An Economic Analysis of the European Space Economy

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Programa de Doctorado en Finanzas y Economía Cuantitativas

Bilbao, 15 de febrero de 2021.

ACKNOWLEDGEMENTS

I, first, want to thank the Department of Economic Analysis of the University of the Basque Country; my supervisors, María Paz Espinosa and Aitor Ciarreta, with their stimulating questioning, inspiring technical support and motivation and my tutor, Victoria Ateca, for her challenging approach and continuous support. Without them, this thesis could not ever be possible.

I am sure, after these years of space sector analysis, we share certain love for the space activity and a notable interest about the economics around it.

I want also to thank the two institutions that have supported this thesis. The University of the Basque Country, for giving me the opportunity to be educated in economic sciences and to open the scope of my understanding as an engineer. I am especially grateful to Elena Iñarra and Federico Grafe, supervisors of my minor thesis and Josu Arteche; and the Aerospace Technology Centre (Fundación CTA), where, together with my colleagues, I have had the chance to be closely connected to the space industry.

Financial support from MINECO (PID2019-108718GB-I00) and the Basque Government (IT 1336-19) is gratefully acknowledged. European Space Agency and European Commission project data availability have been also key for this thesis.

Finally, I want to thank my family and closest friends for their support and encouragement.

To Marta, Juan and Carlota.

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Resumen

El sector del espacio está creciendo desde muchos puntos de vista. Se trata de un sector económico en expansión que genera importantes contribuciones a la actividad económica en términos de producción, empleo y desarrollo de capacidades tecnológicas. Además, gracias a ese desarrollo tecnológico, es capaz de ofrecer beneficios a la sociedad en dimensiones como la seguridad, la agricultura y alimentación o la salud. Por último, ayuda a la generación de intangibles como el orgullo nacional o los modelos valiosos para despertar vocaciones científicas entre los más jóvenes. La exploración y la explotación del espacio exterior se configuran así, como la 'próxima frontera', abriendo la puerta a nuevos y potencialmente ilimitados retos y posibilidades para el progreso social

El objeto de estudio de esta tesis es la innovación que se genera como principal producto de las actividades de exploración y de explotación del espacio. Se estudian las características del sector espacial en Europa utilizando una aproximación económica. Para ello, se tienen en cuenta las especiales características económicas del sector, en gran medida derivadas de las propiedades de la innovación como bien económico, así como los retos que se plantean para las organizaciones e instituciones del sector espacial europeo. Empresas y gobiernos interaccionan para conseguir sus objetivos y promueven instituciones como mercados o alianzas en las que el diseño de los incentivos determina un mejor o peor funcionamiento encaminado a la consecución de objetivos sociales.

Las instituciones del espacio están condicionadas por el extraordinario entorno en el que se desarrollan muchas de las actividades de exploración y explotación del espacio, el espacio exterior. Hay características económicas y aspectos regulatorios de este entorno que explican muchos de los argumentos para que la intervención pública haga posible la actividad espacial. Algunos de los rasgos más relevantes son el riesgo y la incertidumbre inherentes a estas actividades, así como la definición de los derechos de propiedad sobre algunos de los recursos espaciales y características como la rivalidad en su consumo o la posibilidad de exclusión de sus beneficios que generan fallos de mercado.

Hay diferentes áreas de la Economía que pueden aportar interesantes puntos de vista y herramientas para el análisis de esta actividad. Por ejemplo, los modelos de Organización Industrial ayudan a entender las características de la innovación y de la interacción estratégica entre agentes. La Economía Pública trata de las soluciones a los fallos de mercado para conseguir niveles óptimos de provisión ante la presencia de, entre otros, bienes públicos y externalidades, fenómenos muy relevantes para caracterizar recursos naturales del espacio y la innovación como bien económico. La Teoría de Juegos y la lógica de la Acción Colectiva sirven para que la Elección Pública permita entender las motivaciones de los agentes para promover que existan instituciones en las que cooperar y coordinar sus acciones. Los modelos de Economía Espacial y de Geografía Económica explican las relaciones entre las condiciones físicas y las económicas, importantes para sectores susceptibles de generar economías de aglomeración dado su carácter intensivo en conocimiento. El análisis de Redes Sociales, por último, contribuyen con la caracterización de las relaciones de cooperación y de interdependencia de una forma que permite entender qué estructuras emergen de las relaciones y qué posibilidades tiene la política industrial para generar estructuras que favorezcan la difusión del conocimiento entre los agentes.

Europa es uno de los actores relevantes dentro de la *Nueva Economía del Espacio Global*, el término empleado en la comunidad internacional para referirse al conjunto de actores y actividades desarrolladas en la actualidad en torno a la exploración y explotación del espacio exterior. Junto a potencias tradicionales como los Estados Unidos de América o Rusia, operan actores como China, Japón, India, Brasil, Canadá o Irán. Europa, a través de organismos supranacionales de diferente membresía, ha operado siempre de manera conjunta en este contexto internacional, siendo un interesante ejemplo para el estudio de la colaboración en el marco de los procesos de integración económica y política de la zona.

Esta tesis hace un análisis económico de las actividades colaborativas en Europa en el sector del espacio, caracterizando la innovación como un bien económico y analizando el funcionamiento de dos instituciones supranacionales que operan en la promoción de la exploración y explotación del espacio. Por una parte, se estudia un organismo intergubernamental, la *Agencia Espacial Europea* (*European Space Agency,* ESA). Por otra, se estudia el funcionamiento de los programas de investigación de la institución supranacional que goza de forma compartida con sus Estados Miembros de las competencias en espacio, la *Unión Europea*.

Esta tesis está organizada en dos partes. claramente diferenciadas: una delimitación del sector como objeto de análisis económico y un análisis empírico de algunas de las instituciones que favorecen la actividad en el espacio.

El Capítulo 1 delimita el objeto de estudio, la *Economía de la Actividad Espacial* (Space Economy), prestando atención al contexto europeo. Se presenta una caracterización de los bienes económicos: recursos y bienes y servicios producidos. Dado el importante componente innovador y tecnológico del sector, se desarrollan los argumentos sobre las características económicas de la innovación y los fallos de mercado que surgen.

La descripción de los principales agentes e instituciones del sector espacial europeo aparece en el Capítulo 2 en base a tres niveles. En un primer nivel, la *Agencia Espacial Europea* y la *Unión Europea;* en un segundo nivel, los países y sus agencias nacionales; en un tercer nivel, los agentes individuales que conforman los sectores espaciales nacionales: empresas y corporaciones, centros de investigación, instituciones de educación superior y entidades públicas. Esta distinción ayuda a presentar los diferentes enfoques seguidos en los capítulos que conforman la parte empírica de la tesis.

Así, en el Capítulo 3 se estudia el funcionamiento de la *Agencia Espacial Europea* desde el punto de vista de los países y de sus incentivos nacionales para incorporarse a este organismo intergubernamental y/o para contribuir al desarrollo de sus programas. Los incentivos están relacionados con los beneficios de cada país en función de la capacidad de apropiarse del resultado de los programas conjuntos en forma de efectos de ‘spillover’ a otros sectores de la economía nacional. Para representar el modelo de decisión individual que explica la decisión de membresía y de contribución, se modela un mecanismo de contribuciones voluntarias en un juego de provisión de bienes públicos con umbral. De su solución se derivan hipótesis contrastables sobre la relación entre las variables que explican diferencias en los beneficios individuales de los países y su comportamiento observado (unirse a la Agencia y contribuir a programas de suscripción voluntaria). Se construyó un panel para el periodo 1997-2016 que caracteriza la membresía y el volumen de contribuciones para una muestra de países que incluye a los estados miembros, cooperantes, asociados y otros que serían susceptibles de estar en alguna de esas situaciones, dadas las relaciones de cooperación (pasada o presente) en otros ámbitos políticos y tecnológicos. El panel también incorpora las características políticas, económicas, tecnológicas y estratégicas sobre los países.

La estimación de un modelo *logit* de efectos aleatorios permite concluir que la pertenencia a la ESA se explica por la pertenencia a la Unión Europea, por el número de investigadores del país, por el hecho de tener una agencia espacial nacional y por el gasto general en investigación y desarrollo. Para explicar las contribuciones, los resultados de la estimación de modelos *tobit* de efectos aleatorios indican que las variables más relevantes son el gasto general en investigación, la existencia de una agencia, la cantidad de investigadores y la alineación entre la estrategia por campos tecnológicos de la ESA y los intereses sectoriales de la industria espacial nacional. Así. la probabilidad de membresía está determinada particularmente por variables políticas y variables que representan la capacidad de la industria, mientras que las contribuciones también dependen de las variables estratégicas que son indicadores de la capacidad de los subsectores nacionales de la industria para aprovechar los beneficios.

La segunda institución que se examina en la parte empírica es el *Programa Horizonte 2020 Espacio* (*H2020-Space*) de la Comisión Europea. A través de este programa se financian programas cooperativos de investigación en áreas definidas en programas plurianuales. Los agentes elegibles de diferentes países (representados en el tercer nivel de la descripción que hacemos del sector en el Capítulo 2) presentan propuestas de consorcio que son seleccionadas en procesos competitivos y se comprometen a desarrollar la investigación de una forma cooperativa. Así, el resultado del proyecto tiene características de bien público que beneficia a los miembros de cada consorcio y la relación entre éstos puede modelarse por medio de una red social. Del solapamiento de proyectos y actividades cooperativas surge una red social mayor y más tupida, que es el objeto de análisis de los Capítulos 5 y 6. Cada capítulo realiza un análisis desde un enfoque diferente: un enfoque de país y un enfoque de agentes, respectivamente.

El proceso de generación de innovación favorece la emergencia de efectos de 'spillover' a otros sectores productivos dentro de cada país. El Capítulo 4 analiza el *H2020-Space* en el contexto de los países participantes. Con datos de las subvenciones otorgadas para el período 2014-2020, cada proyecto se modela como una red colaborativa, donde diferentes países interactúan y producen un bien público puro cuyo valor se mide por la financiación total recibida del programa. Al describir las actividades cooperativas de investigación de esta manera, desvelamos las características de las colaboraciones en estos proyectos, el flujo de conocimiento creado entre países y cómo la red resultante ha evolucionado en este período. La arquitectura de la red, representada por sus indicadores de propiedad global, afecta la difusión del conocimiento científico y las innovaciones en la industria espacial europea. Los resultados indican que *H2020-Space* ha proporcionado al sector una estructura de 'pequeño mundo', un rasgo que tiene importantes consecuencias para la transmisión de la innovación y la adopción de tecnología en Europa.

El Capítulo 5 considera las interacciones a través de *H2020-Space* a nivel de agentes. Existe una amplia variedad de agentes elegibles para participar en proyectos financiados, por lo que esta es una buena representación de la pluralidad de actores del sector en Europa, más allá de la *Agencia Espacial Europea*, de los países y de las agencias espaciales nacionales. Además, en este capítulo se detallan las redes sectoriales por tecnología, utilizando la clasificación de actividades empleada por la ESA para definir sus programas. Esto permite comparar las redes que surgen en diferentes campos tecnológicos: observación de la tierra, ciencia, vuelo humano, lanzadores, programas de tecnología de apoyo general, navegación y exploración robótica. Se encuentra un entorno de cooperación real en el que las empresas privadas desempeñan el papel de liderazgo del proyecto y son los socios preferidos en los nuevos desarrollos. Además, las instituciones de educación superior muestran una cooperación eficaz entre ellas. La dinámica de la red apunta a un entorno de cooperación que favorece una creciente difusión del conocimiento.

Por último, el Capítulo 6 presenta las principales conclusiones de este trabajo. Se resumen los resultados del análisis empírico y se discuten algunos de los temas que merecerían ser desarrollados y estudiados en el futuro, a la luz de los factores tecnológicos, políticos y económicos que se prevén que definan el devenir del sector en los próximos años.

List of Acronyms

AIC: Akaike Information Criteria

ANBERD: Analytical Business Enterprise Research and Development Classification

ASD: AeroSpace and Defence Industries Association of Europe

BEA: Bureau of Economic Analysis

CFAA: Centro de Fabricación Avanzada Aeronáutica

COFOG: Government Expenditure by Function Classification

COMPET: Competitiveness of European Space Technology

COMM: Communications

CORDIS: Community Research and Development Information Service (European Commission)

CTA: Fundación Centro de Tecnologías Aeronáuticas

EC: European Commission

ECS: European Cooperating State

ECSC: European Coal and Steel Community

EEC: European Economic Community

EGNOS: European Geostationary Navigation Overlay Service

ELDO: European Launcher Development Organization

EOBS: Earth Observation

ESA: European Space Agency

ESRO: European Space Research Organization

EU: European Union

FAA: Federal Aviation Administration

GBAORD: Government Budget Appropriations or Outlays on R&D

GDP: Gross Domestic Product

GPS: Global Positioning System

GSA: European Global Navigation Satellite Systems (GNSS) Agency

GVA: Gross Value Added

HMFL: Human Flight

Horizon2020-Space: Horizon 2020 Space Programme

INTELSAT: International Telecommunications Satellite Organization

LNCH: Launchers

NASA: National Aeronautics and Space Administration

NATO: North Atlantic Treaty Organization

NAVI: Navigation

OECD: Organisation for Economic Co-operation and Development

PPP: Public-Private Partnerships

PROTECT: Protection of European assets in and from space

R&D: Research and Development

RBEX: Robotic Exploration

SCNC: Science

SESA: Space Economy Satellite Account

SME: Small and Medium Enterprises

SU: Soviet Union

TLR: Technological Level Readiness

TT: Technology Transfer

UKRI: United Kingdom Research Institution

UNOOSA: United Nations Offices for Outer Space Affairs

UPV/EHU: University of the Basque Country UPV/EHU

U.S.: United States of America

WB: World Bank

Introduction

Introduction

The space sector is growing in terms of the economic activity that it generates, the societal impacts that it delivers in other dimensions, and in terms of intangible values such as national pride. Many consider the exploration and exploitation of outer space the 'next frontier', in the sense that it opens a door to unknown and potentially unlimited possibilities and challenges to the satisfaction of human needs and societal progress.

Object of study

Innovation is the main output that space exploration and exploitation activities generate and this is precisely the focus of this thesis, which studies the characteristics of the sector in Europe using an economic approach. Many special characteristics of the sector are driven by the economic properties of innovation and by the challenges that it poses to organizations. Firms and governments interact and have to promote the emergence and good functioning of institutions such as markets and alliances.

The relevance of economic properties and regulatory aspects of the exceptional environment in which some activities of the space exploration and exploitation take place also characterize space institutions. Elements such as risk, rivalry in the enjoyment of space resources, excludability and property rights determine the emergence of different institutions and are behind many of the arguments that call for government intervention to make exploration and exploitation feasible.

Several fields of Economics are relevant in the study of those interactions. Industrial Organization models help to understand the characteristics of innovation and the strategic interaction among agents. Public Economics carefully deals with market failures and arrangements to reach socially optimal levels of provisions, related with externalities and public goods. Collective Action brings light into what motivates that agents promote the emergence of institutions to cooperate and coordinate. Economic Geography models the relations of physical and economic conditions in the space sector and analyses clustering phenomena. Social networks analysis contributes with the characterization of the cooperation and interdependencies, so to explain the nature of the network as a whole or the relative situation of a particular agent.

This thesis examines the collaborative space activities in Europe, focusing on the functioning of an intergovernmental and a supranational institution involved in the promotion of the space exploration and exploitation, namely the *European Space Agency* (ESA) and the *European Union* (EU) and its most recent research programme in the sector, the Horizon 2020 Space Programme (H2020-Space). Europe is a relevant player in the global New Space Economy and it is a particularly interesting example of collaboration based on the political and the economic integration processes.

The first part of the thesis delimits the sector, present a description of the economic characteristics of the goods and services produced, the agents involved and the emergent institutions. The second part of the thesis is based on the results of empirical research performed to test hypotheses about why agents in the European Space Economy behave as they do, and about the characterisation of the relationships among those agents.

Plan of the thesis

This thesis presents the results of the research on collaborative space innovation processes in Europe in the following way.

Chapter 1 makes a delimitation of the object of study, the Space Economy, with a special focus on the European context, a description of the characteristics of the economic goods produced, and of the institutions that emerge. Given the high technological content of the space sector, the economic dimensions of innovation and the induced market failures are specifically considered.

Chapter 2 contains a description of the main actors and institutions for the European space sector: the ESA and the European Union, the countries and their national agencies, and the individual agents, such as firms and research centres. The presentation introduces the different scope used in each of the parts of the empirical analysis.

Chapter 3 studies the *European Space Agency* (ESA) from the point of view of the national incentives of countries to join this intergovernmental institution and to contribute to its functioning. The characteristics of the institution are examined in terms of the individual incentives that country members have to contribute, according to the individual benefits and the capacity of appropriability of the output from the joint programmes.

Using a voluntary contribution mechanism for a public good provision game, a model is proposed to represent the individual benefits of countries to join and/or contribute to the alliance. The theoretical model sheds testable hypotheses about the heterogeneous benefits for individual agents and the expected behaviour. The empirical evidence that is used to test the hypotheses related to the correlates of membership and national contributions to mandatory and voluntary programmes is collected using a variety of data sources. A panel covering the 1997-2016 period is constructed, to characterize the membership and contributions for a sample of countries that includes ESA member states, cooperating countries and some non-members. The panel further incorporates individual characteristics of the countries in terms of political, economic and technological characteristics of the research sector and of space national industries.

The estimation of a random-effects logit model allows concluding that ESA membership is explained by European Union membership, the number of researchers in the country, having a national space agency and the Gross Domestic Expenditure on general R&D. However, results of the estimation of a random effects logit model to explain the probability that a country is a contributor depends on EU membership, expenditure on general R&D and researchers. The estimation of random-effects tobit models to explain the national mandatory and voluntary contributions indicate that the most relevant variables explaining contributions are the Gross Domestic Expenditure in general R&D, the existence of a national space agency, the number of researchers over population and the alignment with ESA technology fields' activity share. As expected, the probability of membership is particularly determined by political variables and variables that represent the capacity of the industry, whereas contributions also depend on those strategic variables that are indicators of the ability of national subsectors of the space industry to appropriate from the benefits of the joint programmes.

The second institution that is examined is the collaborative research programme of the European Commission, the principal executive body of the European Union. For the 2014-2020 period, the Horizon 2020 Space Programme (*H2020-Space*) has been the instrument of the EU to promote research and development in the space sector. The programme funds, among other actions, cooperative research projects in topics defined in pluriannual work programmes. Agents from different countries present proposals to competitive processes and take the compromise to develop funded projects in a truly collaborative way. Each of the projects constitute in this way a social network where agents interact. The overlapping of projects generates a bigger network and this is the object of our analysis in Chapters 5 and 6. In this thesis, the analysis of *H2020-Space* is done from two alternative points of view: the network of countries participating in the programme, its emergence and evolution, and the network of agents participating. There are different aspects to be analysed under each of the approaches. In the first one, it is particularly interesting to see how innovation flows among participant countries. In the second one, the affinities between different types of agents (public, private…) are examined.

Chapter 4 analyses the *H2020-Space* in the context of participant countries. With data of the awarded grants for the period 2014-2020, each project is modelled as a collaborative network, where different countries interact and produce pure public goods whose value is measured by the total funding received from the programme. By describing the cooperative R&D activities in this way, we unveil the characteristics of collaborations in the projects, the flow of knowledge created among countries, and how the resulting network has evolved in this period to reach the existing network in 2020.

The study of the programme results and its impact on the network architecture is important, as it has the potential to generate spillovers at the national level and facilitate subsequent collaborations. Actually, the architecture of the network, represented by its global property indicators, affects diffusion of scientific knowledge and innovations in the European space industry. The findings indicate that *Horizon2020-Space* has provided the sector with a 'small world' structure, a trait that has important consequences for innovation transmission and technology adoption in Europe.

Chapter 5 considers the interactions through *Horizon2020-Space* at the agents' level. There is a wide variety of agents eligible for participation in funded projects, so this is a good representation of the plurality of the players in the European Space Economy beyond the ESA, countries and national agencies: private for-profit entities, research organizations, higher education institutions, and public bodies. Further, this chapter goes into detail about sectoral networks, using the classification of activities used by the ESA to define its programmes. This allows for the comparison of the networks that emerge in different technology fields: earth observation, science, human flight, launchers, general support technology programmes, communications, navigation, and robotic exploration.

An actual cooperative environment where private companies hold the project leadership role is found. Firms appear to be the preferred partners in new developments. Higher education institutions exhibit an effective cooperation among themselves. Agents as a group, show a high level of alignment with the EU space technology development strategy, matching perfectly with the preferences of ESA member states. Network dynamics points to a cooperation environment favouring an increasing knowledge diffusion.

Finally, Chapter 6 presents the main conclusions of this research and discuss about some insights that would deserve future consideration at the light of current developments and trends in the sector.

Chapter 1

Space Economy and Space Economics: a general overview

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Global Space Economy

The Space Economy started with the pioneer attempts of space exploration in the geo-strategic context of the Cold War. The emerging system was characterised by the division, rivalry and competition between the two superpowers: The United States of America (U.S.) and the Soviet Union (USSR). This led to a space race that started with the launch of the *Sputnik 1* in 1957 and ended in 1975 with the joint *Apollo-Solluz Test Project*, well before the end of the Cold War itself, dated in 1991. Collaborative actions started integrating more countries. In the 1986 space mission where the *MIR* Soviet Space Station hosted astronauts of several nationalities or in the 1998 collaboration between the U.S., Russia, Canada and Japan in the *International Space Station*, probably the most successful example of international collaboration that proves how fruitful pooled efforts can be when compared with individual national efforts (Brennan et al., 2018; Sandler 2004).

The huge technological achievements, the strategical interest of the space exploration and exploitation, and socio-economic trends related to globalization increased the interest of space not only by other countries, but also by agents different to nations. Nowadays, there are many national superpowers in the space, with the original U.S. and Russia plus Europe, Canada, India, Japan, Brazil and Iran. Having started with the narrow view of space exploration for military aims, the sector has enabled the emergence of 'super markets' in the areas of space travel and tourism, mining of resources, manufacturing opportunities, satellite technologies, … and it has facilitated the entry in those markets of many firms and even private entrepreneurs, the 'astropreneurs' (Brennan et al., 2018; Vernile, 2018). For instance, the developments of earth observation, communication and all the possibilities to provide new services based on those technologies created business opportunities for private firms and consolidated a competitive sector in Europe.

The first economic activity around space, the so-called 'Old Space Economy', rapidly expanded and created opportunities for radical innovation in those areas, thus leading to the emergence of the 'New Space Economy'. In this thesis, when the Space Economy term is used, it will refer to this last phenomenon. Figure 1.1 below, reproduced from European Parliament (2020), shows how the addition of new activities actually transformed the scope of the field and opened it to new operators.

These processes have led to a redefinition of the Space Economy. To adapt to the changing trends in the space related activities, organizations have recently adapted their definitions, choosing broad approaches to encompass the complexity and the potential of space operations and uses, as well as the growing diversity of actors in the sector.

Figure 1.1. The configuration of the New Space Economy.

Source: European Parliament (2020)

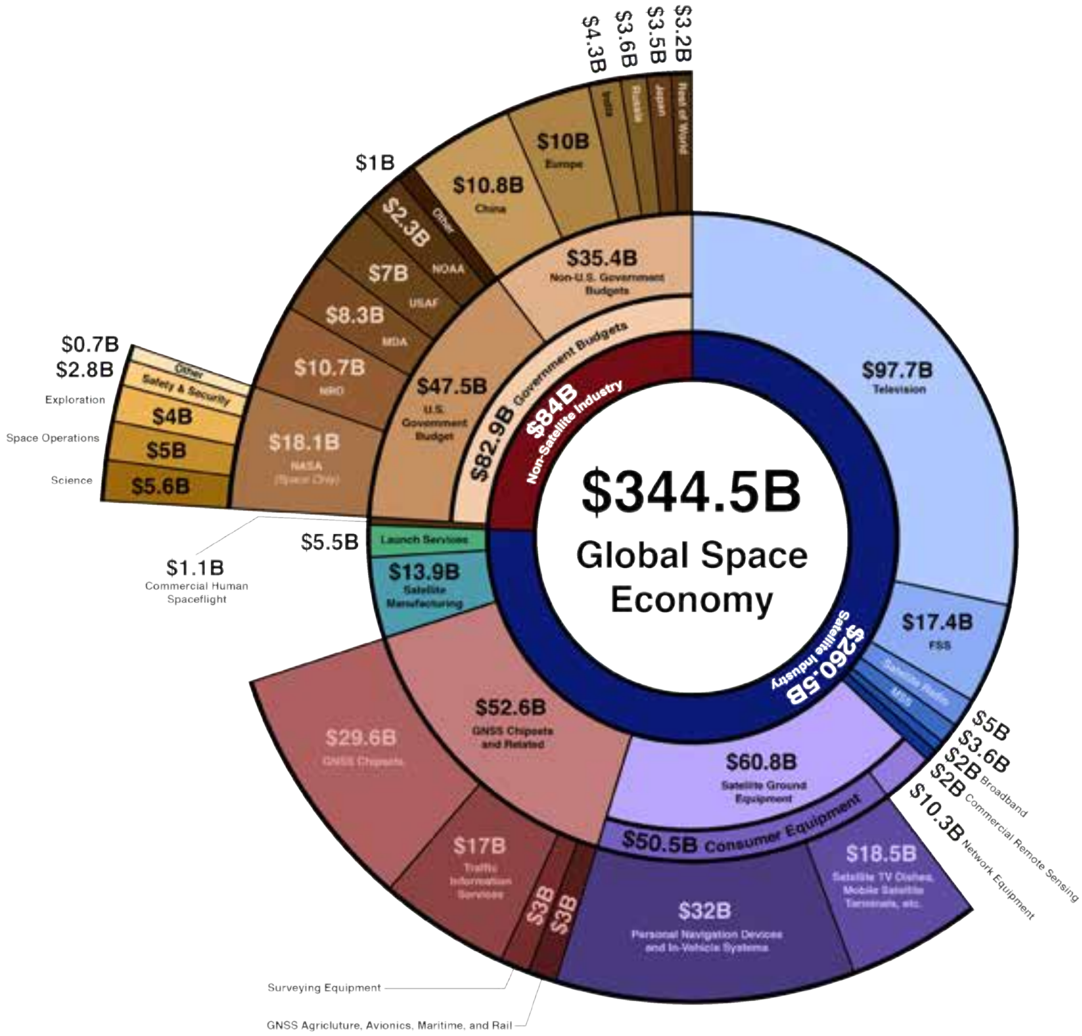
It is extremely difficult to describe this global and changing phenomenon with a plurality of agents taking part. It is further more difficult to quantify its economic relevance in terms of the generated output and employment. Figure 1.2 shows the representation of the global space economy and the estimations about the main sectors and public actors involved as it is included in the Yearbook of the *Federal Aviation Administration* of the U.S for the year 2016, the last year available and reported in their Compendium of 2018 (FAA, 2018). According to the estimates published there, the global Space Economy, as the addition of private industry revenues and government, was 345B U.S.D., with about 76% being revenue generated by companies manufacturing and providing services, and 24% being government space budgets (83B U.S.D.) and commercial human spaceflight (2B U.S.D.).

The figure for government space budgets for the year 2019 (including G20 governments) is estimated by the Organisation for Economic Co-operation and Development (OECD) to be around 70B U.S.D. (OECD, 2020).

Private companies in the manufacturing sector generated around 13.9B U.S.D. in the satellite manufacturing sector, with around 246.6B U.S.D. generated by services that comprise television, mobile, fixed and broadband communications, remote sensing, satellite systems and launch services.

Doing empirical research on the Space Economics is a challenging task. The main problems are the scarcity of harmonized data, the existence of lags between the initial investments and realised outcomes, and, as the OECD points out, the evolving nature of the Space Economy itself and the increasing connections with other economic sectors (OECD, 2020). For instance, Guffarth and Barber (2017) observe that, aerospace industry, civil aeronautics, military aeronautics and space industries overlap concerning actors and technology, and that they mutually influence each other. From the statistical point of view, space closely intertwines with the aeronautical sector in the NACE system, which is the statistical classification system in the European Union (OECD, 2012).

Figure 1.2: The Global Space Economy in context, 2018.



Source: Federal Aviation Administration (2018)

Because of all those sectoral interrelations, estimating the economic value of the space activities is extremely complicated, and several ongoing initiatives try to complete this task. George (2019) explained the benefits of using traditional Input-Output tables to quantify the impact of the sector, once delimited in a way such that industrial codes were carefully selected for an exercise about the commercial space sector in Florida and in the whole U.S. using official statistics. The United States' Bureau of Economic Analysis (BEA) that prepared a Space Economy Satellite Account (SESA) for the first time recently conducted one of the most sophisticated attempts to quantify the economic impact of the space activity. The SESA intends to measure the relative importance of the space sector on the U.S. economy in terms of contribution to *Gross Domestic Product* (GDP) and to measure the contributions of individual industries to the Space Economy and employment estimates (Highfill et al., 2019). The recently released statistics for the 2012-2018 period shows that, in 2018, the U.S. Space Economy accounted for $177.5 billion of gross output, 0.5 percent ($108.9 billion) of current-dollar GDP, $41.2 billion of private industry compensation, and that it supported more than 356 000 private sector jobs (Highfill et al., 2020).

The most defining feature of the space sector is its high intensity in research and development (R&D). According to the *Analytical Business Enterprise Research and Development* (ANBERD) classification proposed by the OECD, this is the first economic sector in terms of the average level of R&D intensity, where the measure of R&D performance intensity is indicative of high technology (Galindo Rueda and Verger, 2016). The estimated average value of R&D as a percentage of the *Gross Value Added* (GVA) of the space industry – embedded in the D303 ANBERD code for 'air and spacecraft and related machinery' – is 31.69%, the highest value for the industries classified in the first category of 'High R&D intensity industries'. Finest statistical delimitations and measures of the space sector itself would certainly lead to even higher values for this metric. Other sectors included in this category are, for the manufacturing sector, pharmaceuticals (27.98% of R&D as percentage of GVA) and computer, electronic and optical products (24.5%). On the non-manufacturing sector included in the first category, the two sectors also have lower values than the space one, as even scientific R&D has a value of 30,39%, followed by software publishing 28.94%.

The high technology profile of the sector and the efforts to develop new technologies, products and services are, without any doubt, the most important characteristic of this sector. A characteristic that influences all the agents that engage in this sector, the economic activity that they produce, how they generate institutions (markets and collaborative instances), and how they interact in those institutions.

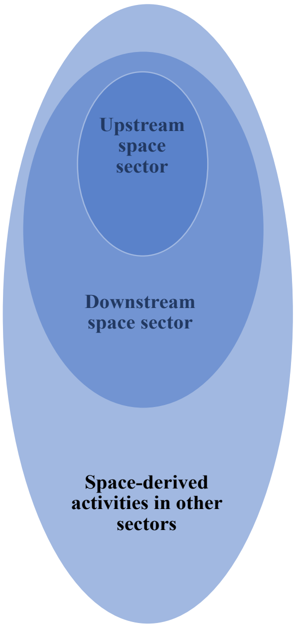
Defining the Space Economy

The OECD defines Space Economy in the following terms (OECD, 2012):

"*The full range of activities and the use of resources that create and provide value and benefits to human beings in the course of exploring, understanding, managing and utilizing space. Hence, it includes all public and private actors involved in developing, providing and using space-related products and services, ranging from research and development, the manufacture and use of space infrastructure (ground stations, launch vehicles and satellites) to space-enabled applications (navigation equipment, satellite phones, meteorological services, etc.) and the scientific knowledge generated by such activities. It follows that the Space Economy goes well beyond the space sector itself, since it also comprises the increasingly pervasive and continually changing impacts (both quantitative and qualitative) of space-derived products, services and knowledge on economy and society*."

The complexity of the Space Economy is organized by the delimitation of different perimeters (OECD, 2020). Figure 1.3 shows how up to three different components are identified in the full range of activities considered. This distinction is relevant in terms of measurement and in terms of the analysis of value chains and actors in each of them. The first component is the co-called 'upstream sector', which could be considered the core activity including R&D, manufacturing and launch. In the second component, the 'downstream" space sector, daily operations of space infrastructure and down to earth products and services directly related to satellite are considered. Last, there is a third perimeter for the economic activities derived from space but that do not depend on its functioning.

Figure 1.3: Delimitation of the Space Economy



Scope	Activities
Scientific and technological foundations of space programmes, manufacturing and production of space infrastructure	Fundamental and applied research, scientific and engineering support, Dedicated ancillary services (e.g. insurance) Supply of materials and components Design and manufacturing of space equipment and subsystems Integration and supply of full systems Space launch
Daily operations of space infrastructure and 'down-to-earth' activities that directly rely on the provision of space capacity (satellite technology, signals or data to exist and function)	Operations of space and ground systems Supply of devices and products supporting consumer markets (e.g. GPS-enabled devices, set-top boxes, selected GIS) Supply of services supporting consumer markets (e.g. satellite television broadcast)
New activities in various economic sectors that derive from or have relied on space technology transfers	Activities / products / services derived from space technology but not dependent on it to function (e.g. ad-hoc space technology transfers in the automotive or medical sectors)

Source: OECD (2020)

Even the same OECD had adopted the broad and comprehensive definition that intendedly avoids narrow industrial classifications or value-chain approaches in the past. There are at least two reasons for this choice. On the one hand, the sector is growing and evolving based on technological grounds, an evolution that facilitates the development of new services and products that leads to new applications and to spillovers in other sectors. This makes the space sector not only valuable by itself and its growth potential but also an enabler of growth in other ones. On the other hand, there is a further integration of space into society and into the economy, as can be seen in the relevant activities included in the third perimeter of the delimitation of the sector, leading to more value creation and socio-economic benefits in the scientific, technological, strategic, societal or economic dimensions (OECD, 2019 and ESA, 2019).

As an example, Figure 1.4 presents an overview of the benefits derived from the *European Space Agency* (ESA) space activity, articulated in the four pillars that currently define its operational plans and in the aforementioned dimensions. This reflects that the three perimeters of the Space Economy in the area and how activity space transcends the mere R&D activities. Further, the figure shows the great relevance of spillover and adoption effects, as well as the growing integration of technological, economic and institutional considerations.

Figure 1.4: The societal value of space activity for European societies.

Source: own elaboration based on ESA (2019) and ESPI (2020)

Research-intensive industries have the potential to create technological spillovers and knowledge externalities that are difficult to define. They are complex phenomena that trigger situations where the private rates of return to R&D investment are lower than social return rates, leading to firms underinvesting in R&D, as other agents can benefit from the firms' newly created knowledge without incurring in costs. Competitive and cooperative efforts to develop R&D take different forms, with patent races widely studied in the literature of Industrial Organization (Tirole, 1988) and less studied in the form of cooperative R&D activities (d'Aspremont and Jacquemin, 1988) because of the problem of modelling and quantifying these externalities

Other phenomena that are important in the space sector are technology transfers and adoptions. The main difference between these phenomena and spillovers is that, in the case of transfers and adoptions, firms need to invest capital to develop their capacities, not only free-riding on the public good characteristics of others' innovations. In the case of space, the potential to extend space related achievements to other areas, in intended or unanticipated ways has been an interesting and well-documented phenomenon since the beginnings of space exploration in the 60's. For example, estimates indicate that, since its introduction in the 80's, the *Global Positioning System* (GPS) may have generated socio-economic benefits worth some 1.4 trillion U.S.D. in the United States alone (OECD, 2020). More recently, developments transferred to areas such as health and medicine, environment monitoring and agriculture and food sectors, transports and manufacturing, hospitality industry and sports (OECD, 2019). Two examples are the micro interferometer and the ROSAT X-rays algorithms. The Italian *Mach-Zehnder* project to develop the micro interferometer, a technology to analyse planetary gases, applies to the monitoring of air quality and of fermentation and other chemical processes in wine production. The research from the *German Max Planck Institute for Extra-terrestrial Physics* on ROSAT X-rays has enabled a mathematical algorithm used to analyse data from X-ray satellite ROSAT and has also contributed to a computer-aided early recognition system to recognise melanomas through digital image analysis. Recent applications of technologies developed by the ESA include air purification systems in hospital intensive care wards, radar surveying of tunnel rock to improve the safety of miners, and enhanced materials for a wide variety of products.

