geography* 85 (3), 289–311. https://doi.org/10.1111/j.1944-8287.2009.01034.x

Boyack, K. W., Klavans, R., & Bo¨rner, K. (2005). Mapping the backbone of science. *Scientometrics* 64 (3), 351–374.

Bozeman, B., Fay, D. & Slade, C.P. (2013) Research collaboration in universities and academic entrepreneurship: the-state-of-the-art. *Journal of Technology Transfer* 38, 1–67. https://doi.org/10.1007/s10961-012-9281-8

Breschi, S. and F. Lissoni (2009) Mobility of skilled workers and co-invention networks: an anatomy of localized knowledge flows, *Journal of Economic Geography* 9 (4), 439-468.

Broekel, T. and A. Meder (2008) The bright and dark side of cooperation for regional innovation performance, Papers in Evolutionary Economic Geography, no. 08.11, Utrecht: Department of Economic Geography, Utrecht University.

Bruneel J., D'Este P., Salter A. (2010) Investigating the factors that diminish the barriers to university industry collaboration. *Research Policy* 39(7), 858–868. https://doi.org/10.1016/j.respol.2010.03.006

Burt, R.S. (2004) Structural holes and good ideas, *American Journal of Sociology* 110 (2), 349-399.

Capello, R., & Caragliu, A. (2018). Proximities and the Intensity of Scientific Relations: Synergies and Nonlinearities. *International Regional Science Review* 41(1), 7–44.

Cassi, L., Morrison, A., & Rabellotti, R. (2015). Proximity and Scientific Collaboration: Evidence from the Global Wine Industry. *Tijdschrift voor Economische en Sociale Geografie* 106(2), 205–219.

Catalán, P., C. Navarrete and F. Figueroa (2022) The scientific and technological crossspace: Is technological diversification driven by scientific endogenous capacity? *Research Policy* 51, 8, 104016, https://doi.org/10.1016/j.respol.2020.104016

Cohen, W.M., Levinthal, D.A. (1990) Absorptive Capacity: A New Perspective on Learning and Innovation, *Administrative Science Quarterly* 35, 128-152

Davies, B., & Maré, D. C. (2020). Relatedness, complexity and local growth. *Regional Studies* 55 (3), 479–494. https://doi.org/10.1080/00343404.2020.1802418

D'Este, P., F. Guy and S. Iammarino (2013) Shaping the formation of university–industry research collaborations: what type of proximity does really matter?, *Journal of Economic Geography* 13 (4), 537-558.

Dosi G. (1982) Technological paradigms and technological trajectories. A suggested interpretation of the determinants and directions of technical change, *Research Policy* 11, 147–162.

Eck, N. J. van, & Waltman, L. (2009). How to normalize co-occurrence data? An analysis of some well-known similarity measures. *Journal of the American Society for Information Science and Technology*, *60*(8), 1635–1651. https://doi.org/10.1002/asi.21075

Figueiredo, N. and C. Fernandes (2020) Cooperation University–Industry: A Systematic Literature Review, *International Journal of Innovation and Technology Management* 17 (08), 2130001, https://doi.org/10.1142/S0219877021300019

Friant, M. C., Vermeulen, W. J. V., and Salomone, R. (2024). Transition to a Sustainable Circular Society: More than Just Resource Efficiency. *Circular Economy and Sustainability* 4 (1), 23–42.

Geissdoerfer, M., Savaget, P., Bocken, N. M. P. and Hultink, E. J. (2017). The Circular Economy – A new sustainability paradigm? *Journal of Cleaner Production* 143, 757–768.

Gilsing, V., B. Nooteboom, W. Vanhaverbeke, G. Duysters and A. van den Oord (2007) Network embeddedness and the exploration of novel technologies. Technological distance, betweenness centrality and density, *Research Policy* 37, 1717-1731.

Giuliani, E. and M. Bell (2005) The micro-determinants of meso-level learning and innovation: evidence from a Chilean wine cluster, *Research Policy* 34, 47–68.

