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Concentration versus excellence: lessons learned of European R&D &I framework programs

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Abstract

Framework programs (FPs) are the main research policy tools of the European Union (EU), attracting substantial attention from policy-makers and scholars. Therefore, an increasing number of studies have investigated the EU's FPs from various angles; however, very few studies address the effect of the complex nature of the concentration of resources and their implementation. While several studies have examined the concentrations of collaboration structures, much less attention has been given to institutions, especially the concentrations that appear during implementation. Institutions that have been awarded several projects at the same time are forced to share their resources between the running projects, which can make the implementation of the projects riskier and thus jeopardize the project's outcome. Therefore, the role of project management, which must allocate resources among complex implementation structures, such as multiprojects and programs, across portfolios, is appreciated. The aim of this study was to analyze the progression of the nature of concentration, such as institutional concentration in the four most recent framework programs (FPs), namely, FP5, FP6, FP7, and Horizon 2020 (H2020), and the structural and implementation concentrations in the last two framework programs. The study employed the CORDIS database, which encompasses both institutional and project-related information derived from four distinct framework programs. The findings indicated that the parameters of the collaboration network exhibited minimal changes; however, the concentrations of institutions experienced significant alterations. The concentration of complex project structures increased along with institutional concentration, which in turn led to greater efficiency and productivity and, in this way, excellence. Hence, it can be inferred that the output-increasing effect of the program structure is undermined in the deployment of other implementation structures by the need to share resources among several projects running in parallel. The strategy of using parallel projects involves inherent hazards because of the finite nature of resources, which consists primarily of human talent in the form of researchers. The results currently support policy-makers in three ways: (1) an improved understanding of how implementation structures evolve in EU-funded Framework Programs; (2) strengthened linkages among institutional concentration, productivity and excellence; and (3) insights into the design of the EU FP ecosystem.

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Introduction

The Framework Programs (FPs) of the European Union (EU) are highly significant policy instruments that promote research and innovation, facilitating scientific partnerships among member states. While functioning as sources of financing, they also exert significant influence on the European research scene through their power as policy instruments. FPs have a long history of more than forty years (Le Boulay, 2023) and have consistently provided open data to researchers as well as participation and funding opportunities (Moreira Da Silva et al., 2017). This set of programs allows for valuable insights into the complexities of funding large-scale research (Breschi & Malerba, 2011) and the dynamics of research collaboration (Defazio et al., 2009). Table 1 shows a comparison of framework programs.

Table 1 highlights both the stable components and the changing features of the European framework programs. The primary objectives of all initiatives have invariably been to augment research and innovation to stimulate economic growth and enhance quality of life. Each program has prioritized scientific excellence, technical advancement, and innovation, with a consistently expanding budget and a growing number of participants, which reflects an increased commitment to research and collaboration within the scientific community.

Nevertheless, there have been major alterations in the specific objectives and areas of emphasis of each program. The primary focus of FP5 was on increasing industrial competitiveness and quality of life by means of research and technical advancement. The focus of FP6 changed toward establishing an authentic European research area, with a strong emphasis on scientific excellence, competitiveness, and innovation. To foster excellence in scientific and technical research, FP7 expanded its scope to encompass ideas, people, capabilities, and collaboration. The H2020 initiative broadened its focus to encompass outstanding scientific research, industry leadership, and societal issues, with the goal of promoting innovation and research to stimulate economic development. The evolution of these programs illustrates their ability to adjust and respond to changing demands and priorities throughout time.

Compared with the FP5 framework program, the number of participants doubled, whereas the budget increased more than fivefold. In contrast to the increase in participants, numerous studies (see e.g., Garas & Argyrakis 2009; Scherngell & Lata 2013; Bouquet et al., 2019) have shown that the concentration of collaborative structures has not changed and is high in all framework programs. Moreover, it is not enough to examine the structural concentration because it focuses only on collaboration, and in this case, less attention is given to the fact that not only collaboration but also funded projects can be concentrated, which results in the organization managing several projects at the same time. Therefore, it is important to ascertain how funding and awarded projects are concentrated around a few institutions because these institutions must share their resources between their parallel running projects. As a result of institutional concentration, one researcher may participate in several projects, which can affect the outcome of the research. Therefore, instead of focusing only on structural concentration, *we focus on the effects of the complex nature of the concentration on productivity and excellence*. Our study examines three aspects of concentration: structural, institutional and implementation concentrations (see Table 2).

Table 1 Comparison of FP5, FP6, FP7, and H2020 Framework Programs

	FP5	FP6	FP7	H2020
Main Goals	Enhance industrial competitiveness and improve quality of life	Create a genuine European research area	Promote excellence in scientific and technological research	Foster innovation and research to drive economic growth
Main Focus	Research, technological development, and demonstration	Scientific excellence, competitiveness, and innovation	Ideas, people, capacities, and cooperation	Excellent science, industrial leadership, and societal challenges
Budget	14.96 billion	17.5 billion	50.5 billion	80 billion
Period	1998–2002	2002–2006	2007–2013	2014–2020
Number of Participants	Over 16,000 projects	Over 16,000 projects	Over 25,000 projects	Over 31,000 projects

Table 2 Three aspects of concentrations

	Structural concentration	Institutional concentration	Implementation concentration
Description	The degree to which collaborations are centralized around certain key nodes or participants.	Degree of concentration of institutional funding	The rate of complex implementation structures (multiprojects, programs)
Measure	With network centralizations	What percentage of institutions receive 80% of the funds?	Complex implementation structures / All projects

An investigation into these programs involves the examination of collaborative project structures (Kosztyán et al., 2022), the comprehension of the relationships between research funding and performance (Defazio et al., 2009), the management of the delicate equilibrium between policy objectives and funding decisions (Bloch et al., 2016), a solution for the persistent difficulty in designing programs that aim for excellence while guaranteeing fairness (Kaló et al., 2019), and observations of the increasing tendency to concentrate funding among a restricted number of recipients (Aagaard et al., 2020) (see RQ_1).

In the contemporary landscape, when resources are limited, the global trend is to emphasize the significance of quality and the use of competitive funding schemes. This is particularly highlighted in FPs (Aagaard et al., 2020; Moore et al., 2017). The main goal of this approach is to strategically allocate resources while prioritizing highly skilled research efforts (Aagaard, 2017), both aimed at maintaining global competitiveness. This policy effort thus inevitably perpetuates the cycle of preferential treatment for certain high-performing institutions, resulting in the concentration of funding among the most successful entities, as shown in scientific research (Aagaard et al., 2020) (see RQ_2).

Opinions vary on the positive and negative impacts of funding concentration within a few institutions on financing (see the astutely presented details in Aagaard et al., 2020). The majority of researchers attribute the excellence of the final results to institutional concentration. Nevertheless, the emphasis of framework programs has expanded to include cooperation and collaboration in addition to excellence. (Aagaard, 2017). Consequently, we might anticipate a gradual decrease in institutional concentration. (see RQ_2). Simultaneously, the demand for publications creates an advantageous position for countries and institutions that can provide the required research infrastructure (Jones & Bice, 2021). The distribution of resources has an effect on the concentration of larger institutions as funding recipients (Breschi & Malerba, 2011). More powerful institutions have the ability to efficiently distribute their resources among multiple concurrent initiatives, decreasing their expenses and gaining an extra competitive edge (Daumann et al., 2023) (see RQ_3). However, there has been limited exploration of the factors that motivate institutions to pursue membership within a concentration of funding recipients. To ascertain what stimulates institutions to pursue research funding, it is important to consider how projects are implemented. Therefore, this research will also investigate the impact of complex implementation structures, such as the collaborative supervision of multiple parallel projects (called multiprojects) and program structures, where a successor project builds upon the results of the preceding projects.

With respect to project portfolios, extensive research has demonstrated that the utilization of multiprojects can lead to cost reduction by facilitating efficient resource allocation (Pillai et al., 2002). Additionally, projects that leverage the outcomes of other projects funded at the same institution in a program structure tend to exhibit higher levels of productivity (Iamratanakul et al., 2008). Nevertheless, the project portfolio literature does not clearly demonstrate that the impact of complex implementation structures (multiprojects, programs) would be positive in all cases to achieve the strategic goal (Teller et al., 2012). Moreover, few studies have investigated the connections within framework programs (Kosztyán et al., 2022). Therefore, the relationships between institutional concentration and complex implementation structures, especially the impact of the concentration of complex implementation structures in framework programs, are still open questions. Our research addresses determining the degree to which institutional concentration impacts the use of complex implementation structures (RQ_3). How does the pooling of resources among a limited number of consortium partners, who often work on multiple projects simultaneously, impact productivity (RQ_4)?

RQ_1 How does institutional concentration change in each country and in each framework program?
RQ_2 What is the impact of changing institutional concentration on performance excellence?
RQ_3 Does institutional concentration have an effect on implementation structures?
RQ_4 How does the concentration of complex implementation structures impact productivity?