The research intensity of the space sector creates also a distinctive knowledge base in its industrial activity that differ with other ones jointly developed in previous stages, such as the aviation sector. Following the classification of industries according to their degree of embeddedness into knowledge bases, by which they can be described as synthetic (engineering-based), analytical (science-based), or symbolic (artistic-based), the space industry is found to be mostly analytic, whereas the aviation industry is mostly synthetic (Broekel and Boschma, 2011; Boschma, 2018). When applied to the study of the two industries, this feature had important implications in how knowledge networks develop in each one, with the space industry characterized by denser collaborative networks explained by higher levels of trust among agents, lower levels of competition and high competences. Besides, key players in the space knowledge networks are firms and public agencies more frequently, whereas associations are the essential brokers in the case of the aviation industry.

The growth in other sectors and the potential to contribute to contemporary societal challenges have been key reasons for countries to launch national space programmes or to join already existing cooperative transnational efforts. Some authors consider that the major challenges for which space may play a relevant role are related to the environment, the use of natural resources, the increasing mobility of people and goods, and its consequences in the form of growing security threats and the claims of the information society (OECD, 2005). To unlock full potential, some specific framework conditions need to fulfil. According to the analysis of the OECD related to legal, regulatory and public awareness aspects.

Regarding legal aspects, the *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies* (the *Outer Space Treaty*) – opened in 1967, and followed by four subsequent treaties and five regulatory principles– and the *International Telecommunications Union* – a United Nations' Agency since 1949 – serve as the constitutional legal framework. They set the principles and procedures constituting space as defined by the *United Nations Offices for Outer Space Affairs* (UNOOSA, 2017). This international governance framework, together with national legislation that regulates issues as appropriation of extra-terrestrial resources (e.g., asteroid mining), creates a legal context that suffers, in the words of OECD, of major gaps (OECD, 2005). For the regulatory framework, there are issues related to the allocation of limited resources as radiofrequency and geostationary orbital slots (a relatively scarce resource in an apparently unlimited common resource), the proliferation and management of space debris, and the lack of standardization that prevent the full potential development of the sector, as well as the dilemma between market competition and state interference. Last, the OCDE identifies the obstacle of the lack of visibility of space activities and the poor understanding of the value of space-related services in the daily life of the population, which translates into disengagement and little public awareness.

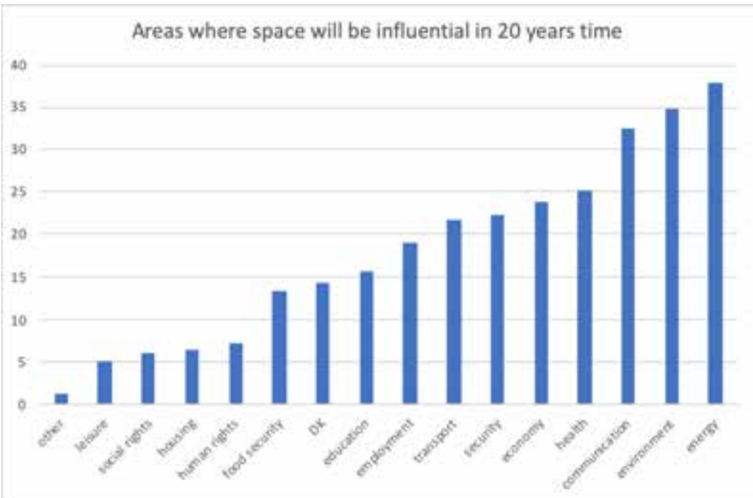
Public awareness and attitudes

Public awareness of the benefits of space activities and attitudes of public support vary a lot by country, depending on individual and contextual characteristics. A Eurobarometer survey was conducted in 2013 to explore the opinions of Europeans about the role of space-based services in daily lives, assess the perceptions of their role in addressing societal challenges, threads and expectations over a sample of 27,680 citizens living in the 28 countries of the EU (Eurobarometer, 2013 and 2014).

Considering the needs of European citizens in about 20 years, the survey envisaged the technologies, products and services derived from space activities that could be available to improve daily life and address global future challenges such as health, security, housing, environment, energy, transport, communication, food security and distribution, leisure, education, social rights, human rights, employment and economy. This is the most updated source of information to describe attitudes and to explore the variations among countries and in terms of individual characteristics for the citizens of the European Union.

When asked about the areas in which the space derived technologies and services are most likely to play an important role in 20 years' time, three main areas emerge, with proportions of the population that identify them above 30%: communication (32.5%), environment (34.9%), and energy (37.9%). Areas above 20% are transport, security, economy and health.

Graph 1.1: Europeans' perceptions about space derived technologies

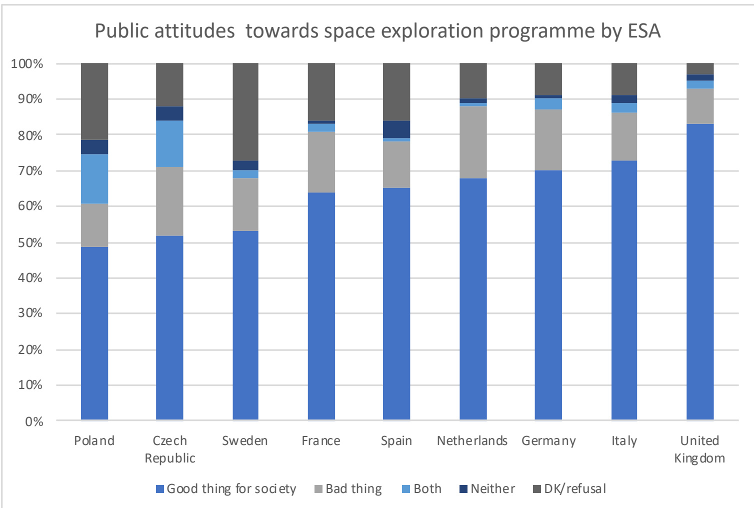


Source: Own elaboration with data from Eurobarometer 79.4 (Eurobarometer, 2013)

The identification of the benefits of space activity for the society are one of the drivers of national policies to enhance space exploration and exploitation in the form of public industrial and R&D policies. A more recent survey conducted by the *Pew Research Center,* the *International Science Survey*, from October 2019 to March 2020, asked about the advantages and disadvantages of the government's space exploration programme at the ESA for a sample of European countries. Countries included are the Czech Republic, France, Germany, Italy, The Netherlands, Poland, Spain, Sweden and the United Kingdom (together with the views of the national agencies of the following countries: Australia, Brazil, Canada, India, Japan, Malaysia, Russia, Singapore, South Korea, Taiwan and the United States).

The question posed in the following terms: *"Consider all the advantages and disadvantages of the government's space programme at ESA. Overall, would you say this has mostly a good thing or a bad thing for society?"* 'Good' and 'bad' were available answers, with spontaneous both or neither allowed, though not read during the survey. We present the distribution of resources by countries in Graph 1.2. The positive visions vary a lot by country, ranging from a mere 41% in Poland to values above 70% in Germany, Italy and the United Kingdom.

Graph 1.2: Positive and negative views towards the national space programme at ESA



Source: Own elaboration with data from the International Science Survey 2019-2020 (Pew, 2020)

When considering how these differences could relate to the respective national contributions to the ESA (represented by the contributions per inhabitant for the last available year, 2016), we find a positive, though somehow weak, correlation of 0.41 between the two variables.

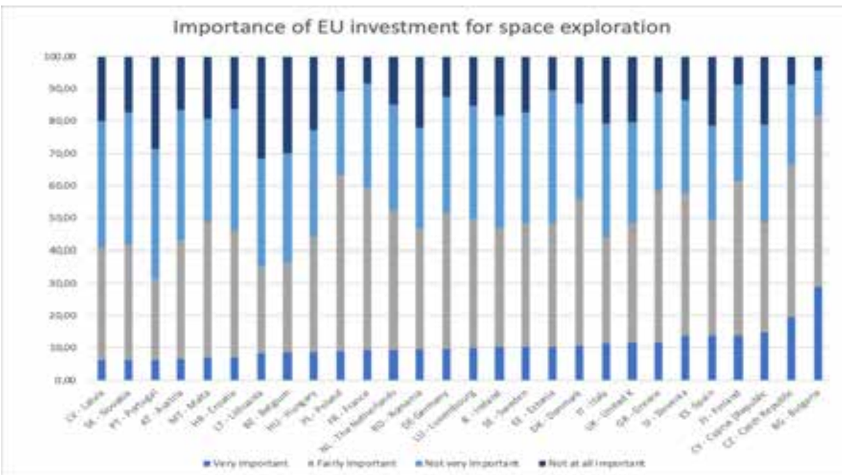
Table 1.1. National contributions to the ESA and positive opinions about their societal impact

	Poland	Czech Republic	Spain	Netherlands	United Kingdom	Italy	Sweden	France	Germany
ESA contribution (Euros/inhabitant)	1,01	1,31	2,76	4,28	5,03	7,41	7,77	10,27	10,38
Government's programmes at ESA are mostly a good thing for society (%)	48	52	65	68	83	73	53	64	71

Source: ESA and Pew (2019)

The Eurobarometer in 2013 also asked about the importance of the EU investment for space exploration (Graph 1.3). Considering the EU-28 sample, here also opinions diverge a lot and are not consistent with the more updated situation as represented in the Pew survey. Actually, the country with the worse appreciation of his programme at ESA, Poland, is one of the countries where more opinions identify the importance of the investments of the EU for space exploration (63.17% adding ‘very important’ and ‘fairly important’, just following Bulgaria – 81.64% -, and the Czech Republic – 66.43%).

Graph 1.3: Opinion about relevance of EU investment for space exploration



Source: Own elaboration with data from Eurobarometer 79.4 (Eurobarometer, 2013)

Research on public attitudes has analysed the evidence contained in the *Eurobarometer* (for European countries), the *Pew Research Center's Surveys* (for an international sample of countries), and in the *General Social Survey* (for the U.S.). Knowledge, interest and public support are different dimensions that influence public awareness of space benefits. Previous research has found that individual correlates of attitudes and spending preferences in the U.S. are related with scientific literacy and opinions about science (Nadeau, 2013), religiosity (Ambrosius, 2015), with mixed results for political affiliation and partisanship (Nadeau, 2013; Burbach, 2019). In the international sample covered in the Pew Science survey, some cross-country regularities emerge. Men and more educated people (though not especially those with more scientific education) are found to be more positive about the impacts of space programmes on society, while only modest differences by age or by political ideology are found (Pew, 2020).

Attitudes and policies

Individual attitudes translate into political preferences at the country level, thus creating different attitudes of states toward space exploration and exploitation that reflect into different policies and levels of public expenditure on space activities. For a sample of European countries and the period 2004-2011, Machay and Pochylá (2013) analyse how public expenditure in space evolves with economic fluctuations, finding that budgets allocated to space do not show clear continuity in spending and that they evolve more or less randomly in time, creating significant funding fluctuations. This suggests the existence of some 'national preferences' that are manifested through distinct behaviours. In the case of the European countries, they could be classified as 'activist' countries (notably Denmark, Norway and Germany, which attracts also some central European countries), 'active' countries (Finland and Ireland), and 'passive' countries (with some of the biggest ones in space activity, as France, United Kingdom, Italy and Spain), according to their public policies.

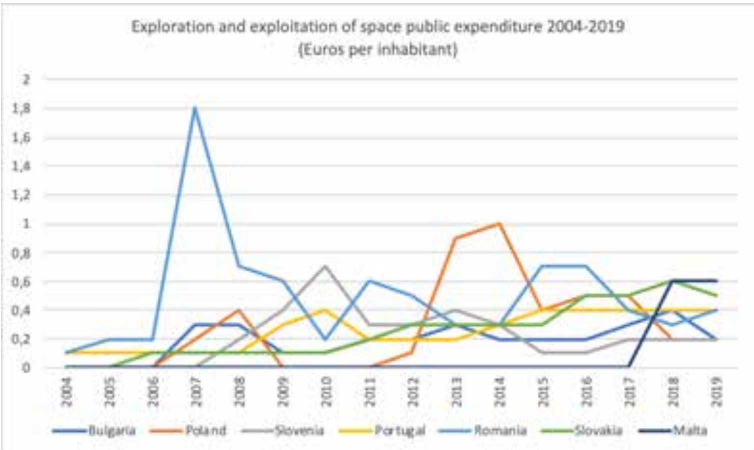
It is difficult to find an accurate measure of public expenditure on space exploration and exploitation. Eurostat offers a representation of this magnitude: The *Government Budget Appropriations or Outlays on R&D*, (GBAORD). It is a way of measuring government support for R&D activities that includes all appropriations (government spending) given to R&D in central (or federal) government budgets, with provincial (or state) government posts included only if the contribution is significant. Thus, it provides information about the priority that governments give to different research activities. This is a superior alternative to the traditional *Government Expenditure by Function Classification* (COFOG), as there is a special code for space exploration and exploitation. Further, it complies with some of the indications of the 2015 edition of the Frascati Manual, the blueprint for R&D indicators (OECD, 2015).

There is a wide variety in the levels of public expenditure on space for EU countries. In the following three graphs (Graphs 1.4 a, b and c), we show the evolution of the *Government Budget Appropriation or Outlays on R&D in Space Exploration and Exploitation*, measured in Euros per inhabitant for the 2004-2019 period and showing the last data released by Eurostat. Countries grouped into three categories according to expenditure in 2019. The first group includes countries with expenditure below one euro per inhabitant; the second one, countries with expenditure between 1 and 5 euros; the last one, countries that spend more than 5 euros per inhabitant.[1]

We cannot find clear patterns of how this expenditure variable relates to the business cycle across countries. This result similar to the finding of Machay and Pochylá for the 2004-2011 period (Machay and Pochylá, 2013).

We do not replicate their analysis in order to classify the countries regarding their responses of space expenditure to changes in National Income – what they refer to as 'income elasticity' – , but we can highlight some facts. For instance, some countries reached by 2019 values notably higher than those reached at the beginning of the 2007 financial crisis, with sharp increases for Ireland (93.5%), Germany (68.2%), Italy (55%), and Sweden (43%).

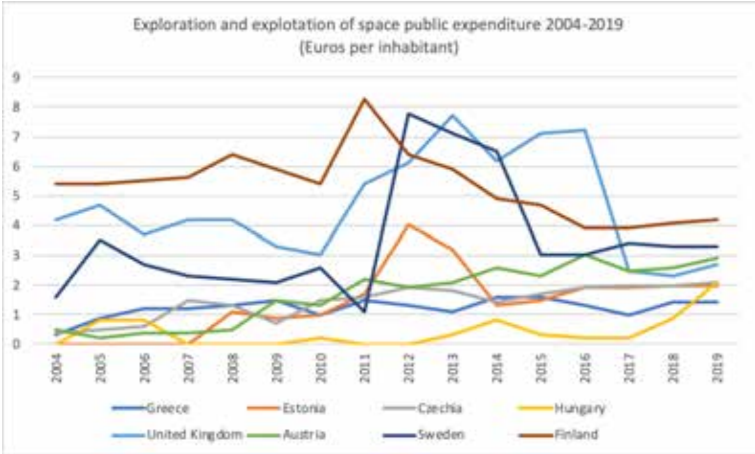
Graph 1.4a: Government Budget Appropriation or Outlays on R&D in Space Exploration and Exploitation – group 1



Source: Own elaboration using data from Eurostat

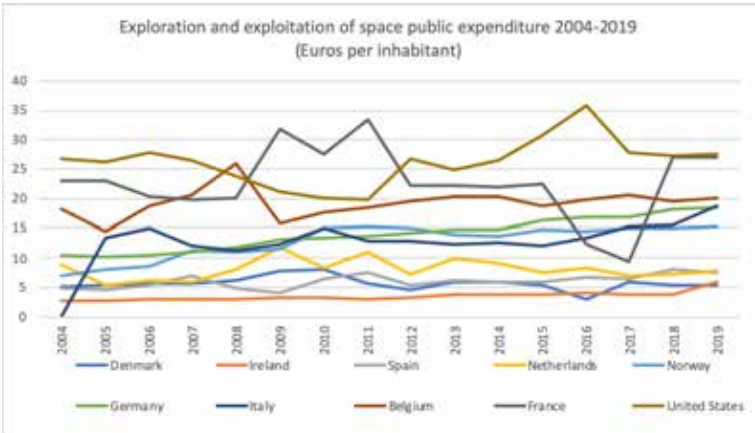
[1] Total GBAORD by NABS 2007 socio-economic objectives [gba_nabsfin07].
NABS07 - Exploration and exploitation of the earth. Euros per inhabitant.
Static link to the series is available here.
For comparison purposes, the time series for the United States is included in this last group, as this is the country with the highest overall expenditure in the sector.
NOTE: data for Croatia, Cyprus, Lithuania, Latvia and Luxembourg are not considered either because of lack of data or because the values are small and are rounded to zero in the reporting made by Eurostat.

Graph 1.4b: Government Budget Appropriation or Outlays on R&D in Space Exploration and Exploitation – group 2



Source: Own elaboration using data from Eurostat

Graph 1.4c: Government Budget Appropriation or Outlays on R&D in Space Exploration and Exploitation – group 3



Source: Own elaboration using data from Eurostat

As described in these first sections, the complexity of the activities related to space exploration and exploitation lead to the interactions between a wide variety of agents that relate in markets and that create other institutions. Their motivations are diverse, with national security and technological non-dependence being key for some agents (e.g., countries), and profit maximization being the main driver for others (e.g., firms operating in the sector). Necessarily, the analysis of the Space Economy requires from the concurrence of multiple disciplines that bring different insights into the possibilities of space as a driver of economic growth and social prosperity.

Space Economics as the Economic Approach to the Space Economy

The study of the Space Economy requires multidisciplinary approaches. As noted in Sandler (2004), the logic of space exploration has been very similar to the maritime exploration (and, actually, the regulation in international law has treated outer space in a similar way to international maritime domains). This is necessarily a field of convergence for contributions from technological and science fields, law, international relations, political studies and, of course, economics.

Space Economics is the field where the space exploration and exploitation are the object of economic analysis. The analysis of the challenges to develop economic activity in the outer space is relevant in order to set the rules of the game and to propose suitable governance institutions. In the opinion of some economists, even though a big part of the challenges to the development of activities in the space will be technological, the analytical tools of the economy are already necessary, among others, to design institutions suitable for the development of 'supraurban' societies (Weinzierl, 2018). Some special characteristics of the economic approach to study the Space Economy make it different from law or policy approaches.

At the individual level, the behaviour of the agents grounds in some rational decision-making process, i.e., decisions that optimize their interests, represented by the benefits that can be appropriable by them, in contexts of scarcity of resources and uncertainty about the outcomes of their decisions. This applies to any kind of agents such as individual agents (consumers and firms) and countries. Firms have to take optimally their research investment decisions in order to maximize profits. Since financial and human resources are limited, could alternatively be assigned to other activities. They have to decide optimally if they want to cooperate with each other in the development of a given technology or engage in a competitive process of patent races. Countries have to decide how to allocate a limited public budget to space related activities accounting for the costs and benefits associated to such decisions and considering the opportunity cost of those funds in terms of the forgone benefits of using those funds for alternative public programmes.

At the collective level, these agents create institutions and interact to satisfy their interests and their needs. On many occasions, agents interact in markets. In many others, they interact in other type of institutions such as coalitions or supranational organizations in order to pursue cooperative efforts. In any instance, incentives matter, and the design of institutions has to account for the fact that rational agents will respond to those incentives and will act accordingly.

There are some specific features of the Space Economy, when characterizing the economic behaviour of agents in the exploration and exploitation of the resources of the outer space. Many of them anticipated and discussed in the previous section, thus here we concentrate on the economic characteristics of the goods and services produced in the space activity and in the specific structures of the institutional structures.

Complex product systems. Characteristics and market structures

The space sector nowadays relies on institutional markets with limited room for global competition and that can be modelled as an example of a 'complex product system' (Barbaroux, 2016 and Giannopapa et al., 2018). The remarkable technology level with a high R&D intensity together with the central role of the government who acts as an active agent, a regulator and a customer, determine the functioning of this market (Guffarth and Barner, 2017). In this section, we describe some of the singular features of the sector.

On the supply side, the market is concentrated because there are few agents operating. This characteristic has slightly changed within the last decades with the development of the downstream sector and of the broader perimeter related to services. However, there are still few agents with a large market share of the upstream sector, with big research, manufacturing and assembling capacity. On the demand side, the space sector can be classified as a demand-driven industry, with a very small number of clients demanding the most complex products, as in the case of spacecraft (Barbaroux, 2016). The consequences of this monopsony structure are diverse, ranging from the setting of technological standards to the importance of customers' interests in shaping the life cycles phases of the industries associated with space. This fact typically puts national agencies at a prominent place of the knowledge networks in the space industry, as they are often the most important clients for that sort of innovations (Broekel and Boschman, 2011).

At the beginning, few large transactions characterized the space sector. This is still the case for the economic activity in the narrower perimeters and in the case of the most complex products (e.g., spacecraft). However, the extension of the perimeters of the sector to the space related activities in the last decades has created opportunities for more transactions, notably activities related to satellite manufacturing and services provided from satellites in the form of earth observation and its applications.

In the space sector, markets procurement or contractual mechanisms are a common centralized solution, where the government controls access to the research market (Tirole, 1988). In such mechanisms, the government chooses a certain number of firms, sometimes after a competitive process, and signs a contract with them. The main benefit of these processes is that they avoid excessive duplication of research costs; the main drawback relates to limited yardstick competition. In order to be a successful mechanism, there must be a balance between those two forces. This is easier to attain when the contracting firms and the agency know the value of the innovation because the government is the main customer for the innovation. Space and defence sectors were pioneers in the adoption of this type of contracts, and they are one of the most common ways in which private agents cooperate with national (governmental) or international space agencies.

The presence of the government is not only relevant due to its prominent role as main client of space related innovation, but also because of active regulation and administration of transactions. Besides, considerations about national security, regulations, subsidies and incentives distort competition among the agents in the space industry. The role of the public sector in space has always been active, though also changing according to the accomplishment of up to three different functions. In the first instance, it created market; then, it refined it (in the sense that the government had to solve market failures); last, it tempered that market by means of regulation (Weinzierl, 2018). As we describe below, market failures arise in this economic activity because of the high R&D efforts and the problems with the definition and allocation of property rights.

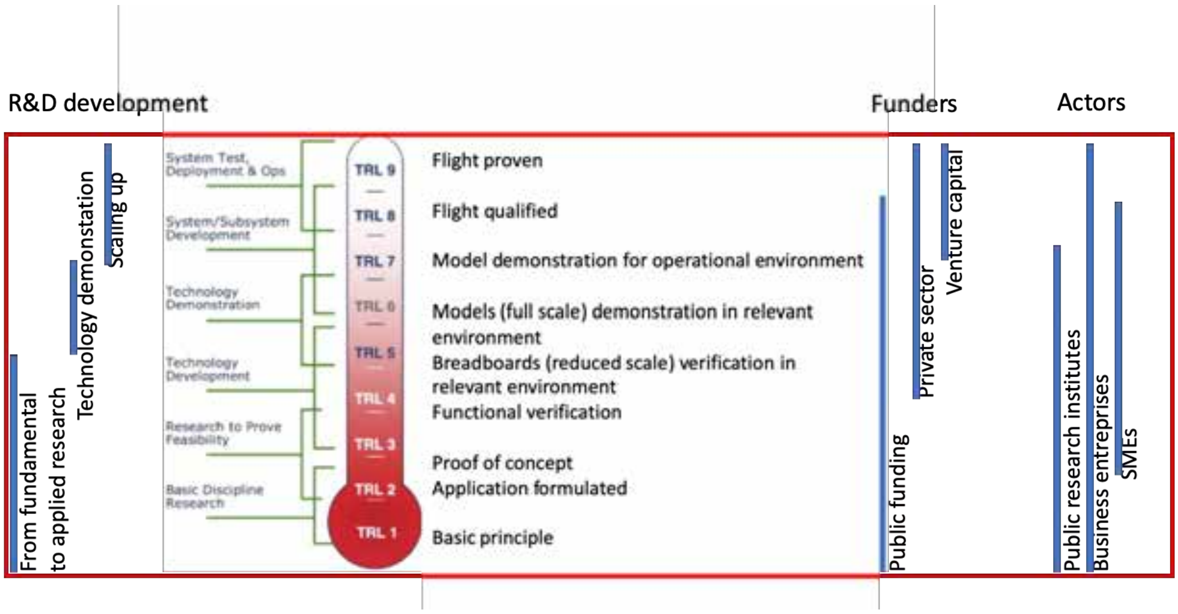
There might be some distortions caused by the intervention of the government by means of policies or regulations (OECD, 2016). As we have seen, the market structures that emerge in the space sector are far from perfect competition. For instance, there are negotiated prices between suppliers and customers, sometimes because of procurement contracts or grants and awards. Rather than engaging in competitive efforts for R&D activities, such as patent races, agents engage in different collaborative actions. Finally, the government as a regulator allows and incentivises these collusive practices to promote innovation and it does not take into consideration competition policies, indeed ill suited for this particular sector (EC, 2013). In what follows, we discuss the relevance of risk in its technological dimension and the need for cooperative efforts and institutions.

Risk

The *Federal Aviation Administration* (FAA) reports on worldwide launch events. For the year 2017, the failure rate for the best established and most reliable programmes (such as ESA's Ariane) ranged between 1% and 5% (FAA, 2018, 99-104). When analysing the Space Economy from the economic perspective, risk and uncertainty are crucial issues that condition how agents behave and how incentives and institutions must be designed. One example of this is the 'geo-return' or 'fair return' principle of the ESA, which guarantees a balance between national contributions and procurement for each national industry, as a mechanism to reduce the risk (Brennan et al., 2018). We further explain this in Chapter 3, when we discuss the different types of national contributions to the Agency. Another example is the different role of the government in terms of active promoter of cooperative research and collusion or a guarantee of competition.

A popular concept in technology developed by the *American National Aeronautics and Space Administration* (NASA) relates risk with innovation. The *Technological Level Readiness* metric (TLR) helps assessing the risks associated with technological development and is, logically, related with the funding and the agents involved in each of the stages of the development of space innovation and used to define boundaries between different organizational and financial modes of technological development (Mankins, 2009; OECD, 2016). Figure 1.5 illustrates the 9-point scale in which the metrics classifies the technological development, along with the logic model that represents the traditional research life cycle. The cycle starts with fundamental and applied research, progresses towards technological demonstration and ends with the scaling up, the definitions for each level by the ESA, and the involvement of funders and R&D actors in each of the levels.

Figure 1.5: Assessing Technology Readiness Levels in the space.



Source: Own elaboration based on Mankins (2009), OECD (2016) and ESA (2020)

The particular characteristics of the innovation in the space sector determines that the EC promotes and funds research in space for a wide range of TRL levels. Whereas in other sectors concerns about competition arise, such as in the space sector, the EC funds both emerging space technologies expected to derive on disruptive technologies but still at levels below 4, it also funds higher TRL projects in other subsectors. The problem of inherent risk and uncertainty of private investors is a first argument for governmental intervention in the space sector. If private capital markets fail to finance those technologies, it might be unfeasible to support with funds to scale up space systems and applications to full use (OECD, 2016).

Cooperative efforts.

The technology, products and services of the space sector are highly complex products that require technological collaborations between many agents as no one has all that knowledge within its organization or within its country (Kishi, 2017). Even in the case where countries decide to create an independent institution to undertake space activities, typically under the form of a space agency, their efforts need to be coordinated with other countries (Adams, 2019). When international collaboration is in place, national security concerns appear. However, space activities also provide some of the most successful illustrations of international cooperation, as in the case of the *International Space Station* (ISS), one of the best examples of situations where pooling resources turns out to be much more profitable than launching independent national initiatives, as the benefits of joint research can be shared among more countries.

As space has a large discovery component, it involves intergenerational public goods in the form of knowledge creation (Sandler, 2004). It is likely that this situation is susceptible of being described by a best-shot public good game in which the greatest effort is the most likely to end in success. This also implies that few agents can engage in space exploration and that inequalities will exacerbate in the future. A logical solution in some contexts has been the long-term cooperation between agents, as in the case of European countries and the *European Space Agency* (ESA).

Market failures in space

Many of the market failures call for regulation of the markets and supranational coordination of exploration and exploitation activities. There are characteristics derived from the intensity of R&D activities and characteristics derived from the definitions of property rights as inherited from the international treaties of the 20^{th} century and, more important, because of the extraordinary characteristics of resources and activities in the outer space. For instance, the fact that International Space Law is public regime somehow interferes for the bad with individual incentives for business transactions (OECD, 2005). In what follows, we comment on some of the market failures relevant for the Space Economy.

Public goods

Public goods are defined by non-rivalry and non-excludability, leading to the problems of free riding and under-provision, thus being an argument for public intervention. Many of the benefits of R&D are not appropriable by the private agents that fund them. There could be knowledge that is non-excludable (and it is non-rival), so some public good characteristic emerges with all the space innovations. Other intangible goods that derive from space research such as national security, national pride or basic science have also public goods characteristics (Weinzierl, 2018). Other goods, such as satellite produced data, have public goods characteristics in that they are non-rival in use (the use of the information derived can be used by as many agents as possible) and they are non-excludable (so they can be widely distributed and once being made public and available, non-exclusion is not possible or is not technically profitable). The non-rivalry and the non-excludability public good properties would lead to an under-supply of satellite derived information and suboptimal provision (Sandler and Schulze, 1981).

Club goods

When goods are non-rival, but excludability is possible, clubs as a member-owned institutional arrangement are possible as a form of provision of the good to avoid congestion or crowding that would reduce the quantity or quality of the good (Sandler, 2013). One of the clearest examples are space orbits (Chiu, 2019), especially the geostationary (GEO) orbit, a resource congested and competitive (Sandler and Schulze, 1981; Sandler, 2004). Radio frequency is also an essential global commons that calls for international cooperation. Actually, the *International Telecommunication Union* declared both ‘limited natural resources’ (Chui, 2019). An example in Sandler and Schulze (1981) is the *International Telecommunications Satellite Organization* (INTELSAT), where the private system manages the external communication network. Geostationary orbits and associated electromagnetic bandwidth can be allocated in a club arrangement to avoid crowding of signal interference (to be solved by user tolls based on signals sent and received) and danger of satellite collision (to be solved by stablishing fees for ‘parking spaces’ in the orbit). Technology and innovations are continually creating club goods, as the International Space Station, reusable suborbital spacecraft and satellites (Sandler and Schulze, 1981; Sandler, 2013).

Commons

A commons is an economic good whose consumption is rival though it is not feasible to exclude from its enjoyment those that do not contribute to its funding. This is the case of material resources in the outer space, where property rights are incomplete and access to the resource is open. Just as international fisheries, asteroid mining could be challenged by the tragedy of the commons. Furthermore, many immaterial resources of the outer space are rival, though excludability from its consumption is not feasible. This non-excludability is, in the case of space, due to technological reasons. Far from being infinite, outer space can be rather limited and subject to the tragedy of the commons, thus creating the possibility of resource depletion.

Externalities

As mentioned in the description of Space Economy, there are important technological spillovers in space research. These are hard to measure and other metrics, such as patents and patent citations, are susceptible of being a bad representation of spillovers in space. A seminal study was the research on knowledge spillovers generated by NASA patents, with patent citations being proxies for technological impact of public research activities and knowledge spillovers in Jaffe et al. (1998). The authors concluded that more than half of the companies and patents on the Electro-physics Branch of NASA were involved in reliable technology spillovers. However, a better knowledge of the space sector justifies the reluctance to considering patents. Space is a sector where little use of patents is made in relative terms, with firms only patenting minor results. Niosi and Zhegu (2005) concluded that patent citation in space was a relatively useless method because the firms tend to maintain secrecy rather than apply for a patent.

The actions of individual agents in the space can create negative externalities as in the case of space debris (Weinzierl, 2018). Risks from space debris and collision already arise in the international governance of the outer space. The *European Space Agency* (ESA) has calculated that approximately 25 000 objects weighing over 8 700 tons were orbiting the earth in 2019, posing a risk to space infrastructure (ESA, 2020).

Other market failures

Complementarities and coordination problems emerge necessarily in the development of the hyper complex technologies related to the space (Weinzierl, 2018). Many business models are only feasible when other complementary models are already in place. Besides, it is often more profitable to pool resources and coordinate efforts to engage in more complex projects rather than starting smaller and less ambitious projects individually. The asymmetries of information, the high level of risk, and the challenges from capturing the surplus from collective projects make collective projects difficult. There are many situations that can be modelled as the classic 'stag-hare hunt game' where, under no coordination, an inferior and less-risky equilibrium – hunt a hare – is selected, rather than the more efficient coordinated one – hunt a stag.

The existence of these market failures is another call for public intervention. It implies that carefully designed public sector coordination can help. However, it is complex to define the terms of that coordination, and questions emerge about the role of the public sector in the promotion and funding under different subsidy schemes, about the regulation needed if new technologies exhibit features of natural monopoly, and about the sharing of the surplus among its participants.

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Chapter 2

Space in Europe: Economics and Politics

Chapter 2. Space in Europe: Economics and Politics

Most of the analyses of the Space Economy treat Europe, under different institutions composed by different countries, as a single global agent. The last official estimate about the Space Economy in Europe, made by the EC for the year 2014, quantified its contribution to the EU economy around 46 to 54B € and its contribution to employment at around 230,000 highly skilled professionals (EC, 2016). Probably, the most relevant achievements of the European efforts in space have been the *Copernicus* earth observation system, Galileo, the European global navigation satellite system, and the *European Geostationary Navigation Overlay Service* (EGNOS), the regional satellite-based augmentation system used to improve the performance of the *Global Positioning System* (GPS) and of Galileo. Those achievements translated into the 27% of current market share of total industrial revenues in the market for global navigation satellite systems for Europe (comprising EU-27 plus Norway, Switzerland and the United Kingdom, ranging between U.S. and Japan with 29 and 20%, respectively (European Parliament, 2020).

The current contribution of the Space Economy and the Space Policy in Europe intends to enable the achievements of European goals in a variety of fields (Höber, 2012). It expects to reach the European Green Deal aims related to sustainability, growth and increased innovation. It should also be relevant in the digitization process of the European society, promoting Europeans' quality of life and giving Europe a strategic autonomy in space.

Despite these facts, and the increasingly positive perception of the benefits of space exploration and exploitation described in the previous chapter, the active involvement of the EU in the Space Economy has also drawbacks. These are based on the ground of the extreme costs of space programmes for public finances and, in the view of some policy-makers and a part of the general population, their low and very uncertain return.

The space landscape in Europe has responded to changing political and institutional forces during the last decades (Sagath et al., 2018) and European Space Policy is called to be a cornerstone for the industrial growth and the strategic autonomy of European countries (European Parliament, 2020). The space activity in Europe is called to contribute to the solution of a number of societal challenges (Giannopapa et al., 2018). Apart from becoming a key element of national defence systems, some challenges that are to be addressed at the supranational level, such as security and border control, disaster management and migrations, climate change, maritime management and food security are a pillar of the design and implementation of security plans from space, relying on earth observation technologies (Remuss, 2018).