Guevara, M.R., D. Hartmann, M. Aristarán, M. Mendoza and C.A. Hidalgo (2016) The research space: using career paths to predict the evolution of the research output of individuals, institutions, and nations, *Scientometrics* 109, 1695-1709.

Hausmann, R., Hidalgo, C. A., Bustos, S., Coscia, M., Simoes, A., & Yildirim, M. A. (2014). *The Atlas of Economic Complexity*. The MIT Press. https://doi.org/10.7551/mitpress/9647.001.0001

He V.F., von Krogh G., Sirén C. and Gersdorf T. (2021) Asymmetries between partners and the success of university-industry research collaborations. *Research Policy* 50(10), 104356. https://doi.org/10.1016/j.respol.2021.104356

Heimeriks, G., and Boschma, R. (2014). The path- and place-dependent nature of scientific knowledge production in biotech 1986–2008. *Journal of Economic Geography*, 14, 339–364. doi:10.1093/jeg/lbs052

Heimeriks, G. D. Li, W. Lamers, I. Meijer and A. Yegros (2019) Scientific knowledge production in European regions: patterns of growth, diversity and complexity, *European Planning Studies*, 27 (11), 2123-2143.

Heiner R. A. (1983) The origin of predictable behaviour, *American Economic Review* 73, 560–595.

Hidalgo, C. A. (2023) The policy implications of economic complexity. *Research Policy*, *52*(9), 104863. https://doi.org/10.1016/j.respol.2023.104863

Hidalgo, C. A. and Hausmann, R. (2009) The building blocks of economic complexity. *Proceedings of the National Academy of Sciences*, *106*(26), 10570–10575. https://doi.org/10.1073/pnas.0900943106

Hidalgo, C. A., Klinger, B., Barabási, A.-L. and Hausmann, R. (2007) The Product Space Conditions the Development of Nations. *Science 317*(5837), 482–487. https://doi.org/10.1126/science.1144581

Hidalgo, C., Balland, P.A., Boschma, R., Delgado, M., Feldman, M., Frenken, K., Glaeser, E., He, C., Kogler, D., Morrison, A., Neffke, F., Rigby, D., Stern, S., Zheng, S., and Zhu, S. (2018) *The principle of relatedness*, Springer Proceedings in Complexity, 451-457.

Hoekman, J. (2012) Science in an age of globalisation: the geography of research collaboration and its effect on scientific publishing, PhD thesis, Technische Universiteit Eindhoven. https://doi.org/10.6100/IR735405

Hoekman, J., Frenken, K. and Van Oort, F. (2009) The geography of collaborative knowledge production in Europe. *Annals of Regional Science* 43 (3), in press.

Huang, C.-K. (Karl), Neylon, C., Brookes-Kenworthy, C., Hosking, R., Montgomery, L., Wilson, K. and Ozaygen, A. (2020) Comparison of bibliographic data sources: Implications for the robustness of university rankings. *Quantitative Science Studies*, 1–34. https://doi.org/10.1162/qss_a_00031

Jaeger-Erben, M., Jensen, C., Hofmann, F. and Zwiers, J. (2021) There is no sustainable circular economy without a circular society. *Resources, Conservation and Recycling* 168, 105476.

Johnson, S. (2010) *Where good ideas come from. The natural history of innovation*, Riverhead Books.

Jones, B. F. (2009) The burden of knowledge and the death of the Renaissance Man: Is innovation getting harder? *Review of Economic Studies* 76 (1), 283–317.

Katalevsky D., Kosmodemianskaya N., Arutynyan A. and Fortin C. (2022) University 3.0: A Portfolio Approach to the Technology R&D Management. *Foresight and STI Governance* 16 (2), 15–30. https://doi.org/10.17323/2500-2597.2022.2.15.30

Katz, J.S. and Martin, B.R. (1997) What is research collaboration? *Research Policy* 26 (1), 1-18. https://doi.org/10.1016/S0048-7333(96)00917-1

Kirchherr, J., Reike, D. and Hekkert, M. (2017) Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling* 127, 221–232.