Background

In this study, we used three aspects of concentration, i.e., (1) structural, (2) institutional and (3) implementation. Table 2 summarizes the description and how it can be measured.

In the context of the EU, institutional concentration in FPs pertains to the extent to which a small number of institutions are involved and have control over research and development (R&D) projects funded by the EU. Recent studies have focused on the crucial role of these central organizations in the network of R&D projects (Chessa et al., 2013; Morescalchi et al., 2015). The concentration of institutions can provide both benefits and drawbacks for the EU, the participating institutions, and the scientific community (see Table 3).

The involvement of recognized and experienced institutions in research and development can improve the quality and effectiveness of outcomes. These institutions can utilize their expertise and resources to carry out advanced research and innovation (Lepori et al., 2015). However, the reduction in diversity and inclusivity in the R&D &I landscape can occur when less prominent or experienced institutions encounter constraints and barriers to access when competing for EU funding opportunities (Aagaard et al., 2020). This can result in the marginalization or exclusion of these lesser-known institutions from R&D networks and collaborations (Aagaard, 2017). However, this research did not consider FP programs. Similarly, Hoekman et al. (2009) emphasized the emergence of elite structures in scientific collaboration networks and stated that the gap between these players is expected to increase rather than decrease in the future. In addition, the presence of power imbalances and conflicts may arise among project partners, as dominant institutions exert greater influence and control over project objectives, activities, and outcomes. Consequently, the interests and demands of less powerful institutions may be disregarded or overridden (Aagaard et al., 2020).

Institutional concentration can promote the formation of robust and enduring networks and partnerships among top institutions, which can facilitate the sharing of knowledge and best practices and enhance the efficiency and efficacy of the research and development process (Fazio et al., 2020). However, the creativity and innovation potential of R&D &I outputs can be constrained when dominant institutions adhere to established paradigms and techniques, potentially disregarding the innovative and alternative ideas and viewpoints of less represented institutions. In addition, the project's ability to adapt and respond to changes in the environment and in demands may be hindered, as dominating institutions may resist or oppose amendments to the project plan. Additionally, these institutions may impose strict and inflexible regulations and procedures on the execution of the project (Mossberg et al., 2020).

The visibility and appeal of the EU as a global leader and partner in research, development and innovation (R&D &I) can be enhanced by showcasing the excellence and relevance of EU-funded R&D &I activities through prestigious and influential

Table 3 Advantages, disadvantages and possible risks of increasing institutional concentration

Advantage	Disadvantage	Potential risks
Quality and impact of the R&D outputs.	Reduce the diversity and inclusiveness of the R&D landscape.	Power imbalances and conflicts among the project partners.
Strong collaborations and knowledge sharing.	Limit the creativity and innovation potential of the R&D outputs.	Reduce the adaptability and responsiveness.
Excellence may increase the visibility of the EU's R&D &I activities.	Excellence may increase the risk of dependency and vulnerability of the R&D system.	Excellence may undermine the sustainability and scalability of the project results.

institutions (Aagaard et al., 2020). However, reliance on a limited number of institutions in the R&D &I system can heighten the likelihood of dependency and vulnerability. This is because external shocks and uncertainties, such as political, economic, or social changes, can impact the performance or availability of these dominant institutions, thereby increasing the risk to R&D &I activities. Additionally, a project's sustainability and scalability may be compromised if dominant institutions monopolize or restrict the dissemination and use of the project outputs; this could hinder or prevent the transfer and replication of project outcomes in different settings (Mossberg et al., 2020).

Institutional excellence can be defined through several criteria, and institutions can be evaluated via multiple ranking methodologies (Doulatabadi & Yusof, 2015). However, prior scientific endeavors play a significant role in all the ranking criteria, including but not limited to, the quantity and quality of publications (Valmorbida & Ensslin, 2017). Publication activity is a significant requirement of projects awarded within framework programs (Delanghe & Muldur, 2007). It is mandatory to include this information in the report for each project. Additionally, in the H2020 framework program, publication activity is even documented for each project.

Several studies highlight the importance of internal factors related to the excellence and efficiency of R&D &I projects by considering what types of proximities, organizational, structural, cultural, cognitive, and language, are prevalent in collaborative knowledge creation (Boschma, 2005; Crescenzi et al., 2016; Enger, 2018; Scherngell & Barber, 2009). Kosztyán et al. (2022) recognized that structures within framework programs are similar to those in project portfolios. Portfolio management was initially devised by Markowitz (1952) for financial applications and subsequently was expanded to encompass project management (McFarlan, 1981). A synchronized project portfolio embodies the sponsor's investment strategy, enhances value beyond the outcomes of a single project, maximizes the utility of the resources at hand, and maintains a harmonious equilibrium among related risks. Portfolio management with projects primarily emphasizes ensuring that projects and programs are aligned with the sponsor's strategy and that the project portfolio is well balanced. This includes acknowledging the potential risks and potential rewards of exceeding time and budget constraints. The process of scoring, screening, and selecting projects is crucial for identifying an appropriate structure for a project portfolio (Wei et al., 2020). Since Kosztyán et al. (2022) showed that implementation structures, whether for individual projects, multiprojects or programs, can be identified in framework programs, several differences have been identified between project portfolios and framework programs. First, framework programs have no steering committee, which is typically charged with resolving conflicts and issues among the portfolio components, providing support and resources to the project and program managers and ensuring alignment and compliance with the organizational strategy and policies in the strategic direction and objectives of the portfolio. As a result, a complete, logical plan is not prepared for the entire project portfolio. Portfolio projects are managed by strategies that can be inferred only from schedule, content and consortium data (see in Kosztyán et al., 2022). Nevertheless, the EU organizations responsible for tenders prioritize and approve new projects and programs and monitor and evaluate the performance and outcomes of portfolios. The implementation structure is not preplanned but rather self-organizing, and the structure can be influenced by the tendering priorities of the framework programs. Despite the presence of self-organization, Kosztyán et al. (2022) showed that, albeit to a small extent, complex structures still form in the FP7 (e.g., several multiprojects running in parallel and program structures containing projects that build on each other's results).

We considered the structures that have no logical connections among themselves and do not share their resources with each other *individual (or single) projects* (Hans et al., 2007) owing to geographical, temporal and compositional differences among consortia. Given the absence of resource sharing and a lack of logical interdependence among individual projects, the failure or delay of one project does not have any impact on other initiatives (Hans et al., 2007). In a *multiproject structure*, consortium institutions simultaneously manage multiple projects, enabling them to pool resources and consequently achieve cost reduction (Archibald, 2003; Clegg et al., 2018). Nevertheless, several concurrent initiatives may lead to delays if researchers from consortium partners become overwhelmed with work (Kosztyán et al., 2022; Miloševic et al., 2009). With respect to *program structures* (Platje & Seidel, 1993; Miloševic & Patanakul, 2002), it is presumed that a coherent relationship exists between the preceding and subsequent projects (Patanakul & Miloševic, 2009). The subsequent project is thus based on the findings of a previous study. Hence, any delay in the previous project has a direct effect on the timetable of the subsequent project (Iamratanakul et al., 2008). Simultaneously, if the subsequent project shares identical content with the prior project, the product can be expected to have superior quality, as indicated by the number of publications as a proxy in this instance (Delanghe & Muldur, 2007).

FPs can yield diverse outputs, including publications such as scientific articles, books, book chapters, conference papers and proceedings, symposia and seminar contributions, and dissertations. Additional outcomes associated with EU-funded initiatives may include patents, enhanced tools, methodologies, procedures, novel networks, (inter)national acclaim, and doctoral research projects (Tuominen et al., 2011; Muldur et al., 2006; Larédo, 1998). Muscio (2006) reported in a preliminary investigation that the main outcome of FPs, quantitatively speaking, was an academic publication. Scientific publications and citation measurements have a long tradition of being indicators of research impact (Gonzalez-Brambila et al., 2013; Ovalle-Perandones et al., 2013). Assessing the quality of a scientific article and making predictions about its impact can be challenging. A reliable measure of quality can be the inclusion of one's work in peer-reviewed and prestigious academic journals. The prevailing assumption is that the citation impact score of international coauthored publications is typically higher than that of publications that are only national in scope (Muldur et al., 2006). While the majority of FP projects produce peer-reviewed articles as part of their output (Muscio, 2006), it is still crucial for both the applicant and the funder to disseminate the findings of the earned research, development, and innovation initiatives in a reputable academic journal (Delanghe & Muldur, 2007).

We believe that institutional concentration can impact implementation structures (see Fig. 1). If support is focused primarily on a small number of institutions and if the support for individual projects and the duration of the framework program are also restricted, then it becomes necessary for the winning institutions to coordinate multiple projects simultaneously. In view of the limited number of researchers in these institutes, individual researchers may be required to concurrently participate in multiple projects. Unfortunately, there is a lack of public information regarding the logic guiding framework programming schedules. To estimate a potential implementation structure, it is necessary to have access to the schedule, content, and consortium data of all related projects. Kosztyán et al. (2022) suggested a methodology for ascertaining the logical framework of the FP7. We thus employ this methodology to analyze the H2020 framework program. Simultaneously, we want to investigate the impact of alterations to institutional concentration on implementation and productivity (see Fig. 1).