Context

The European Space Policy is related to the history of the European integration process, though some authors signal that it started relatively late in comparison with common cooperation in akin areas, such as atomic energy (Remuss, 2018). Therefore, the history of space in Europe started with bilateral cooperative projects between the countries (Hörber and Stephenson, 2016). The beginning of the Space Economy in Europe was through collaborations under two clear blocks. On the one hand, the *European Space Research Organization* (ESRO) and the *European Launcher Development Organization* (ELDO) were created in 1964, the two predecessors of the *European Space Agency* (ESA), which was created in 1975. The *Treaty of Paris*, creating the *European Coal and Steel Community* (ECSC), had been signed in 1951, and the *Treaties of Rome*, establishing the *European Economic Community* (ECC) and the *Euratom*, had been signed in 1957. On the other hand, Central and Eastern European countries under communism had their own history of cooperation processes under *Interkosmos*, which began its missions in 1967 (Sagath et al., 2018).

The ESA was the only agent in charge of the (Western) European Policy until the EEC / EU introduced, first, R&D as a European competence in 1986 and, second, the inclusion in the *Lisbon Treaty* (2009) an article on space as a shared competence between the EU and the Member States. The relationship between the EU and the ESA is ruled by a Framework Agreement, which entered into force in 2004 that introduced a "Space Council" as a common decision-making body. Though having the common goal of strengthening Europe and benefiting its citizens and explicit claims of having "indeed different ranges of competences, different Member States and are governed by different rules and procedures",[2] the ESA and the EU act in the area of space with substantial 'dual' membership (see Figure 2.2. in next section) and somehow overlapping functions. This is controversial issue and new proposals for institutional design are under debate in the academic and the political field (Hörber, 2012; Hörber, 2016; Remuss, 2018). These proposals range from a true division between the implementation and the political roles (for ESA and EU, respectively), to integration of EU into the ESA's institutional structure or the integration of ESA in the EU's institutional framework as a EU's agency. The last model is the one for the *European Global Navigation Satellite Systems (GNSS) Agency (GSA)*, the Community Agency created under the partnership of ESA and the EU for the development of the satellite sector to guarantee that its benefits reach European citizens.

Montluc (2012) claimed that Europe had not succeeded in formulating a complete strategical approach to Space Policy as other powers had already done (the U.S., Russia and China). Cooperation has always been the rule in space in Europe, though Space Policy is not fully integrated among other reasons, because of the lag of political integration, defence and international action with respect to economic integration process. Though collaborative actions had rendered Europe excel in some space fields (science, observation and climate, communication, navigation and launchers since the beginning of the century), two endemic problems, common to other areas of European integration, are found. First, the limited ability to respond and adapt to external changes, a fact which affects space and military developments. Second, the lack of ambition and foresight for the future of Europe in space. These political factors added to the economic and technological factors identified by Hansen and Wouters (2012), who argued that special characteristics of the space industry were not carefully considered in the design of space policies and space industrial policies, creating wide gaps between ambitions and the suitability of legal and political instruments.

Still today, there are some of those forces making European Space Policy and Space Economy challenged by a changing global sector. Europe needs to be a competitive player in the global space arena, characterised by an increased number of space actors and growing dynamically in upstream, downstream and applications sectors. Europe also needs to reinforce its programmes to achieve autonomy, security and resilience. In this

[2] https://www.esa.int/About_Us/Corporate_news/ESA_and_the_EU [Accessed 2/2/2021].

respect, EU, ESA and their respective Member States have parallel competences in European Space Policy for determining European needs for technological independence and autonomy, without prejudice to national security (ESA, 2020).

In what follows, we present the most relevant actors in the European Space Policy and Space Economy.

European Actors

We can characterize the European landscape in terms of the three different levels in which to classify actors.

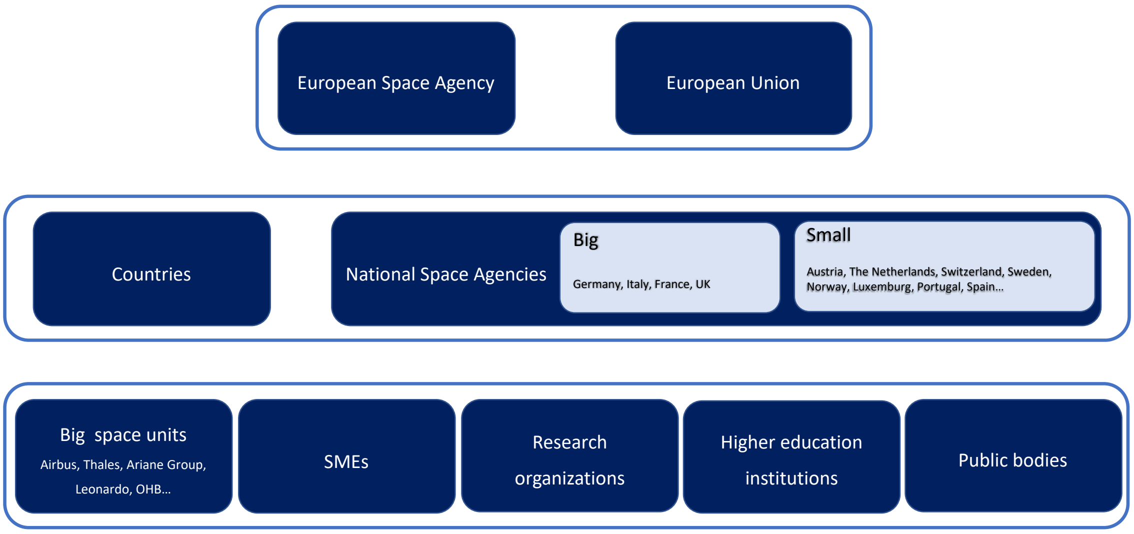
- First, the level of the supranational actors as the regulators and active players. The ESA, an intergovernmental organization, and the EU, a supranational organization, are in that first level.

- Second, the national level, as nations still have a prominent role as regulators, clients in the market (particularly in the national defence demand for space manufactures and services) and, more important, because they are the only players that can decide joining or not joining the supranational institutions and how to behave there. Even for countries that belong to the European Union, where single market, standards and competition considerations are important, the influences of space in other sectors and policies give still a prominent role to member states.

- Third, the players in each of the countries: public and private agents, profit and non-profit organizations, research or manufacturing oriented agents.

We represent these levels in Figure 2.1. Further, the description of the main players in the European space sector serves to motivate the different approaches adopted in the three empirical analyses of this thesis.

Figure 2.1. Players in the European Space Economy



Source: own elaboration

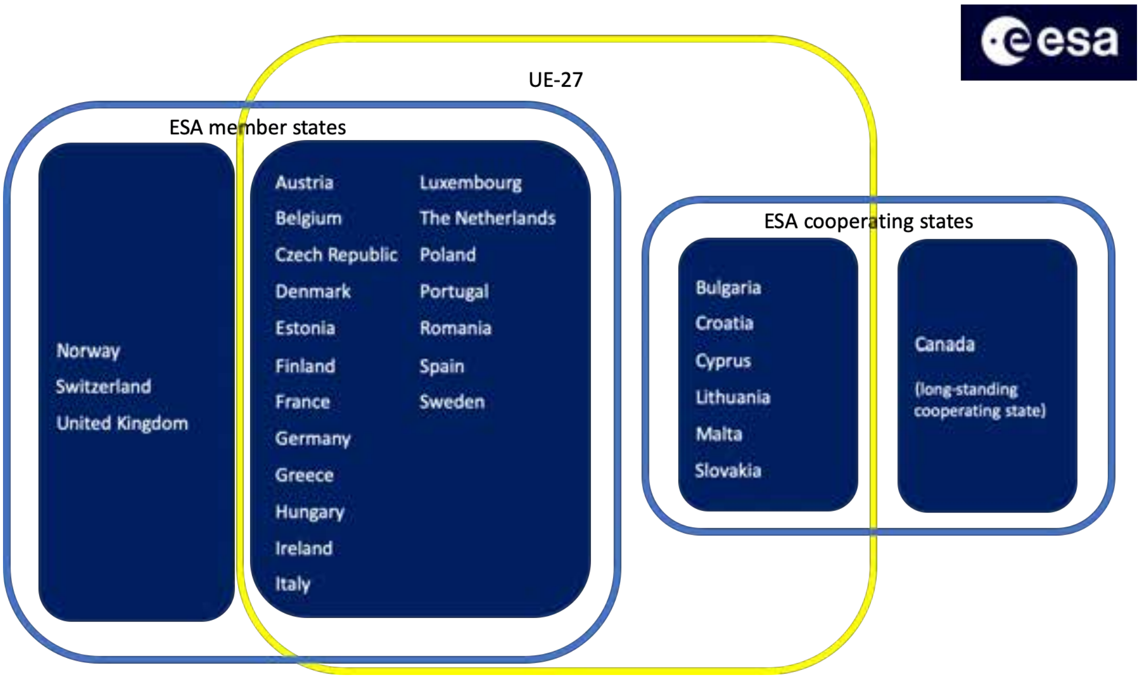
European Space Agency

Belgium, France, Germany, Italy, the Netherlands and the United Kingdom, associated with Australia, created the *European Launcher Development Organization* (ELDO) in the early 60's. In 1964, those countries plus Denmark, Spain, Sweden and Switzerland created the *European Space Research Organization* (ESRO), to develop satellite programmes.

The design of these two institutions and their functioning already manifested some of the problems derived from the diversity of agents and benefits in intergovernmental institutions because of the heterogeneity of their members. On the one side, smaller countries (Italy in ELDO and Spain in ESRO) claimed that their contributions benefited the already stronger and more competitive industries in bigger countries (as France and the United Kingdom) and proposed the implementation of fair geographical return principles, threatening with withdrawal from the organization. On the other side, bigger countries claimed that such a principle would penalize countries with firms that are more competitive and would consequently undermine the international competitiveness of the European countries (Remuss, 2018).

Therefore, the functioning of those two pioneer organizations and the negotiations to find the correct incentives to promote common interests informed the institutional design chosen for the creation of the *European Space Agency* (ESA), when the *Convention for the Establishment of a European Space Agency* opened for signature.[3] During 1975, it was signed by the Federal Republic of Germany, the Kingdom of Belgium, the Kingdom of Denmark, Spain, the French Republic, the Italian Republic, the Kingdom of the Netherlands, the United Kingdom of Great Britain and Northern Ireland, the Kingdom of Sweden, and the Swiss Confederation, followed by Ireland. This entered into force in 1980, and successive enlargements have increased the number of members and cooperation states to reach the current configuration of this intergovernmental organization. Figure 2.2 represents the membership as 2021 along with the cooperating states.

Figure 2.2: ESA membership and cooperating states 2021



Source: ESA

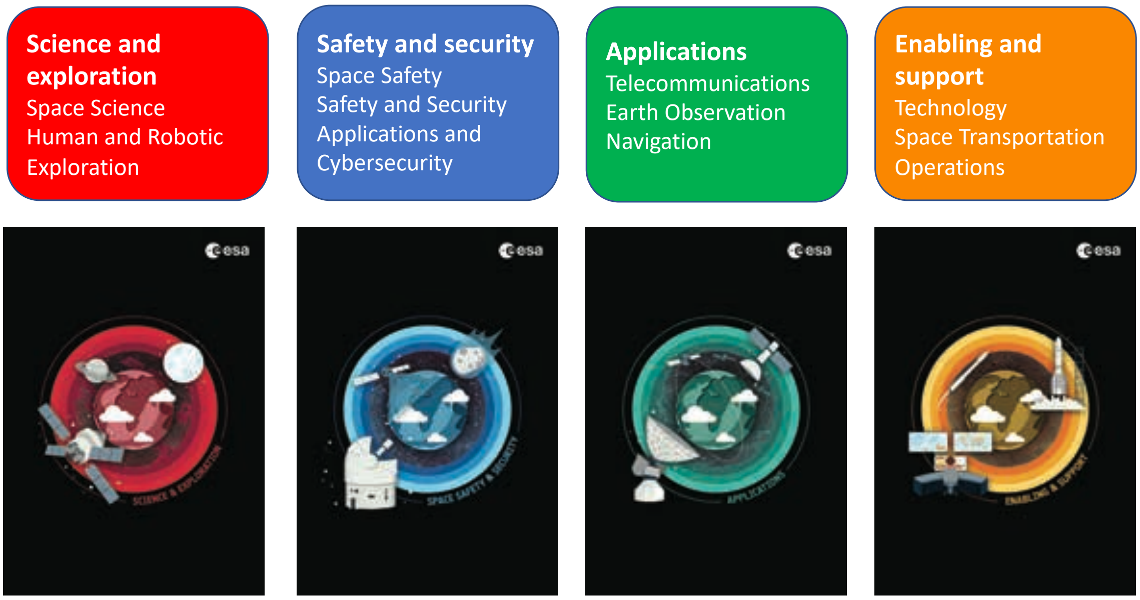
Note the dual membership in the ESA and in the EU (highlighted in yellow). Cooperating states nowadays include six EU-27 countries and Canada, which enjoys this status based on the long-standing cooperation between the Canadian Space Agency and the ESA. Actually, Canada also sits on the *ESA Council* -the ruling body- and takes part in some

[3] *Convention for the establishment of a European Space Agency* (CSE/CS(73)19, rev.7).

projects under a *Cooperation Agreement.* Latvia and Slovenia have currently the status of associate members.

The action of ESA is currently defined over four 'pillars' for Europe's future in the space, each of them in charge of different thematic areas.

Figure 2.3: ESA's four pillars

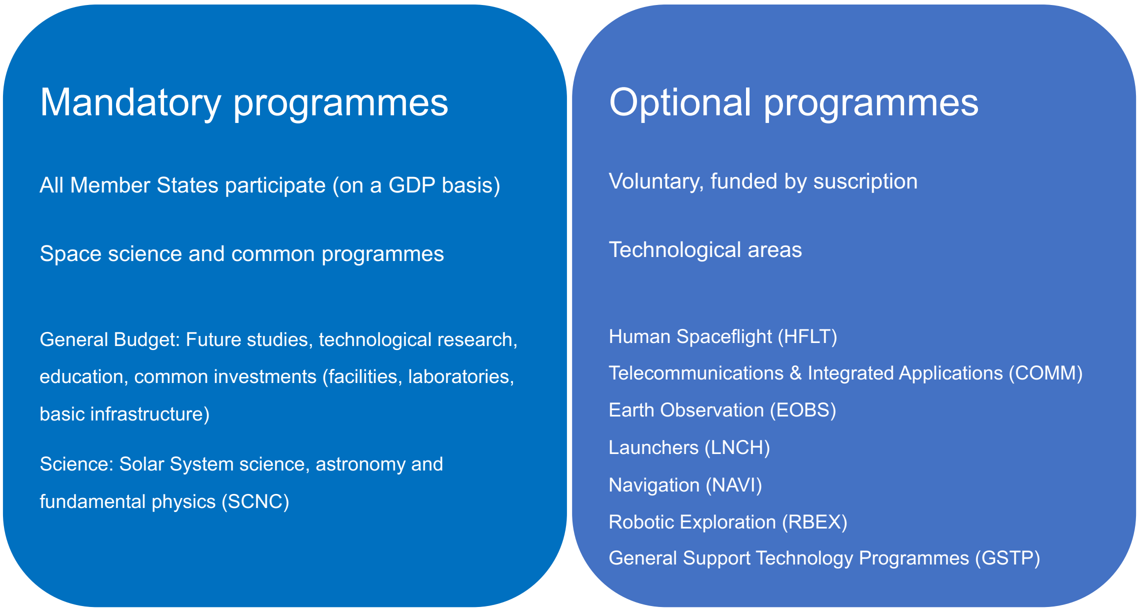


Source: ESA

To identify the different areas of action of the ESA, an alternative classification of activities can be presented in terms of the technological areas. This classification is also relevant for the governance of the institution as it relates to its funding and benefits of membership, in terms of how different programmes fund.

There are two broad groups of programmes: mandatory and optional. While mandatory programmes include those related to general functioning of the institution and basic science, optional programmes relate to different technological areas presented in Figure 2.4. The funding of mandatory programmes is through the mandatory contributions of the member states, which are calculated as a basis of their *Gross Domestic Product* (GDP). This amounts ca. 20% of the ESA budget. The participation on the optional programmes is voluntary and they are funded by subscription. This represents around the 80% of the budget.

Figure 2.4: ESA's founding and activities



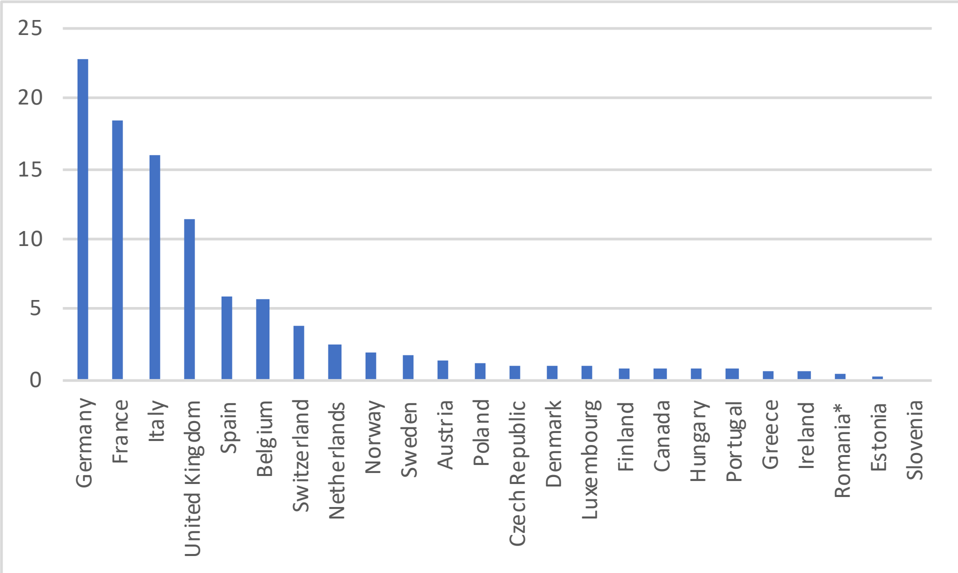
Source: Own elaboration.

Both programmes, mandatory and optional programmes, are subject to the general principle of fair return or 'geo-return'. To ensure that all members benefit in an 'equitable' way, the distribution of the contracts of the ESA among the countries following the rule the 'overall return coefficient' of each country should be one. This coefficient is the ratio between its share of the total value of all contracts and its share of contributions (with some weighting factors used to value the contracts in terms of their technological interest). The return is also computed for each of the programmes and applies in a somehow looser way, with limits fixed for the minimum return in each category not to allow that excess activities in one programme compensate with low activities in another considering respective contributions (Hansen and Wouters, 2012).

There is further an additional source of funding of the ESA derived from third parties' activities, as when the EU funds ESA to manage some space activity on its behalf in Galileo or Copernicus, or as when Eumetsat funds ESA to manage Meteosat and Metop satellites.

The design is flexible enough to fit better the heterogeneity in national interests and industries and to overcome problems that emerged in previous intergovernmental cooperative instances. Graph 2.1. represents national shares in terms of contributions to the ESA for the year 2019. The biggest contributors in 2019 were Germany, France, Italy and the United Kingdom.[4]

Graph 2.1: ESA's share per contributor 2019 (%)



Source: ESPI (2020) using data from ESA

Note: (*) Romania as initially reported

European Union

The activity of the EU in the sector started with the competences on R&D policies and consolidated in the Lisbon Treaty as a common competence between the EU and the Member States (Wouters, 2009), having the EU a 'support competence' and being space added to the broad category of 'research, technological development and space'. The two relevant articles that define the derived Space Policy are Article 4(3) and Article 189, reproduced here:

Art. 4(3) "In the areas of research, technological development and space, the Union shall have competence to carry out activities, in particular to define and implement programmes; however, the exercise of that competence shall not result in Member States being prevented from exercising theirs."

[4] Data as reported by ESA are available in: https://esamultimedia.esa.int/docs/corporate/Space19plus_charts.pdf [Accessed 2/2/2021].

Art. 189 "1. To promote scientific and technical progress, industrial competitiveness and the implementation of its policies, the Union shall draw up a European space policy. To this end, it may promote joint initiatives, support research and technological development and coordinate the efforts needed for the exploration and exploitation of space.
2. To contribute to attaining the objectives referred to in paragraph 1, the European Parliament and the Council, acting in accordance with the ordinary legislative procedure, shall establish the necessary measures, which may take the form of a European space programme, excluding any harmonization of the laws and regulations of the Member States.
3. The Union shall establish any appropriate relations with the European Space Agency.
4. This Article shall be without prejudice to the other provisions of this Title."

There are several instances involved in the space sector in different ways: the European Parliament, the European Council and the European Commission (Sigalas, 2016; Athanasopoulos, 2016; Marta and Stephenson, 2016, respectively). The most relevant one for this study is the European Commission in two different aspects: 1. The definition of the Space Strategy and of the Space Industrial Strategy for Europe (European Commission, 2013, 2016a, and 2016b) and the support of R&D activity in space.

The EU industrial policy in the space sector suffered from rather incomplete policy tools and legal instruments to meet its ambitions. This problem is partially due to the lack of consideration of the special characteristics of space due to economic reasons as reviewed in Chapter 1, namely the high technology component, the high costs and the relatively small size of the European market (Hansen and Wouters, 2012). Some instruments, such as the first attempts to design successful Public-Private-Partnerships (PPP) under Galileo, proved that risk and policy aspects had to be considered in the formulation of industrial policies (Feyerer, 2016).

In the space sector, the Commission funds R&D activities under its Framework Programmes. The Horizon 2020 Space Programme (*Horizon2020-Space*) has been the 8th Framework Proactive during 2014-2020, and the Horizon Europe forthcoming programme is called to further enhance and articulate the sector.

National Agencies

It is common to organize the implementation of the national Space Policy (dependent on the interaction between national defence, national R&D, national industrial policies…) by some independent public arm's length body, that frequently takes the form of a public agency.

There are many benefits associated to this type of organizations in the field of external relations as vehicle for international cooperation (Adams, 2019). Some of these benefits are the participation in space programmes, new creation of business opportunities, the acquisition of relevant scientific and technological knowledge, and the development of other industrial activities. In our context, some national agencies only cooperate with the ESA and some others do it with other agencies as well (for instance, Spain cooperates with the national space agencies of the U.S., Russia, France and Canada based on bilateral agreements). Some other benefits are associated with how the value of cooperative actions bring back home, as dissemination of space knowledge and skills to companies enable the growth of national space industries, in particular in the case of SMEs (Petroni et al., 2018).

There is not a single criterion to define which organizations are 'true' space agencies. In this thesis, we adopt the most restrictive one as proposed by the UNOOSA to identify which countries do have space agencies. A more pragmatic criterion is the delimitation between big space agencies (Germany, France, Italy and UK in the European context), and medium-size agencies (for instance, Austria, The Netherlands, Switzerland, Sweden, Norway, Luxemburg, Portugal and Spain). Some limits of ESA collaboration for medium-size agencies are found in terms of the high level of ESA resources consumption that prevents these national agencies from developing some other opportunities (Petroni et al., 2018).

Private agents

Eurospace describes the market structure of the European space sector, the main representative of the European space industry, as very concentrated and, at the same time, highly fragmented. Eurospace, the Space Group of the *AeroSpace and Defence Industries Association of Europe* (ASD) and recognized by the ESA as the representative body of the European space industry, considers a 'space unit' any corporate entity or business unit or department involved in the design, development and production of space systems. The industry is composed of a small number of large units (very large corporations as Airbus Defence and Space, Thales Alenia Space or SNECMA) and a quite extensive number of very small units (Eurospace, 2019).

Small and Medium Entreprises (SMEs) are defined by the EC in a rather restrictive sense for the firms operating in the space sector. Eurospace adopts more a flexible approach to define the sector and considers 'space units' (Eurospace, 2019). SMEs for the EC are companies with employment below 250, total sales below 50M € (or balance sheet inferior to 43) and with their capital not controlled by a large company. It is precisely this last criterion the most difficult one to meet for many of the operators in Europe, as they are frequently subsidiaries of larger groups. This makes it difficult to leave oligopolistic market structures. Actually, there are precedents of processes in which traditional large units operating in the field secured important innovations and market opportunities by acquiring small manufacturers in the satellite sector that emerged around the Galileo initiative (Petroni and Santini, 2012).

As we mentioned in the previous chapter, few companies have the capacity to develop and assembly those complex products, so markets tend to be highly concentrated. For the period 2003 to 2010, the concentration of the European space industry increased. When using the C(4) ratio of concentration (measuring the market share of the four biggest firms), an increase from 51 to 83% is found; for the C(8) ratio (measuring the market share of the eight biggest firms), the increase was from 80 to 91%. The Herfindahl-Hirschman index (calculated by adding the square root of the percentage market share of each individual firm in the industry) jumped from 928 to 3445.1, thus providing evidence of a process in which large companies are becoming larger (Giannopapa et al., 2018).

This is precisely one of the trends that the EC wants to change with its R&D and industrial policies. In the EU, the *Space Industrial Policy* builds upon five principles: one of them is to "further develop a competitive, solid, efficient and balanced industrial base in Europe and support SME participation"; another is to "develop markets for space applications and services" (EC, 2013). Thus, the policy aims at expanding the third perimeter of the space sector and at increasing the presence of SMEs, encouraging space entrepreneurship and promoting access to finance and funding opportunities for start-ups, scale-ups, SMEs and mid-caps to unlock their full innovation potential.

In terms of employment, the data reported by Eurospace in 2020 for the space manufacturing industry in Europe show that eight medium-large industrial groups generate the 65% of employment in the sector: Airbus (25.02%), Thales (17.01%), Ariane Group (9.01%), Leonardo (6.7%), OHB (5.18%), RUAG (2.29), GMV (2.06%), and Safran (1.62%). Space industry employment is unevenly distributed in Europe, with six countries providing around 90% of European jobs in the sector: France, Germany, Italy, Spain, United Kingdom and Belgium (Eurospace, 2020).

There are different degrees of concentration in the national space industries. Germany tops industry concentration, followed by Luxemburg, Sweden, Romania, Austria, Denmark, Norway, Switzerland and Poland. Finland, the United Kingdom, France, Italy and Spain form a second group with moderately concentrated industries. Last, the countries with the least concentrated industry are Greece, Belgium, the Netherlands, Iceland and Portugal (Giannopapa et al., 2018).

Research centres and higher education institutions.

Universities and research centres in Europe are active promoters of innovation in space. Universities and other higher education institutions contribute to basic and applied science. The *Fraunhofer-Gesellschaft* in Germany and the *United Kingdom Research Institution* (UKRI) are examples of leading institutions in applied research for the development of space technologies.

These agents have a leading role in the development of science and applications. Based on the bibliometric analysis of scientific publications, some European countries lead scientific excellence on space and planetary science, engineering and applications. The United Stated, followed by the United Kingdom, Germany, China, France and Italy, led the production of highly cited scientific papers for the year 2018. The analysis of international collaborations and co-authorships also show the prominent role of European institutions in the field (OECD, 2020).

Subnational Public bodies

Space Economy, as all the highly intensive R&D activities, is subject to generate agglomeration economies because of the positive externalities in terms of spillovers. The highest ratios of R&D intensity are concentrated in Europe in German, Austrian and UK regions. The South Eastern French region of Midi-Pyrénées takes a leading position precisely because of the high-level research in aeronautics and space (Eurostat, 2018). Regional policy is relevant in Europe, especially in the context of the EU and, as some countries have highly decentralized political structures with regional bodies active in the research and in the industrial sectors (for instance, in the case of Austria, Germany and Spain). Regional clusters and regional industrial groups emerge as important players in the European landscape (Guffart and Barber, 2014).

Of course, agents of different nature and level also interact and generate cooperative structures. In many cases, the research centres are independent bodies that take the form of *Public Private Partnerships* (PPP). The *Foundation Centro de Tecnologías Aeronáuticas* (CTA), with big corporations, SMEs and public regional institutions in its governing body, or the *Centro de Fabricación Avanzada Aeronaútica* (CFAA), a mixed centre oriented to TRL 6-7 with the partnership of the *University of the Basque Country UPV/EHU* (UPV/EHU), and the regional industrial cluster, are examples in our closest context.

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Chapter 3

Contributions to the European Space Agency

Chapter 3. Contributions to the European Space Agency

In this chapter, we investigate the determinants of the decisions by national authorities to join and contribute to a supranational institution in charge of space exploration. We model the decision of the individual countries and institutions using a non-cooperative game theory approach in the form of a voluntary contribution mechanism. From the solution of the model, we derive several testable hypotheses about the motivation for joining and contributing in terms of the country characteristics. We use our model to explain the functioning of the *European Space Agency* (ESA), an intergovernmental organization that is responsible for coordinating the collective efforts of European countries in the space sector. To do so, we construct a panel covering the 1997-2016 period, to characterize the membership and contributions for a sample of countries that includes ESA member states, cooperating countries and European non-members. The panel further incorporates individual characteristics of the countries in terms of political, economic and technological characteristics of the research sector and of space national industries. Our estimates indicate that the most relevant variables explaining contributions are the *Gross Domestic Expenditure* in general R&D, the existence of a National Space Agency, the number of researchers over population and the alignment with ESA technology fields' activity share.

Contributing to space exploration: transnational and intergovernmental initiatives

Space exploration is a highly demanding enterprise in terms of infrastructure, equipment, skilled labour and materials. This feature, combined with reliable procedures, intense quality controls and continuous research, requires long-term financing to maintain its high technological level. The fact that funding of space exploration is subject to huge and very risky investments, together with its strategic national relevance for military purposes, have justified the national support of space activities as market-maker and regulator (Weinzierl, 2018; Petroni et al., 2018). This implies that, in its initial stages, starting in the decades of the 40's and 50's of the 20th century, only the SU and the U.S. engaged in the first activities of space exploration. Some other countries joined and they founded their own national agencies to organize the complex technological demands, highly linked with military and national defence objectives and strategic purposes (Brennan et al., 2018). Pioneer countries involved in space activity were the U.S., SU, Europe and Japan. There is an expanding set of new players with China, India, Brazil, Israel, Iran, South Korea, Pakistan and Saudi Arabia involved in national and collaborative space programmes. Globalization has further introduced new players in the space activity such as Argentina, Australia, Iran, South Africa and Ukraine, creating their own space agencies and increasing the scope of their activities (Brennan et al., 2018).

This is an ideal environment for international cooperation given that it is an activity out of the scope of national boundaries. Some benefits of this activity can be considered as public goods and, probably more importantly, too expensive and too complex to be undertaken by a single country. Space exploration and exploitation is an example of ′collective action′, with space activity led by transnational institutions in a context of global public goods and transnational externalities (Sandler and Hartley, 2001). Cooperation aimed to solve problems in such an unfriendly environment as space or to design different equipment or mechatronics to accomplish the planned missions lead to numerous spillovers relevant to different industrial processes. Although a high share of the advantages of those new developments flow to those countries with a better-established industry, cooperation brings new knowledge and industrial capacity to all participants.

In the case of European countries, the possibility of joining the exploration of space appeared during the political and economic integration processes in the post-war period. The geopolitical context favoured the collaborative vision of Western European states and the creation of economic and political institutions. These needs shaped the creation of the *European Space Research Organization* and the *European Launcher Development Organization* in 1964, the two predecessors of the ESA, which was created in 1975 (Brennan et al., 2018; Giannopapa et al., 2016). Launched with 10 founding members, membership has steadily increased to its current 22 members and 7 cooperating states.

With the general objective of steering a peaceful, scientific, industrial and cooperative frame, the industrial development policies of ESA promote the enhancement of specialized SMEs all over the member states territories and look after a fair activity share and the highest industrial development (Giannopapa et al., 2016). ESA is an institutional structure aimed at promoting transnational collective action. The success of its governance depends on the individual incentives to join and contribute which, in turn, depends on countries' characteristics that determine their ability to enjoy private benefits from the joint products and the utility that they derive from the pure public goods jointly produced by the institution.

This chapter organizes as follows. In the next section, we present a review of the literature on collective action in the provision of transnational public goods. We describe some of the characteristics of the ESA that are relevant for this study. Section 2 develops a theoretical model based on a voluntary contribution public goods game to elaborate on the value that each country obtains from being a member of the agency and from public and private provision of goods. The solution of the theoretical model sheds light on the reasons why countries become members or contributors to the ESA and about the differences in the levels of contributions. To test the hypotheses that emerge from the model, we require suitable data. Section 3 presents the sample and variables that we use. Our sample includes 33 countries over the period 1997-2016. Then, we present the methodology and the results from the model estimation and explore correlations of the membership and the contribution decisions. The last section summarizes the main conclusions of the chapter and presents some questions for further discussion and future research.

Review of the literature

Economics of alliances and the production of transnational public goods

The collaboration in space is a fruitful area for the application of global collective action (Sandler, 2004). The economic analysis of alliances builds upon the logic of 'collective action' proposed by Olson (Sandler, 2015), whereby collective action is the form to overcome situations in which public goods, commons and externalities are present due to non-rivalry, non-excludability and uncompensated interdependencies, thus challenging the possibility of optimal provision. These are market failures very likely to emerge in space resources and in the activities linked with its exploration and exploitation.

The analysis of the *North Atlantic Treaty Organization* (NATO) in Olson and Zeckhauser (1964) was a pioneer analysis of the alliances from the theoretical and empirical point of view. Differences in the benefits received from the pursuing of a collective good – a purely public defence good in terms of deterrence of the Warsaw Pact - are explained in terms of the heterogeneity of the members of the alliances. This influential paper inspired the literature on the topic with recent examples as George and Sandler (2018) that analyse the military spending of countries in the NATO for a long period, and in Kim and Sandler (2020) that analyse the evidence to test for the burden sharing in the alliance and to identify exploitation and free-riding.

Sandler and Hartley (2001) use a joint product model to analyse how agents are involved in collaborative space projects, programmes and consortiums such as Airbus, Eurofighter or ESA. In the case of ESA, some of the jointly produced goods have public good characteristics to members and excludability for non-members is possible. The main public good that members enjoy is the direct benefit from the results of R&D joint activities, but there could also be benefits derived from the promotion of political unity in Europe and standardizations. At the same time, the ESA collaborative activity yields private benefits to each of the member states, as there are fair sharing principles of the work, based on the so-called 'geo-return'. These private benefits come in the form of jobs, technology and economic activity developed in each member state in the execution of the work programmes.

Decisions to join supranational institutions come in terms of the potential benefits (Campos et al., 2019 for the case of the EU). Benefits are heterogeneous for different countries and, in the case of the EU accession correlated to three main factors: trade openness, financial integration and the adoption of the Euro. In the case of ESA membership, cooperation benefits that are superior to the ones associated with having a national agency that cooperates with other national agencies appear (Adams, 2019). The emergence of European integration processes in multiple dimensions, first economic and later political, goes hand in hand with a shift from territorialization to deterritorialization. The governance and functioning at the ESA have been previously studied from the Political Science point of view, mostly relying on descriptive analysis of the emergence of the institution and its evolution to our days (Remuss, 2018). Our perspective in this study is to uncover the economic incentives that underlie these processes.

The Governance of ESA

There are currently 22 members of the ESA. Along with them, there are countries that participate trough cooperation agreements. The ESA member states contribute to the agency in two ways. The participation in the so-called 'mandatory activities' is related to the country's GDP. The participation in the 'optional programmes' is by subscription.

Countries differ in many characteristics though they also share short run and long run goals as to engage in membership or cooperation. The literature on space politics has identified some of the relationships between idiosyncratic institutions and industrial and scientific effort and membership. For instance, at the national level, there is wide representation of interests of the ministries in charge of space, ranging from science, technology, research and education to economy, industry and innovation, defence, transport, communication, environment or foreign affairs. This would imply that different countries focus their attention on different aspects of the Space Policy accordingly (Giannopapa et al., 2016). Some countries, such as Luxemburg and the Czech Republic, have significant space heritage, while others are newcomers, such as Greece and Portugal.