Klavans, R. and K. W. Boyack (2017), Research portfolio analysis and topic prominence, Journal of Informetrics 11 (4), 1158-1174, https://doi.org/10.1016/j.joi.2017.10.002

Kogut, B., Zander, U. (1993) Knowledge of the firm and the evolutionary theory of the multinational corporation. *Journal International Business Studies* 24, 625–645.

Korhonen, J., Honkasalo, A. and Seppälä, J. (2018) Circular Economy: The Concept and its Limitations. *Ecological Economics* 143, 37–46.

Leipold, S., Weldner, K. and Hohl, M. (2021) Do we need a 'circular society'? Competing narratives of the circular economy in the French food sector. *Ecological Economics* 187, 107086.

Lewis, J.M., S. Ross and T. Holden (2012) The how and why of academic collaboration: disciplinary differences and policy implications, *Higher Education* 64, 693-708. https://doi.org/10.1007/s10734-012-9521-8

Leydesdorff, L., Rafols, I. (2009) A global map of science based on the ISI subject categories. *Journal of the American Society for Information Science and Technology* 60 (2), 348–362.

Linton, J. and Vonortas, N. S. (2015). From research project to research portfolio: Meeting scale and complexity. *Foresight and STI Governance*, 9(2), 38–43.

Mascarenhas C., Ferreira J.J. and Marques C. (2018) University-industry cooperation: a systematic literature_review and research agenda. *Science and Public Policy* 45 (5), 708–718. https://doi.org/10.1093/scipol/scy003

Melles, G. (2021) Figuring the Transition from Circular Economy to Circular Society in Australia. *Sustainability* 13 (19), 10601.

Mewes, L., Broekel, T. (2022) Technological complexity and economic growth of regions. *Research Policy* 51 (8), 104156, https://doi.org/10.1016/j.respol.2020.104156

Murray, A., Skene, K. and Haynes, K. (2017) The Circular Economy: An Interdisciplinary Exploration of the Concept and Application in a Global Context. *Journal of Business Ethics* 140 (3), 369–380.

Muscio A. and Pozzali A. (2013) The effects of cognitive distance in university-industry collaborations: some evidence from Italian universities. *Journal of Technology Transfer* 38 (4), 486–508. https://doi.org/10.1007/s10961-012-9262-y

Neffke, F., Henning, M. and Boschma, R. (2011). How Do Regions Diversify over Time? Industry Relatedness and the Development of New Growth Paths in Regions. *Economic Geography* 87 (3), 237–265. https://doi.org/10.1111/j.1944-8287.2011.01121.x

Nelson, R. R. and Winter S. G. (1982) *An Evolutionary Theory of Economic Change*. Cambridge, MA and London: The Belknap Press.

Nooteboom, B. (2000) *Learning and Innovation in Organizations and Economies*, Oxford: Oxford University Press.

Nooteboom, B., Van Haverbeke, W., Duysters, G., Gilsing, V., and Van den Oord, A. (2007) Optimal cognitive distance and absorptive capacity, *Research Policy* 36(7), 1016-1034.

Olechnicka, A., Ploszaj, A. and Celińska-Janowicz, D. (2019). *The geography of scientific collaboration*. Taylor & Francis.

Perkmann M., Tartari V., McKelvey M., Autio E., Broström A., D'Este P., Fini R., Geuna A., Grimaldi R., Hughes A., Krabel S., Kitson M., Llerena P., Lissoni F., Salter A. and Sobrero M. (2013) Academic engagement and commercialisation: a review of the literature on university–industry relations. *Research Policy* 42(2), 423–442. https://doi.org/10.1016/j.respol.2012.09.007

Pintar, N. and T. Scherngell (2020) The complex nature of regional knowledge production: Evidence on European regions, *Research Policy*, doi.org/10.1016/j.respol.2020.104170.