On the basis of a review of the literature, institutional and national concentrations in framework programs are attributed primarily to institutional excellence (Özbolat

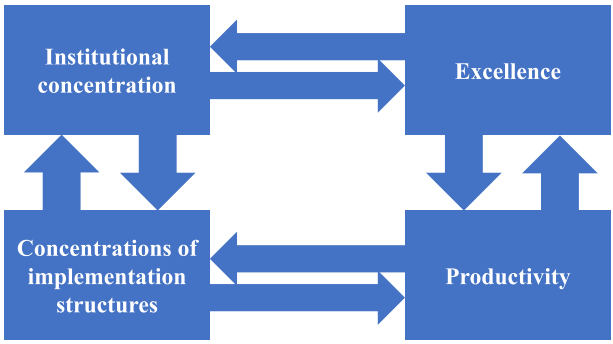


Fig. 1 Research model

et al., 2018), as determined by the grants received. It is uncertain whether increased institutional concentration leads to an increase in research performance among these institutions and subsequently among these countries. While we were unable to find any relevant literature, it is plausible that institutional concentration leads to a greater proportion of complex structures, such as multiprojects and programs. This is because multiple awarded projects can be implemented only simultaneously or with slight time differences to meet the deadlines in the framework program. Simultaneously, it remains uncertain whether the rise in the percentage of intricate formations and the potential cost savings associated with them, along with the growing publication efficiency, would steer the key players toward institutional concentration. Excellence is often assessed by prior research and publication outcomes (Delanghe & Muldur, 2007). However, attaining exceptional research performance requires additional time and an interconnected series of projects, which can potentially hinder productivity. Analyzing this aspect can provide valuable contributions that have not been previously studied.

This study does not examine, but cannot rule out, that there is a direct relationship between excellence and complex implementation structures since the ability to carry out complex implementation structures may be a sign of excellence, irrespective of being a large or productive institution. Despite these caveats, we believe that an obvious relationship between them does not always exist; an example is the role of European Research Council (ERC) funding.. These are mostly single projects, but only the best researchers will be selected for this tender.

This research also does not examine whether there is a direct relationship between institutional concentration and productivity. However, we believe that this connection is more indirect. Institutional concentration and the management of parallel projects force organizations to apply complex project and resource management (Islam et al., 2020); only then can increased productivity be ensured in research. Moreover, Kosztyán et al. (2022) noted that managing complex research projects also has limitations for increasing productivity. Therefore, increasing productivity beyond all limits with the concentration of resources alone is not possible. In the same way, the concentration of resources can help attract world-class researchers. Thus, excellent researchers, in cooperation, can increase the number of high-quality publications, but numerous Eastern European examples (Nagy, 2016) show that this is not necessarily evident when resources are grouped and concentrated.

The following contributions to the literature are made in this study:

C_1 We show the relationship between the institutional structure and complex implementation structures.

C_2 We show that the productivity of complex implementation structures increases with institutional concentration but cannot increase in direct proportion to each other.

C_3 We show that differences in excellence actually strengthen institutional concentration. However, increasing institutional concentration alone does not necessarily increase excellence.

We show that an increase in the rate of complex implementation structures leads to greater efficiency and productivity, which in turn pushes institutions toward greater concentration (C_1). These complex implementation structures offer the potential for enhanced efficiency and productivity, which in turn contributes to institutional concentration. However, this productivity increase is constrained by the finite availability of resources that may be deployed (C_2). Disparities in excellence effectively enhance the concentration of institutions. Nevertheless, the mere augmentation of institutional specialization does not automatically lead to an enhancement in excellence (C_3).

Data and methods

Figure 2 shows the research process.

For our study, we used the CORDIS database, which encompasses both institutional and project-related information derived from four distinct framework programs, namely, FP5 (1998–2002), FP6 (2002–2006), FP7 (2007–2014), and H2020 (2014–2020). By utilizing institutional identifiers, we successfully correlated the institutional data and conducted geocoding for all relevant institutional information. The cooperation network was constructed by representing institutions as vertices and consortium project relationships as edges, as shown in Fig. 2b. The analyses were subsequently performed in two different directions. On the one hand, a content analysis was conducted (refer to Fig. 2c) utilizing the project descriptions. By incorporating time and cost data from each project, an estimation was made regarding the logical framework program (refer to Fig. 2d) and its execution structure (refer to Fig. 2e). The aforementioned structure demonstrated the potential for collaboration among the consortium partners, both in terms of sharing projects within the consortium (referred to as the multiproject structure) and building upon each other's findings (referred to as the program structure). The lead time, cost, and resource needs for the execution structure acquired via this method may all be ascertained. With respect to the concentration and costs associated with various implementation structures (namely, individuals, multiprojects, and programs), as well as one of the primary commitments of the projects, our analysis aimed to establish correlations between publication achievements. Our findings indicate that these implementation structures play crucial roles in project fulfillment, which in turn contributes to the overall success of the framework program and significantly impacts its associated risks. Separately, we proceeded to analyze the potential outcomes of the undue influence of decision-makers manipulating the makeup of consortia and implementation structures through modifications to the tenders (refer to Fig. 2f). The rise in intricate implementation structures, such as multiprojects and programs, is accompanied by corresponding growth in institutional concentration. Consequently, we have been able to ascertain the advantages associated with further augmenting institutional

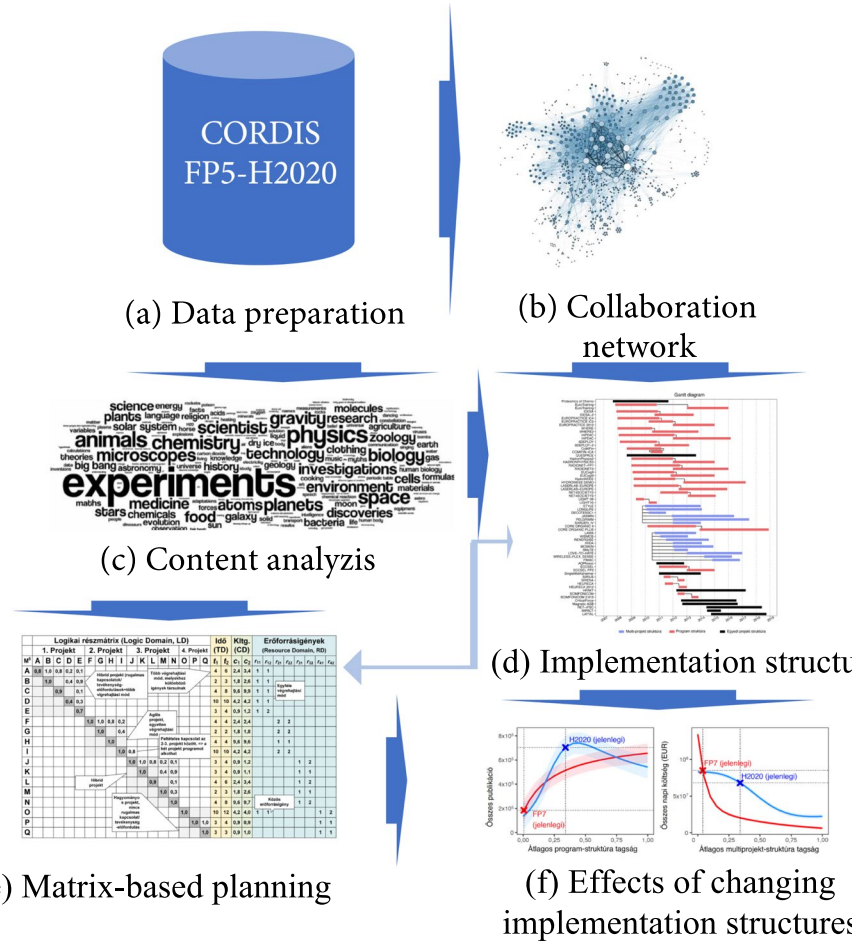


Fig. 2 Research design

concentration, specifically in relation to publication commitments and adherence to cost and time constraints.

Data employed

To perform the analysis, data from FP5 (33,668 organizations) to H2020 (55,613 organizations) were obtained from the CORDIS database. Two tables were applied: first, a project data table that included the following information about the projects (*project ID, start date, end date, project acronym, project title, project description, project cost, participant institutes, and coordinator institute)*; second, in H2020, a publication data table that included the list of publications resulting from H2020 projects was used. To consider the excellence of EU countries, the ranking list from the SCImago Journal and Country Rank database is employed (www.scimagojr.com).

Measuring structural concentration

Within a collaboration network, the entities involved are represented by vertices, also known as nodes, which symbolize the organizations. The connections between these vertices are represented by edges, which signify the partnerships formed within a project. Prior to conducting an analysis of collaboration networks, it is necessary to eliminate loops, which indicate the absence of collaboration, as well as many edges, which signify the occurrence of multiple projects shared between institutions. To assess the structural concentration, several metrics are computed, including edge density, number of components, and centralization.