Asymmetries are also apparent in the degree of concentration of the national space industries. Germany tops industry concentration, followed by Luxemburg, Sweden, Romania, Austria, Denmark, Norway, Switzerland and Poland. A second group with moderately concentrated industries: Finland, the UK, France, Italy and Spain. Last, the countries with the least concentrated industry are Greece, Belgium, the Netherlands, Iceland and Portugal.

Petroni et al. (2018) study the heterogeneity in the benefits that derive for different countries from their ESA membership, accounting for having or not a space agency. In a descriptive analysis of the potential gains for countries that have middle-size space agencies, they highlight the idea that the involvement in space programmes provides an important source of technological spillovers that, in turn, contribute to the economic development of other sectors in the economy. In the case of ESA membership, they identify the benefits of membership for countries with medium-size agencies: the participation in space programmes that would be unattainable at the individual level, the creation of new business opportunities, the acquisition of relevant scientific and technological knowledge, and the development of other industrial activities. However, there could be some restrictions for these countries to capture the benefits. For instance, their limited autonomy from ESA or the lack of technical organizational units in the organizational structures of the agencies, that result in a limitation for TT activities, and a non-collaborative approach resulting in a limited access to the space industry allowed to new SMEs.

The priorities of the ESA member states and its implication for the ESA functioning and governance is a complex issue (Giannopapa et al., 2016). It is difficult to find an accurate representation of the interests and motivations of each of the countries, as they turn out to be very different in the technological, in the sustainability and in the motivational frames. In this chapter we focus on economic incentives related to the countries' capacity to take advantage of the technological knowledge.

A general principle: geo-return

ESA and its preceding organizations have been always using a 'fair return', 'industrial return' or 'geo-return' principle, whereby there should be a balance between contributions and the value of the contracts for each country. This principle assures returns to the home industry and incentivizes membership (Remuss, 2018). Thus, the industrial return coefficient, defined by the rule adopted since the March 1997 Council at Ministerial level, as the ratio between the share of a country in the weighted value of contracts and its share in the contribution paid to the Agency, must be a certain percentage by the end of a given period. It is looked upon globally and constraints may be imposed to ensure a balanced result, including a trend towards leveling off the disparities between member states.

The Convention of the ESA relating to Industrial Policy requires to "*ensure that all Member States participate in an equitable manner, having regard to their financial contribution*".[5] The industrial return figures for member states are reported in ESA annual reports, where industrial return is defined as the ratio between the share of contracts to a

[5] Updated in September 2007. See Article VII, Section c on the industrial policy design of the agency.

given country and the share of its contribution to the agency. Table 3.1 shows how in the 1997-2016 period there seems to be an effort to achieve the desired 'fair return'.

Table 3.1: Industrial return available data for the 1997-2014 period

	Country	**Status**	**Year**	**1997**	**1998**	**2012**	**2013**	**2014**
AT	Austria	MS	1986	0.96	0.97	1	0.99	1.01
BE	Belgium	MS	1975	0.99	1	0.96	0.97	1
CA	Canada	Coop.		0.91	0.96	0.98	0.96	0.99
CZ	Czech Republic	MS	2008				0.91	0.98
DK	Denmark	MS	1975	1.08	1.09	0.95	0.93	0.98
EE	Estonia	MS	2015					
FI	Finland	MS	1995	0.73	0.97	0.95	0.92	0.99
FR	France	MS	1975	1.02	1.01	1.02	1.02	1.01
DE	Germany	MS	1975	1	0.99	1.02	1.02	1.01
GR	Greece	MS	2005			0.99	0.9	1.06
HU	Hungary	MS	2015					
IE	Ireland	MS	1975	1.07	1.08	0.96	0.94	1
IT	Italy	MS	1975	0.98	1	1.02	1.04	1.02
LU	Luxembourg	MS	2005			0.9	0.89	1
NO	Norway	MS	1986	1.04	1.05	0.94	0.93	0.99
PL	Poland	MS	2012				0.56	0.73
PT	Portugal	MS	2000			0.95	0.93	1.03
RO	Romania	MS	2011				0.65	0.75
SI	Slovenia	Ass. MS	2016					
ES	Spain	MS	1975	1	1.04	1.01	1.01	1.01
SE	Sweden	MS	1975	0.94	0.95	0.98	0.98	0.99
CH	Switzerland	MS	1975	0.92	0.97	0.98	0.97	0.99
NL	The Netherlands	MS	1975	1	1.01	1.11	1.11	1.14
UK	United Kingdom	MS	1975	1.06	1.05	0.98	0.99	0.99

Source: ESA Annual Reports. MS: Member State.

Note that there are few exceptions on this principle of "fair return". For instance, Poland and Romania are systematically below 1 and France, Spain and Netherlands are systematically above 1. Over the years, there is an attempt to set a fair return to contributing participants with the purpose of feeding the technological and industrial level of those countries. According to Remuss (2018), the success of the optional programmes is due to the industrial policy of the ESA based on this contracts allocation principle.

Theoretical framework

In this section, we propose a theoretical model that represents the interrelationships between the contributions that countries make to an intergovernmental organization such as the ESA, the individual returns from those contributions, and the interaction between countries. From the setting and solution of such a model, we obtain implications for the functioning of the organization and hypotheses to be further tested with our panel data.

A transnational public good game.

Assume there are N countries (players) which get involved in the production of some transnational public good. Each country i is committed every year to contribute to the general expenses and scientific activities an amount x_i, which is related to its GDP over the total GDP of the member states.[6]Each country i also decides a voluntary contribution y_i, which may be different from year to year and that depends on the interests of country i in the optional programmes to be launched or activities where that country wants to participate in.

Benefits from contributions

The value of contributing to the agency for each individual country i is the difference between the individual benefits that it obtains and the cost of the contribution. Each country may value the public good differently and may further enjoy different levels of private and public benefits (Sandler and Hartley, 2001).

Valuation depends positively on its technological development and its industry workload capability, measured by a parameter A_i. Parameter A_i indicates that cooperation in R&D creates a larger surplus for a country with high technological development and a lower surplus for a less developed country. For example, the same patents may have more value

[6] The mandatory contribution is $x_i = GDP_i / \sum_{j=1}^{N} GDP_j$.

in a more developed country as they may be used in many technological applications (citing patents) even though they are not related with space activities.

Valuation depends negatively on the discrepancy between the country's research interests and those of the ESA. That is, the value V_i of the public good for country i is affected not only by its technological development but also by how the selection of research fields fits with its technological characteristics and industrial capabilities:

$$V_i = \overbrace{A_i f_i \left[\emptyset_k\left(\sum_{j=1}^{n}(x_j + y_j - Z)\right)\right]}^{\text{Public good with threshold}} + \overbrace{g_i(x_i + y_i)}^{\text{Private good}} \overbrace{- x_j - y_j}^{\text{Contribution}}$$

if $\sum_{j=1}^{n}(x_j + y_j) > Z)$ and $x_j + y_j > 0$.

This formulation corresponds to a public good game with a threshold Z, a fixed cost that accounts for the general expenses of the agency. Contributions need to cover the fixed cost before any funding directs to research. We assume that $V_i = 0$ for all i when contributions are not able to cover the fixed cost.

The function f_i may be different for each country. For example, patents related to new materials may be particularly useful to countries with a well-developed aeronautical, high speed trains or automotive industry, while patents in telecommunications may be more interesting to countries with a different technological profile.

To summarize, A_i measures the level of technological development and f_i indicates the type of technological profile. We will assume that there are *k* types and the technological profiles of countries fit better with some types of research outcomes and worse with others. We assume f'_i>0 and f''_i<0, that is, valuation is increasing in the research output, but the marginal return of additional research output is decreasing.

The function $\emptyset_k$ represents the outcome of R&D investment for each of the *k* technological profiles. In other words, countries have preferences on the type of research undertaken by the agency and the lower the discrepancy between the research interests of the agency and those of the country, the higher the valuation. We assume $\emptyset_k' > 0$ and

$\emptyset_k'' < 0$, that is, the research output in each domain is increasing in the budget but marginal return is decreasing. Given the preferences of the agency and the net total budget $\sum_{j=1}^{n}(x_j + y_j - Z)$, $\emptyset_k$ yields a vector with *K* components; each denotes the research output of technological domain *k=1,2,…K*.

In our empirical implementation, we define technological domains following ESA disaggregation: Space science, Earth observation, Telecommunications, Manned space flight, Microgravity, Launchers, Robotics and Navigation. The ESA reveals its preferences from the distribution of the budget to the different domains, and the technological profile of each country is based on revealed preferences. The value of contributing to this public good includes also contracts, in exchange for the committed contribution, awarded following the geographical return principle (geo-return).

As noted before, the ruling fairness principle is commonly referred as 'geo-return'. Thus, in our model, geo-return g_i reflects the value for country i of getting procurement contracts from the ESA of $(x_i + y_i)$. Note that function g_i is different across countries depending on their technological productive capacity. A_i and g_i measure different characteristics of country i: technology profile and technological productive capacity, respectively. Function g_i represents the availability in country i of an industrial sector capable of participating in the agency's procurement activity. It is a measure of productive capacity. A_i is the general level of technological development, the ability to take advantage of the R&D created (e.g. patents).

How much to contribute?

We analyse the optimal decision for a country *i*. First, we provide conditions for a country to contribute to the agency. Second, in case of contribution, we determine the optimal level.

We denote $V_i(x_i, y_i; x_{-i}, y_{-i})$ the valuation of country i as a function of its own contributions (x_i, y_i) and those of the rest of countries combined (x_{-i}, y_{-i}). If country *i* does not contribute $(x_i = y_i = 0)$ we assume that it still obtains a benefit from spillovers; the fraction of the public good that is non-excludable is denoted λ:

$$V_i(0,0;x_{-i},y_{-i}) = A_i\lambda f_i\left[\emptyset_k\left(\sum_{j\neq i}(x_j+y_j)-Z\right)\right]$$

Thus, country *i* would contribute $x_i + y_i > 0$ as long as:

$$A_i f_i\left[\emptyset_k\left(\sum_{j=1}^{n}(x_j+y_j-Z)\right)\right]-x_i-y_i+g_i(x_{i+}y_i) > A_i\lambda f_i\left[\emptyset_k\left(\sum_{j\neq i}(x_j+y_j)-Z\right)\right]$$

From this decision rule, we obtain the following testable hypotheses:

(H1): The higher A_i, the more likely a country *i* contributes.

(H2): The higher the value of the geo-return g_i, the more likely a country contributes.

(H3): The higher the spillovers to non-members, λ, the less likely a country *i* contributes.

These three predictions refer to the decision whether or not to contribute. Provided a country has decided to contribute a positive amount, we have to determine also the optimal contribution x_i^*. To maximize valuation, given the contributions by the other countries, in an interior solution the optimal contribution x_i^* should satisfy:

$$V'_i = A_i f'_i \emptyset'_k - 1 + g'_i = 0$$

To illustrate our model, we present a simple example with two countries that have different technological level and preferences. There are two domains *a* and *b*. We do not distinguish between mandatory and elective contribution and denote *x* the sum of the two. Preferences of the agency, in terms of budget and effort assigned to each domain, are represented by parameters α in domain *a* and $\beta = 1 - \alpha$ in domain *b*. The research outcome is a vector giving the outcome in each domain as a function of the budget and effort assigned to each domain:

$$\phi = [\phi_a, \phi_b] = [(x_1+x_2)^{\alpha}, (x_1+x_2)^{1-\alpha}]$$

Where x_1 and x_2 denote the contributions of country 1 and 2, respectively. The outcome is valued by each country depending on its preferences (technological profile), represented by weights α_i and β_i for each of the two domains:

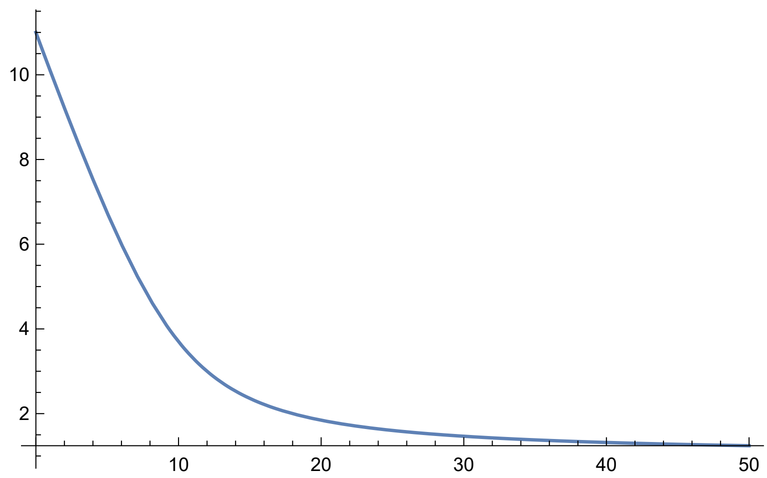
$$f_i = \alpha_i f(\phi_a) + \beta_i f(\phi_b)$$

where $\beta_i = 1 - \alpha_i$. We assume the following functional forms: $f(\phi) = \ln(\phi)$, $f_i = \alpha_i ln(x_1 + x_2)^{\alpha} + (1 - \alpha_i) ln(x_1 + x_2)^{1-\alpha}$ and $g_i(x) = \mu_i ln(x)$. Then, the first order condition for country *i* is:

$$\frac{A_i[\alpha\alpha_i + (1-\alpha)(1-\alpha_i)]}{(x_1 + x_2)} - 1 + \frac{\mu_i}{x_1} = 0$$

Note that the term $[\alpha\alpha_i + (1-\alpha)(1-\alpha_i)]$ is affected by the agreement or discrepancy between the agency preferences and those of the country; perfect agreement yields a high value for that term and total disagreement yields zero ($\alpha_i = 0$ and $\alpha = 1$, for example).

Figure 3.1: Contribution of country 1 as a function of the contribution of country 2.



This first order condition is, in fact, a reaction function of country *i* to the contribution of the other country and we can see that contributions are strategic substitutes, the more one country contributes the less the other contributes.

Figure 3.1 above shows this function for parameter values such that $A_i[\alpha\alpha_i + (1-\alpha)(1-\alpha_i)] = 10$ and $\mu_i = 1$. Note that, given the contribution by the other country, the larger the technological development A_i or the agreement between the agency and the country's preferences $[\alpha\alpha_i + (1-\alpha)(1-\alpha_i)]$, the higher x_i will be. If the two countries are symmetric, the equilibrium values for contributions are:

$$x = \mu + \frac{A_i[\alpha\alpha_i + (1-\alpha)(1-\alpha_i)]}{2}$$

.

Concerning the optimal level of contribution, and provided a country has decided to contribute, we also test the following hypotheses derived from our model:

(H4) The higher A_i, the larger the country's contribution.

(H5) The higher the value of the geo-return g_i (parameter μ), the larger the country's contribution.

(H6) The larger the agreement between the agency's objectives and those of the country, $\alpha\alpha_i + (1-\alpha)(1-\alpha_i)$, the larger the contribution.

Methods and Data Sources

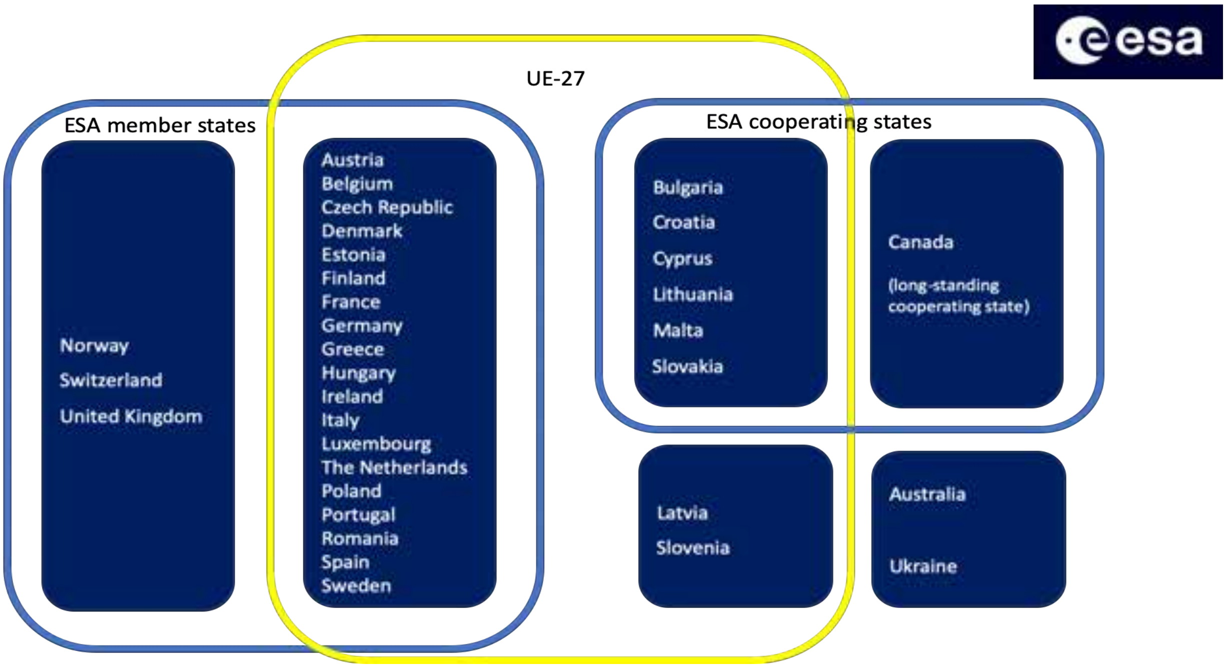
Sample

To test the implications of the model, we build a panel that covers contributions by ESA member states, as well as other cooperating countries and non-members, and their relevant characteristics, from 1997 to 2016. Our main data sources come from ESA dataset, completed with other space related sources such as the OECD documents on space activity, the WB database and the information contained in CORDIS about the EU R&D Framework Programme *H2020-Space* (see Annex – Chapter 3).

We consider 33 countries: All EU-27 countries plus Australia, Canada, Norway, Switzerland, Ukraine, and UK. Our choice is based on current membership, on past or current cooperation status (as for Australia, founder of ELDO and ESRO), on potential membership and cooperation with the ESA based on membership in common supranational institutions (EU or the Council of Europe), and on collaborative ongoing projects funded by other European institutions.

Figure 3.2 presents the classification of the countries in our sample, according to their current (2021) status in terms of membership or cooperation with the ESA and the EU.

Figure 3.2: ESA membership in 2021, EU-27 and other cooperating countries



Source: Own elaboration from ESA dataset.

Countries interested in their space industry development may contribute to ESA optional programmes to take advantage of the benefits of cooperation in space missions. In Table 3.2, we collect the member states or formal agreements with ESA and the first cooperation with ESA through an optional contribution.

Table 3.2: Optional programmes first contribution vs membership/formal agreement year

Country	1st Cooperation	Membership / Agreement	
Australia	-	-	N/A
Austria	1985	1986	MS
Belgium	1975	1975	MS
Bulgaria	2016	2015	ECS
Canada	1970	1999	CA
Croatia	2014	2018	CA
Cyprus	2016	2016	ECS
Czech Republic	2001	2008	MS
Denmark	1975	1975	MS
Estonia	2011	2015	MS
Finland	1989	1995	MS
France	1975	1975	MS
Germany	1975	1975	MS
Greece	2003	2005	MS
Hungary	2001	2015	MS
Ireland	1975	1975	MS
Italy	1975	1975	MS
Latvia	2016	2020	AM
Lithuania	2016	2014	ECS
Luxembourg	2003	2005	MS
Malta	2012	2012	CA
Norway	1987	1986	MS
Poland	2009	2012	MS
Portugal	2001	2000	MS
Romania	2008	2011	MS
Slovakia	2016	2015	ECS
Slovenia	2012	2016	AM
Spain	1975	1975	MS
Sweden	1975	1975	MS
Switzerland	1975	1975	MS
The Netherlands	1975	1975	MS
Ukraine	-	-	N/A
United Kingdom	1975	1975	MS

Source: ESA. Own construction from ESA dataset.

We observe how, among those countries joining ESA after 1975, only Norway and Portugal began contributing to optional programmes just after becoming member states of ESA. We may highlight the cases of Czech Republic and Hungary, with 7 and 14 years of cooperation, respectively, before becoming members, while others vary from 2 to 4 years. In fact, there are European states that have signed formal cooperation agreements with ESA and that contribute to optional programmes. The types of agreements are: *General Cooperation Agreement*, the *European Cooperating State* (ECS) and *Associate Membership*. These agreements intend to involve non-member states in ESA activities, "*expand the scientific and industrial base and to enrich ESA as a research and development organization*" (ESA). Canada, with a special relationship with ESA since the 70's, as the only non-European country that cooperates with ESA, contributes to optional programmes from the very beginning.

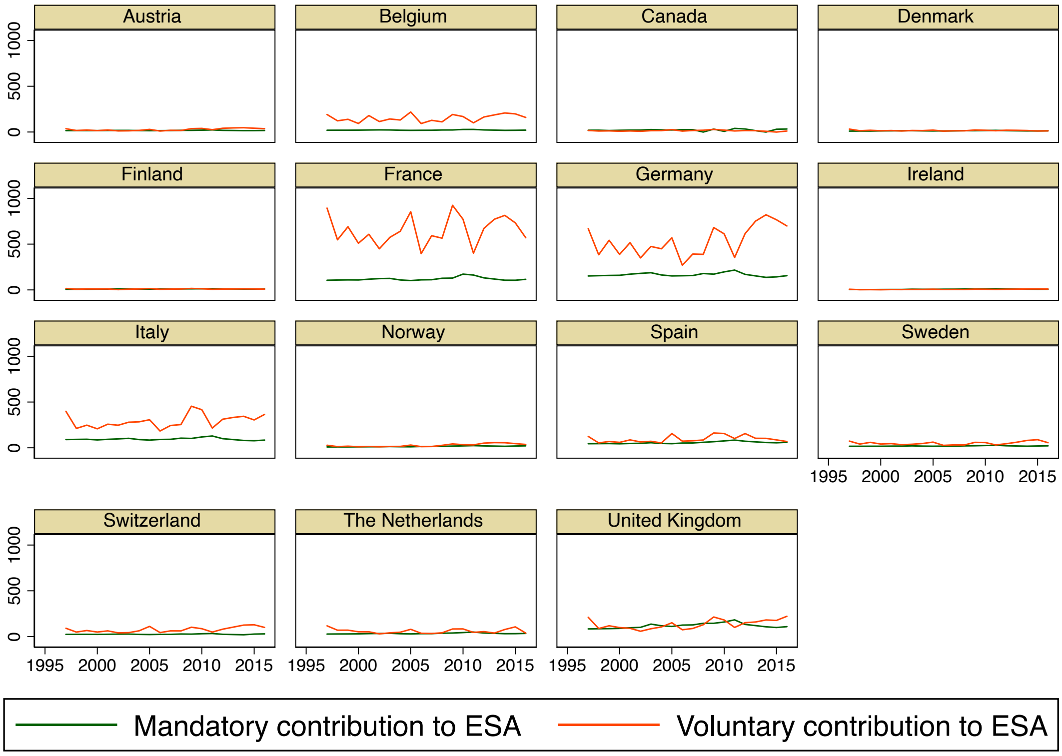
Variables

Contributions (x, y)

Data on contributions are collected from the published ESA annual reports, from 1984 to 2016, extracting total budgets, contributions, and the budget distribution among technological activities. Although those reports are published from 1984 to 2017, not all of them contain a thorough and homogeneous set of data, thus we limit our study to the 1997-2016 period. The annual reports provide us with information on mandatory and optional contributions coming from member and cooperating states.

Graph 3.1 shows the evolution of mandatory and optional national contributions by year for the 15 countries who joined or who started cooperation with ESA before 2000 (the contributions for the rest of the countries are presented in Graph A3.1 in the Annex – Chapter 3).

Graph 3.1: Evolution of mandatory and voluntary contributions (M €) for selected countries (1997-2016)



Source: ESA. Own construction from ESA dataset.

Regarding member states and cooperating countries' contribution, there is detailed information on optional and mandatory activity contribution since 1997. 2008 and 2013 are two years with missing information about countries' contribution to ESA. We complete the missing data with simple interpolation calculated as the media of the preceding year and the next year data. We denote mandatory contribution and optional programmes contribution as $(X_i)_t$ and $(Y_i)_t$ respectively, for each country (i) in a year (t). We also create a variable $(T_i)_t = (X_i)_t + (Y_i)_t$ equal to the yearly total contribution of a country, and a dummy variable $(Cd_i)_t$ called Contribution Dummy with value 1 if a country has contributed a positive amount, with either a mandatory contribution or an optional one.

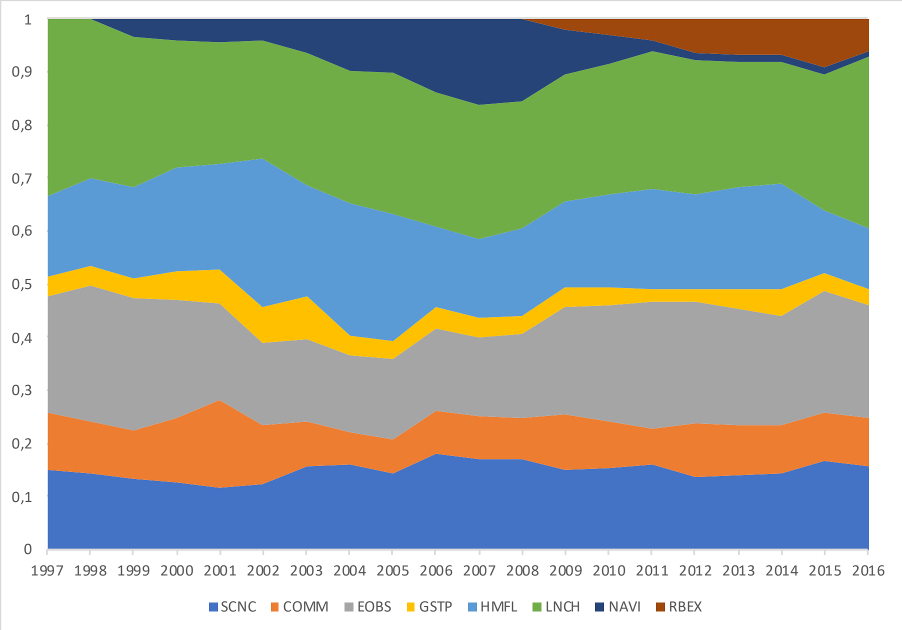
Technological Preferences ($\emptyset_k$)

Our empirical analysis requires information about the distribution of the R&D effort on the main technical activities carried out by the agency, to represent the technological preferences of ESA and those of the individual countries.

In this study, we consider the following technical areas: (EOBS) Earth Observation; (SCNC) Science; (HFLT) Human Flight; (LNCH) Launchers; (GSTP) General Support Technology Programmes; (COMM) Telecommunications; (NAVI) Navigation, and (RBEX) Robotic Exploration. These fields define the variable (k) with values from 1 to 8. In the period of analysis, these areas are not constant. For instance, Navigation and Robotic Exploration appeared for the first time in 1999 and 2009, respectively; Microgravity, although an independent area until 2011, becomes part of Human Flight activity from 2012 onwards.

ESA, upon deciding the scientific programme, the technology developments of interest for the Agency and the missions to accomplish, deploys its budget in the different technology fields. In Graph 3.2, we observe the budget share among technology fields. It is affected by the commencement of Navigation (NAVI) in 1999 and Robotic Exploration (RBEX) in 2009. The effort in the Galileo mission, consisting in a global positioning system interoperable with the American GPS and the Russian GLONASS, based on a satellite constellation of 24 operational satellites providing navigation signals under civil control is clearly perceived under the budget variation over time (402M€ in 2008; 16% of ESA budget for science and technology programmes). We may also see the Earth Observation (EOBS) variation, and how the budget recovers its level after Galileo effort.

Graph 3.2: ESA Technology Fields Budget Share (1997-2016)

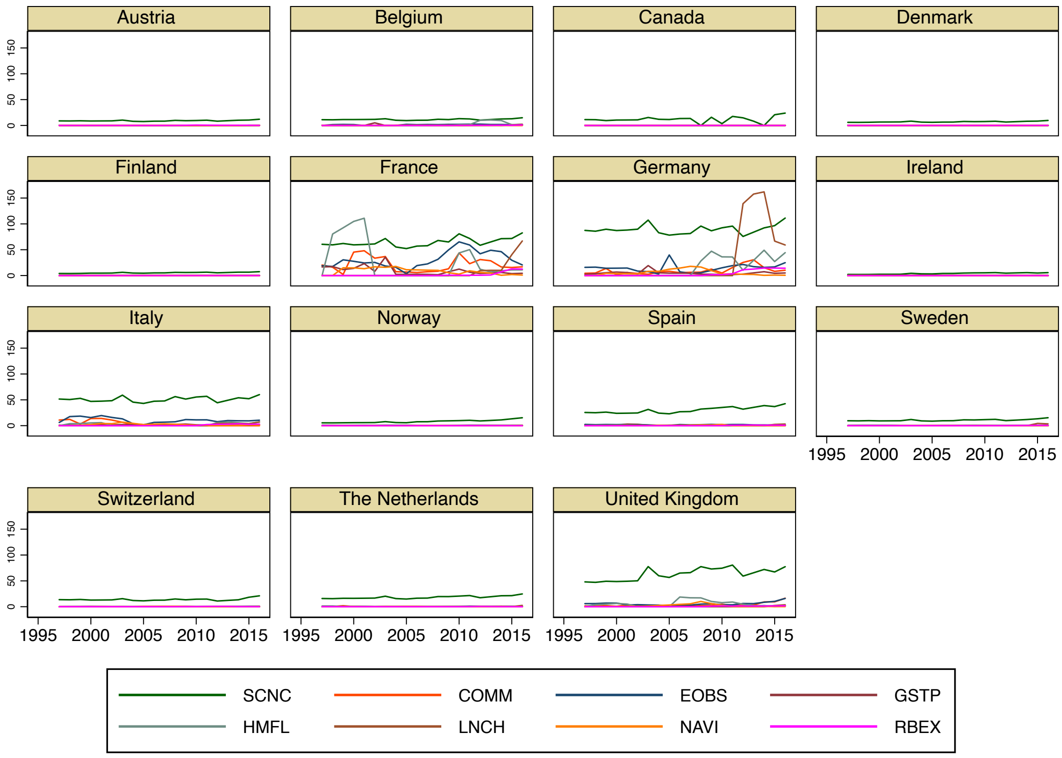


Source: ESA. Own construction from ESA dataset.

In our model, countries have technological preferences over the fields SCNC, COMM, EOBS, GSTP, HMFL, LNCH, NAVI and RBEX. We measure their preference profiles through project participation in the space related EU framework programmes. Since our sample spans the period 1997-2016, we take project and organizations data from FP4 to H2020 from CORDIS database. FP1 and FP2 have no projects starting in 1997 or later and FP3 has two projects beginning after 1997 but unrelated to space.

We define the technology profile of country *i* in year *t*, $(F_i)_t$, as a matrix with the budget for each technology field *j*: $(f_{j,i})_t$. These variables are denoted by the technology field acronym: f1_SCNC, f2_COMM, f3_EOBS, f4_GSTP, f5_HMFL, f6_LNCH, f7_NAV and f8_RBEX. Graph 3.3 plots interests in the different fields for the 15 countries who joined ESA before 2000 (for the rest of the countries, Graph A3.2 can be found in the Annex – Chapter 3).

Graph 3.3: National revealed preferences in the technology fields for selected countries (1997-2016)



Source: ESA. Own construction from ESA dataset.

Technological development (A)

To provide a measure for each country broad technological development, we use the WB database.[7] We collect information on R&D activity of each country as a percentage of its GDP and multiply it by GDP to obtain the absolute value (million current PPP $). This variable is a proxy for the technological development of a country and it is denoted $(A_i)_t$ for each country (i) in a year (t).

From $(A_i)_t$ we create a dummy variable, $(Ad_i)_t$, that takes value 1 when the technological development of country *i* in year *t* is at least 20% of the average of all the countries considered in the sample. This arbitrary threshold classifies countries in two groups, those with a notable R&D activity and the rest.

[7] OECD database provides similar information, but there are ESA contributing countries not belonging to OECD.

Space productive capacity (g)

To obtain information about the space industry capacity of a given country, we use OECD Main Science and Technology Indicators Database. We use as an indicator of the space capability of a country, the Civil Government Budget Allocations on R&D for space programmes (million current PPP $). We denote this variable $(G_i)_t$ for country i in year t; the variable $(Gn_i)_t$ is equal to $(G_i)_t$ normalized by the country population $(P_i)_t$. For those countries not belonging to OECD, we use the ESA database. For the few years with missing values we use a linear interpolation. From the WB database, we obtain each country's population (millions) $(P_i)_t$. This variable is used to normalize quantities in order to evaluate the country relative effort or capacity in space technology.

Spillovers (λ)

Another variable included in the model are the potential spillovers $(\lambda_i)_t$, that open the possibility to take advantage of the ESA research output without membership. Spillovers depend on the nature of research outcomes, whether they are protected by patents, etc. However, the extent a country may benefit from spillovers through free-riding depends also on its technological development and human capital. Even when the knowledge generated is potentially public, spillovers may be low for those countries without the scientific base or human capital to benefit from the innovation. Thus, we use as a proxy the number of researchers per million population, to account for the effect of country size, published by the WB.

Preferences Alignment

We measure the misalignment of a country technological preferences with the ESA preferences, $(W_i)_t$. Its inverse $(IW_i)_t$, measures alignment with ESA global technology preferences. $(W_i)_t$ is calculated for each country and year as the sum of the squared differences of each of the 8 technology fields shares between ESA and the country.

Dummies

We create two dummy variables $(ESA_i)_t$ with value 1 if a country (i) is member of ESA in a given year (t), and $(EU_i)_t$, with value 1 if a country (i) is part of the EU in that year (t). Table 3.3 summarizes the variables used in the empirical analysis. Further details can be found in the Annex – Chapter 3.

Table 3.3: Variables description

VARIABLE	LABEL	UNITS	SOURCE
Countries	Countries	string	ESA
EU membership	EU	binary	EU
Space agency	SpAg	binary	UNOOSA
ESA membership	ESA	binary	ESA
States Contribution - Mandatory	X	M€	ESA
States Contribution - Optional	Y	M€	ESA
States Contribution - Total	T	M€	ESA
States Contribution - Dummy	Cd	binary	ESA
Technological Development	A	M$ PPP	WB
Technological Development - Dummy	Ad	binary	WB
Space Industry Capacity	G	M$ PPP	OECD & ESA
Space Industry Capacity Normalized by Population	Gn	€/Pop	WB
Participation in Science technology field ESA projects	f1_SCNC	M€	ESA
Participation in Communications technology field ESA projects	f2_COMM	M€	CORDIS & ESA
Participation in Earth Observation technology field ESA projects	f3_EOBS	M€	CORDIS & ESA
Participation in General Support Technology Programmes technology field ESA projects	f4_GSTP	M€	CORDIS & ESA
Participation in Human Flight technology field ESA projects	f5_HMFL	M€	CORDIS & ESA
Participation in Launchers technology field ESA projects	f6_LNCH	M€	CORDIS & ESA
Participation in Navigation technology field ESA projects	f7_NAVI	M€	CORDIS & ESA
Participation in Robotic Exploration technology field ESA projects	f8_RBEX	M€	CORDIS & ESA
Misalignment with ESA technology fields activity share	W	Dimensionless	CORDIS & ESA
Alignment with ESA technology fields activity share	IW	Dimensionless	CORDIS & ESA
Population	P	Mpop	WB
Spillovers	λ	Researchers / Mpop	WB
Gross Domestic Product	GDP	M$ PPP	WB

Table 3.4 reports descriptive statistics of all variables for the 33 countries in the sample period.