Powell, W.W., White, D.R., Koput, K.W., Owen-Smith, J. (2005) Network Dynamics and Field Evolution: The Growth of Interorganizational Collaboration in the Life Sciences. *American Journal of Sociology* 110 (4), 1132-1205.

Prieto-Sandoval, V., Jaca, C. and Ormazabal, M. (2018) Towards a consensus on the circular economy. *Journal of Cleaner Production* 179, 605–615.

Pugliese, E., G. Cimini, A. Patelli, A. Zaccria, L. Pietronero and A. Gabrielli (2019) Unfolding the innovation system fort he development of countries: Coevolution of science, technology and production, *Sci. Rep.* 9, 1-12.

Romero-Goyeneche. O.Y., G. Heimeriks and F. Arroyave (2025) How Uncertain is the Emergence of Knowledge Related to the United Nations Sustainable Development Goals? An Analysis of Scientific Knowledge Diversification at Utrecht University, Sustainable Development 0: 1-19, https://doi.org/10.1002/sd.3392

Rossoni, A.L., E. Pinheiro Gondim de Vasconcellos and R. L. de Castilho Rossoni (2024) Barriers and facilitators of university-industry collaboration for research, development and innovation: a systematic review, *Management Review Quarterly* 74, 1841–1877. https://doi.org/10.1007/s11301-023-00349-1

Rybnicek, R, and R. Königsgruber (2019) What makes industry–university collaboration succeed? A systematic review of the literature, *Journal of Business Economics* 89, 221–250. https://doi.org/10.1007/s11573-018-0916-6

Singh, J. (2005) Collaborative networks as determinants of knowledge diffusion patterns, *Management Science* 51 (5), 756-770.

Sjöö K. and Hellström T. (2019) University–industry collaboration: a literature review and synthesis. *Industry and Higher Education* 33 (4), 275–285. https://doi.org/10.1177/0950422219829697

Stahel, W. R. (2016) The circular economy. *Nature*, 531 (7595), 435–438.

Teece, D. J., Rumelt, R., Dosi, G. and Winter, S. (1994) Understanding corporate coherence. *Journal of Economic Behavior and Organization*, 23, 1–30. doi:10.1016/0167-2681(94)90094-9

Torre, A. and Rallet, A. (2005) Proximity and localization. *Regional Studies* 39 (1), 47-60.

Tsouri, M. (2018) Knowledge transfer in time of crisis: evidence from the Trentino region. *Industry and Innovation* 26 (7), 820–842. https://doi.org/10.1080/13662716.2018.1551124

Tuesta, G.F., Tuesta, E.F., Digiampietri, L.A. and D. Hartmann (2024) The diversity and (dis-)similarity of Brazilian universities' research portfolios. *Scientometrics*. https://doi.org/10.1007/s11192-024-05191-0

Vallance, P. (2016) Universities, public research, and evolutionary economic geography, *Economic Geography* 92, 355-377.

Van de Klippe, W., Yegros-Yegros, A., Willemse, T., & Rafols, I. (2023). Priorities in research portfolios: exploring the need for upstream research in cardiometabolic and mental health. *Science and Public Policy* 50 (6), 961-976.

Van Raan, A. F. J., & van Leeuwen, T. (2002). Assessment of the scientific basis of interdisciplinarity,
applied research. Application of bibliometric methods in Nutrition and Food Research. *Research Policy*, 31, 611–632.

Vicente, J., P.A. Balland and O. Brossard (2011) Getting into networks and clusters: evidence from the Midi-Pyrenean GNSS collaboration network, *Regional Studies* 45 (8), 1059-1078.

Visser, M., van Eck, N. J., & Waltman, L. (2021). Large-scale comparison of bibliographic data sources: Scopus, Web of Science, Dimensions, Crossref, and Microsoft Academic. *Quantitative Science Studies*, *2*(1), 20–41. https://doi.org/10.1162/qss_a_00112

Vonortas, N., & Ràfols, I. (2019). The use of research portfolios in science policy. *Journal for Research and Technology Policy Evaluation*, 47, 106–117.