The term "density" pertains to the ratio of existing connections to a node to all potential connections to that node inside a network. In the context of a collaboration network, a high density value signifies a substantial level of collaboration among multiple organizations. In contrast, a low density implies a reduced level of interorganizational communication. The concept of assortativity refers to the propensity of nodes to establish connections with other nodes that possess comparable attributes. The predominant metric is degree assortativity, which examines the association between the degrees of interconnected nodes. The calculation can be performed by utilizing the Pearson correlation coefficient of the degrees of connected nodes. Within the context of a collaboration network, a high degree assortativity indicates a positive correlation between the degrees of connected nodes; this means that high-degree nodes (those with many connections) tend to connect with other high-degree nodes and that low-degree nodes connect with other low-degree nodes. This frequently indicates the presence of robust community structures or clusters inside the network. It has the potential to improve collaboration and the exchange of information inside these clusters, but it can also result in the establishment of isolated groups where different clusters are less connected []. Networks with negative assortativity tend to have a more hierarchical or core-periphery structure. This can facilitate the spread of information across the entire network but might also create dependencies on central nodes, making the network more vulnerable if these nodes fail. If the degree assortativity value is close to 0, it indicates that there is little to no correlation between the degrees of connected nodes in the network. In other words, nodes do not show a strong preference for connecting to other nodes with similar or dissimilar degrees. The network exhibits neutral mixing patterns, meaning that connections are formed without regard to the degree of the nodes.

Degree centralization in a collaboration network measures the extent to which connections are concentrated around a few central nodes. A high degree of centralization indicates that a small number of nodes have a disproportionately large number of connections. This can lead to efficient dissemination of information and resources through these central nodes, but it also makes the network more vulnerable to disruptions if these key nodes fail or are removed. Additionally, high centralization can create power dynamics where central nodes have significant influence over the network.

Conversely, low-degree centralization suggests that connections are more evenly distributed among nodes; this can enhance the network's robustness, as the failure of any single node is less likely to disrupt the overall connectivity. It also promotes a more egalitarian structure, where influence and control are more evenly spread, potentially leading to more democratic decision-making processes. A low degree of centralization refers to a situation where partnerships are distributed more fairly among several organizations. Betweenness centralization in a collaborative network quantifies the degree

to which a small number of nodes serve as crucial mediators in the shortest routes between other nodes. High betweenness centralization signifies that a limited number of nodes play a crucial role as intermediaries, enabling communication and collaboration throughout the network. The presence of these nodes is essential for ensuring the smooth transmission of information and allocation of resources. Removing them could have a substantial effect on the network's connection and efficiency. Within the framework of the European Funded Framework Programs, high betweenness centralization can indicate the presence of crucial organizations or individuals who serve as connectors between different research groups and promote interdisciplinary collaboration. Conversely, a low level of betweenness centralization indicates a network that is more evenly spread out, with more nodes serving as intermediaries; this can improve the network's resilience, as the failure of any individual node is less likely to result in severe interruption. Additionally, it suggests a more equal and fair structure, where multiple nodes have a role in the network's connectedness and collaboration. In the context of European Funded Framework Programs, a low level of betweenness centralization can suggest a network that is well integrated, with extensive collaboration and reduced reliance on a small number of influential individuals.

Eigenvector centralization in a collaboration network quantifies the degree to which the most important nodes in the network are linked to other nodes that are also extremely important. High eigenvector centralization signifies that a small number of nodes have numerous connections and are also linked to other nodes with significant influence; this indicates the presence of a highly interconnected network with robust central nodes that enable effective cooperation and the sharing of resources. A high value of eigenvector centralization can indicate the presence of crucial organizations or persons who have a significant effect on connecting different research groups.

In contrast, a low eigenvector centralization indicates that the network's connections are dispersed more evenly, without any one node or small group of nodes exerting dominance over the network's structure. In the context of the European Funded Framework Programs, a low eigenvector centralization value suggests a network that is more decentralized; this means that collaboration and influence are distributed more evenly across participants.

The concept of modularity pertains to the extent to which a network is partitioned into discrete subgroups. A high modularity value signifies that the network exhibits a high density of connections among nodes within the same module while having a low density of connections across nodes in different modules; this indicates the presence of a well-delineated community structure characterized by a higher frequency of cooperation within distinct groups. Within the framework of the European Funded Framework Programs, a high level of modularity can indicate robust internal cooperation across research groups or institutions, which may result in targeted and specialized research outcomes.

A low modularity score suggests less distinct community structures, with a greater number of links between different modules; this implies a network that is more interconnected, with cooperation distributed across different organizations. A low modularity value suggests a greater emphasis on interdisciplinary collaboration, encouraging partnerships between different research fields and organizations. Comprehending these modularity values can assist in formulating tactics to either enhance internal collaboration within particular groups or foster more extensive, multidisciplinary connections throughout the network.

In addition, an attempt is made to apply a power-law distribution to the degree distribution, with γ serving as a metric to quantify the extent to which the network's degree distribution deviates from a random distribution. In the context of a collaboration network, a high value of γ signifies a scenario where a small number of organizations engage in numerous

collaborations, whereas the majority of organizations participate in only a limited number of collaborations. A lower value of γ indicates a more equitable distribution of collaboration among organizations. Furthermore, we computed the average length of the collaboration network, which quantifies the average shortest path between every pair of nodes inside the network. In the context of a collaboration network, a lower average length signifies that collaborations predominantly occur between organizations that share a direct connection, indicating shorter distances between them. Conversely, a longer average length indicates that collaborations occur between organizations that lack direct connections and necessitate intermediaries, implying longer distances. In the context of a collaboration network, elevated levels of degree, betweenness, and eigenvector centralization, as well as γ, can potentially signify the concentration of collaborative efforts within a limited number of organizations. Conversely, diminished values of density, assortativity, and modularity may suggest a more equitable distribution of collaborations across multiple entities. In instances where a collaboration network exhibits a high level of concentration, there exists a notable disparity in the distribution of collaboration among organizations, wherein certain entities engage in numerous collaborations while others partake in far fewer collaborations.

Measuring institutional concentrations

To assess the levels of funding concentration within specific countries, an analysis was conducted on the cumulative distributions of money. The employed CORDIS database contains not only the project budget but also the earned contribution (EC) of each organization. EC depends on its tasks and the specifics of the given country. The (countrywise) institutional concentration is the percentage of organizations in country i that contribute to 80% of the total earned contribution for country i. The details of the calculation can be found in the Supplementary Material.

The underlying premise posited is that within the collaborative network of any given country, a minority of groups hold a significant proportion of the available resources. This assumption originated from the Pareto principle, sometimes known as the 80/20 rule, as proposed by Pareto. This principle posits that a relatively small proportion of causes or efforts can account for a significant majority of effects or outcomes. The data on participant funding, encompassing the periods from FP5–H2020, were organized into subgroups on the basis of member state categories (old and new member states), nations, and programs. The organizations within the subgroups were organized in a decreasing manner by the amount of funding acquired, ranging from the highest to the lowest. The cumulative funding allocated to each subgroup was computed, and subsequently, the organizations were ranked by their respective proportions of financing. The groups that constitute 80% of the financing were classified as 'top performers', whereas the remaining organizations were labeled 'periphery'. The table shown herein illustrates the proportion of organizations, expressed as a percentage of the total number, that are accountable for securing 80% of the financing in each member state of the European Union. This technique, which can be described as naive, uncovers a property of collaboration networks that has not been extensively examined previously.

Measuring concentrations of implementation structures

Following the methodology introduced by Kosztyán et al. (2022), the analysis framework can be divided into three fundamental parts: (1) project membership calculation, (2) relationship estimation and (3) simulation. Figure 3 shows the structure of the analysis.