Table 3.4: Descriptive statistics

Variable	**Obs**	**Mean**	**Std. Dev.**	**Min**	**Max**
ESA	660	.536	.499	0	1
EU	660	.688	.464	0	1
SpAg	660	.303	.46	0	1
X	660	23.315	41.299	0	216.866
Y	660	65.81	153.412	0	924.426
T	660	89.125	189.127	0	1,053.469
Cd	660	.621	.485	0	1
A	660	10,075.016	17,302.785	0	11,1348.49
Ad	660	.524	.5	0	1
G	660	161.965	376.965	0	2,582.719
Gn	660	1.135	1.709	0	15.563
f1 SCNC	660	12.586	22.137	0	111.318
f2 COMM	660	1.216	4.987	0	48.053
f3 EOBS	660	2.022	6.807	0	65.279
f4 GSTP	660	.537	2.412	0	35.644
f5 HMFL	660	1.601	9.154	0	111.012
f6 LNCH	660	1.176	11.301	0	162.042
f7 NAVI	660	.583	2.324	0	17.907
f8 RBEX	660	.235	1.431	0	14.602
P	660	18.529	21.674	.383	82.534
λ	660	2,932.313	1,630.957	175.196	8,331.319
W	557	.552	.256	.074	1.253
IW	557	2.223	1.117	.798	13.425
GDP	660	5,290.776	7,869.277	37.054	38,839.202

Empirical analysis

Note that our model not only identifies the variables that determine the decision whether to contribute to ESA, but also those that determine the level of contributions. We model the probability of contributing as a function of the technological development of a country, its space industry capacity, the presence of spillovers and technology misalignment:

$$P_i = a + b_1 A_i + b_2 g_i + b_3 \lambda + b_4 W$$

Our model produces precise empirical predictions on the effect of the independent variables (H1, H2 and H3): $b_1 > 0$, $b_2 > 0$ and $b_3 < 0$.

Estimating the probability of ESA membership

The probability of being a member of ESA at a given point in time is associated with a series of factors, as already discussed in the implications of the theoretical model. We can broadly classify those factors into three groups, namely institutional, industrial and strategic. In the group of institutional variables, we consider whether the country is a member of the EU at that point in time and if the country has a space agency. The group of industrial variables captures national R&D activity at different points in time. We include three variables measured in logarithms: (1) Gross Domestic Expenditure on R&D, (2) Civil Gross Domestic Expenditure on R&D for space programmes, and (3) number of researchers over population. Last, to account for strategic effects, we use our misalignment index to represent the divergences between national space interests in a given year and the interests of the agency.

We estimate panel logit models for which the dependent variable is being a member of the ESA at time t $(ESA_i)_t$. The variability arises by the fact that not all the ESA members in 2016 entered ESA at the same time. We run different regressions for each of the three groups of factors, considering both fixed effects and random effects specifications. We conduct Hausman tests after each of the estimations to test whether the errors (u_i) are correlated with the regressors; under the null hypothesis that they are not, rejection implies that the fixed-effect estimators are preferred (Greene, 2018).

Table 3.5: Random Effects Logit Estimation of ESA Membership.

ESA membership	Institutional	Industrial	Strategic	All
EU membership	11.919***			21.579***
Space Agency	6.638**			8.707**
GD Expenditure on general R&D		3.511***		2.851**
Civil GD Expenditure on space R&D		0.148*		0.081
Researchers over population		7.876***		12.546**
Sectoral misalignment			-3.760***	1.586
Constant	-9.576***	-85.256***	4.293***	-137.787***
$\ln\sigma^2$	3.960***	4.389***	3.719***	4.239***
AIC	272.913	211.741	286.711	184.187

** p<0.05; ** p<0.01; *** p<0.001*

We find that both institutional factors are associated with a higher probability of being a member of the agency, with a higher impact of the political variable of EU membership than the variable of having an active and well-established space agency. Note that those are random effects estimations, so they are to be interpreted as the average effect of each of the dummy variables (EU membership and having a space agency) over the probability of ESA membership, including both between-country and within-country effects. For the technological factors, the largest coefficient appears for the variable of researchers over population, capturing the stock of human capital of the country. Note that this variable was intended to measure the possibility of free-riding on the spillover effects, with a negative effect on membership; however, the variable is highly correlated with the potential of execution of projects intensive in R&D and this explains the positive effect shown in the regression. For the third empirical specification, we find that the variable that captures the mismatch between the national interests and strategies of a given country and the contemporary interest of the agency in terms of distribution of the budget is negatively related with the probability of ESA membership.

The last model allows to jointly test for all the hypotheses derived from the theoretical model, as all three types of factors are explanatory variables. Here, we have that institutional and technological factors are the ones for which we find conclusive evidence of a positive association with being a member of the ESA.

Estimating the probability of contributing

Now, we replicate the estimations above to explain the probability of contributing to the activities of the ESA, regardless of the membership status of the country. We consider all EU countries in 2019 (i.e., EU-28) both contributing countries and non-contributing countries as well as other countries that at some point have contributed to or become a member of ESA.[8]

The dependent variable is *CONTRIBUTE*, a dummy variable that takes value 1 if it is a contributing country and 0 otherwise. Table 3.6 shows how the contribution decision depends on each of the three groups of variables that we have considered.

Table 3.6: Random Effects Logit Estimation of ESA Contribution

CONTRIBUTE **(dummy)**	**Institutional**	**Industrial**	**Strategic**	**All**
EU membership	6.972***			8.076**
Space Agency	8.023**			8.432
G D Expenditure on general R&D		5.320***		4.371***
Civil GD Expenditure on space R&D		0.139*		0.068
Researchers over population		8.655***		13.444***
Sectoral misalignment			-4.790***	1.544
Constant	-4.339*	-102.102***	6.154***	-140.326***
$\ln\sigma^2$	3.757***	4.406***	3.707***	4.531***
AIC	264.712	176.539	264.552	161.658

** p<0.05; ** p<0.01; *** p<0.001*

Qualitatively, the results are very similar, though there are two differences worth noting. First, it appears that considering only institutional factors, having a national space agency has a larger impact on being a contributor than being a member of the EU. This seems reasonable, as contributions are more closely linked to the support to certain programmes coordinated and executed by the ESA than to the long-term goals of the agency, more related to the EU political entity. Note that, according to our model, the reasons for contributions are associated with the benefits derived from the public and private goods developed. Thus, non-member countries take their decisions accordingly.

[8] See Chapter 2 for more detail on the methods of analysis and the sources of information that are used in this research.

In the last model that considers institutional, technological and strategic variables jointly, the stronger impact is for the variable that measures the human capital in science and, thus, the capacity of extending positive spillovers to other knowledge intensive sectors in the national economy. Again, this variable is not reflecting the possibility of free-riding effects, which would imply a negative coefficient.

Estimating contributions

We follow with the analysis of country level contributions. We include as independent variable the degree of discrepancy between the agency priorities and the country's preferences on domains, W, as well as well as A_i and g_i. We also consider the national space activity in the different generations of EU Framework Programmes for the sample period, as a proxy of technological preferences $\emptyset_k$, that is, the variables f1_SCNC, f2_COMM, f3_EOBS, f4_GSTP, f5_HMFL, f6_LNCH, f7_NAV and f8_RBEX previously defined.

Therefore, the level of contributions at a given year *t* is

$$C = a + b_1 A_i + b_2 g_i + b_3 W + b_4 \emptyset_k$$

In this equation, we test H4, H5 and H6.

Estimating total contributions

Table 3.7 presents the estimation results for the model of total contribution of a country (logarithm) using a panel Tobit model, because the distribution of the contributions is left truncated at zero. Total contribution includes the mandatory contribution of member states.

Table 3.7: Random Effects Tobit Estimation of Total Contribution to ESA

Log Total Contributions	Inst.	Tech.	Inst. & Tech.	Inst. & Tech & Stra 1	Inst. & Tech & Stra 1 & Stra2
EU membership	1.437**		0.705	0.650*	0.507
Space Agency	0.227		-0.046	-0.063	-0.063
GD Expenditure on general R&D		0.375***	0.345**	0.333***	0.327***
Civil G D Expenditure on space R&D		0.015	0.016	0.017	0.018
Researchers over population		0.251	0.195	0.084	0.028
Sectoral misalignment			-0.281*		-0.275*
f1_SCNC				0.033***	0.033***
f2_COMM				0.003	0.004
f3_EOBS				-0.006	-0.006
f4_GSTP				-0.009	-0.009
f5_HMFL				0.000	0.000
f6_LNCH				0.007*	0.007*
f7_NAVI				-0.019	-0.018
f8_RBEX				-0.079**	-0.078**
Constant	1.729**	-1.992*	-1.762	-1.320	-0.549
σ_u	2.075***	1.397***	1.462***	1.022***	0.999***
σ_e	0.440***	0.406***	0.400***	0.384***	0.382***
AIC	644.716	576.100	569.490	541.226	536.939

** p<0.05; ** p<0.01; *** p<0.001. Inst: Institutional; Tech: Technological; Stra: Strategic.*

As most of ESA members are also members of EU, EU membership has a big influence in this contribution as expected.

General expenditure on R&D influences not only the contribution decision but also the level of such contribution. A unitary increase in the general R&D investment of a country boost up 1/3 the total contribution to ESA. Although the space sector investment is lower than in other industrial fields, it is influenced by the R&D expenditure of a country. The sectorial misalignment with ESA preferences also shows an influence on the total contribution level. As the misalignment is mainly shown in optional programmes activity, we expect to see a higher influence of this variable in the optional contribution. Note that the mandatory contributions are such that each member state contributes a fixed percentage of its gross domestic product (GDP) so that the factors affecting mandatory contributions are just those that are related to GDP.

Estimating voluntary contributions

We estimate voluntary contributions to ESA and present the results in Table 3.8. In the first estimation [1], we only consider the EU and ESA membership. In the second model, we consider as covariates the expenditure on general R&D, civil expenditure on space R&D, and the researchers to population ratio. In addition, model three adds sectoral misalignment. Finally, models four and five are equivalent to models two and three but including preferences by technology field.

Table 3.8: Random Effects Tobit Estimation of Voluntary Contributions to ESA

Log Voluntary contributions	**[1]**	**[2]**	**[3]**	**[4]**	**[5]**
EU membership	0.869		0.112	0.270	0.054
Space Agency	0.198		-0.122	-0.107	-0.118
GD Expenditure on general R&D		0.333**	0.305*	0.351**	0.324**
Civil GD Expenditure on space R&D		0.014	0.012	0.013	0.012
Researchers over population		0.333	0.316	0.243	0.205
Sectoral misalignment			-0.445**		-0.448**
f1_SCNC				0.013*	0.013*
f2_COMM				0.003	0.004
f3_EOBS				-0.001	-0.001
f4_GSTP				0.006	0.006
f5_HMFL				0.000	-0.001
f6_LNCH				0.003	0.003
f7_NAVI				-0.017	-0.016
f8_RBEX				-0.030	-0.030
Constant	1.567*	-2.920**	-2.383*	-2.691*	-1.738
σ_u	2.166***	1.617***	1.669***	1.406***	1.408***
σ_e	0.462***	0.424***	0.416***	0.422***	0.415***
AIC	642.921	573.563	568.052	583.016	574.589

** p<0.05; ** p<0.01; *** p<0.001*

To have a national institution devoted to the space related activity has no clear influence in the voluntary contribution. GD expenditure in general R&D has a positive and significant effect on the voluntary contribution. However, expenditure in space R&D or the number of researchers over population have no effect on voluntary contributions. Regarding technology preferences, coefficients are small in magnitude. Only in the field of Science (f1_SCNC) the coefficient is weakly significant.

A highly relevant factor is the degree of misalignment between the country's preferences and ESA's. The coefficient is negative, significant, and larger than in the case of Total Contributions, reflecting the fact that it is in the optional programmes where differences between ESA and the country's preferences have the larger effect.

Finally, in the light of these results, we assess the theoretical hypotheses derived from the model.

(H1): The higher A_i, the more likely it is that a country *i* contributes.
We find evidence in support of this hypothesis: a country with a larger number of researchers over population and higher GD Expenditure in general R&D is more likely to contribute to ESA.
(H2): The higher the value of the geo-return g_i , the more likely it is that a country *i* contributes.
We find weak evidence in support of this hypothesis: a country with a higher Civil GD Expenditure on space R&D is more likely to contribute to ESA, although it does not seem to affect the level of contributions.
(H3): The higher the spillovers λ, the higher the possibility of free-riding, and the less likely it is that a country *i* contributes.
We have not been able to capture the potential free-riding effect of spillovers. Therefore, we could not confirm nor reject this hypothesis.
(H4) The higher A_i, the larger the country's contribution.
We find evidence in support of this hypothesis: a country with a high GD Expenditure in general R&D is more likely to make a larger contribution to ESA.
(H5) The higher the value of the geo-return g_i, the larger the country's contribution.
We find no evidence that a country with a higher Civil GD Expenditure on space R&D is more likely to make a larger contribution to ESA.
(H6) The larger the agreement between the agency's objectives and those of the country, the larger the contribution.
We find evidence in support of this hypothesis: a country with better alignment with ESA technology preferences is more likely to make a larger contribution to ESA.

Conclusions

In this chapter we have modelled the decision to contribute to ESA and how much to contribute as a function of the costs and benefits of the decision. According to our model, the variables that positively affect contributions are the level of technological development of a country (A), the space industry capacity (g), the potential free-riding behaviour associated to spillovers (λ) and the misalignment between the technological preferences of the country and those of ESA (W). We also control for institutional factors that may affect the decision such as having a national space agency or EU membership, and the relevance of each technological field in the country's preferences.

We find that institutional factors such as being a member of the EU or having a national space agency are associated with a higher probability of being a member of the agency and a higher probability of contributing to ESA. We proxy the technological development of a country by its general expenditure in R&D, and this variable influences the decision to contribute, the level of the total contribution and specially the optional part of the contribution to ESA. The rate of researchers over the population of a country is also highly correlated with contributions. We find that the sectorial alignment with ESA preferences is an important factor for contributions.

We find evidence in support of our hypotheses (H1), (H4) and (H6). For the rest, some of the variables we use may not be reflecting the intended characteristic and our results are inconclusive. This is the case of (H2) and (H5). We hypothesized that a larger space industry capacity would allow a country to benefit from the geo-return rule; we measure this capacity through *Civil GD Expenditure on space R&D*, but this variable turns out to be weakly significant for the probability of contributing and non-significant for the level of contributions. In the case of (H3), we were not able to capture the potential free-riding effect of spillovers and therefore, we could not confirm nor reject the hypothesis.

This analysis has not addressed several important questions that are left for future research. First, we have modelled the decision to contribute in terms of the costs and benefits, but upon entry, membership may well affect the future technological development of a country and even its technological preferences between fields. Second, a more detailed breakdown of a country's industrial capacity by agents (firms, organizations) may shed some light on the bidirectional effect of contributions to the global public good and the country's space industry development. Finally, ESA scope programmes participation creates a network that may be quite influential in cooperation when opting to external competitive offers.

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Chapter 4

Network under H2020-Space and Knowledge Diffusion across Countries

Chapter 4. Network under H2020-Space and Knowledge Diffusion across Countries

The Horizon 2020-Space Programme has had a profound impact on the space industry of European countries. In this chapter, we present a characterization of the funded projects and the resulting innovation and research network. Not only the programme results are important, but also their impact on the network architecture that may potentially shape future collaborations and spillovers at the national level. The architecture of the links between the collaborating countries will affect the interaction between them in future projects and the diffusion of scientific knowledge and innovations in the European space industry. Our research hypothesis is that the *H2020-Space* has provided the industry with a small-world structure. Our findings indicate that this is in fact the case. This will have important consequences for innovation transmission and technology adoption in Europe.

Introduction

For the 2014-2020 budgetary period, Horizon 2020 has been the flagship initiative of R&D in the EU. Following previous framework programmes, it has contributed to the development of scientific knowledge by fostering collaboration between agents from different state members and other countries, leading to the emergence and consolidation of a collaborative research and innovation network. The formation of such a network has a value in itself, since it affects the diffusion of innovations and scientific knowledge, extending the impact of the projects' results and shaping future R&D activities. Particularly, for the outer space sector, H2020 has the objective to promote a competitive and innovative space industry in Europe keeping in mind the relevance of the sector as a service to European citizens and a driver of growth of innovation that would contribute directly to the political objectives of the EU defined by the 2020 Strategy. Under the moto "Prepare for the increasing role of space in the future and reap the benefits of space now", the EC recognized the importance of the political dimension of space, beyond economic or technological considerations (EC, 2013).

Space research is considered a ‘key industrial technology’ due to its large potential for innovation. Because of its complexity and investment requirements, cooperation between different types of agents from different countries is needed. Actually, the EC recognized “the need to mobilise existing innovation support mechanisms at European, national and regional level, and consider new support instruments to ensure cross-fertilisation of knowledge, innovation and ideas between space and non-space sectors, and between space industry and leading research organisations and universities” (EC, 2013, p. 3). One of the responses to these challenges was the Horizon 2020 Space Programme, and its multiyear Working Programmes. Because of its implementation, the resulting R&D activity generated a network with a high cooperation and knowledge diffusion rates.

In this chapter, we use Social Network Theory to describe the results of cooperative project calls in *H2020-Space*. With data of the awarded grants for the period 2014-2020, we model each project as a collaborative network where different countries interact and produce a pure public good whose value is measured by the total funding received from the programme. For each call, the awarded projects’ networks overlap, creating a bigger network that represents the collaborative relationships that emerge between the countries. By describing the cooperative R&D activities this way, we unveil the characteristics of collaborations in these projects and how the resulting network has evolved in this period to reach the existing network in 2020.

Each country is the result of the aggregation of the R&D activity performed by its domestic agents participating in the programme. We model the flows of funds as links between the coordinator of the project and the participants. We assume that when a link forms it does not become obsolete.

We study the countries’ network shaped by *H2020-Space* and its characteristics. Besides, how it affects the transmission of knowledge within the network. The main results are that the H2020 programme has increased the degree of cooperation measured by the number of projects (degree) and the embeddedness of countries (triangles and clustering); a strong leadership by the big European countries has developed over time and the effort of newcomers to join the space activity has been boosted.

From *H2020-Space* project data, we obtain the number of projects, project size and number of participants. We have information on the number of participations per country and calculate the weighted participation based on the funds of the project, the number of participants and the role of coordinator. In order to get a better picture of the space R&D activity of a given country, the effect of projects carried out by R&D agents of the same country or projects accomplished by a single organization are taken into account.

We first present several descriptive statistics of the data, and rankings by technology field, in order to evaluate the influence in the network of countries or groups of countries. We also analyse countries R&D organization structure looking for similarities and the deviations from the average. Then, we build the network with the existing project links, which allow us to obtain the revealed cooperation preferences of different countries and compute the network metrics and their evolution over time. Lastly, we define a success indicator based on the participation as project coordinator, normalised by the country population, looking for a "punch over their weight" condition. This allows us to characterize the most successful manner to achieve a better space technology development.

This chapter structures as follows. Section 2 contains a review of the literature on networks and collaborative R&D. Section 3 presents data sources, and description and construction the networks. In Section 4, we analyse the data and, by representing the network's evolution year by year, we discuss countries' performance in H2020 Space R&D programme. Section 5 asserts the degree of success of the different ESA participants in *H2020-space* programmes. Finally, Section 6 presents the conclusions and propose directions for further research to understand better the R&D network in the field of space science and technologies.

Review of the literature

Horizon-2020 in the area of space emerged with the aim to support the development of innovation and to take advantage of complementarity between space R&D project participants. The priorities were set to ensure the protection of space infrastructure, support the EU industry through R&D activity to maintain competitiveness, to position well in the global market and to integrate the space into society.

Knowledge spillovers are important at the national level, as they create important network effects and agglomeration economies. Social Network models appear to be a very suitable tool to analyse how collaborative actions create networks in which agents interact and bring back to their regions those innovations. For instance, Jaffe et al. (1997) found that the knowledge spillovers generated by NASA patents are linked to important network effects and generated agglomeration economies. Firms working with federal labs benefited from tacit knowledge largely than from the transfer of specific technologies (Jaffe et al., 1997).

The existence of framework programmes, such as *H2020-Space*, boost both the development of technologies and the cooperation between different manufacturers. Guffarth & Barber (2014) show how successful regions maintain their position and grow on a larger scale. The analysis based on network indicators favours their hypotheses such as density, short average path length, and very high and increasing clustering coefficient. They use the Centrality metrics to assess the position of the R&D agents in the network and to analyse their influence concluding about the strong correlation of the different facets of the power of organizations.

In their work on the Aerospace industry, Guffarth & Barber (2017) point out the increasing development costs, long break-even periods, and small markets, difficulties with cash flow, high market entry barriers and high governmental impact, both as a regulation body and as a customer. Given these features, innovation ability links to cooperation that enables access, integration and use of external knowledge. Peres (2014) also analyses the impact of network characteristics on the diffusion of innovations. High average degree and relative degree of social hubs contribute to a high rate of diffusion of innovations while clustering characteristic has a negative impact.

This study focused on countries as an aggregation of the different types of agents participating in *H202- Space*, will show also a concentration of the R&D activity in core countries. However, a further analysis taking into account other characteristics such as technology field activity, evolution over time or parameters normalised with the population, will shed more light on countries that may be core in the network even though do not necessarily have the highest absolute metrics.

Breschi & Cusmano (2004), Barber et al. (2006), Protogeru et al. (2012), Amoroso et al. (2018), and Siokas (2018) are studies on collaboration networks of EU-funded research projects and the organizations involved in those projects. These studies focus on several areas of the information and communication technologies field. They mostly find stability on the linkages among countries. Besides, larger countries tend to keep highly interconnected and attract a valuable number of connections with other smaller countries. Similar conclusions achieve Amoroso et al. (2018) when evaluating the involvement of peripheral regions in European R&D collaborative networks. These studies conclude that the networks are becoming deeper more than broader.[9]

Our approach follows Protogeru et al. (2012) who study the structure of European FPs emerging networks holding the existence of an oligarchic core whose centrality and connectivity strengths over programmes. They build a uni-partite graph with a star network shape. They claim it is likely that organisations involved in a project may not have any connection with other than the coordinator. We follow the same network approach with countries.

We use their results in order to compare the space related activity to the broad R&D projects carried out under the different framework programmes, obtaining proof of higher international cooperation and "small-world" properties. Apart from big countries and the EU-15 effect in the network, we also analyse the ESA group effect and cooperation preferences between groups.

[9] Similarly García Muñiz & Vicente Cuervo (2018) find France, Germany, Italy, Spain, United Kingdom and Belgium to have many links and easiness to connect projects, as compared to smaller countries, for environmental technologies.

Barber, Krueger, Krueger & Roediger-Schluga (2006) conclude that EU funded project network along the first four framework programmes follows scale-free, small diameter and high clustering properties and show a European Research network with a solid structure. They suggest extending studies to network vertices, also to the network microstructures in order to analyse clustering and to include weights to the edges of the network and how does this weight influence on the network structure.

Our network will consider the weight of the vertices between nodes (countries) as the number of links along the space framework programme. We also compute another type of weight, based on the cost of the accomplished projects, in order to better analyse the influence of a given country in the network and its evolution.

Amoroso, Coad, & Grassano (2018) evaluate the involvement of peripheral regions in the European R&D collaborative network against several types of distances: geographical, economical, technological, social and human capital. They remark that after more than 30 years of Framework Programmes, an integrated research area is far to be achieved. In fact, they conclude that the network is becoming deeper more than broader. They observe that objective of a more integrated research area may suffer from different policy objectives such as the support of competitiveness and the social and territorial cohesion. Richer regions, with higher density of researchers and research and technology resources will benefit from the research grants disproportionately to the other regions. They conclude in the existence of a high degree of continuous cooperation among closer and similar regions. They also observe that economic, human capital characteristics and knowledge network proximity are key to cooperate. The figures they obtain in percentage of collaborations between more and less developed regions are definitely different.

We analyse such effect in our space network and we do not find geographical or cultural issues in the cooperation. However, cooperation rates between more developed and less developed regions are even more unbalanced. Besides, we also study the cooperation rates between more developed and less developed agents but we consider different classifications so we can evaluate the effect of ESA or the EU-15 group.

Grandjean & Jacomy (2019) propose a table of correspondence between the theory and a network graphic analysis resulting a useful tool for first network architecture interpretations before analysing all network parameters in depth. In those graphic interpretation tips, apart from a gravitational graphic and network evolution in time analysis recommendations, they use global properties including number of nodes and edges, density and the average path length as well as local properties such as the degree, as they define as the simplest centrality measure, and other centrality measures: betweenness, closeness and eigenvector centralities. They observe the advantages of a hierarchy analysis, metrics comparison and metrics combination in the study of a network.

In our study, we apply some of those proposed methods, creating different layouts looking for the clearest way to see the differences of agents' position and behaviour inside the network, applying filters by technology field and analysing their evolution over time. We highlight individual networks and their evolution. Different metrics calculations complement graphic tools for each layout, so we are able to support our conclusions about the network.

Siokas (2018) in the network analysis of EU-funded R&D collaboration defines a centralized score index from four centrality indicators together: Degree, Betweenness, Closeness and Eigenvector. The first three measure the participation whilst the last one relates to the involvement in the network. However, the article highlights the importance of analysing all of them because they provide complementary information. This article also concludes that those nodes with central roles have a greater play in the regulation and access to the resources. Those nodes are involved from the early stages and their central position helps to the diffusion of knowledge, set standards and exploit the benefits of research. Even though they study the *European Security Research Programme* (ESRP) network with agents as nodes, an analysis of the network at a country level also obtains the central nodes in a few countries, the biggest ones in fact.

H2020-Space network shows the biggest countries holding central roles and get the highest centrality measures. Our study confirms this effect taking into account the weight of the links. However, we find differences caused by the technology capacity as we may see bigger countries showing lower centrality metrics than those countries with more technological capabilities and space related history. See Figure 4.9, where several states (i.e. Norway, Czech Republic and Austria) show higher degree metrics even though their population is much lower than others (i.e. Poland and Romania) are. The early-stage participation also shows some differences when weighting the edges, as we see UK first year influence decreasing in favour of Spain, Italy and Germany.

García Muñiz & Vicente Cuervo (2018) study the role of countries acting as hubs and gatekeepers in the promotion of research and the improvement of energy efficiency. They define Hubs as those nodes with high levels of degree and betweenness in a network with 43 countries and 710 links between them. They find high values of degree and betweenness but low closeness in France, Germany, Italy, Spain, United Kingdom and Belgium.

In our *H2020-Space*, we see how Greece, Portugal and The Netherlands have high values of Authority / Hub although they have lower values in degree and betweenness and higher clustering figures. Those differences in countries position in the network uncover a clear difference between the energy and the space sectors.

The effect of penetration process is particularly high in networks that demonstrate what Muller and Peres (2019) call the "3Cs": Cohesion, Connectedness and Conciseness including several network parameters. Besides, they play with innovation performance metrics and define dimensions to be bear in mind when analysing a network: magnitude; threshold; speed; time to take-off and market share net present value. They hold that "the more connected the network is, the higher its growth performance". More links between nodes make easier the take-off, penetration of innovation in a network. The average degree impacts directly in the network growth an also, a high density in a network, meaning a high number of links among nodes, infers a higher growth rate. However, they consider that a look to the degree distribution is key. Heterogeneity may cause a lower take off in those innovations generated in low connected nodes. In those cases where edges distribution shows an elevated number of nodes highly associated with others, will lead to a more connected and better growing network. Clustering may imply both a high speed of diffusion between highly connected nodes but also may cause redundancy and thus, to stop the network growth in a given cluster. On the one hand, a minimum clustering is needed to launch a diffusion process, a kind of critical mass for an innovation diffusion take-off. On the other hand, if there is not enough connection between clusters, there will be no latter diffusion. Therefore, a low enough clustering coefficient linked to a small number of hubs may lead to an optimum diffusion framework. Moreover, Muller and Peres (2014) use a matric on degree correlation of clustering and degree distribution called degree of assortativity measuring how many nodes with similar number of edges link to each other, equivalent to eigenvector centrality. They conclude that the degree of assortativity may cause opposite effects on innovation diffusion and it will depend on market conditions and on how network growth behaves in time.

Beaman & Ben Yishay & Magruder & Mobarak (2018) study how to enhance technology diffusion through a Network theory-based strategy. They use the "threshold model" of diffusion and they find that theory-driven seed nodes lead to a much better technology diffusion results as it happens to those complex contagion models. In fact, a poor targeting process may imply a failure in the diffusion.

Our network counts with several nodes leading projects (seed nodes) with high space technology capacity and a notable size that attract to the other network members from the very beginning, reaching a 93% participation since the second year of the programme.

Balland, Boschma & Ravet (2019) describe collaborative research considering older members of the European Union, EU-15, against, EU-13 new members, in the period 2013-2017. They study the structure and differences in network metrics between older and newer members, as well as the barriers to the entry of new players in H2020, compared to previous FPs. They discuss several metrics such as the average degree, average path length and the persistence of collaborations.[10]

Our analysis focuses on the network structure in 2014-2020 and its adequacy for the transmission of knowledge, in particular its small-world structure; we also emphasize the role of ESA members and the so-called big-5 (Germany, France, United Kingdom, Italy and Spain). We also rank the effort of countries with metrics normalised with the population and compare the space sector results to the global H2020 figures from Balland et Al (2019).

[10] See Cunningham & Link (2016) for a firm-level analysis where younger companies are more eager to join collaborative R&D programmes to improve their low TRLs while older firms have a higher response to direct business R&D.

Data Sources

Our study about the European Space R&D network is based on *H2020-Space* project data from CORDIS database.[11] Using these data, we build a database of countries' R&D relationships through projects belonging to space area from the different work programmes: 2014-2015, 2016-2017, and 2018-2020. The space programme includes the following projects: Applications in Satellite Navigation (GALILEO), Earth Observation (EO), Protection of European Assets in and from space (PROTECT), The Competitiveness of European Space Technology (COMPET) and International Cooperation in Space matters (SPACE).

Each project characterizes by ESA Technology Field as EOBS: Earth Observation; SCNC: Science; HFLT: Human Flight; LNCH: Launchers; GSTP: General Support Technology Programmes; NAVI: Navigation and RBEX: Robotic Exploration.

Balland et al. (2019), in their description of collaborative research, consider two groups of countries: Older members of the EU (EU-15) versus new members (EU-13). However, given the ESA relevance and the high level of international cooperation in the space field, we classify the following groups: ESA member states and out of Europe areas: Asia, America, Africa and Oceania. Furthermore, we emphasize the role of the Big-5 European countries (France, Germany, UK, Italy and Spain), as a reference for activity concentration.

Data allow us to identify R&D links. These are lasting relationships between countries from the project start date to the end of the H2020 Space Programme. The economic return from cooperation in a given project will be the total amount of funds granted. We obtain several network metrics and their evolution over time, both from a global perspective and at the country level as well.[12]

Our database contains information on the coordinator's and the participating agents' country of origin. For each project, we define a link between the coordinator agent's

[11] CORDIS dataset is available at https://data.europa.eu/euodp/es/data/dataset/cordisH2020projects.
[12] Network graphics are drawn using Gephi 0.9.2 software.

country and each of the participants' countries. That is, we define as many links from the coordinator's country to other countries as the number of participants including those belonging to the coordinator's country (self-links). We perform the analysis with and without these self-links, to evaluate the difference in the resulting networks, the network parameters and the position of each country.

For some network metrics, it is worth normalising them over the population so we may evaluate the per capita effort in R&D of a given country. Balland et al. (2019) propose this normalisation when ranking countries participation in European R&D framework programmes. We collect population data from the World Bank.[13]

Countries R&D *H2020-Space* activity.

In this section, we measure cooperation between countries within the H2020 Space activity programme. We overview the programme and how the network of countries forms and evolves. The target is to draw a picture on how countries R&D structure and cooperation interact.

H2020-Space Overview.

Space is a high technology industry that comprises very specialized companies. We should expect larger cooperation in projects compared to other fields less technology intensive fields. Therefore, we begin comparing the number of projects, the participation of agents and countries to the rest of H2020 programmes. In Table 4.1, we shed light on this fact by comparing the total H2020 programmes to the H2020 Space programmes. For the entire duration of the H2020 programme, we include the number of projects, individual projects, average participation of agents and average participation of countries. We find a much lower number of individual projects in the space field (16.7%) compared to the total H2020 programme (64.6%) and higher averages in cooperation of agents and countries.

[13] https://data.worldbank.org/indicator/SP.POP.TOTL.

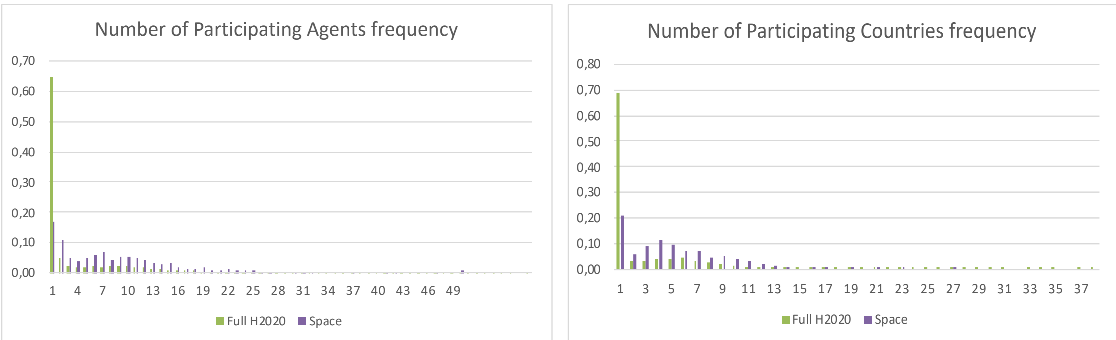
Table 4.1: H2020 vs H2020-Space Projects. 2014-2020(p).

Project Participation metrics	**H2020**	**H2020-Space**
Number of Projects	26,500	347
Number of individual projects	17,117	58
Individual projects percentage	64.6 %	16.7 %
Average participation agents	4.26	6.98
Average participation countries	2.66	4.37
Countries over agents ratio	0.624	0.626

Source: Own elaboration from H2020-Space data from CORDIS database.

Even though the ratio of countries over agents is almost identical in both cases, the frequency distribution is different (see Figure 4.1). Ignoring the few projects with a huge number of agents, we see a more cooperative pattern in space with a larger number of countries and agents participating in a given project and a lower density of single agent or single country projects.[14]

Figure 4.1: Full H2020 vs H2020-Space Projects participation frequency distribution 2014-2020 (p). Agents and Countries.



Source: Own elaboration from H2020-Space data from CORDIS database.

[14] See Annex – Chapter 4 (a).

As far as *H2020-Space* programmes is concerned, there are 347 projects (from 2014 to January 2020) and 61 countries taking part in *H2020-Space* related technology. As noted before, we consider the following groups: EU-15, EU-13, ESA membership and out of Europe groups. All EU-15 countries are members of ESA, only 6 of EU-13 are in ESA and there are 3 non-EU countries (Norway, Switzerland and Canada) who are also ESA member states.

In Table 4.2, for the period from 2014 to January 2020, we collect the number of granted projects, the average of R&D agents and countries participating in these projects, the average funds per project and funds per participant country.

Table 4.2: H2020-Space Projects. 2014-2020(p).