Wagner, C. S., Roessner, J. D., Bobb, K., Klein, J. T., Boyack, K. W., Keyton, J., Rafols, I., & Börner, K. (2011). Approaches to understanding and measuring interdisciplinary scientific research (IDR): A review of the literature. *Journal of Informetrics*, 5(1), 14–26.

Wallace, M. L., & Rafols, I. (2015). Research portfolio analysis in science policy: Moving from financial returns to societal benefits. *Minerva*, 53(2), 89–115. https://doi.org/10.1007/s11024-015-9271-8

Waltman, L., van Eck, N.J., Noyons, E.C.M. (2010) A unified approach to mapping and clustering of bibliometric networks. *Journal of Informetrics* 4 (4), 629–635.

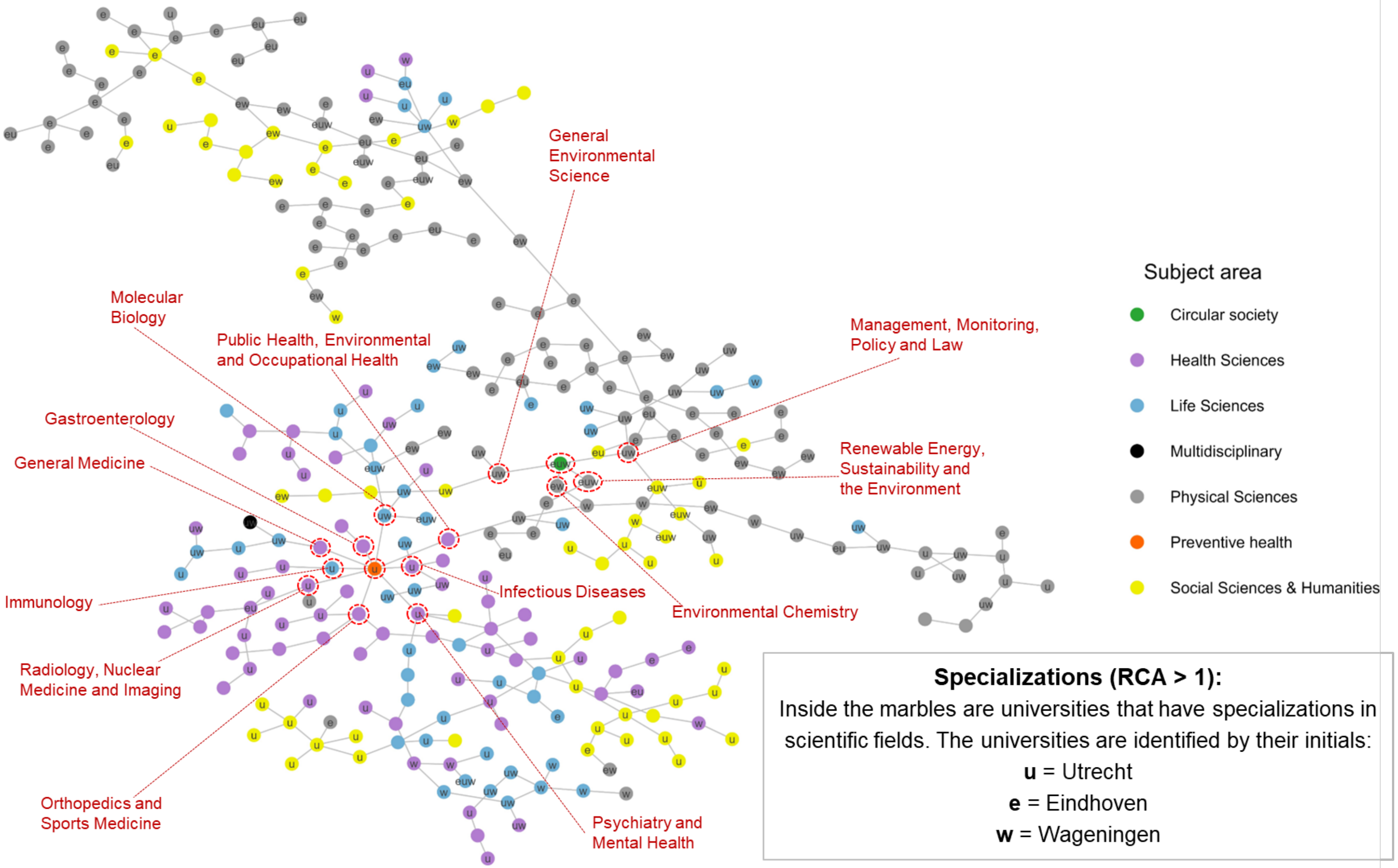
Wuchty, S., Jones, B. F. and Uzzi, B. (2007) The increasing dominance of teams in production of knowledge. *Science* 316, 1036–1039.