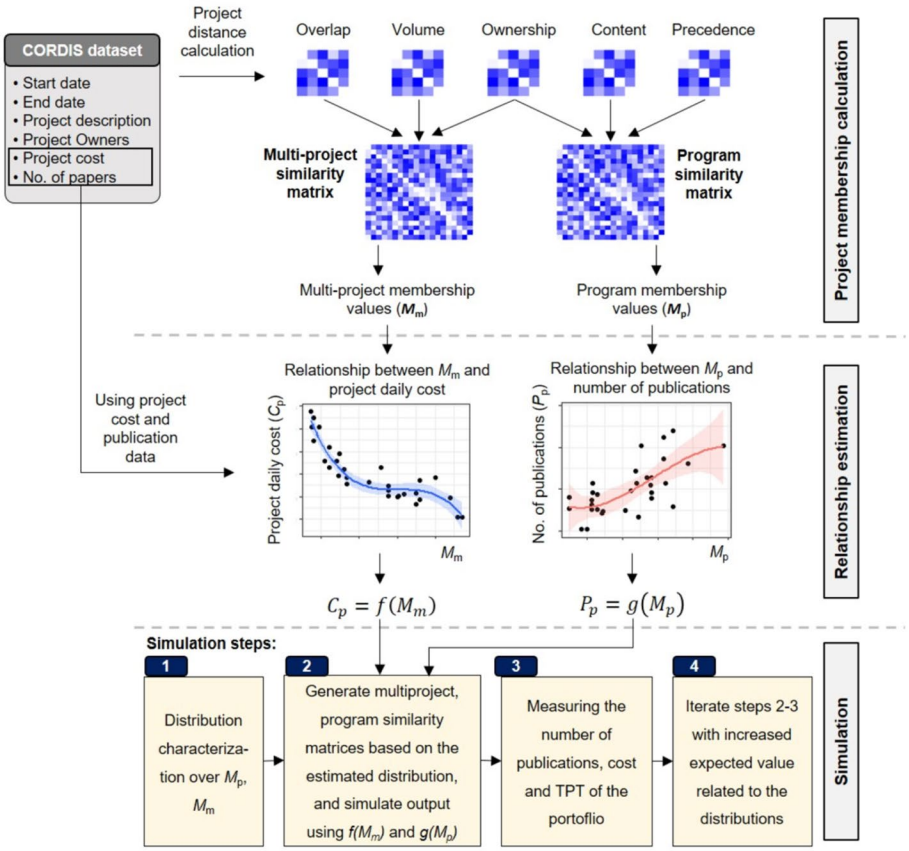


Fig. 3 Analysis framework

Project membership calculation

During the first phase, distance matrices were calculated among the projects on the basis of overlapping durations (d_t), precedence (d_p), ownership (d_o), volume (d_v) and description (d_{xy}). For the detailed calculation of the distance metrics, please see the Supplementary Material. Using the pairwise distance values, the multiproject and program membership values can be calculated as follows:

$$\mathcal{M}_m(p_i) = \max_j \left\{ \left(1 - d_t(p_i, p_j)\right) \cdot \left(1 - d_o(p_i, p_j)\right) \cdot \left(1 - d_v(p_i, p_j)\right) \right\} \tag{1}$$

$$\mathcal{M}_p(p_i) = \max_j \left\{ \left(1 - d_p(p_i, p_j)\right) \cdot \left(1 - d_{xy}(p_i, p_j)\right) \right\} \tag{2}$$

where p_i and p_j denote the i^{th} and j^{th} projects within H2020, respectively, and where $\mathcal{M}_m(p_i)$ and $\mathcal{M}_p(p_i)$ are the multiproject and program membership values related to project p_i, respectively.

Relationship estimation

The aims of this phase are (1) to identify how multiproject membership affects the daily cost of projects (C_p) and (2) to determine how program membership affects the number of publications (P_p) as the project output. To characterize the relationships, curve fitting was performed. After finding the best-fitting curves, functions $f(\mathcal{M}_m)$ and $g(\mathcal{M}_p)$ are saved.

Simulation

The aim of this phase is to simulate the performance of the entire portfolio while using the information related to the relationships among project membership values, time, cost and total number of publications. After generating similarity matrices (for both multiprojects and programs) on the basis of a selected expected value, project-level estimations were performed via $f(\mathcal{M}_m)$ and $g(\mathcal{M}_p)$ to estimate the output and daily costs of each project, respectively. These results were aggregated, and duration, i.e., total project time (TPT), was calculated for the entire portfolio. The expected value for the generation was changed in a stepwise manner, and the TPT, daily cost, and total number of publications were measured at each iteration for the entire portfolio.

Results

Structural concentration

Table 4 shows the main structural properties of the collaboration networks.

The scale and complexity of the network comprising vertices (nodes) and partnerships (edges) have expanded over time, mirroring the European Union's objectives to promote knowledge exchange and collaboration in research and development. The observed changes in the network metrics, including network density, modularity, assortativity, degree and betweenness centralization, suggest a decrease in the level of interconnection, integration, clustering, dominance, and intermediation among nodes. Nevertheless, the centralization of eigenvectors has remained consistently high, suggesting that a small number of highly linked nodes continue to serve as crucial links to other prominent nodes. The stability of the parameter γ is indicative of the persistent variability observed in the degrees of nodes. The average path length decreased, implying enhanced interconnectivity and a reduced distance between nodes within components; however, these changes were accompanied by

Table 4 Evolution of network indicators from FP5-H2020

	FP5	FP6	FP7	H2020
Vertices	33,668	21,578	39,471	55,613
Edges	346,495	403,031	608,128	933,905
Components	1240	61	134	590
Density	0.00061	0.00173	0.00078	0.00060
Assortativity	−0.05454	−0.08354	−0.10862	−0.10395
Degree centralization	0.07786	0.18036	0.20041	0.16456
Betweenness centralization	0.04086	0.10222	0.12509	0.08152
Eigenvector centralization	0.98578	0.97654	0.98546	0.98787
Modularity	0.57640	0.49722	0.48231	0.53868
Gamma (γ)	2.13676	2.26921	2.16957	2.27602
Average length	3.25531	2.92061	2.89846	2.89809

a diminished overall density. The observed decrease in assortativity within the network implies that the players within the network engage in collaborative efforts with partners that possess complementary attributes, aligning with the assumption made by the European Union. The diminishing role of intermediaries and the reduced reliance on centralization could impede the efficacy and widespread dissemination of research findings.

Institutional concentration

Table 5 shows the institutional concentrations of FP5-H2020. Each value in the table represents the percentage of the number of institutions in the given country that received 80% of the subsidies in the given framework program.

Table 5 Institutional concentration by countries from FP5-H2020

Joining period	Country name	FP5	FP6	FP7	H2020
Before 2004 (mean values)		16.63%	13.46%	17.37%	11.41%
Old member states	Austria	26.05%	20.30%	19.95%	11.06%
	Belgium	21.44%	13.13%	19.40%	10.55%
	Denmark	19.01%	19.23%	14.74%	7.29%
	Finland	15.03%	17.85%	13.20%	10.86%
	France	18.50%	11.40%	20.60%	12.84%
	Germany	13.95%	11.47%	14.61%	7.34%
	Greece	22.49%	13.02%	16.36%	32.60%
	Ireland	10.53%	11.25%	17.53%	11.06%
	Italy	18.40%	17.03%	17.10%	10.60%
	Luxembourg	30.00%	40.00%	29.21%	38.39%
	Netherlands	11.83%	11.81%	12.32%	7.59%
	Portugal	18.54%	23.50%	22.07%	17.77%
	Spain	17.74%	15.58%	25.26%	11.03%
	Sweden	16.63%	10.30%	15.03%	8.88%
	United Kingdom	10.21%	8.28%	10.27%	3.65%
After 2004 (mean values)		26.19%	27.89%	29.40%	20.79%
New member states	Bulgaria	30.23%	30.04%	31.88%	27.39%
	Croatia	29.63%	29.21%	31.70%	28.22%
	Cyprus	25.93%	18.75%	33.05%	31.04%
	Czechia	27.36%	27.03%	31.53%	11.89%
	Estonia	19.35%	23.67%	25.64%	9.78%
	Hungary	26.97%	27.85%	27.97%	20.66%
	Latvia	20.91%	29.91%	23.33%	15.29%
	Lithuania	25.00%	30.11%	29.59%	23.69%
	Malta	27.03%	26.09%	33.70%	20.86%
	Poland	23.56%	26.79%	25.31%	15.22%
	Romania	32.52%	34.09%	32.83%	29.36%
	Slovakia	26.64%	28.86%	35.14%	21.35%
	Slovenia	22.46%	24.53%	25.07%	14.77%
Total		17.50%	15.82%	18.81%	12.59%

Table 5 presents an analysis of the leading organizations that earned 80% of the funding in EU nations. This analysis offers additional understanding of the distribution of funding across different framework programs. The predominant feature exhibited by the time series data presented in the table is the discernibly increasing concentrations of funding. Notably, the phenomenon of concentration is not limited solely to more developed member states but rather extends to all countries. In addition to the transient decrease in concentrations observed in FP7, it is evident that the share of high-performing institutions responsible for 80% of financing has consistently decreased in size across most nations in the succeeding FPs. Importantly, the transitory rise in decentralization observed in FP7 was a consistently observable occurrence across all member states, suggesting a structural outcome rather than an individual response. Importantly, FP7 exhibited the lowest level of institutional concentration for both long-standing and recently joined member states. Conversely, the almost complete Horizon 2020 (H2020) framework program displayed the highest degree of institutional concentration. Hence, we conducted a comparative analysis of the implementation structures employed in the two framework programs that have been formally finished.

Figure 4 shows the distribution of projects on the basis of program and multiproject membership values related to H2020 and the FP7. In both subfigures, x represents the multiproject membership value, y represents the program membership value, and z represents the project frequency.