Year	Num.of projects	Av. Part. Agents	Av. Part. countries	Av. Project Total Funds	Av. Funds per Part. Country
2014	9	13.00	6.33	2,165,942.56	285,642.90
2015	113	6.00	3.84	1,578,722.79	315,825.99
2016	76	6.72	4.14	2,433,265.76	393,286.10
2017	42	7.90	4.74	3,489,613.88	518,492.70
2018	44	7.23	4.59	2,394,928.66	352,425.00
2019	47	7.28	4.96	2,452,329.32	439,555.80
2020 (p)	16	7.75	5.13	2,459,519.69	367,594.57
totals	347	6.98	4.37	2,274,840.90	380,325.35

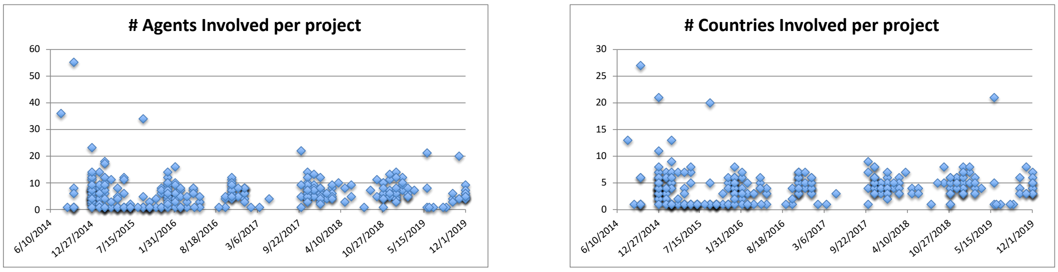
Source: Own elaboration from H2020-Space data from CORDIS database

The year 2015 stands out with around one third of the total number of projects, and 2017 has the highest funds per project in the period. The rest of the years have figures of the same order of magnitude. When we compare the number of participating countries to the number of participating agents we find a ratio in the range of 0.48 to 0.68) which is very close to the total average ratio (0.63).

One of the objectives of the R&D Framework Programme was the cooperation among countries and these ratios show that, in average, from each 7 agents cooperating in a project, they belong, at least, to 4 different countries. This country diversity shows up from the very first years of the framework programme in space.

Regarding the evolution of the cooperative pattern, Figure 4.2a shows the distribution over time of the number of participants in each project (agents on the left and countries on the right).

Figure 4.2a: H2020-Space Projects participation distribution 2014-2020(p).

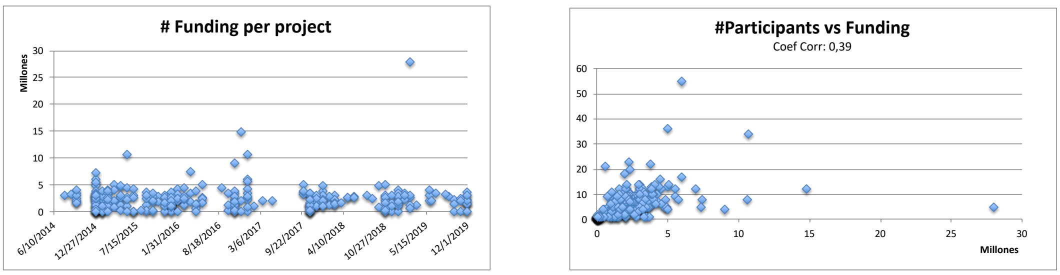


Source: Own elaboration from H2020-Space data from CORDIS database

Observe how the number of projects with a high number of participating agents or countries and the number of single agent or single country projects are decreasing over time.

We are not only interested in the number of agents or countries involved in different space projects but also the value of the projects. Figure 4.2b presents the distribution of funds per project and the funds over number of participants' ratio.

Figure 4.2b: H2020-Space Projects funds distribution 2014-2020 (p).



Source: Own elaboration from H2020-Space data from CORDIS database

There are few projects with a higher than the average funding. The most expensive 50 percent projects add up to 78 percent of the total funding, thus, the cost of the median project is 2.99 M€. Half of the total cost is achieved with the 25 percent (87 projects) of the most expensive projects, being also 2.99 M€ the cost of the 88th most expensive project.

If we take the top 15 projects in number of participating countries (Table 4.3a) and the top 15 in project funds (Table 4.3b), we find only four matches among them (denoted by m in the tables), showing a relatively low correlation (0.41) between the number of participants and the funds of a project.

Table 4.3a: Top 15 Funds H2020-Space projects

Start Date	Acronym	Total Funds (€)	# Project Participants	AREA	# part countries
2017-10-01	2-3SST2016	27,999,088	5	GSTP	4
2016-11-01	CHEOPS	14,792,359	12	GSTP	7
2015-09-01	EPN2020-RI (m)	10,712,125	34	GSTP	20
2017-01-01	GIESEPP	10,602,867	8	LNCH	3
2016-01-01	3SST2015	9,017,432	4	GSTP	4
2017-01-01	HEMPT-NG	7,388,834	8	GSTP	5
2016-12-01	INTERSTELLAR	7,309,500	5	GSTP	5
2018-01-01	Hi-FLY	6,997,016	12	GSTP	6
2014-10-01	MyOcean FO (m)	6,000,000	55	EOBS	27
2015-03-01	GAIA-CLIM (m)	5,999,726	17	EOBS	9
2017-01-01	DISCOVERER	5,726,750	8	GSTP	6
2015-02-01	ERSAT EAV	5,518,703	9	NAVI	4
2015-03-01	FIDUCEO	5,497,798	12	EOBS	4
2017-11-01	LEA	5,021,681	14	GSTP	6
2014-08-01	MACC-III (m)	5,000,000	36	EOBS	13

Source: Own elaboration from H2020-Space data from CORDIS database

Table 4.3b: Top 15 # Participating Countries H2020-Space projects

Start Date	Acronym	Total Funds (€)	# Project	AREA	# countries
2014-10-01	MyOcean FO (m)	6,000,000	55	EOBS	27
2015-01-01	COSMOS2020	2,221,150	23	GSTP	21
2019-06-01	COSMOS2020plus	600,000	21	GSTP	21
2015-09-01	EPN2020-RI (m)	10,712,125	34	GSTP	20
2014-08-01	MACC-III (m)	5,000,000	36	EOBS	13
2015-03-01	BEYOND	1,914,053	18	NAVI	13
2015-01-01	Odysseus II	2,076,788	14	GSTP	11
2015-03-01	GAIA-CLIM (m)	5,999,726	17	EOBS	9
2017-10-01	CHE	3,765,190	22	EOBS	9
2016-01-01	SMILE	4,058,642	14	LNCH	8
2019-02-01	EROSS	3,937,223	10	RBEX	8
2019-01-01	KEPLER	2,899,156	14	EOBS	8
2020-01-01	CERTO	2,843,000	9	EOBS	8
2020-01-01	CURE	2,805,012	9	EOBS	8
2015-01-01	PROGRESS	2,359,235	8	GSTP	8

Source: Own elaboration from H2020-Space data from CORDIS database

Countries Network

We are interested in how country networks build under *H2020-Space* projects with data from 2014 to January 2020.[15] We consider countries of origin of the agents as the nodes of the network and the project links as edges. The resulting network has 61 nodes or participating countries and 2,102 edges or links between the country of origin of the project coordinator and the countries of the other participating agents.

We build the network that emerge from the *H2020-Space* projects. We will use a star network architecture for each project following Breschi & Cusmano (2004). We work with countries as network nodes instead of organizations but we keep projects as edges of the network and keep the coordination role feature of the country of the coordinating research body. Despite those differences, we also infer the emergence of a dense and

[15] Protogeru et al. (2012) work on cross-country collaboration activity along FP programmes, Balland et al. (2019) compare H2020 full programme and FP6 results. Finally, Breschi & Cusmano (2004) analyse the structure of European FPs emerging networks.

hierarchical network where 21 percent of the countries are responsible for 90 percent of the edges of the network.

We study the network microstructure along the lines of Barber et al. (2006); in particular, we analyse clustering taken together and for each technology field separately. Following Balland et al. (2019), we also filter the whole network in ESA, EU-15, EU-13 and out of Europe nodes groups to see the clustering properties of each one, under the assumption that it is likely that collaborative research is more frequent between older members of the European Union (EU-15) versus new members (EU-13). As cooperation in space development in Europe is developed mainly through ESA, we will use ESA participation as a group.

We also calculate the weight of participations as the sum of the funds assigned to each participating agent. We define each participant's weight share as the project total funds over the number of participants.

In Table 4.4 we collect the first network metrics regarding the full number of participations (edges) of countries (nodes) compared to the external links.

Table 4.4: H2020-Space Countries' Participation & External Cooperation. Ranked by total number of participations.

Country	Location_Group	Total # Part.	External # Part.	Total Part Weight	External Weight Part
FR	EU-15-ESA	344	245	283,784,676	238,894,594
DE	EU-15-ESA	320	271	256,719,935	227,646,992
IT	EU-15-ESA	299	232	193,169,195	166,536,678
ES	EU-15-ESA	280	219	208,988,946	183,412,675
UK	EU-15-ESA	236	196	150,763,571	138,977,393
BE	EU-15-ESA	139	132	78,707,798	76,746,463
NL	EU-15-ESA	101	91	54,336,756	51,451,176
EL	EU-15-ESA	76	63	58,337,316	53,955,395
CH	ESA	56	53	30,192,387	29,082,373
AT	EU-15-ESA	55	51	25,701,600	23,934,911
PT	EU-15-ESA	52	45	35,170,861	31,669,746
NO	ESA	39	32	32,583,634	29,679,015
PL	EU-13-ESA	38	38	12,799,053	12,799,053
SE	EU-15-ESA	37	32	22,066,572	19,772,123
FI	EU-15-ESA	35	31	21,869,481	18,842,846
DK	EU-15-ESA	32	32	10,140,590	10,140,590
CZ	EU-13-ESA	32	27	10,674,832	9,901,009
RO	EU-13-ESA	22	22	6,093,363	6,093,363
SI	EU-13-ESA	16	14	6,395,660	5,404,067
IE	EU-15-ESA	16	16	6,172,282	6,172,282
LT	EU-13	11	11	2,834,372	2,834,372
CY	EU-13	10	9	5,421,992	5,261,692
IL	ASIA	10	10	6,143,381	6,143,381
BG	EU-13	10	10	4,366,187	4,366,187
RS	EUR	10	10	2,688,156	2,688,156
EE	EU-13-ESA	9	9	2,272,142	2,272,142
HU	EU-13-ESA	9	9	2,630,829	2,630,829
TR	EUR	8	8	1,631,429	1,631,429
LV	EU13	6	6	748,948	748,948
SK	EU13	5	5	602,854	602,854
UA	EUR	5	5	799,893	799,893
RU	EUR	5	5	1,234,671	1,234,671
US	AMERICA	5	5	2,092,605	2,092,605
BR	AMERICA	5	5	832,903	832,903
IN	ASIA	5	5	1,112,142	1,112,142
SN	AFRICA	4	4	1,510,327	1,510,327

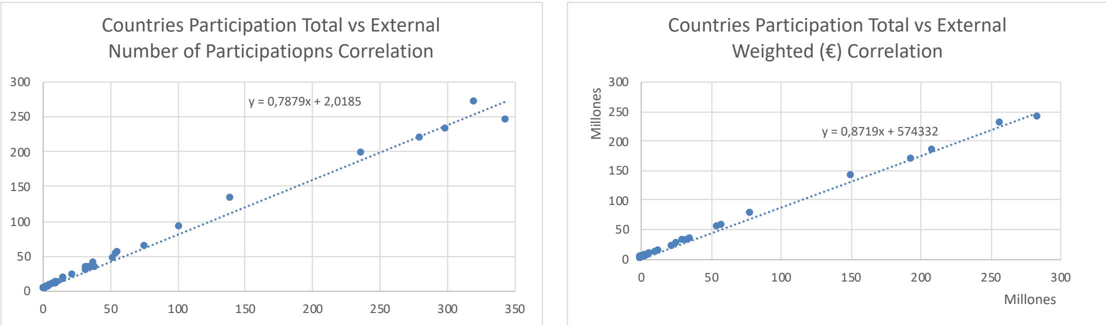
Country	Location_Group	Total # Part.	External # Part.	Total Part Weight	External Weight Part
KR	ASIA	4	4	869,204	869,204
LU	EU-15-ESA	3	3	886,558	886,558
IS	EUR	3	3	440,206	440,206
CA	ESA	3	3	1,321,334	1,321,334
AU	OCEANIA	3	3	833,018	833,018
ZA	AFRICA	3	3	625,472	625,472
JP	ASIA	3	3	496,816	496,816
MT	EU-13	2	2	685,136	685,136
XK	EUR	2	2	212,673	212,673
HR	EU-13	2	2	301,400	301,400
TN	AFRICA	2	2	470,970	470,970
TW	ASIA	2	2	324,404	324,404
MA	AFRICA	2	2	215,427	215,427
TH	ASIA	2	2	247,747	247,747
VN	ASIA	2	2	247,747	247,747
CN	ASIA	2	2	324,404	324,404
AI	AMERICA	1	1	325,867	325,867
MD	ASIA	1	1	106,336	106,336
ME	EUR	1	1	106,336	106,336
MK	EUR	1	1	106,336	106,336
TG	AFRICA	1	1	260,288	260,288
PS	ASIA	1	1	106,336	106,336
GE	ASIA	1	1	28,571	28,571
MY	ASIA	1	1	160,300	160,300
EG	AFRICA	1	1	106,336	106,336

Source: Own elaboration from H2020-Space data from CORDIS database

We may expect that high participation figures in projects may imply high weighted participation figures. We see how Big-5 European countries keep the top 5 positions in all cases, and ESA and EU-15 countries prevail over EU-13. However, we see some differences between rankings in number of participations and weighted participation of countries: PT, NO and PL get more weight than the number of projects they participate. There are, as well, other ranking differences in total and external participation figures: France and Germany change rankings in number of participations and Italy and Spain change in the weighted participation too.

Total participation and external participation seem to be correlated. Figure 4.3 plots total countries participation with respect to external number of participants and external weights.

Figure 4.3: H2020-Space projects Countries' Participation vs External Cooperation.



Source: Own elaboration from H2020-Space data from CORDIS database

The linear correlation coefficients are 0.9962 and 0.9993, respectively. Although correlation coefficients are high, we observe how the number of participations corresponding to FR, DE and BE, show the biggest deviations from the calculated linear trend.

We also may expect that countries with higher number of agents will show higher number of participations in projects and high internal cooperation rates.[16] We use the country population to normalize the number of agents and the weighted participation.[17] The goal is to check whether the size of a country drives the participation ranking or if the interest of some countries may lead to a better positioning in the space field. In Table 4.5, we show the top 25 countries ranked by the number of agents, normalized over population, participating in *H2020-Space* R&D Projects.

[16] See Annex – Chapter 4 (c).
[17] Protogeru et al. (2012) also use population to normalize the country size effect.

Table 4.5: TOP 25 Countries ranking by # Participations over Population & H2020-Space participation figures.

Country	Pop (M)	Location	Part (M€)	Part(M€) / Pop(M)	# Part	# Part / POP (M)
BE	11.48	EU-15-ESA	78.71	6.85	139	12.10
NO	5.35	ESA	32.58	6.09	39	7.29
EL	10.72	EU-15-ESA	58.34	5.44	76	7.09
CY	1.20	EU-13	5.42	4.52	10	8.34
ES	47.08	EU-15-ESA	208.99	4.44	280	5.95
FR	67.06	EU-15-ESA	283.78	4.23	344	5.13
FI	5.52	EU-15-ESA	21.87	3.96	35	6.34
CH	8.57	ESA	30.19	3.52	56	6.53
PT	10.27	EU-15-ESA	35.17	3.42	52	5.06
IT	60.30	EU-15-ESA	193.17	3.20	299	4.96
NL	17.33	EU-15-ESA	54.34	3.13	101	5.83
DE	83.13	EU-15-ESA	256.72	3.09	320	3.85
SI	2.09	EU-13-ESA	6.40	3.06	16	7.66
AT	8.88	EU-15-ESA	25.70	2.90	55	6.20
UK	66.83	EU-15-ESA	150.76	2.26	236	3.53
SE	10.29	EU-15-ESA	22.07	2.15	37	3.60
DK	5.82	EU-15-ESA	10.14	1.74	32	5.50
EE	1.33	EU-13-ESA	2.27	1.71	9	6.78
LU	0.62	EU-15-ESA	0.89	1.43	3	4.84
MT	0.50	EU-13	0.69	1.36	2	3.98
IE	4.94	EU-15-ESA	6.17	1.25	16	3.24
IS	0.36	EUR	0.44	1.22	3	8.30
LT	2.79	EU-13	2.83	1.02	11	3.95
CZ	10.67	EU-13-ESA	10.67	1.00	32	3.00
IL	9.05	ASIA	6.14	0.68	10	1.10

Source: Own elaboration from H2020-Space data from CORDIS database

Observe how BE keeps the highest number of participations and most of them are external. BE is involved in many technological fields and this may explain the large number of agents normalized by population. CZ, with low participation number and a low participation over population rate, holds very high internal cooperation rates. The Big-5 have a low normalized rate, leaded by Spain, and get the highest scores in internal cooperation. Israel is at the tail of top 25 showing a very little space R&D activity relative to its population and SI and FI are in a position in the normalized ranking, according to their internal activity rates.[18]

Another important factor for the position of countries in the network is the coordination role. Table 4.6 sorts countries according to their weighted project coordination over population relevance.

Table 4.6: TOP 25 Countries ranking by Weighted Project Coordination over Population.

Country	Location Group	Population	# coord.	% coord	#coord / Pop (M)	Proj coord	Weighted Coord/Pop
NO	ESA	5,347,896	7	2.02%	1.31	20,250,268	3.79
EL	EU-15-ESA	10,716,322	17	4.90%	1.59	37,861,372	3.53
BE	EU-15-ESA	11,484,055	14	4.03%	1.22	37,288,245	3.25
CY	EU13	1,198,575	2	0.58%	1.67	3,889,334	3.24
FR	**EU-15-ESA**	67,059,887	**60**	**17.29%**	**0.89**	**165,582,978**	**2.47**
ES	**EU-15-ESA**	47,076,781	**60**	**17.29%**	**1.27**	**111,591,059**	**2.37**
PT	EU-15-ESA	10,269,417	11	3.17%	1.07	21,734,771	2.12
FI	EU-15-ESA	5,520,314	5	1.44%	0.91	10,755,347	1.95
DE	**EU-15-ESA**	83,132,799	**51**	**14.70%**	**0.61**	**146,323,285**	**1.76**
IT	**EU-15-ESA**	60,297,396	**54**	**15.56%**	**0.90**	**95,944,747**	**1.59**
NL	EU-15-ESA	17,332,850	14	4.03%	0.81	25,567,973	1.48
CH	ESA	8,574,832	4	1.15%	0.47	10,967,601	1.28
UK	**EU-15-ESA**	66,834,405	**23**	**6.63%**	**0.34**	**70,456,429**	**1.05**
SI	EU-13-ESA	2,087,946	3	0.86%	1.44	2,126,045	1.02
SE	EU-15-ESA	10,285,453	4	1.15%	0.39	8,437,286	0.82
AT	EU-15-ESA	8,877,067	4	1.15%	0.45	6,462,885	0.73
IL	ASIA	9,053,300	3	0.86%	0.33	4,596,250	0.51
BG	EU-13	6,975,761	1	0.29%	0.14	2,845,001	0.41
DK	EU-15-ESA	5,818,553	1	0.29%	0.17	2,047,657	0.35
IE	EU-15-ESA	4,941,444	1	0.29%	0.20	1,599,924	0.32
CZ	EU-13-ESA	10,669,709	1	0.29%	0.09	1,857,175	0.17
LV	EU-13	1,912,789	1	0.29%	0.52	71,429	0.04
LT	EU-13	2,786,844	1	0.29%	0.36	71,429	0.03
PL	EU-13-ESA	37,970,874	3	0.86%	0.08	898,445	0.02
HR	EU-13	4,067,500	1	0.29%	0.25	71,429	0.02

Source: Own elaboration from H2020-Space data from CORDIS database

[18] We do not take into consideration Anguilla (AI), as it is a launch site with a population so short that the participation over population rate is exceptionally high and does not reflect the R&D effort. The whole ranking with all country participants is available upon request.

We see how the European Big-5 countries hold 61.86 percent of project participations while their Coordination role reaches 71.47 percent of all projects. If we focus on the weighted participation, their performance is even larger: 70.48 percent in participation and 74.73 percent in coordination. If we extend to EU-15 members, they reach 98 to 99 percent of all projects.

Siokas (2018) emphasizes the key role of project coordinators to structure the research team, define the research proposal and exploit the results. Note that the coordination role affects also the weighted participation by construction. Balland et al. (2019) find dominance in the participation of the largest EU-15 countries. We also find (see Table A4.4 in Annex – Chapter 4 (d)) a strong correlation in EU-15 between country size and project weighted participation (0.945), and with the project coordination role (0.923). Slovenia leads EU-13 coordination countries. However, if we consider the number of coordinated projects and the weighted coordination normalized with countries population, we obtain a very different ranking. Norway, Greece, Belgium and Cyprus have better ranking than France and Spain. UK has an unexpectedly low rate.

Countries' R&D Structure.

In this subsection, we analyse the space agents' structure of countries involved in the *H2020-Space* projects. The agents' structure of a country is studied bearing in mind the types of agents participating in R&D projects and the countries' activity in the different technology fields, no matter the type of agent involved. We compare both structures to the average of the programme in order to detect asymmetries.

Countries Agents' Structure.

Each country shows a different composition of agents participating in *H2020-Space* R&D programme. In Table 4.7 we present the percentages of each type of agent per country. Besides, we rank countries by the degree of misalignment which is calculated as the sum of squared differences to the average.

Table 4.7. Countries' agents composition percentages per type of agent.

Country	# Coord	# Part	# agents	PRC	REC	HES	PUB	OTH	Mis-alignmnt
DE	**51**	**320**	**130**	**59%**	**15%**	**18%**	**4%**	**5%**	**0.002**
IT	**54**	**299**	**151**	**60%**	**14%**	**16%**	**5%**	**5%**	**0.003**
ES	**60**	**280**	**134**	**56%**	**17%**	**13%**	**8%**	**6%**	**0.004**
SE	4	37	26	62%	12%	15%	8%	4%	0.007
EL	17	76	43	63%	14%	14%	5%	5%	0.008
CH	4	56	34	53%	18%	24%	0%	6%	0.008
CZ	1	32	24	50%	13%	21%	4%	13%	0.009
AT	4	55	37	57%	8%	22%	3%	11%	0.010
RS	0	10	8	50%	13%	25%	0%	13%	0.016
HU	1	9	9	56%	22%	11%	11%	0%	0.016
BE	14	139	70	54%	17%	7%	7%	14%	0.018
NL	14	101	59	68%	12%	14%	3%	3%	0.020
DK	1	32	15	67%	13%	20%	0%	0%	0.021
FR	**60**	**344**	**146**	**68%**	**7%**	**14%**	**3%**	**8%**	**0.024**
UK	**23**	**236**	**107**	**53%**	**7%**	**32%**	**6%**	**2%**	**0.028**
PL	3	38	29	52%	31%	14%	0%	3%	0.032
RO	0	22	20	45%	30%	15%	5%	5%	0.034
PT	11	52	38	53%	29%	5%	8%	5%	0.036
IL	3	10	8	50%	13%	13%	25%	0%	0.047
BR	0	5	3	67%	0%	33%	0%	0%	0.067
NO	7	39	25	40%	36%	12%	4%	8%	0.071
SK	0	5	4	50%	0%	25%	25%	0%	0.072
IN	0	5	4	50%	25%	0%	0%	25%	0.083
KR	0	4	4	50%	25%	0%	0%	25%	0.083
TR	0	8	6	33%	17%	33%	17%	0%	0.088
BG	1	10	7	43%	43%	14%	0%	0%	0.101
LT	1	11	8	38%	0%	25%	25%	13%	0.101
SI	3	16	11	45%	36%	0%	18%	0%	0.106
IE	1	16	12	33%	8%	42%	8%	8%	0.111
LU	0	3	3	33%	33%	33%	0%	0%	0.113
LV	1	6	4	50%	0%	50%	0%	0%	0.137
MT	0	2	2	50%	0%	50%	0%	0%	0.137
RU	0	5	4	25%	25%	25%	0%	25%	0.145
HR	1	2	2	50%	50%	0%	0%	0%	0.163
MA	0	2	2	50%	50%	0%	0%	0%	0.163
FI	5	35	14	21%	29%	36%	7%	7%	0.165
ZA	0	3	3	33%	33%	0%	33%	0%	0.193
US	0	5	4	25%	25%	50%	0%	0%	0.213

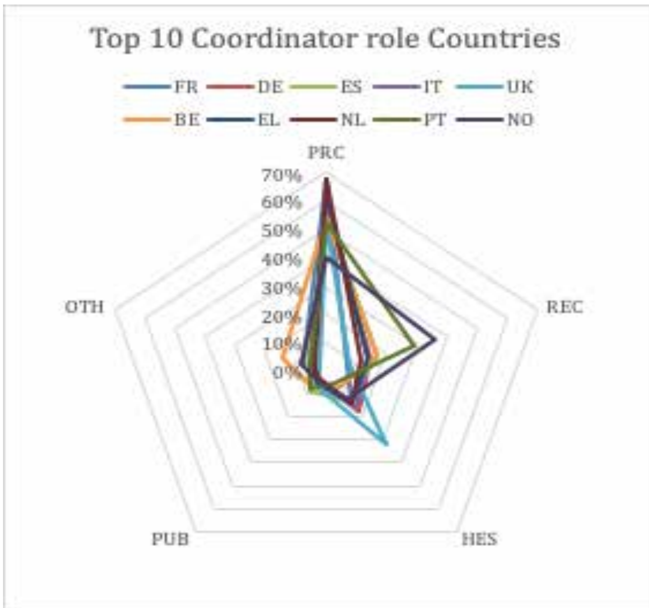
Country	# Coord	# Part	# agents	PRC	REC	HES	PUB	OTH	Mis-alignmnt
CY	2	10	9	22%	0%	33%	33%	11%	0.235
SN	0	4	2	50%	0%	0%	50%	0%	0.257
UA	0	5	4	25%	0%	50%	25%	0%	0.259
MK	0	1	1	100%	0%	0%	0%	0%	0.262
MD	0	1	1	100%	0%	0%	0%	0%	0.262
AI	0	1	1	100%	0%	0%	0%	0%	0.262
CA	0	3	3	33%	0%	67%	0%	0%	0.317
AU	0	3	3	33%	0%	67%	0%	0%	0.317
EE	0	9	6	17%	0%	50%	0%	33%	0.353
TN	0	2	2	0%	50%	50%	0%	0%	0.538
IS	0	3	2	0%	50%	0%	50%	0%	0.658
XK	0	2	2	0%	0%	0%	50%	50%	0.747
VN	0	2	1	0%	0%	100%	0%	0%	1.012
MY	0	1	1	0%	0%	100%	0%	0%	1.012
TG	0	1	1	0%	0%	100%	0%	0%	1.012
GE	0	1	1	0%	0%	100%	0%	0%	1.012
JP	0	3	2	0%	100%	0%	0%	0%	1.065
EG	0	1	1	0%	100%	0%	0%	0%	1.065
TH	0	2	1	0%	100%	0%	0%	0%	1.065
PS	0	1	1	0%	100%	0%	0%	0%	1.065
CN	0	2	1	0%	0%	0%	0%	100%	1.243
TW	0	2	1	0%	0%	0%	0%	100%	1.243
ME	0	1	1	0%	0%	0%	100 %	0%	1.252
Avrg				**55%**	**15%**	**18%**	**6%**	**6%**	

Source: Own elaboration from H2020-Space data from CORDIS database

There is evidence of differences in asymmetries between the Big-5 countries. FR and UK have a distribution more asymmetric than DE, IT and ES.

In Figure 4.4, we plot a radial graph of countries composition by type of agent participating in *H2020-Space*.

Figure 4.4: Countries composition by Type of agent participating in H2020-Space.



Source: Own elaboration from H2020-Space data from CORDIS database

We find a similar structure in seven of the top-ten project coordinator countries. UK shows a higher percentage of HES versus REC, while Portugal and Norway have more REC instead of PRC. France has a high PRC and low REC percentages. These top-10 countries by coordination role (FR, DE, ES, IT, UK, BE, EL, NL, PT and NO) keep their leadership in number of participations and in their weighted participation.

Note that most of these countries with a deeper involvement in the R&D programme show a similar percentage share of agents per type. However, the variations in those figures do not allow us to agree in a common structure neither for the top coordinators nor for the countries with higher participation.

Countries' Technology Field Structure.

We are also interested in the technology field share of the involved countries. In Table 4.8, we report the distribution of the countries' activity by technology field. Besides, we rank countries by the misalignment to the average. We highlight the capacity of a country in a given technology field, and therefore its preferences in joint research projects. Furthermore, we study whether there is any evidence that a country or group of countries distribution mandates over the whole space framework activity.

Table 4.8. Countries' project participation by technology field.

Ctry	# coord	# Part	# agents	T.Part (M€)	EOBS	GSTP	HMFL	LNCH	NAVI	RBEX	SCNC	Mis-align. avrg.
UK	23	236	107	150.8	28%	44%	1%	6%	13%	6%	3%	0.005
CH	4	56	34	30.2	27%	40%	1%	2%	26%	4%	0%	0.008
ES	60	280	134	209.0	20%	39%	1%	3%	26%	9%	2%	0.013
BE	14	139	70	78.7	18%	39%	2%	2%	20%	16%	2%	0.021
PL	3	38	29	12.8	17%	49%	0%	2%	18%	14%	0%	0.021
DE	51	320	130	256.7	21%	51%	6%	10%	9%	3%	0%	0.022
FR	60	344	146	283.8	18%	55%	1%	4%	14%	8%	0%	0.022
DK	1	32	15	10.1	38%	49%	0%	3%	10%	0%	0%	0.031
US	0	5	4	2.1	28%	59%	0%	0%	13%	0%	0%	0.034
IT	54	299	151	193.2	16%	39%	8%	1%	33%	2%	1%	0.036
IE	1	16	12	6.2	20%	54%	14%	0%	12%	0%	0%	0.037
PT	11	52	38	35.2	30%	61%	0%	0%	7%	1%	0%	0.053
LU	0	3	3	0.9	40%	30%	0%	0%	29%	0%	0%	0.057
NL	14	101	59	54.3	44%	30%	2%	9%	13%	0%	1%	0.058
HU	1	9	9	2.6	13%	60%	0%	0%	27%	0%	0%	0.060
AT	4	55	37	25.7	48%	32%	3%	7%	10%	1%	0%	0.073
RU	0	5	4	1.2	39%	61%	0%	0%	0%	0%	0%	0.092
ZA	0	3	3	0.6	43%	57%	0%	0%	0%	0%	0%	0.092
LT	1	11	8	2.8	47%	53%	0%	0%	0%	0%	0%	0.098
SE	4	37	26	22.1	29%	19%	2%	22%	28%	0%	1%	0.101
RO	0	22	20	6.1	44%	18%	0%	17%	16%	0%	5%	0.118
NO	7	39	25	32.6	45%	17%	13%	4%	19%	1%	0%	0.120
CZ	1	32	24	10.7	17%	29%	0%	0%	50%	0%	4%	0.131
EL	17	76	43	58.3	54%	26%	1%	0%	9%	1%	8%	0.132
EE	0	9	6	2.3	59%	41%	0%	0%	0%	0%	0%	0.155
FI	5	35	14	21.9	60%	34%	0%	0%	4%	2%	0%	0.158
SK	0	5	4	0.6	28%	21%	0%	0%	51%	0%	0%	0.165
IL	3	10	8	6.1	20%	24%	0%	0%	55%	0%	0%	0.181
LV	1	6	4	0.7	15%	85%	0%	0%	0%	0%	0%	0.232
UA	0	5	4	0.8	0%	40%	0%	0%	60%	0%	0%	0.240
CA	0	3	3	1.3	0%	24%	29%	0%	47%	0%	0%	0.250
TR	0	8	6	1.6	49%	8%	0%	0%	43%	0%	0%	0.250
CY	2	10	9	5.4	58%	5%	0%	0%	37%	0%	0%	0.297
SI	3	16	11	6.4	73%	19%	0%	0%	8%	0%	0%	0.301
HR	1	2	2	0.3	76%	24%	0%	0%	0%	0%	0%	0.340
KR	0	4	4	0.9	56%	0%	0%	0%	44%	0%	0%	0.352
MA	0	2	2	0.2	51%	0%	0%	0%	49%	0%	0%	0.352
IN	0	5	4	1.1	36%	0%	0%	0%	64%	0%	0%	0.409
TN	0	2	2	0.5	0%	100%	0%	0%	0%	0%	0%	0.429
GE	0	1	1	0.0	0%	100%	0%	0%	0%	0%	0%	0.429

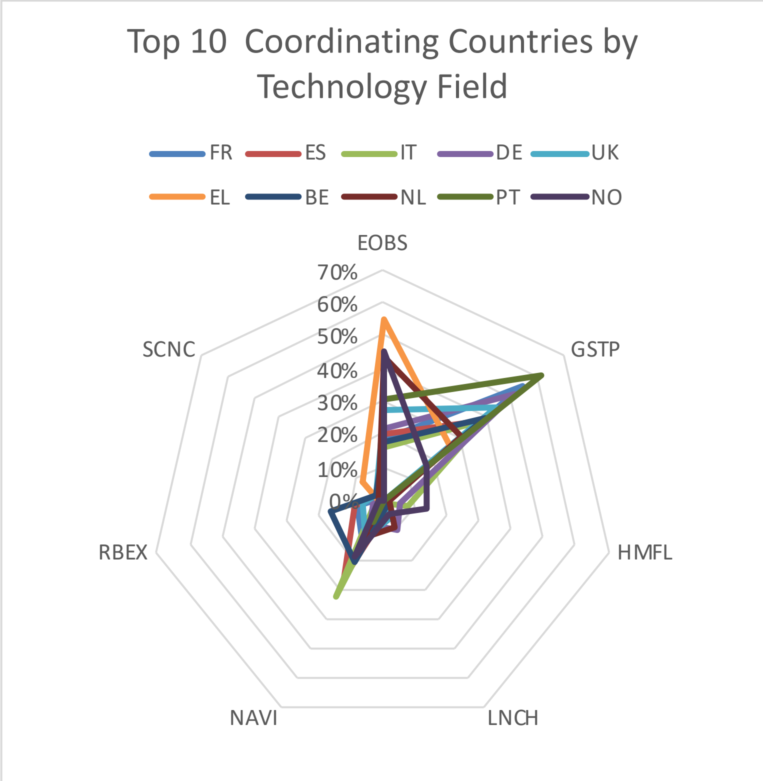
Ctry	# coord	# Part	# agents	T.Part (M€)	EOBS	GSTP	HMFL	LNCH	NAVI	RBEX	SCNC	Mis-align. avrg.
IS	0	3	2	0.4	0%	100%	0%	0%	0%	0%	0%	0.429
RS	0	10	8	2.7	74%	1%	0%	0%	13%	0%	12%	0.438
SN	0	4	2	1.5	27%	0%	0%	0%	73%	0%	0%	0.493
AU	0	3	3	0.8	80%	0%	0%	0%	20%	0%	0%	0.493
BG	1	10	7	4.4	5%	12%	0%	10%	7%	0%	65%	0.554
JP	0	3	2	0.5	0%	0%	35%	0%	65%	0%	0%	0.572
MT	0	2	2	0.7	16%	0%	0%	0%	84%	0%	0%	0.631
AI	0	1	1	0.3	100%	0%	0%	0%	0%	0%	0%	0.786
CN	0	2	1	0.3	0%	0%	0%	0%	100%	0%	0%	0.920
BR	0	5	3	0.8	0%	0%	0%	0%	100%	0%	0%	0.920
EG	0	1	1	0.1	0%	0%	0%	0%	100%	0%	0%	0.920
VN	0	2	1	0.2	0%	0%	0%	0%	100%	0%	0%	0.920
TH	0	2	1	0.2	0%	0%	0%	0%	100%	0%	0%	0.920
MY	0	1	1	0.2	0%	0%	0%	0%	100%	0%	0%	0.920
TW	0	2	1	0.3	0%	0%	0%	0%	100%	0%	0%	0.920
TG	0	1	1	0.3	0%	0%	0%	0%	100%	0%	0%	0.920
PS	0	1	1	0.1	0%	0%	0%	0%	100%	0%	0%	0.920
MK	0	1	1	0.1	0%	0%	0%	0%	100%	0%	0%	0.920
XK	0	2	2	0.2	0%	0%	0%	0%	100%	0%	0%	0.920
ME	0	1	1	0.1	0%	0%	0%	0%	100%	0%	0%	0.920
MD	0	1	1	0.1	0%	0%	0%	0%	100%	0%	0%	0.920

Source: Own elaboration from H2020-Space data from CORDIS database

Big-5 countries have different interests or technology fields share. Although they are all in the top ten and most of them closely aligned to the total space programme average, they do not seem to enforce the global funding allocation to their own interests. FR and DE, for example, with the highest participation figures in the programme, have notable differences between their interests and the global funding share.