Wouden, F. van der, and D.L. Rigby (2019) Co-inventor networks and knowledge production in specialized and diversified cities, *Papers in Regional Science*, 98 (4), 1833-1853, https://doi.org/10.1111/pirs.12432

Wouden, F. van der (2018) Exploring the Changing Structures of Inventor Collaboration in U.S. Cities between 1836 and 1975, PhD manuscript, UCLA, Los Angelos.

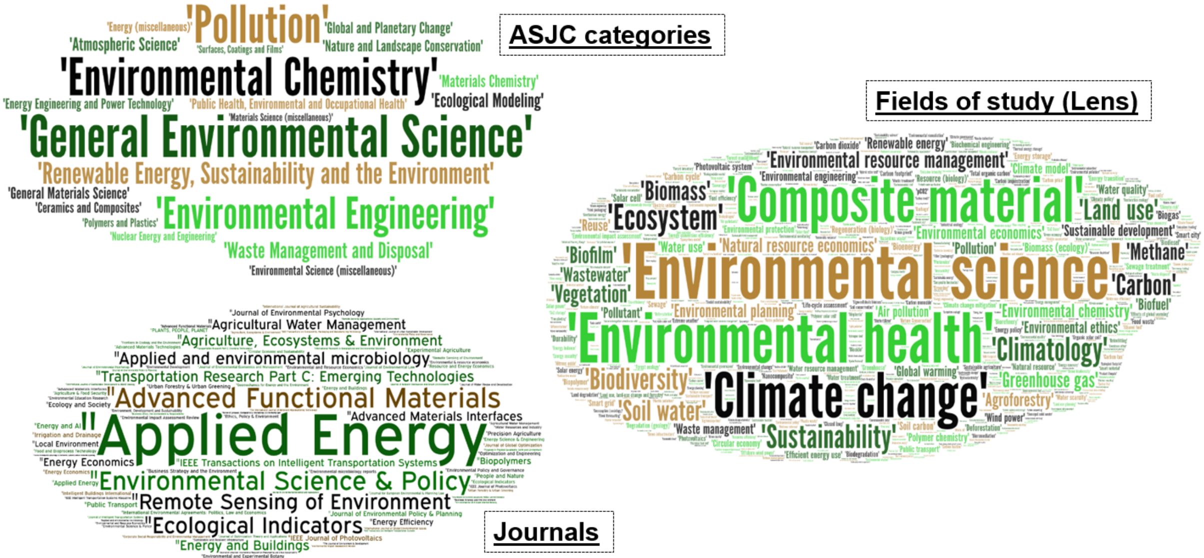
Zhang, L. and Leydesdorf, L. (2021) The scientometric measurement of interdisciplinarity and diversity in the research portfolios of Chinese universities. *Journal of Data and Information Science*, 6(4), 13–35.

Appendix Figure A.1: Science Space



Note: Nodes directly linked to the Circular Society and Preventive Health fields are identified in red.

Appendix Figure A.2: Word clouds for circular society from ASJC categories, Lens fields of study and journals



Source: Authors' elaboration.