Figure 4a shows that in H2020, there are numerous projects that show strong program characteristics and many others that simultaneously show both program and multiproject characteristics. In addition, it is important to investigate whether this distribution is different than that of the former, i.e., FP7. The most striking differences between H2020 (Fig. 4a) and FP7 (Fig. 4b) are that (1) the number of multiprojects and programs increased in H2020 and (2) there were significantly more projects included in both multiprojects and programs. This result, despite the initial goals of H2020, indicates that the earned projects are concentrated in fewer organizations. In addition, to earn grants, former experience with project funding is emphasized.

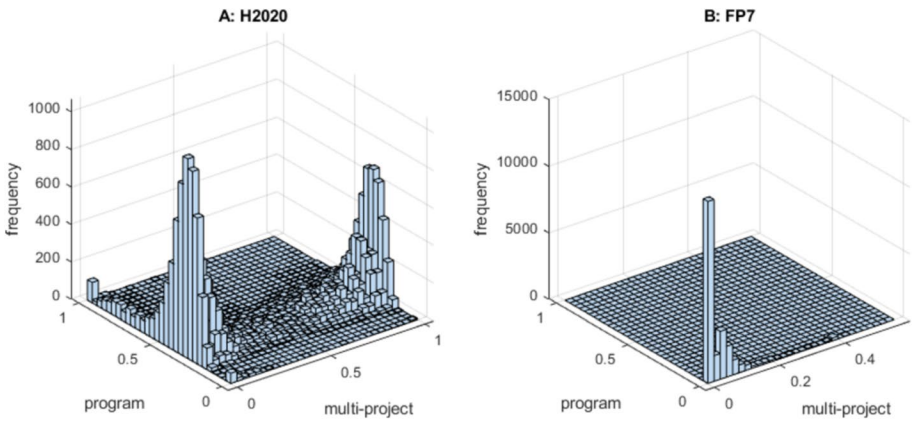


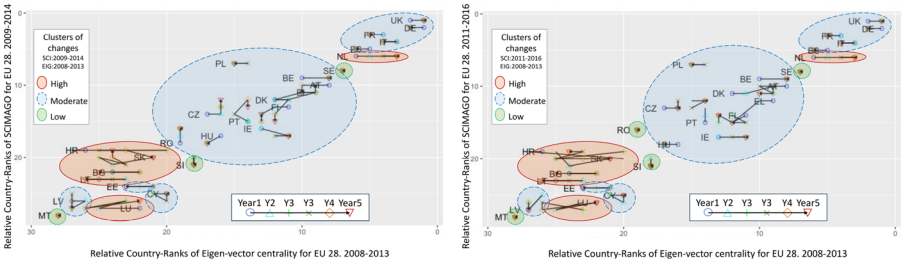
Fig. 4 Comparison of the two frameworks

Concentration versus excellence

The locations of each organization are known. An aggregated countrywise network can be specified to analyze countrywise collaboration. In the aggregated network, node-level indicators, such as centralities, can be calculated. The eigenvector centralities in the countrywide collaboration network can be ordered. In this way, we can determine how embedded a country is in the collaboration network. We argue that countries whose institutions are more embedded, i.e., whose institutions play a central role in consortium networks, also occupy a higher position in the country ranking according to the SCImago Journal and Country Rank database. Considering that publications can be published even 1–3 years after the project is closed, comparisons were evaluated with 1- and 3-year delays. We were also interested in how this position would develop when it was calculated each year. We clustered the data according to the size of the movements. On the basis of the movements in the rankings, we were able to identify three groups, which are shown in Fig. 5.

Figure 5 shows the embeddedness of organizations in countries measured by average eigenvector centralities in a collaboration network and SCImago's country ranking positions with 1-year (a) and 3-year (b) delays.

Figure 5 shows that countries whose institutions are better embedded in the cooperation network are generally in a higher position in the SCImago country ranks. In this case, the relative ranking means that only the rankings of the EU-28 countries in comparison to each other were examined in the country rankings. This finding strengthens the assumption that institutional concentration is attributed primarily to institutional excellence. However, if we examine the movement of the relative rankings, we can see that primarily horizontal shifts are observed; i.e., although the embeddedness of the institutions of the given country changed, this did not change the relative rankings either 1 or 3 years later. This phenomenon is common and especially evident for countries that are at the bottom of the relative rankings as well as those that are at the top. With respect to movements, we did not observe any significant difference between the 1- and 3-year delays. During this period, according to SCImago, neither the rankings of the European countries, compared with those of the non-EU countries, nor the rankings between them increased significantly. It seems that active participation in grants conserved the differences in existing excellence between the institutions of each country.



(a) 1-year delay in rankings between centralities and country ranks

(b) 3-year delay in rankings between centralities and country ranks

Fig. 5 Movement of countries' rankings in eigenvector centrality and the relative country ranks in the SCImago Journal and Country Rank for 28 EU members

Concentration versus performance

Figure 6 shows the relationship between the multiproject membership value and the daily project cost. The black dots represent the observations for the H2020 projects, whereas the green dots depict the observations for the FP7 projects. The solid blue and red lines represent the fitted curves for H2020 and FP7, respectively. The corresponding prediction The bounds are denoted by dashed lines.

Figure 6 shows that although daily costs increased in H2020 and the slope of the fitted curve was smaller for H2020 projects, the cost-reducing effect of multiprojects is still observable. This result indicates that the FP7-related observation by Kosztyán et al. (2022) is true for H2020. Figure 6 illustrates why it is worthwhile for organizations to coordinate several projects simultaneously by forming consortia, thus allowing them to reduce their daily costs by sharing resources. If this direction is supported by further calls for proposals, then the number of multiprojects increases, as shown in Fig. 4.

Figure 7 depicts the relationship between the program membership value and the number of publications in H2020. To achieve acceptable goodness of fit, fitting was performed for three different intervals in terms of the program membership value. Low values were considered where $M_p < 0.35$, medium values were considered where $0.35 \leq M_p < 0.6$, and finally, high membership values were considered where $0.6 \leq M_p$. Different cutoff points were examined, but this structure achieved the best results from the goodness-of-fit and interpretability perspectives. The blue dots represent those projects where strong multiproject characteristics were highlighted, meaning that $M_m > 0.7$ in those cases. The red solid lines denote the fitted curves for the observations.

Figure 7 shows that the FP7-related observation (Kosztyán et al., 2022), namely, that the increase in the rate of programs increases publication output, is still relevant for H2020. The reason for this phenomenon is that building on the previous experience of former projects can accelerate the production of publications. More precisely, Fig. 7 shows that this increasing

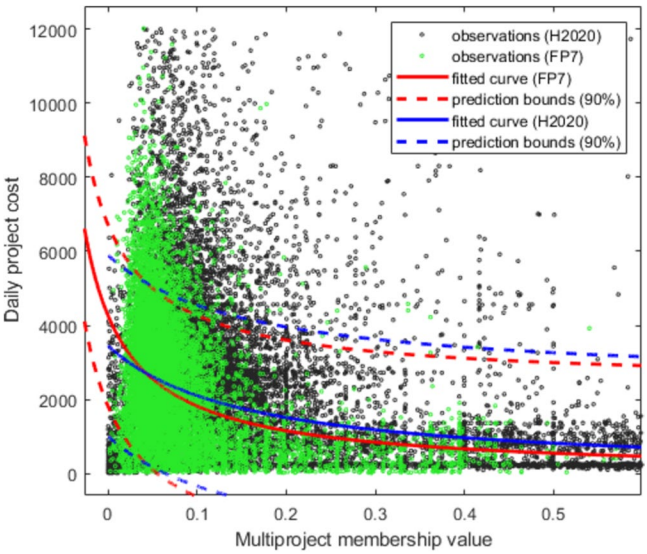


Fig. 6 Comparison of the two frameworks (project daily cost)

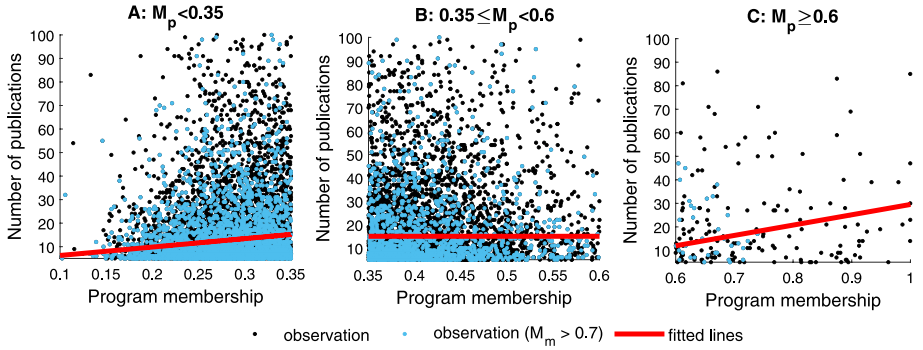


Fig. 7 Relationship between the number of publications and the program membership value

effect can be observed in the cases of low (Fig. 7a) and high program membership values (Fig. 7c), but the effect is weak in the medium interval (Fig. 7b). Those projects marked with blue dots have a lower publication output than do those without parallel project implementation. Figure 7b also shows that in the middle phase, where the program character is already significant, the publication-enhancing property of programs that build on previous experience is not prevalent because such projects run in parallel. These results indicate that the output-increasing effect of programs is undermined by the need to share resources among several parallel projects. In other words, the benefits (daily cost reduction and increase in publication output) of the two structures (multiprojects and programs) work against each other.