H2020-Space network has few agents with very high levels of connections (degree) and project participation (weighted degree) and they may influence the rest of agents and drive the technological development to their own interests. Our measure of misalignment highlights the influence of countries in the H2020 Space Programme technology fields' shares. In Figure 4.5, we show the top-10 countries per number of projects in a coordination role by technology field.

Figure 4.5: Countries technology field share in H2020-Space.



Source: Own elaboration from H2020-Space data from CORDIS database

In contrast to the previous classification by type of agent in Table 4.7, there are large discrepancies among the countries. Other rankings such as number of participations or participations weighted by project funds show the same pattern of dissimilarity among those countries. In fact, Big-5 countries remain in the top-10 of these rankings and do not match in their technology field preferences. Then, there seems to be no correlation between the participation intensity in *H2020-Space* and the technology field preferences.

In Table 4.9, we assemble countries by groups and compute participation by technology field and degree of misalignment.

Table 4.9. Countries Groups' project participation per Technology Field.

Location Group	# coord	# Part	# agents	T.Part (M€)	EOBS	GSTP	HMFL	LNCH	NAVI	RBEX	SCNC	Misalign
EUROPE	344	2,327	1,207	1,533	25%	43%	3%	5%	18%	5%	2%	0.00003
ESA	338	2,249	1,146	1,512	25%	43%	3%	5%	18%	5%	1%	0.00007
EU-28	333	2,197	1,120	1,463	24%	44%	3%	5%	18%	5%	2%	0.00019
EU-15-ESA	319	2,025	985	1,407	24%	44%	3%	5%	17%	5%	1%	0.00041
Big-5	248	1,479	668	1,093	20%	47%	3%	5%	18%	5%	1%	0.00388
EU-13-ESA	8	126	99	41	32%	35%	0%	3%	24%	5%	2%	0.01571
EU-13	14	172	135	55	33%	31%	0%	3%	23%	3%	6%	0.02638
AMERICA	0	14	11	4.6	20%	34%	8%	0%	38%	0%	0%	0.05701
AFRICA	0	13	11	3.2	25%	26%	0%	0%	50%	0%	0%	0.13279
ASIA	3	34	26	10.2	21%	15%	2%	0%	62%	0%	0%	0.27954
OCEANIA	0	3	3	0.8	80%	0%	0%	0%	20%	0%	0%	0.49292
TOTALS	**347**	**2,391**	**1,258**	**1,551**	**25%**	**43%**	**3%**	**5%**	**18%**	**5%**	**2%**	

Source: Own elaboration from H2020-Space data from CORDIS database

EUROPE, ESA and EU-28 groups match almost perfectly the programme average. However, the Big-5 group does not align that well to the global programme. EOBS and GSTP are the fields with the larger discrepancy. EU-13 group does not follow the average.

We have seen, so far, indicators of high cooperation between countries in the European space R&D activity, with an average of 6 agents from 4 countries different from the coordinator's. Concerning the agents' structure of the countries, we conclude there is no evidence of a relationship between participation or coordination roles in *H2020-Space* projects and the structure of a country internal R&D agents or the country technology field preferences. It is remarkable the existing differences between the European Big-5 countries, even though they are the programme leaders. It is also worth noting that when we consider the population of a country, the ranking by effort in space R&D shifts the leadership to smaller countries such as NO, GR and BE.

Cooperation among groups of countries.

In this section, we provide information about the project links of the coordinator by groups of countries. Table 4.10 summarizes the descriptive results.

Table 4.10: Cooperation in projects by group of Countries.

Coordination	COORD	PART	#	Rel. %
3.7%	ESA	ESA	11	14.1%
	(non EU)	EU-13	0	0.0%
		EU-13-ESA	2	2.6%
		EU-15-ESA	**65**	**83.3%**
		EUR	0	0.0%
		AMERICA	0	0.0%
		ASIA	0	0.0%
		AFRICA	0	0.0%
		OCEANIA	0	0.0%
1.0%	EU-13	ESA	1	4.5%
	(non ESA)	EU-13	4	18.2%
		EU-13-ESA	0	0.0%
		EU-15-ESA	**15**	**68.2%**
		EUR	0	0.0%
		AMERICA	1	4.5%
		ASIA	1	4.5%
		AFRICA	0	0.0%
		OCEANIA	0	0.0%
1.2%	EU-13-ESA	ESA	0	0.0%
		EU-13	4	16.0%
		EU-13-ESA	**12**	**48.0%**
		EU-15-ESA	9	36.0%
		EUR	0	0.0%
		AMERICA	0	0.0%
		ASIA	0	0.0%
		AFRICA	0	0.0%
		OCEANIA	0	0.0%
94%	EU-15-ESA	ESA	74	3.8%
		EU-13	35	1.8%
		EU-13-ESA	108	5.5%
		EU-15-ESA	**1,663**	**84.4%**
		EUR	35	1.8%
		AMERICA	10	0.5%
		ASIA	30	1.5%
		AFRICA	13	0.7%
		OCEANIA	3	0.2%
0.3%	ASIA	**EU-15-ESA**	**4**	**66.6%**
		ESA	1	16.7%
		ASIA	1	16.7%
		TOTAL	**2,102**	

Source: Own elaboration from H2020-Space data from CORDIS database

ESA non EU, EU-13 not belonging to ESA, EU-15 and Asia, tend to work with EU-15. However, we see how EU-13-ESA countries cooperate more between them in the projects they lead than with other countries in other groups, even EU-15.

To compare our results to Amoroso et al. (2018), we classify European countries upon their space technology development in two categories: more developed and less developed. In Table 4.11, we show the collaboration in space R&D projects between those groups measured by the percentages of collaboration in FP7 2007-2013 and *H2020-Space* projects 2014-2019, between EU-15 & EU-13 and between ESA Member states & EU-13 no-ESA. There are two additional rows because of the significant percentage of international cooperation with non-European countries in space. *H2020-Space* collaborations are calculated counting the links in each project leaded by each of the groups defined: EU-15, EU-13, ESA member States, EU-13 no ESA members and foreign countries.

Table 4.11: Cooperation in projects by group of Countries.

	FP7 2007-2013	***H2020-Space* 2014-2019**	
Development	**European Regions**	**EU-15 & EU-13**	**ESA & EU-13 No ESA**
MORE/MORE	76%	82.4%	92.5%
MORE/LESS	22%	8.3%	2.6%
LESS/LESS	2%	1.0%	0.2%
MORE/Foreign	-	8.2%	4.3%
LESS/Foreign	-	0.1%	0.1%

Source: Own elaboration from H2020-Space data from CORDIS database

Protogeru et al. (2012) find that the share of collaborations between European countries and the rest of the world amount to 2.7% from FP1 to FP7. This quantity seems to indicate that European funded projects do not have a global orientation. However, in *H2020-Space*, regarding cooperation with the rest of the world, those collaborations add up to 8.3% of total links in projects. This shows the increasing importance of worldwide knowledge and technology to make a valuable research in space. It is even more relevant considering that the activity of Canada, an ESA member state, accounts for 42% of such cooperation.

The percentages are very similar in the two groups of more developed countries but become lower when dealing with less developed countries. Cooperation in space is more likely to occur among more developed countries disregarding the geography.

Next, we calculate the homophily index, HI, that gives us a measure of the preferences of cooperation towards agents of the same group compared to cooperation with agents of a different group. The definition of the index is as follows:

HI = (external links – internal links) / (external + internal links)

The closer HI to -1, the agent prefers to cooperate with agents from the same group (homophily). If HI is near 1, preferences are closer to out of the group cooperation (heterophily). An index value of 0 means there is no homophily neither heterophily in the cooperation network. Table 4.12 summarizes the homophily index for several groups.

Table 4.12. Homophily index.

GROUP	INTERNAL	EXTERNAL	HI
ESA Member States	1678	393	-0.620
EU-15	1663	308	-0.687
Big-5	981	6609	0.742
EU-13	20	74	0.574
EU-13-ESA	12	13	0.040
EU-28	1850	4204	0.389

Source: Own elaboration from H2020-Space data from CORDIS database

We see the highest homophily index in ESA member states and EU-15 countries. However, the aggregate figures for EU-28 show no homophily. Big-5 countries, with an index near 1, proof a high cooperation with countries out of this group thus fulfilling one of the objectives of the *H2020-Space* Programme. Table 4.13 shows country differences in their in-group/out-group preferences.

Table 4.13. Homophily index.

COUNTRY	INTERNAL	EXTERNAL	HI
FR	104	316	0.505
DE	55	252	0.642
UK	41	196	0.654
IT	84	174	0.349
ES	73	223	0.507

Source: Own elaboration from H2020-Space data from CORDIS database

Observe how within the Big-5 countries preferences are closer to out of the group cooperation.

Network Metrics

In this section, we compute some topological measures that allow the comparison of networks and sub-networks across multiple dimensions: Degree, Weighted degree, Eccentricity, closeness centrality, harmonic closeness centrality, Betweenness centrality, Authority, Hub, modularity class, clustering coefficient, page rank, component number, clustering, triangles, Eigen-centrality and dynamic degree.

First, we start presenting the global characterization of the networks and then proceed with the characterization of local properties.

Global properties

We can characterize a network by its global metrics. In this way, we can compare networks across multiple dimensions. We work first with the complete collection of links and later we compare the results with the network that results deleting all internal links from those countries with agents working together in the same project.

The simplest characterization of the network is with the **number of nodes (*n*)** and **edges (*e*)**. In our R&D network, countries are the nodes of the network and an edge represents a flow of EU funds between two nodes. Since the funds go from the project coordinator to the participants, we could consider that it is a directed graph. However, we are interested only on the connections established for future transmission of knowledge and innovation adoption. For this purpose, the direction of the flow is irrelevant, and we will model it as an undirected graph. Graph theory refers the number of nodes as 'graph order', and the number of edges as 'graph size'. Additional metrics are computed using ***n*** and ***e*** as well.

Using this measure, we define ***average degree*** of a network as the average number of links that a node has,

$$\textit{Average degree} = e/n$$

The **average weighted degree** weights each link either by the flow of funding between nodes or the number of projects in which two nodes have been linked. We use this measure to evaluate the growth of the network relationships relative to the degree.

We compute several centrality measures to assert the relative importance of nodes and edges in the graph: diameter, density, modularity, eigenvector centrality, triangles and clustering.

Density of the network is defined as the number of actual connections over the number of potential connections.

$$\textit{Density} = 2e/n(n-1).$$

Complete networks have a density of 1. The closer to 1, the more connected are countries overall and the higher the chances that knowledge can be spread throughout the network and innovations adopted. The **diameter** of a network provides information about how far the most distant nodes are. It is computed as the longest of all the shortest paths between any pair of nodes in the graph.

Modularity measures the intensity of fragmentation of a network into clusters or modules. It is calculated as the fraction of the connections that fall within the given group minus the expected fraction if links were distributed at random, and takes values in the interval [-1,1]. A high modularity would appear if different groups of countries were specialized in different space technology fields, and therefore did not participate in the same projects. Similarly, **communities** are clusters of nodes classified according to their similarity.

Eigenvector Centrality is a measure of the influence of a node in a network. A node with high centrality has a high proportion of connections to the most influential nodes in the network.

The Number of **triangles** is an important feature of networks to measure the degree of embeddedness or close-knitedness. It indicates how many countries are linked with common co-operators. The maximum number of triangles is $n(n-1)/2$. Thus, the **clustering coefficient** of a node is the ratio of existing triangles to the maximum possible number of triangles. It takes values between 0 and 1. Close-knitedness is measured through the clustering of the network, the average of the clustering coefficients of all the nodes. High clustering is expected in small world networks.

Table 4.14 shows the global metrics for the space Innovation & Research network for each year.

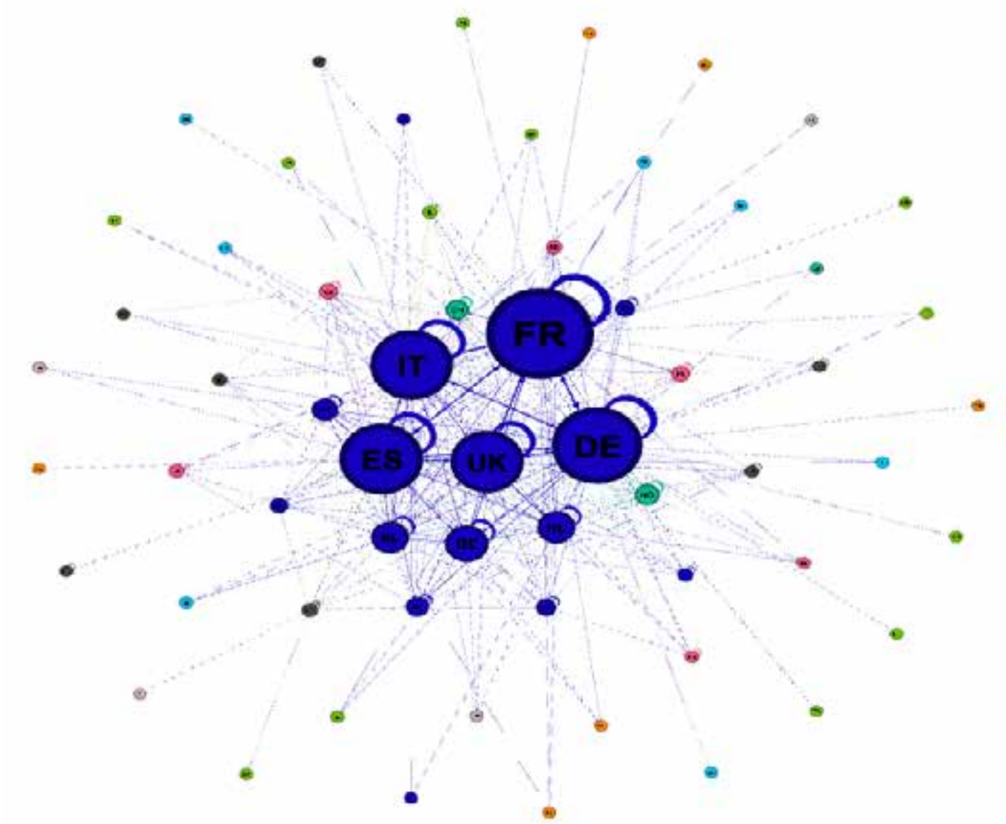
Table 4.14. Research and Innovation Network 2014-2020 (p)

Global Properties Countries Network	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
n	61	61	61	61	61	61	61
e	11	125	197	249	287	338	347
NETWORK OVERVIEW							
Degree	0.18	2.049	3.23	4.082	4.705	5.541	5.689
Weighted degree	0.262	9.41	20.721	24.525	27.820	33.705	34.459
Diameter	2	4	4	3	3	3	3
Average Path length	1.833	2.627	2.266	2.185	2.153	2.080	2.067
Density	0.006	0.067	0.098	0.117	0.131	0.145	0.149
Modularity	0	0.312	0.109	0.073	0.077	0.072	0.063
Number of Communities	50	10	8	5	5	3	3
Number of triangles	0	50	239	393	519	659	698
Number of paths (Length 2)	55	949	2,149	2,998	3,612	4,489	4,715
Clustering Coefficient	0	0.158	0.334	0.393	0.431	0.440	0.444
Number of Weakly Connected Components	50	8	6	3	2	1	1
NODE OVERVIEW							
Average Clustering Coefficient	0	0.258	0.551	0.687	0.719	0.777	0.785
Eigenvector centrality	0.02E-3	2.37E-3	1.51-3	1.19^{-3}	0.74^{-3}	1.02^{-3}	1.06^{-3}

Source: Own elaboration from H2020-Space data from CORDIS database

We observe how this R&D network relationship grows over time and how the ratio between the weighted degree and the degree has stabilized around 6. The degree distribution at the end of the period shows only few countries with a high number of links, while most of the other countries have only one link. To reinforce this evidence, Figure 4.6 represents the Frutcherman Reingold network.

Figure 4.6: Countries Network. 2014-2020(p).



Notes: Self-links included; Country size: weighted Degree; Colour code EU-15 (dark blue); EU-13 (light blue); other ESA member states (purple), non-European cooperating states (green), geographically near (dark grey); other continents participating states (light grey).
Source: Own elaboration from H2020-Space data from CORDIS database

It shows a diameter of 3, the longest distance between two nodes. There is evidence of asymmetries between countries, with EU-15 countries, playing a more central role in the network, as well as NO and CH, ESA member states but not members of the EU. Other network metrics will confirm these asymmetries and the lower profile of EU-13 countries in the *H2020-Space* network.

Although this distribution may indicate a low connection between most of the nodes, we use more network metrics to analyse it. The **distance** between two nodes *u* and *v* is defined as the number of edges along the shortest path connecting them, and denoted ***d(u,v)***. Then, we can compute the **average shortest path length** (***l***) finding the shortest path between all pairs of nodes and taking the average. It provides information about how close the nodes are to each other, on average. It can be used to describe the size, breath or width of the network. But it can also be translated into an indicator of a small world structure. Lower numbers will give us an indication of the efficiency of the information flow of a network. Our network average path length is around 2 so almost all nodes have a common cooperating country, which suggest a high efficiency in the transmission of knowledge. The efficiency of the network will also be studied using different local country network metrics and with the help of a network graphic representation.

Our network reaches a density of 0.149 in January 2020, that is around 15% of all possible direct links between countries have been established. We conclude that the network is sparsely connected. This is because most countries have only few links, while few countries are extremely connected (hierarchic scale-free power-law node degree distribution).

Additional features of the network are a low modularity, which corresponds to a low specialization by technology fields.[19] In addition, it shows a low number of communities which is coherent with the modularity value mentioned above and the lack of specialization of countries by technology field.[20]

In our network with 61 nodes, the maximum number of triangles is 1,830. However, on average there are 128 new triangles every year. Thus, overall clustering is 0.44 which is a relatively high value compared to the average probability of a tie randomly established between two nodes. Related to embeddedness of the network, the **number of paths** measures the number of possible connections between two nodes through project relationships. Although there may not be any direct cooperation, we can connect one agent to another through a path. For each node, our network has on average more than 10 triangles. When the number of paths is high, triangles and longer cycles are easier to form.

One of the network features more relevant for innovation diffusion is the idea of **small-world networks**, that are characterized by high clustering and short path lengths. Human social networks are usually small worlds (Milgram 1967; Travers & Milgram 1969), as well as the collaboration networks of scientific authors (Newman 2001). The high level

[19] This measure increases up to 0.668 when we consider firms and institutions as the technological agents. There are some big actors in the space sector such as OEMs or Technology centres who design the final product and integrate all parts and technologies, but most of the companies are specialist in their fields and are linked to others mainly through the big players.
[20] If instead of countries, we take the agents themselves there are 63 Communities.

of clustering means that knowledge is transmitted easily to the close neighbourhood, but short path lengths mean that information can be spread through the entire network very rapidly. Our network shares these two features, therefore can be characterized as a small-world network.

An important feature of the connectivity of the network is the **number of weakly connected components,** which is an indication of how fragile a network is. A component is a group of connected pairs of nodes that are disconnected from the rest of the network and the robustness of a network to the removal of a node is affected by this type of connectivity. We find a very low rate of weakly connected components over the number of countries (0.016). Therefore, if we remove a country with low connectivity, the effect would be negligible. However, if we deleted one of the European Big-5, the effect in the network would be important.

Finally, there is no trend of the **eigenvector centrality**, it has been almost stable over the last years.[21]

[21] In Annex – Chapter 4 0.3(e), we show the network metrics when the self-links are deleted. Obviously, network parameters depending on the number of edges are affected: number of edges, average degree and weighted degree and modularity. However, variations do not show relevant modifications in the network.

Local properties

Local properties provide information on the nodes of our network and are useful to interpret some global metrics. Clustering, number of triangles and eigenvector centrality are measures computed locally as well.

Degree (Deg) is the number of edges a node (in this case a country) receives. Degree represents connectivity. It is the topological pattern that informs about how well connected a node is that is how many links or how many neighbours. For each country, we get two measures of degree. The **Weighted Degree (W.Deg)** weights the degree by the number of projects, i.e. it counts all the instances of cooperation with other node in projects.

We also compute several centrality measures. The **Eccentricity (Ecc)** measures the maximum distance from a node to others. This parameter, also known as path length is the base for the calculation of the average path length and network diameter global properties. **Closeness** centrality **(clsnss)** measures the average length of the shortest path to all other nodes and it allows us to better understand the existence of a potential ‘center’ (highest score in this dimension) and ‘periphery’ or ‘margins’ (lowest scores). **Harmonic closeness** centrality **(harm cls)** is an alternative to closeness centrality for networks with unconnected components. It is defined as the sum of the inverted distances, instead of the inverted sum of the distances (Rochat, 2009). **Betweenness** centrality **(btnss)** is a measure of how a node facilitates the connectivity of other nodes or group of nodes, that is, if a node acts as an intermediary between other nodes. This is related to the notion of circulation, as it measures the number of times the node intervenes in the shortest path between two other nodes.

There are two additional centrality measures related to influence in the social network. First, **Authority (Atrty)** centrality score tells us the degree of relation of a node with others.[22] **Page rank** is a measure of centrality based on the connections to high-scoring nodes, so a well-connected country gives its neighbours a part of its connectivity capital,

[22] The **Hub** measures the quality of the links to and from a given node. For us, both are equivalent since we are considering an undirected link network.

and the process continues in a cascade.In Table 4.15 we collect the network local parameters of all countries involved in the H2020 Space Programme.

Table 4.15. Countries Local Network Parameters.

Ctry	**Deg**	**W. Deg**	**Ecc.**	**clsnss**	**Harm. cls**	**btnss**	**Atrty**	**Page rank**	**clstrng**	**triang**	**Eigen Centr**
AI	1	1	3	0.35	0.375	0.000	0.00	0.004	0.000	0	0.027
AT	23	77	2	0.56	0.617	0.003	0.18	0.017	0.752	79	0.606
AU	2	3	3	0.42	0.450	0.000	0.03	0.004	1.000	1	0.096
BE	31	227	3	0.58	0.661	0.018	0.22	0.024	0.600	126	0.741
BG	9	12	3	0.50	0.544	0.000	0.10	0.010	0.952	20	0.325
BR	2	5	3	0.39	0.425	0.000	0.02	0.004	1.000	1	0.087
CA	2	3	3	0.47	0.494	0.000	0.03	0.005	1.000	1	0.112
CH	24	75	3	0.56	0.619	0.007	0.19	0.018	0.733	88	0.631
CN	1	2	3	0.43	0.458	0.000	0.01	0.004	0.000	0	0.057
CY	17	24	2	0.55	0.600	0.066	0.14	0.019	0.615	48	0.477
CZ	16	43	3	0.54	0.594	0.005	0.15	0.016	0.731	57	0.505
DE	59	582	2	0.76	0.850	0.292	0.30	0.063	0.198	179	1.000
DK	16	35	2	0.56	0.608	0.002	0.17	0.016	0.846	66	0.548
EE	5	9	3	0.51	0.536	0.000	0.07	0.008	1.000	10	0.242
EG	1	1	3	0.42	0.450	0.000	0.01	0.004	0.000	0	0.055
EL	38	186	2	0.62	0.700	0.030	0.25	0.028	0.483	145	0.839
ES	41	528	2	0.63	0.717	0.110	0.24	0.033	0.390	137	0.824
FI	19	51	3	0.55	0.603	0.002	0.17	0.017	0.780	71	0.570
FR	56	709	2	0.74	0.825	0.310	0.28	0.063	0.214	167	0.955
GE	1	1	3	0.43	0.458	0.000	0.01	0.004	0.000	0	0.057
HR	3	3	3	0.39	0.414	0.000	0.01	0.003	0.000	0	0.050
HU	8	10	3	0.50	0.536	0.000	0.09	0.009	0.762	16	0.310
IE	10	17	3	0.51	0.556	0.000	0.12	0.011	0.833	30	0.408
IL	9	14	3	0.51	0.544	0.000	0.09	0.009	0.762	16	0.308
IN	3	5	3	0.45	0.481	0.000	0.04	0.006	1.000	3	0.148
IS	2	3	3	0.44	0.469	0.000	0.03	0.005	1.000	1	0.107
IT	49	520	2	0.69	0.775	0.119	0.27	0.043	0.291	163	0.922
JP	2	3	3	0.47	0.494	0.000	0.03	0.005	1.000	1	0.112
KR	3	4	3	0.45	0.486	0.000	0.05	0.006	1.000	3	0.159
LT	9	12	3	0.52	0.553	0.000	0.10	0.010	0.786	22	0.353
LU	3	3	3	0.43	0.467	0.000	0.04	0.005	1.000	3	0.134
LV	6	7	3	0.48	0.511	0.000	0.05	0.007	0.700	7	0.199
MA	1	2	3	0.42	0.450	0.000	0.01	0.004	0.000	0	0.055
MD	1	1	3	0.42	0.450	0.000	0.01	0.004	0.000	0	0.055
ME	1	1	3	0.42	0.450	0.000	0.01	0.004	0.000	0	0.055
MK	1	1	3	0.42	0.450	0.000	0.01	0.004	0.000	0	0.055

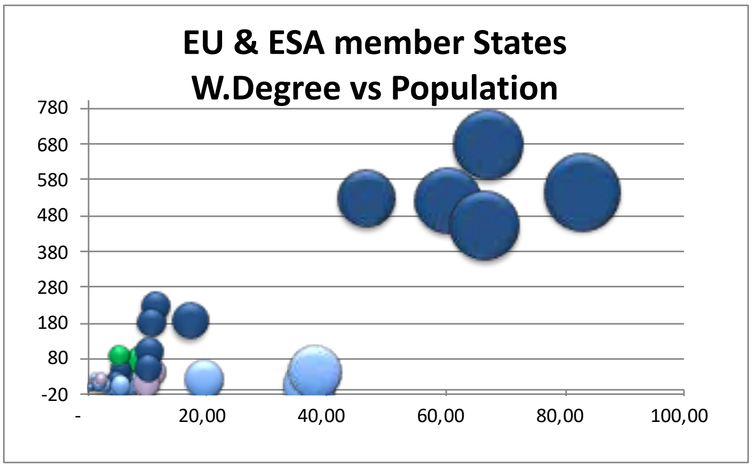
Ctry	Deg	W. Deg	Ecc.	clsnss	Harm. cls	btnss	Atrty	Page rank	clstrng	triang	Eigen Centr
MT	2	2	3	0.45	0.481	0.000	0.03	0.005	1.000	1	0.107
MY	1	1	3	0.35	0.375	0.000	0.00	0.004	0.000	0	0.027
MY	1	1	3	0.35	0.375	0.000	0.00	0.004	0.000	0	0.027
NL	35	187	3	0.60	0.686	0.033	0.23	0.028	0.460	127	0.787
NO	25	87	2	0.58	0.642	0.004	0.21	0.020	0.745	114	0.703
PL	15	42	3	0.53	0.578	0.002	0.13	0.013	0.782	43	0.455
PS	1	1	3	0.42	0.450	0.000	0.01	0.004	0.000	0	0.055
PT	25	100	3	0.57	0.644	0.016	0.21	0.021	0.696	119	0.722
RO	9	22	3	0.53	0.569	0.000	0.13	0.012	0.972	35	0.418
RS	3	10	3	0.45	0.481	0.000	0.04	0.006	1.000	3	0.154
RU	2	5	3	0.45	0.475	0.000	0.03	0.005	1.000	1	0.104
SE	21	54	2	0.57	0.625	0.011	0.18	0.019	0.700	84	0.618
SI	9	21	3	0.50	0.536	0.000	0.08	0.009	0.762	16	0.293
SK	3	5	3	0.45	0.483	0.000	0.04	0.006	1.000	3	0.138
SN	3	4	3	0.45	0.483	0.000	0.04	0.006	1.000	3	0.143
TG	1	1	3	0.39	0.414	0.000	0.01	0.003	0.000	0	0.046
TH	2	2	3	0.45	0.475	0.000	0.03	0.005	1.000	1	0.110
TN	1	2	3	0.43	0.458	0.000	0.01	0.004	0.000	0	0.057
TR	4	8	3	0.49	0.517	0.000	0.06	0.007	1.000	6	0.196
TW	1	2	3	0.43	0.458	0.000	0.01	0.004	0.000	0	0.057
UA	3	5	3	0.45	0.486	0.000	0.05	0.006	1.000	3	0.159
UK	43	451	2	0.65	0.742	0.074	0.26	0.037	0.347	151	0.878
US	4	5	3	0.46	0.497	0.000	0.06	0.007	1.000	6	0.201
VN	2	2	3	0.45	0.475	0.000	0.03	0.005	1.000	1	0.110
XK	1	2	3	0.42	0.450	0.000	0.01	0.004	0.000	0	0.055
ZA	3	3	3	0.40	0.436	0.000	0.04	0.005	1.000	3	0.126

Source: Own elaboration from H2020-Space data from CORDIS database

There exists high correlation between degree and weighted degree. However, the later underestimates the prominence of those few countries with higher contribution to the network activity.[23] Figure 4.7 illustrates how EU-15 countries (dark blue), ESA non EU-15 member states (green), EU-13 ESA member States (purple) have more connections than EU-13 countries (light blue).[24] France is the leader, closely followed by DE, ES, IT and UK.

[23] See Annex – Chapter 4 (f).
[24] In Annex – Chapter 4 (g) we present the same analysis using degree instead of weighted degree.

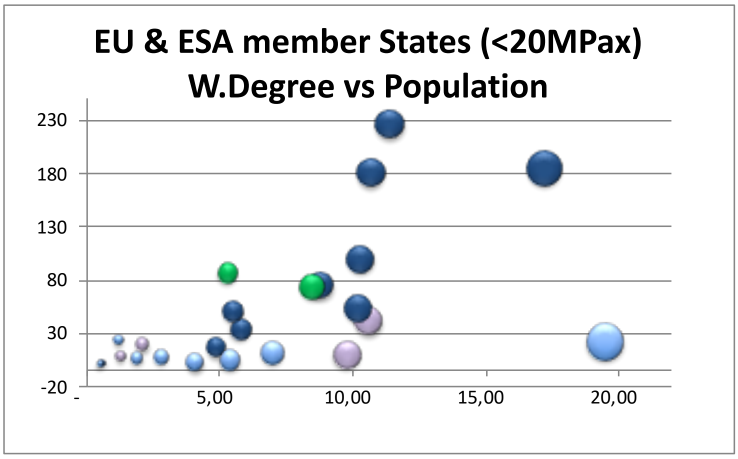
Figure 4.7: H2020-Space Weighted Degree vs Population (EU & ESA member States)



Source: Own elaboration from H2020-Space data from CORDIS database

This feature replicates in medium-size EU-15 countries (those whose population is below 20 million). The detail for countries with less than 20 million people is presented below.

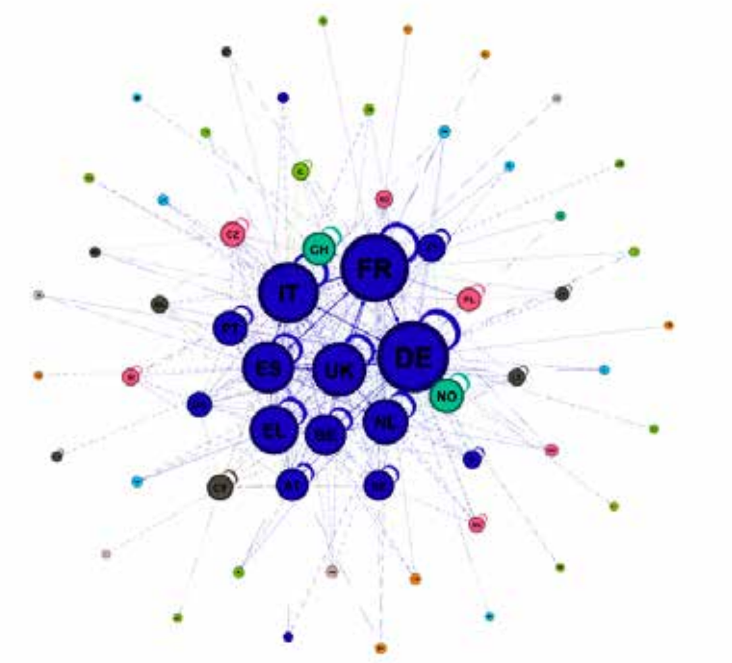
Figure 4.8: H2020-Space Weighted Degree vs Population. EU & ESA member States.



Source: Own elaboration from H2020-Space data from CORDIS database

Concerning the eccentricity of countries in our network, 11 of the 61 involved countries have a value of 2 and all others 3. This result shows that the network diameter value (3) is more representative than the average path length (2.063) to describe paths lengths among nodes. Closeness centrality is above 0.7 for two countries: France and Germany. To illustrate this fact, Figure 4.9 displays a Frutcherman Reingold representation.

Figure 4.9: H2020 Space Network (2014-2020(p))



Notes: Colour code EU-15 (dark blue); EU-13 (light blue); other ESA member states (purple), non-European cooperating states (green), geographically near (dark grey); other continents participating states (light grey). EU-13 non-ESA member states (red); ESA members (light green). Gephi 9,02 Network Graphics.

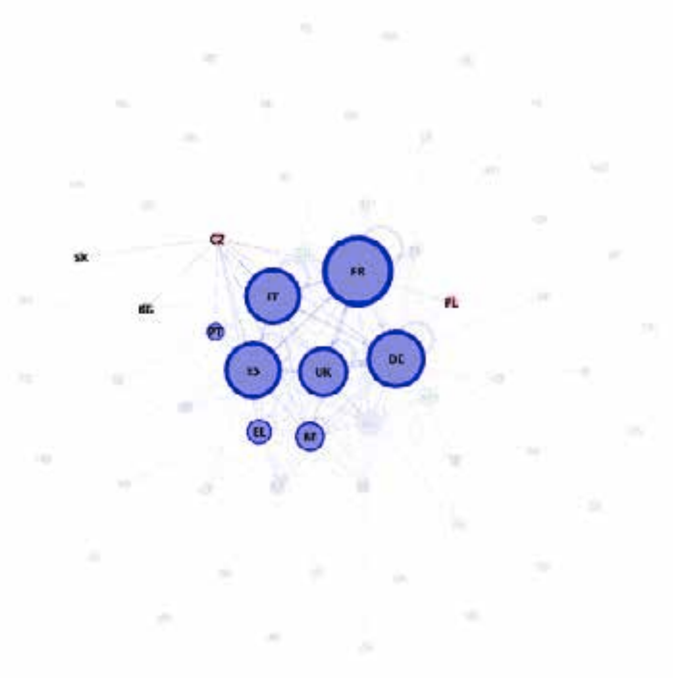
Source: Own elaboration from H2020-Space data from CORDIS database

Note that the newer EU-13 ESA member states (light red) have a less relevant role in the network than EU-15 countries. It is worth noting that all EU-15 states (blue) are ESA member states and that there are some EU-13 not belonging to ESA (light blue): CY, MT, LT, LV, BG and. Besides, we find an important number of unconnected components in the very beginning of the period. From 2017 onwards, it shows no further variation.