Figure 8 shows what would happen if the ratios in complex (multiproject, program) structures were increased or decreased compared with the actual concentrations in FP7 and H2020.

Figure 8a shows that the increase in the number of H2020 projects (approximately 1.5 times the number of FP7 projects) and the increase in program proportion caused significant improvement in the number of publications compared with the program design under the FP7. This result is in line with the observations of Nelis et al. (2022) and Park et al. (2023) on the publication inflation effect. In the case of FP7, the publication output increased monotonically; at the same time, the H2020 curve pattern changed because of the increased number of multiprojects, and the actual output (the blue "x") was near the function maximum and thus could not be further improved significantly. Figure 8b clearly shows that the daily project cost is lower than that in FP7 because of the increased proportion of multiprojects (see red and blue "x"s). The curves, however, show different patterns, indicating that in the case of H2020, the decreasing effect is not as strong because of the increased number of programs. Figure 8c shows no difference in the patterns of the two curves; however, in the case of H2020, the actual TPT is greater due to the increased program proportion. As Fig. 8d shows, the TPT is less sensitive to changes in multiproject proportions in the H2020 case than in the FP7 case.

Discussion

This study comprehensively examined the changes in different aspects (such as structural (see Table 4), institutional (see Table 5) and implementation (see Fig. 4)) of concentration in EU-funded FPs. Although we found that the concentration of the collaboration structure has increased in the H2020 framework program, its extent is the least significant. In line with the literature, we found that the pattern of the structural

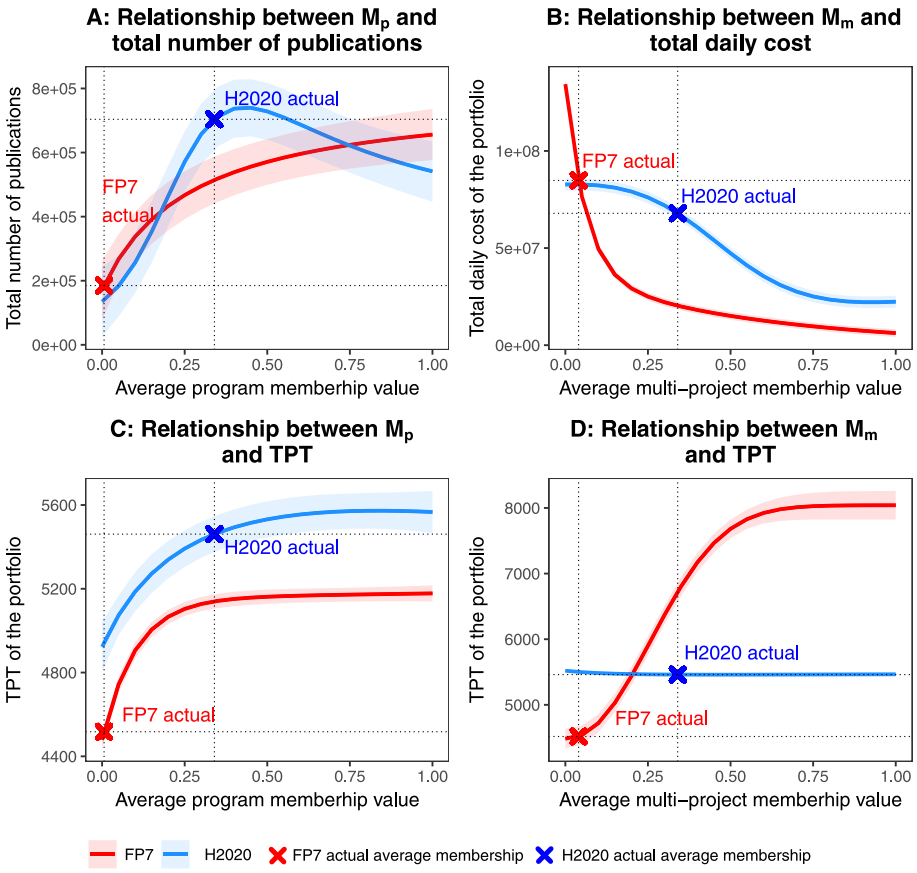


Fig. 8 Simulation results

concentration is remarkably stable (Balland et al., 2019; Ancona et al., 2023). The EU's Framework Programs indicate that networks are expanding in both scale and intricacy (see Table 4). This aligns with the European Union's objective to promote the exchange of knowledge and cooperation across networks for research and development, hence fostering scientific and innovative advancements. The declining assortativity inside the network indicates that the actors in the network conformed to the EU's expectation that mutually supportive and complementary actors collaborate on shared projects. The relative stability of modularity in the collaboration network, as Chessa et al. (2013) also argued, seems to support that the fragmentation of the European Research Area persists. In addition, as Breschi and Cusmano (2006) and Enger (2018) noted, membership in a closed community (i.e., module) can strengthen over time, adding to the cumulative advantage of participating institutions. The growing concentration of research participants, along with the declining interconnectedness of the network, is a worrisome trend as project consortia become less tightly connected. The findings on institutional concentration introduce a novel aspect to Hoekman et al. (2009)'s "elite structures," thereby enhancing the literature by demonstrating elite institutions (even in a network context) and broadening the scope from scientific publications to FP initiatives. A decreasing

number of intermediaries may impede the efficacy of research programs, such as in university–industry cooperation (Santos et al., 2023). This is further corroborated by the declining betweenness centralization, which also signifies a decrease in the number of intermediary actors between consortia, hence diminishing the likelihood of further multidisciplinary approaches. Opinions are divided into the advantages and disadvantages of increasing institutional concentration (see, e.g. Bloch & Sørensen, 2015; Aagaard et al., 2020). Nevertheless, our research showed, in contrast to the very slowly decreasing structural concentration over time, the institutional concentration changed to a much greater extent. In addition, Table 5 shows that institutional deconcentration and diversification are reversed in the H2020 framework program. This reversal becomes much more apparent when considering both the concentration of institutions and collaborative networks. Our research indicates that an increase in institutional concentration through implementation concentration can enhance cost-effectiveness and publication quality, at least temporarily. Simultaneously, excessive attention may manifest as an impediment to growth. Our work also showed that the H2020 projects approached this limit.

According to Table 5, the percentage of high-performing organizations (those that earned 80% of total grants) in historically powerful FP countries such as Germany, France, the United Kingdom, and Italy is rather low in comparison to the overall number of organizations. Enger (2018) also noted the differences in the inequality of resources between countries, which can also be explained by performance differences (Quaglio et al., 2020). At the same time, our study points out that not only can differences be observed between countries but also that the institutional concentration differs between new and old member states. Furthermore, Table 5 suggests that smaller groups that perform well are associated with larger institutions that perform well. An important characteristic of Table 5 is the contrast between the older and newer member states. The average share of top-performing institutions in old member states is 10 percentage points lower than that in new member states. Competitive institutions capable of rivaling the prestigious institutions of former member states have yet to materialize in new member nations (Havas et al., 2015). To achieve success in tenders, an increase in institutional concentration is essential in these countries as well. As Piro et al. (2020) reported, size and, in this way, scientific effort are key indicators for successful application. Therefore, notably, in new member states, the concentration of institutions increased dramatically compared with that in other cases. The concentration in Czechia increased by approximately 20 percentage points, whereas in Estonia, the growth was approximately 16 percentage points, and in Poland, it exceeded 10 points. Notably, concentration substantially increased in the majority of new member nations, except for Romania, Cyprus, Croatia, and Bulgaria. Examining the previous member states also uncovers intriguing data, with Greece and Luxembourg exhibiting concentration traits comparable with those of the new member states.

Figure 5 validates the strong association between (structural) concentration and excellence, which, in line with the findings of Piro et al. (2020), is one of the most important key factors for earning grants. The institutions with exceptional research and publication activities in each nation play a central role in the consortia. Therefore, it is unsurprising that the level of institutional concentration is elevated in these countries. Simultaneously, when analyzing the evolution of rankings over time, it becomes evident that the involvement of national institutions in consortia can undergo significant changes even within the framework program period. However, it is a new finding that this does not impact the growth of scientific performance in the short or medium term. Consequently, we can deduce that grant allocation not only reflects past academic achievements but also maintains those positions. Therefore, even within the context of the most diverse framework program, FP7,

it is evident that there was no trend toward equalization in scientific achievements among countries.

As shown in Table 5, FP7 had the highest level of diversity among the four framework programs analyzed, whereas H2020 demonstrated the greatest concentration. Consequently, the intricate implementation mechanisms of H2020 have experienced substantial growth. These two findings suggest that similarly in a project portfolio (Klingebiel & Rammer, 2014) the organizations within the consortium had to distribute their resources among multiple projects owing to the high concentration of institutions working on grant-funded projects; this led to an increase in the number of complex implementation structures (see Fig. 4). Although framework programs cannot be considered pure project portfolios, what we learned from project portfolio management research (Geraldi et al., 2022) running many projects simultaneously offers the potential to decrease expenses by using shared resources. This correlation, previously observed solely in the context of project portfolios, was illustrated in both the FP7 and H2020 cases (see Fig. 6). This result illustrates why it is worthwhile for organizations to coordinate several projects simultaneously by forming consortia, thus allowing them to reduce their daily costs by sharing resources. If this direction is supported by further calls for proposals, then the number of multiprojects increases, as shown in Fig. 4.

When the H2020 and FP7 framework programs are compared, the implementation structure (refer to Fig. 4) aligns with the changes in institutional concentration (refer to Table 5 concentrations in the FP7 and H2020 framework programs). This large change can be attributed to several interrelated factors, which were identified by Calvo-Gallardo et al. (2022) and reflect the evolving landscape of European research and innovation. An important element is the increasing complexity of societal challenges that H2020 aims to address, which requires a more comprehensive approach to research. In contrast to FP7, for which a primary focus was on promoting scientific excellence, H2020 places greater emphasis on the importance of interdisciplinary collaboration and innovation in addressing urgent challenges such as climate change, health, and sustainable development (Calvo-Gallardo et al., 2022). Our study showed that this shift in focus has led to the formation of multiprojects and program structures that allow institutions to pool resources, share expertise, and leverage synergies across various projects. As a result, the implementation structures in H2020 are characterized by a higher degree of complexity, reflecting the need for coordinated efforts among diverse stakeholders to achieve impactful outcomes. Another contributing factor to the emergence of different implementation structures is the strategic evolution of funding mechanisms and policies within the European Union. H2020 introduced more sophisticated frameworks for resource allocation, encouraging institutions to engage in collaborative consortia that can manage multiple projects simultaneously. This strategic shift not only promotes efficiency in funding distribution but also fosters a culture of collaboration among research entities. Additionally, the lessons learned from the FP7 have likely influenced institutional behavior, prompting organizations to adapt their project management strategies to better align with the goals of H2020. The emphasis on shared resources and collective problem solving has led to an increase in complex project structures, as institutions recognize the benefits of working together to enhance their research capabilities and maximize the impact of their contributions to the European research ecosystem. Overall, these factors highlight the dynamic nature of research funding and the necessity for adaptive strategies in response to changing priorities and challenges in the R&D landscape.

Examining the three types of concentration, we can see that the structural concentration changes the least, and the institutional concentration, especially the implementation

concentration, changes the most over time. In addition, parallel project implementation carries inherent hazards because of the finite nature of resources, where the main resources with finite limits involve the researchers themselves. Given that numerous projects are part of both a program and a multiproject structure in H2020 simultaneously (see Fig. 4), the observed performance improvement in project portfolios inside program projects is lower than suggested, as previously reported in the literature and confirmed in the FP7 (Kosztyán et al., 2022). The primary driver of this phenomenon is the rise in the simultaneous execution of projects and the sharing of resources, driven by institutional concentration (see Figs. 4 and 7). These results indicate that the output-increasing effect of upscaling projects into programs is undermined by the need to share resources among several parallel projects. In other words, the benefits (daily cost reduction and increase in publication output) of the two structures (multiprojects and programs) work against each other.

If Sørensen et al. (2016). We consider publication performance a proxy of excellence and observe that complex implementation structures, such as programs that leverage the outcomes of each other's projects, can enhance publication performance and consequently contribute to increasing excellence (see Figs. 7 and 8). However, since framework programs are similar to a project portfolio, an increased concentration of awarded projects runs simultaneously as a result of institutional excellence, and in this way, institutional concentration can diminish publication performance and thereby obscure the potential for increasing excellence.

Summary and conclusion

The focus of our study was to analyze three aspects of concentrations and their consequences for productivity and excellence. This study aimed to analyze the progression of institutional concentration in the four most recent framework programs. In line with previous studies (see e.g. Balland et al., 2019), our findings also indicated that the parameters of the collaboration network exhibited minimal changes (structural concentration). In contrast, our research also showed that the concentrations of institutions experienced significant alterations. The FP7 has the lowest level of institutional concentration, whereas H2020 has the highest level of institutional concentration (RQ_1). As demonstrated by Nepelski and Piroli (2018) in the structural study of collaborative networks, cooperation with institutions of high centrality can confer a comparative advantage to partner institutions. Nevertheless, this collaboration is also advantageous for the coordinating institution since it can secure multiple projects, typically resulting in substantial budgetary gains, hence enhancing institutional concentration. However, this research has also shown that this increase in institutional concentration has its limits. As Havas et al. (2015); Enger (2018) showed, there are serious differences in the distribution of resources and, in this way, in the scientific performance between the old and new member states. During our research, we have shown that the increase in institutional concentration is most noticeable in new member countries, which also try to overcome their competitive disadvantage. The explanation for this is to be found in the size effect (Lepori et al., 2015). The review of Aagaard et al. (2020) already summarized the advantages and disadvantages of the institutional concentration of funding; nevertheless, our findings showed that the institutional concentration significantly impacts the complex structures (such as multiprojects and programs) used for implementing the projects (RQ_2) (i.e., implementation concentration). The presence of greater institutional concentration leads to the adoption of intricate implementation

structures, which may involve multiple projects, either as multiprojects or programs (RQ_3). A recent study (Kosztyán et al., 2024) indicates that a crucial explanatory variable for the establishment of collaborative relationships in H2020 project awards is prior successful experience, which informs program formation, particularly when the partner, especially the coordinator, possesses an ongoing, successful project. In addition, this research indicates that the rise in complex structures is a result of the increase in institutional concentration. Alongside the potential of increasing complex structures for collaboration and success highlighted by Kosztyán et al. (2024), this research also finds the cost-effectiveness and the anticipated surplus in publication output appealing. Multiprojects can achieve cost reduction via resource sharing. Moreover, programs have the potential to enhance publication performance and thus institutional excellence (RQ_3). However, if organizations are burdened with managing numerous simultaneous projects as a result of increased institutional concentration, this can lead to a decline in performance (RQ_4).

In this study, the complex nature of the concentration was examined. We showed that they are correlated with each other, but the greatest change is the concentration of complex implementation structures. The utilization of complex implementation structures, which leads to cost reductions in multiprojects and an improvement in the program-to-publication performance ratio, can be seen as a double-edged sword (C_1). While the benefit of increasing efficiency and productivity drives institutions toward enhanced concentration, importantly, limited resources impose constraints on both efficiency and performance enhancement (C_2). Our modeling analyses indicated that we are approaching this limit. Continuing to expand institutional concentration will not lead to improvements in performance, excellence, or efficiency (C_3). Therefore, decision-makers should carefully consider the extent to which they attempt to affect institutional concentration. Given that social relevance already holds significance in the tenders for Horizon Europe, it is plausible that the trend of increased concentration of institutions in similar projects will be reversed; this is because, on the one hand, other factors, such as utilization, will gain prominence alongside excellence, and on the other hand, smaller institutions will have greater ease and speed in applying research outcomes.

The results of this study have many ramifications for politicians, funding agencies, and research institutions engaged in research, development and innovation projects. This study highlights that the concentration should be examined in a complex manner. In addition to structural concentration, one cannot forget the examination of institutional and implementation concentrations and their effects on productivity and excellence. The significant correlation between institutional concentration and excellence highlights the need to recognize and utilize the contributions of outstanding research institutions in consortia. Policymakers and funding agencies should evaluate the impact of these institutions on scientific performance and assure their continued involvement while also acknowledging the possible risks involved with simultaneous project implementation. Decision makers should be aware that increasing institutional concentration may no longer result in higher productivity because of the fragmentation of research activity caused by parallel projects.

Moreover, the examination of intricate project frameworks within the FP7 and H2020 emphasizes the necessity of the meticulous allocation of resources and cooperation among participating organizations. Policy-makers and funding agencies should acknowledge the potential advantages of coordinating various projects via consortia to minimize expenses and optimize resource allocation. Nevertheless, it is crucial for them to be aware of the inherent dangers linked to the simultaneous execution of many projects, especially regarding limited resources and the potential negative effects on productivity. Furthermore, the consequences for research performance and output from a

high concentration of institutions necessitate a fair and equitable approach when making decisions. Although institutional quality plays a crucial role in determining grant allocation, it is important to also examine the wider impact of focusing too much on institutional concentration on the long-term viability and replicability of research, development, and innovation activities. Policy-makers and financial agencies should endeavor to achieve a harmonious equilibrium between fostering exceptional quality and embracing variety within research, development, and innovation initiatives to guarantee enduring resilience and influence.

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Data availibility All Python codes are available for decision-makers, who can test different proportions of single projects, multiprojects, and programs to optimize the structure of the desired project portfolio.

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