As expected, France and Germany are the nodes with highest betweenness and page rank. However, note that in the betweenness ranking, just after the Big-5, Cyprus (6^{th} / 0.066) and Czech Republic (13^{th} / 0.005) have the highest betweenness rates among EU-13 countries. Figure 4.10 graphs the network representation for Cyprus. We observe no significant gatekeeping role.[25] It connects only two countries among EU-15 members. France and Germany, however, on the top of this ranking, have a clear gatekeeping position with out of Europe countries and, regarding EU-13 states, both France and Germany have connections almost with all of them.

[25] Gatekeepers are nodes that play an important role in connecting all nodes of the network.

Figure 4.10: CY H2020-Space filtered Network. (Betweenness / Gatekeeping) role.



Source: Own elaboration from H2020-Space data from CORDIS database (Gephi 9,02 Network Graphics).

Balland et al. (2019) study the position in the EU collaborative research network, which of EU-13 new members may act as gatekeepers and whether EU-13 participate in lower complexity activities. They detect a gap between EU-15 and EU-13 countries. In the *H2020-Space* segment we also find that the core participants of the network belong to EU-15 and the average degree of EU-13 is much lower than EU-15's. In our case, the fact that all EU-15 countries are ESA members shows the influence of ESA membership in the EU space R&D.

Table 4.16. Effect of H2020-Space on network degree

All Participants	11.08
ESA Member States	23.67
EU	20.18
EU-15	30.53
EU-13	8.23
ESA EU-13	10.00
EU-13 no ESA	6.71

Source: Own elaboration using H2020-Space data from CORDIS database.

If we rank our network in terms of the 'authority' metrics, we find all European Big-5, led by Germany (0.301), on the top, but Spain (0.249), surpassed by Greece (0.254). Norway closes top ten with 0.212 and only one EU-15, Ireland (0.122), after several EU-13 countries. This is replicated in participation and coordination role for Ireland.

Triangles and clustering confirm previous results. Our top ten countries get more than one hundred triangles and all of them belong to ESA. Again Big-5 countries lead this ranking with Greece just before Spain. Besides, Big-5 countries confirm their star-shaped local network while other EU countries, with lower number of connections show a more connected environment. Those countries with sporadic project participation get zero clustering in this coefficient as they have partners in the network who are unconnected between them, even though they may participate in more than one project.

Finally, in Table 4.17, we compare the results of eigenvector centrality ranking of H2020 full programme with those taken from the space activity. We also compare the Eigenvector centrality normalised rankings. We use the population to normalize each country eigenvector centrality to evaluate the quality of the connections without the influence of the size of a country Balland et al. (2019).

Table 4.17. H2020-Space Countries Eingenvector Ranking & Normalized over Population Eigenvector ranking.

Eigenvector Centrality Ranking H2020 full - H2020-SPACE			**Normalised Eigenvector Centrality Ranking H2020 full - H2020-SPACE - Dif.**			
DE	**DE**		FI	CY	+7	⇑
FR	**FR**		SI	LU	+1	
IT	**IT**		LU	MT	**+10**	⇑⇑
UK	**UK**		BE	EE	+6	
ES	EL	+4	NL	SI	-3	
NL	**ES**	-1	SE	LT	**+17**	⇑⇑
BE	NL	-1	DK	LV	**+13**	⇑⇑
SE	BE	-1	CY	FI	-7	⇓
EL	PT	+3	AT	DK	-2	
AT	SE	-2	EE	IE	+1	
FI	AT	-1	IE	EL	+1	
PT	FI	-1	EL	PT	+3	
DK	DK		MT	AT	-4	
PL	CZ	+2	**ES**	BE	-10	⇓⇓
IE	CY	+9	PT	SE	-9	⇓⇓
CZ	PL	-2	**FR**	CZ	+5	
HU	RO	+1	**IT**	BG	+9	⇑
RO	IE	-3	**DE**	NL	-13	⇓⇓
SI	LT	+6	**UK**	HU	+5	
HR	BG	+1	LV	SK	+5	
BG	HU	-4	CZ	RO	+7	
SK	SI	-3	HR	**ES**	-8	
EE	EE		LT	**IT**	-6	
CY	LV	+2	HU	**FR**	-8	
LT	SK	-3	SK	**UK**	-6	
LV	LU	+1	BG	HR	-4	
LU	MT	+1	PL	**DE**	-9	*
MT	HR	-8	RO	PL	-1	

Source: Own elaboration using H2020-Space data from CORDIS database.

There is not much difference in space related network positions for Big-5 countries. However, Cyprus and Lithuania place better in *H2020-Space* than in the general programme and Hungary is the country with the biggest decrease.

Looking to those "punch above their weigh", Finland, Belgium, Sweden and The Netherlands are not making as well in space as in the H2020 full programme. On the contrary, Cyprus, Malta, Lithuania, Latvia and Bulgaria have a better position in *H2020-Space*.

H2020-Space network success.

Knowledge and Technology Diffusion

In our study of the *H2020-Space* resulting network, we observe the research network parameters evolution. It confirms the scale-free degree distribution, low diameter and high clustering, as Barber et al. (2006) conclude for previous EU funded projects. Protogeru et al. (2012) findings on UE-FPs research collaborating networks indicate the existence of high connectivity, short average distance, high local clustering, few members with high number of participations, and stable core organizations that integrate small peripheral members. In *H2020-Space*, the network hubs lead projects and guarantee a minimum threshold of diffusion for the adoption of new technologies (Beaman et al., 2018). In fact, the number of participating countries reaches a stable cruise level (93% of nodes) from the second year of the space H2020 programme. Following Protogeru et al. (2012), in order to analyse the small-world and scale-free characteristics of our network, we generate a random network with the same number of nodes and using a probability of links between nodes aiming to get a similar number of edges as we have in the *H2020-space* network. Table 4.18 summarizes observed versus simulated metrics in 2019.

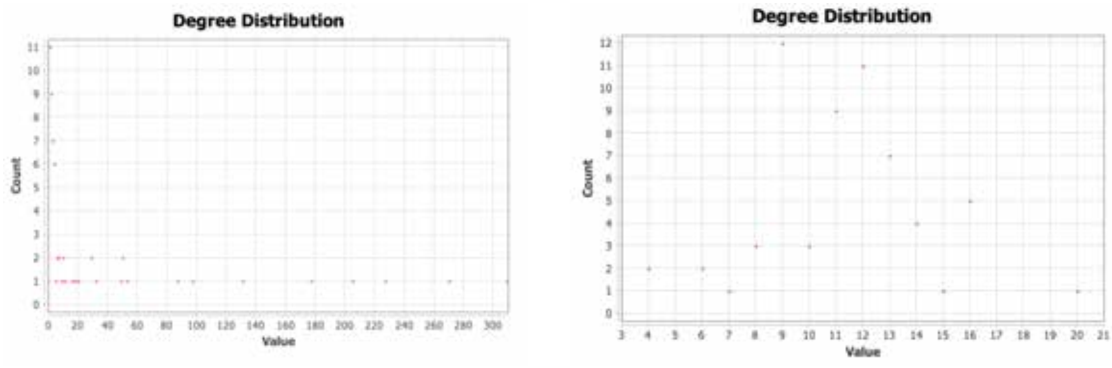
Table 4.18: H2020-Space 2019 vs Random Generated Network.

COUNTRIES' Network	2019	Random
nodes	61	61
edges	338	341
Wiring Probability		0.185
Network overview		
Average Degree	5.54	5.59
Diameter	3	3
Average Path length	2.080	1.905
Density	0.145	0.186
Modularity	0.072	0.215
Number of Communities	3	6
Number of triangles	659	221
Number of paths (Length 2)	4,489	3,740
Value of Clustering Coefficient	0.440	0.177
Number of Weakly Connected Components	1	1
Node Overview		
Average Clustering Coefficient	0.777	0.173
Eigenvector centrality	1.02E-03	1.04E-03

Source: Own elaboration using H2020-Space data from CORDIS database.

Comparing *H2020-Space* to a random network, we find higher local clustering and shorter distances between nodes, properties that match with a small-world network. The *H2020 Space* network degree distribution follows a power-law distribution, matching with a scale-free architecture, as opposed to a random network as illustrated in Figure 4.11. These properties point to *H2020-Space* as an efficient mechanism for the creation and diffusion of technological.

Figure 4.11: H2020-Space 2019 vs Random Network. Distributions.



H2020 Degree distribution (2019) Random degree distribution (eq.2019)

Source: Own elaboration using H2020-Space data from CORDIS database.

The high average degree and high clustering of *H2020-Space* network compared to a similar random network, could open the possibility of redundancies that may affect network efficiency (Peres, 2014).

However, the degree and weighted degree distributions, which follow a power-law distribution, and the fact that each link corresponds not only to transmission but also to the creation of new knowledge, induce us to associate *H2020-Space* to an effective knowledge diffusion process with no redundancies.

Moreover, in Table 4.19 we show the evolution of the network as compared to a random network for each year. Results indicate that those differences appeared already from the very beginning of the period.

Table 4.19: H2020 comparison to Random Networks. 2014-2019.

COUNTRIES ' Network	2014	Rnd	2015	Rnd	2016	Rnd	2017	Rnd	2018	Rnd	2019	Rnd
nodes	61	61	61	61	61	61	61	61	61	61	61	61
edges	11	12	125	125	197	194	249	247	287	292	338	341
Average degree	0.18	0.20	2.05	2.05	3.23	3.18	4.08	4.05	4.71	4.79	5.54	5.59
Number of triangles	0	0	50	14	239	33	393	85	519	140	659	221
Number of paths (length 2)	55	3	949	490	2149	1230	2998	1944	3612	2738	4489	3740
Value of clustering coefficient	0.00	0.00	0.16	0.09	0.33	0.08	0.39	0.13	0.43	0.15	0.44	0.18
Average clustering coefficient	0.00	0.00	0.26	0.08	0.55	0.10	0.69	0.14	0.72	0.15	0.78	0.17

Source: Own elaboration using H2020-Space data from CORDIS database.

R&D development

Following Cunningham & Link (2016), we analyse space newcomers R&D involvement. Using data from H2020 Monitoring flash on the clustering normalised over population ranking and *H2020-Space* equivalent ranking, we find for some new-in-space countries a higher R&D effort in space relative to their population. Cyprus, Luxembourg, Malta and Estonia are at the top of the normalized ranking (see Table 4.17).

Since not all the European countries have a National Space Agency, we may also examine how these agencies relate with the network position of the countries involved. There are many criteria to define what a space agency is. In Chapter 2, there was a classification in terms of ‘big’ agencies (those corresponding to Germany, France, Italy and the United Kingdom), and in terms of ‘medium-size’ agencies (as Spain, and all the newly created agencies across Europe). For the purpose of the analysis in Chapter 3, we adopted the most restrictive criterion applied by *United Nations Office for Outer Space Affairs* (UNOOSA) for a national space organization with certain executive capacity in space affairs and independent stable structure to be considered a space agency. We follow this criterion here too.

In Table 4.20 we show the list of agencies from UNOOSA.

Table 4.20: Space Agencies in European Countries.

Country		Space Agency
DK	Denmark	Danish Agency for Science and Higher Education (DASHE)
FR	France	Centre national d'études spatiales (CNES)
DE	Germany	DLR Space Administration
IT	Italy	Italian Space Agency (ASI)
LU	Luxembourg	Luxembourg Space Agency (LSA)
NO	Norway	Norwegian Space Agency
RO	Romania	The Romanian Space Agency (ROSA)
ES	Spain	Centro para el Desarrollo Tecnológico Industrial (CDTI)
UK	United Kingdom	UK Space Agency (UKSA)

Source: United Nations Office for Outer Space Affairs (UNOOSA)

The countries with high centrality in the network have a space agency, although this is not very significant, since other European countries without a national space agency hold space research institutes participating in R&D projects and space missions and/or offices devoted to the coordination and promotion of space activities (see Annex – Chapter 4(h)).

H2020-Space vs other framework programmes networks.

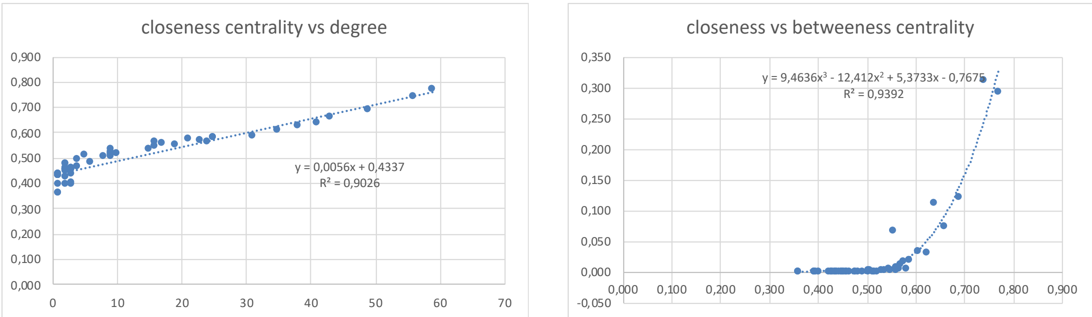
The *H2020 Monitoring Flash 2018* is a good data source and analysis of the countries R&D participation in the framework programme. In this section we compare their analysis to our *H2020-Space* results. First, we find that the average path length is clearly lower in the space field. While in H2020 we find an average of 3 connections to reach the entire network, *H2020-Space* needs only 2.08 steps. This lower path length would facilitate the transmission of technological knowledge.

We find differences in the countries network parameters between FP7 Energy (see the analysis of García Muñiz & Vicente Cuervo, 2018) and *H2020-Space*, with a very close network context of 60 nodes. Hubs in *H2020-Space* have high levels of degree and betweenness and high values in closeness for Germany, France, Italy, United Kingdom and Spain (between 0.64 and 0.77). Furthermore, Greece and The Netherlands are over

0.6. There seems to be no limitation in the capacity of those countries to reach to a large number of members of the network.

As opposed to the energy field network, in the case of space there is a positive correlation between closeness and degree as well as with closeness and betweenness (see Figure 4.12).

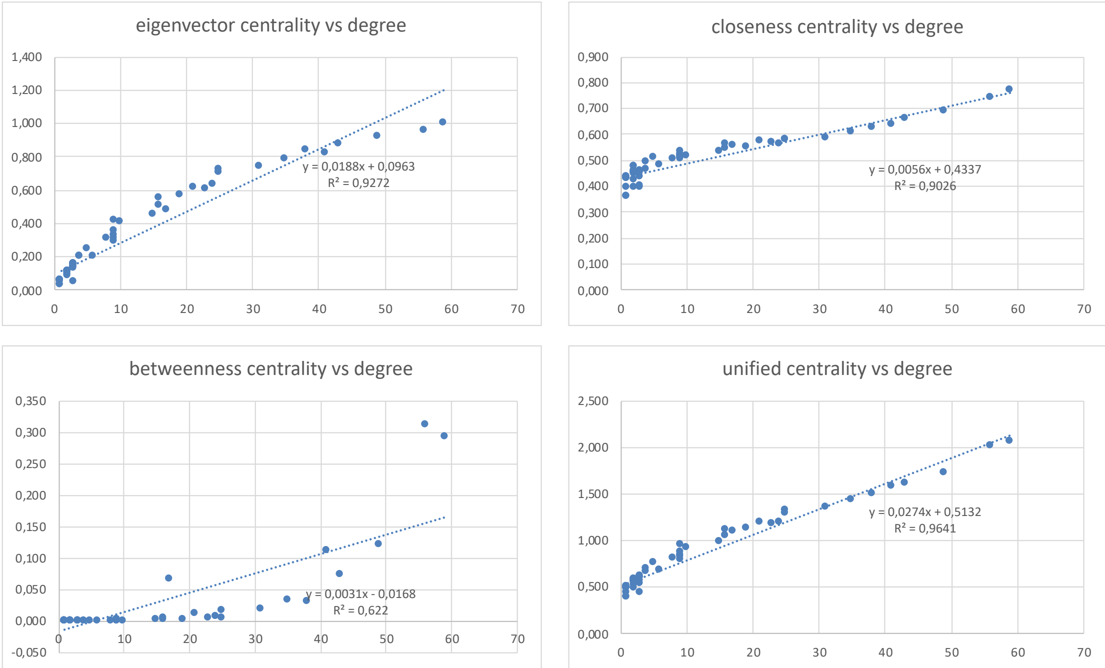
Figure 4.12: Closeness centrality vs Degree & Betweenness.



Source: Own elaboration using H2020-Space data from CORDIS database.

Finally, in Figure 4.13, we assess the positive correlation between the degree and measures of centrality. We also include the graphic containing the unified centrality proposed by Guffarth and Barber (2014) as the sum of the three compared centralities: closeness, eigenvector and betweenness, obtaining a similar asymmetric result: a small set of countries with a high centrality and a large number of countries with low centrality values. We conclude that leading countries will remain in a privileged position as their power and influence grows at higher rates.

Figure 4.13: Correlation between degree and centralities. H2020-Space.

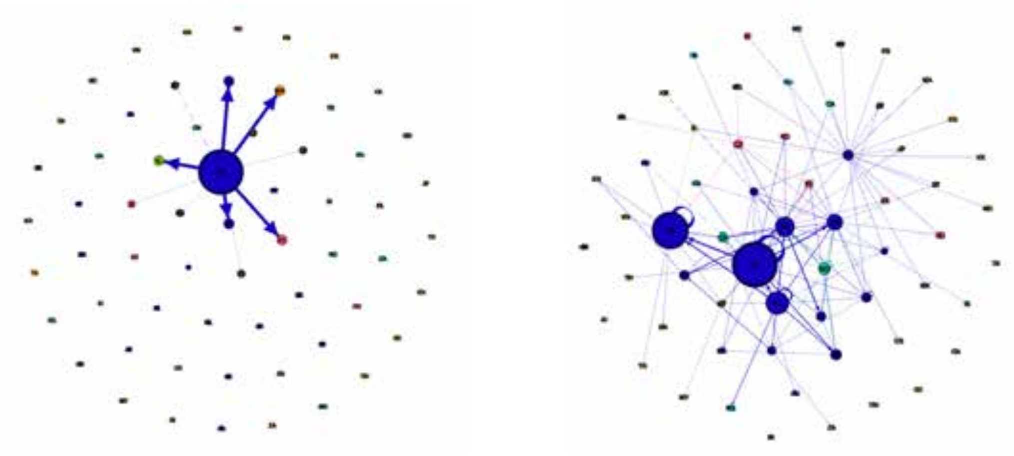


Source: Own elaboration using H2020-Space data from CORDIS database.

Network evolution over time

Siokas' study on the *European Security Research Prog*ramme shows that it is necessary almost 3 years to allow a small member of the network to join the projects (Siokas, 2018). This result is lower in the *H2020-Space* where we find small countries participating in R&D projects from the very beginning of the period; by the second year the maximum number of participants is practically reached (see Figure 4.14). We may consider this result as an indicator of the *H2020-Space* high connectivity and openness. Note also the difficulty for some countries to have enough space related companies with financing capability and technical expertise to reach the technological requirements.

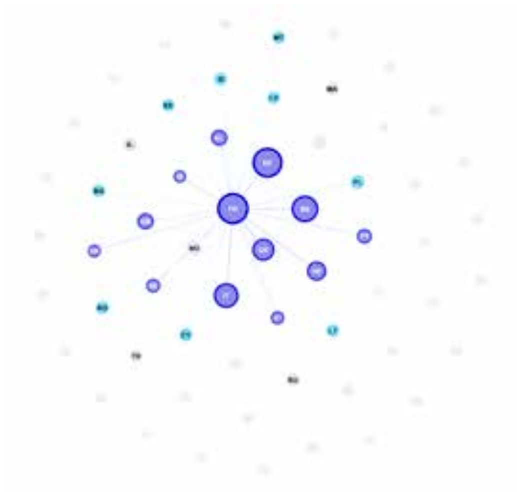
Figure 4.14. H2020-Space Network 2014 and 2015



Source: Own elaboration using H2020-Space data from CORDIS database. (Gephi 9,02 Network Graphics).

If we analyse country networks in the *H2020-Space* first year (from 2014 to 2015), we see large differences between hub countries. At the start of the programme, France and UK had an extensive connectivity while the other big European countries had very little participation, although their participation in H2020 in some cases was from important than UK's. As we see in Figure 4.15, where we keep the final weighted degree indicator (diameter of the country representation), despite their leading role at the end of the period, Germany, Italy and Spain do not act as launchers of the network.

Figure 4.15. H2020-Space Network. Big-5 2014 status.

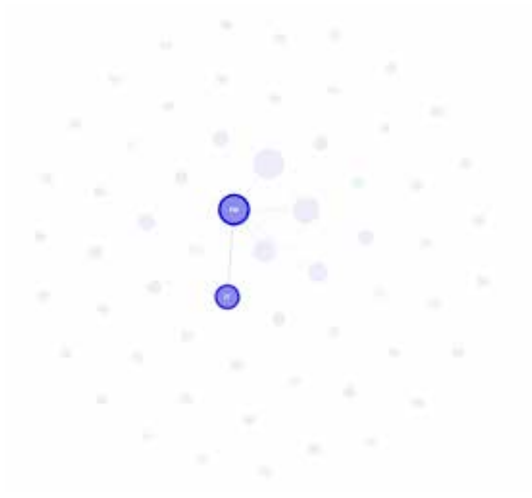


FR 2014

UK 2014

ES 2014

DE 2014



IT 2014

Source: Own elaboration using H2020-Space data from CORDIS database.

H2020-Space successful Countries

Related to the question of the efficiency of the *H2020-Space* network, we can also look at the countries' success in the programme. Successful countries are those achieving knowledge and experience that enables them to exploit the results in the upcoming space market. We propose an index to summarize H2020 Space Programme success criteria.

Success in *H2020-Space*

Participation in a project provides access to new knowledge and enables R&D agents to develop a technology. However, the project coordination role is key to acquire enough knowledge to reach a stage where they will be able to face the complete product development. Thus, those countries with more project coordination activity will be able to create new products, leading their development and achieving an adequate technology readiness level to place it on the market.

We use the weighted coordination defined as the addition of the total funding of all the projects a country agent has coordinated along the H2020 Space Programme, normalised by its population. Therefore, our success criteria will be the project coordination activity in terms of granted funds over the population.

The more successful countries in terms of the number of coordinated programmes (according to the count that appears in column 5, # coordinations) are France, Spain, Germany and Italy with 60, 60, 54 and 51, respectively. However, when normalizing by the size of the country, Norway, Greece, Belgium and Cyprus are found to have a higher success index, with France, Spain, Germany and Italy falling to the 5th, 6th, 9th and 10th position, respectively.

Table 4.21 show the resulting ranking.

Table 4.21. Success Index Ranking

Country	Location Group	Population, 2019	# agents	# coordinatons	Success INDEX
NO	ESA	5,347,896	25	7	3.787
EL	EU-15-ESA	10,716,322	43	17	3.533
BE	EU-15-ESA	11,484,055	70	14	3.247
CY	EU-13	1,198,575	9	2	3.245
FR	EU-15-ESA	67,059,887	146	60	2.469
ES	EU-15-ESA	47,076,781	134	60	2.370
PT	EU-15-ESA	10,269,417	38	11	2.116
FI	EU-15-ESA	5,520,314	14	5	1.948
DE	EU-15-ESA	83,132,799	130	51	1.760
IT	EU-15-ESA	60,297,396	151	54	1.591
NL	EU-15-ESA	17,332,850	59	14	1.475
CH	ESA	8,574,832	34	4	1.279
UK	EU-15-ESA	66,834,405	107	23	1.054
SI	EU-13-ESA	2,087,946	11	3	1.018
SE	EU-15-ESA	10,285,453	26	4	0.820
AT	EU-15-ESA	8,877,067	37	4	0.728
IL	ASIA	9,053,300	8	3	0.508
BG	EU-13	6,975,761	7	1	0.408
DK	EU-15-ESA	5,818,553	15	1	0.352
IE	EU-15-ESA	4,941,444	12	1	0.324
CZ	EU-13-ESA	10,669,709	24	1	0.174
LV	EU-13	1,912,789	4	1	0.037
LT	EU-13	2,786,844	8	1	0.026
PL	EU-13-ESA	37,970,874	29	3	0.024
HR	EU-13	4,067,500	2	1	0.018
HU	EU-13-ESA	9,769,949	9	1	0.007

Source: Own elaboration using H2020-Space data from CORDIS database.

Success index correlation with country's technology characteristics.

We compute the correlation between several variables (such as the country structure per type of R&D agent, country activity share per technological area) and H2020 Space Programme network metrics in order to assess the relation between the relative performance of a country and its characteristics.

We start with the analysis of the correlates of success when examining the composition of the R&D agents in a country. The composition is to check whether there is any correlation between the success index and the country R&D agents composition share, we show in Table 4.22 presents the results of a linear regression with the success index as the dependent variable and the distribution of agents per type for each country as explanatory variables.

Table 4.22. Relationship between Success index and Country R&D structure.

PRC	0.867 (0.252)
HES	-0.265 (0.730)
REC	-0.051 (0.947)
PUB	0.076 (0.939)
Number of obs	61
F(4, 56)	1.02
Prob > F	0.4031
Adj R-squared	0.0016

Note: p-values in parentheses

Source: Own elaboration from H2020-Space data from CORDIS database.

Although there is evidence on how the top participating countries show a similar R&D type of agents' structure, we do not find any statistically significant association between success and structure.

To explore the association between successes, in Table 4.23, we report the estimated coefficients of a linear regression between the success index and the technology field composition.

Table 4.23. Relationship between Success index and Country Technology field activity share.

EOBS	-2.345 (0.439)
GSTP	-3.209 (0.286)
HMFL	0.966 (0.788)
NAVI	-3.399 (0.252)
RBEX	11.134 (0.030)
SCNC	-3.096 (0.398)
Number of obs	61
F(4, 54)	4.18
Prob > F	0.0016
Adj R-squared	0.2411

Note: p-values in parentheses

Source: Own elaboration from H2020-Space data from CORDIS database.

The evidence is consistent with the previous finding, we find only one field positively and significantly related to the success index, RBEX.

Relationship between success and network metrics. Success breeds success.

First, we calculate the linear growth rate of the degree during the period of study. Countries are sorted from the highest to the lowest growth rate.

Table 4.24 shows results for top 10 countries.

Table 4.24: Degree Evolution over time. Degree growth rate. Top-10

Degree	2014	2015	2016	2017	2018	2019	Growth rate
DE	0	18	26	33	42	56	10.26
IT	0	15	26	36	43	49	9.69
FR	11	23	40	45	46	55	8.40
ES	0	12	24	31	33	41	7.86
UK	0	17	28	32	33	43	7.63
NL	0	7	18	25	30	34	7.03
EL	0	15	16	23	29	34	6.26
BE	0	7	19	24	26	31	6.20
PT	0	5	7	10	19	25	4.86
AT	0	6	6	14	20	22	4.57

Source: Own elaboration from H2020-Space data from CORDIS database.

Big-5 countries get the highest growth rates. This could be evidence of the success breeds success hypothesis. Note that the degree distribution is highly asymmetric as a small number of nodes have a large number of links.

Second, we test whether the success index relates to the countries past R&D activity or technology field. We should expect that countries focus on areas where they already have a competitive advantage. Lagged covariates account for time delays.

Table 4.25 presents the estimation results of an Arellano-Bond panel regression model with one lag. To validate the model, we report the observed statistics for the Sargan over-identification test and for the Arellano-Bond test of autocorrelation.

Table 4.25 reports estimation results (p-values in parentheses).

Table 4.25. Regression of Success Index in t, SI_t, on R&D.

SI_{t-1}	0.5790 (0.000)	0.4536 (0.000)
PRC_t	-.0008 (0.979)	
PRC_{t-1}	-.0259 (0.190)	
HES_t	-.0304 (0.379)	
HES_{t-1}	-.0497 (0.008)	
REC_t	-.0047 (0.830)	
REC_{t-1}	-.0369 (0.158)	
PUB_t	-.0127 (0.691)	
PUB_{t-1}	-.0146 (0.488)	
$EOBS_t$		0.0323 (0.012)
$EOBS_{t-1}$		-0.0094 (0.467)
$GSTP_t$		0.0165 (0.273)
$GSTP_{t-1}$		-0.0296 (0.059)
$HMFL_t$		0.096 (0.745)
$HMFL_{t-1}$		-0.0507 (0.058)
NAV_t		0.0180 (0.222)
NAV_{t-1}		-0.0334 (0.022)
$RBEX_t$		0.0108 (0.617)
$RBEX_{t-1}$		-0.1044 (0.002)
$SCNC_t$		0.0478 (0.358)
$SCNC_{t-1}$		0.0787 (0.611)
No. observations	244	244
Abond test order 1	-1.7414 (0.081)	-1.1359 (0.256)
Abond test order 2	0.5481 (0.583)	-1.5081 (0.131)
Sargan test	10.0258 (0.348)	13.19868 (0.153)

Source: Own elaboration from H2020-Space data from CORDIS database.

Results provide evidence against the null hypothesis of zero autocorrelation in the first-differenced errors at order one. However, there is no significant evidence of serial correlation in the first-differenced errors at order 2. Moreover, we reject the over-identification of restrictions, thus instruments are valid.

However, the results by technology field are interesting. Regression results support the idea of persistence in the success index since the lagged variable is significant in both R&D activities. There is a negative pattern on the relevance of past R&D whenever it is significant. This means that a higher past ratio of participations in GSTP, HMFL, NAV and RBEX technology fields, weakens the effect of success inertia. This could be explained by diminishing returns to technological advantage in areas where the country is experiencing an increasing success.

Conclusions

In this chapter, we have characterized the *H2020-Space* network built in the period 2014-2019. Our hypothesis is that the network architecture would facilitate not only the creation but also the transmission of technological knowledge between countries, contributing to a larger research base, necessary for the future challenges of the space field. For that purpose, we have characterized the network and, using the metrics from network theory, we have shown that it has small-world properties.

Previous literature had studied previous European programmes and we have compared the results of *H2020-Space* network to previous or more general programmes. It is worth noting that the space programme shows remarkable international cooperation outside Europe, much larger than in the broader framework programmes.

Regarding the role of the main players, according to our results France definitely leads space research in Europe regarding network launching, coordination and weighted participation in projects, while Germany is leading the broader programme. UK, even though it played a remarkable role in the H2020 Space Programme launching, it is not leading a large number of projects and the weighted participation does not match with the size of the country.

An important result concerning network architecture, as shown by the *H2020-Space* network metrics, is that it is remarkably more open than in the previous programmes. Participation of small countries is higher and the connection path between countries is shorter than in previous FPs and the full H2020. Besides, we can see that individual countries' own interests do not seem to be the only drivers of the space R&D activity, even for the Big-5 countries. In fact, EU-15 joint interests actually drive the projects' technology areas, over EU-13's preferences or those of the Big-5 as a group.

We find asymmetries in the space research effort of some countries, compared to H2020 full programme, pointing to a specialization in space research. This effort has a direct relationship with the condition of ESA membership.

Countries have different sizes and therefore it is convenient to normalize some of the network metrics by population. The normalised metrics show how small countries such as Cyprus, Norway or Finland are making a considerably higher effort than other countries in space research and shows how the countries' relative efforts change the ranking in favour of Spain and Italy over France and Germany.

We define a country's success index based on its ability to lead *H2020-Space* projects, normalized by its population. We do not find evidence about the correlation between the success index and the country R&D agents' type composition or the technology areas of their interest. Previous effort in R&D, however, are correlated with the success rate.

Considering the openness of this network, it would be interesting to analyse the influence of the "success breeds success" effect, the higher effort of some countries and the misalignment of the newcomers' preferences in the space sector.

An interesting area for further research is the detailed analysis of those countries showing singularities in the participation or coordination over population rates. This chapter has focused on countries as the main actors, but the analysis of the network of firms and organizations allows addressing interesting questions such as the role of small companies' specialisation and big companies clustering.

Finally, our study of the *H2020-Space* network has focused on the network conditions for the transmission and creation of new technological knowledge. This knowledge is starting to transfer in the form of market products, such as Satellites in orbit, and the development of such markets may feedback into the countries' R&D activity. This question is relevant and worthy of further research.

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Chapter 5

Network under H2020-Space and Knowledge Diffusion among R&D Agents

Chapter 5. Network under H2020-Space and Knowledge Diffusion among R&D Agents

The *H2020-Space* R&D has a special focus on the promotion of SMEs and research agents to contribute to the European space sector by enhancing the cooperation between companies, research centres and universities in the development of new technologies, products and services. This is precisely one of the principles that inform the European Space Policy and the European Industrial Policy designed by the European Union, as commented in Chapter 2 and 4. In this Chapter, we descend to the third level of agents presented in the definition of the key actors of the Space Economy and Space Policy in Europe: we analyse the role of the European space R&D subnational agents and their interactions. The characterization of this motley group gives an idea of the rich potential of the sector, with some big space units and a myriad of smaller units, research centres and higher education institution that have a wide diversity of capacities, expertise and motivations.

Our hypothesis is that the H2020 Space Programme provides a cooperation network favourable for technology diffusion and innovation transmission in Europe. Our findings indicate an actual cooperation environment where private companies hold the project leadership role and are the preferred partners in new developments. Moreover, Higher or Secondary Education Establishments exhibit an effective cooperation among themselves. Agents as a group, show a high level of alignment with the EU space technology development strategy, matching perfectly with the preferences of ESA member states. Network dynamics point to a cooperation environment favouring an increasing knowledge diffusion.

Introduction

With the target of a cost-effective, competitive and innovative space industry, *H2020-Space* is born following the success of FP7 (seventh European Framework Programme) with the aim to support the development of innovative technologies and operational concepts and to exploit available space data. Complementarity among different actors and coordination between ESA and member states is been remarkable during the preparation of this work programme.

H2020-Space was structured prioritizing the European Global Navigation Satellite System (GNSS – Galileo) and Earth Observation, ensuring the protection of space infrastructure, supporting the EU industry to maintain competitiveness and value-chain in the global market, ensure investments are exploited to the benefit of citizens and become a more attractive global partner for space science and exploration activity.

In the 2014-2015 work programme, the Commission proposed a motto "Prepare for the increasing role of space in the future and reap the benefits of space now" by which this programme supports space research under the priority of a European Industrial Leadership. It aims to build up complementarity among R&D Agents and establish an Open research data Pilot to improve re-use of research results.

During 2016-2017, the focus was on a long-term approach, bearing in mind issues such as critical space technologies, industry capability, technology readiness and space situational awareness. Besides, it promotes the reaping of the benefits of European investments exploiting available data and signals through applications and downstream services. In this period, grant beneficiaries engage data sharing by default.

Lastly, the 2018-2020 work programme declares space as a strategic asset and a great opportunity for European society and economy. With it, the *European Commission* stimulates the integration of space into the European society and economy as space industry provides tools to address societal challenges and big global concerns such as climate change, mobility, migration and energy security. This industry, due to its nature, boosts innovation, help to create high quality jobs, create value added products, gives companies of all sizes access to new markets and contributes to the global competitiveness of European companies. In order to maximise the benefits of space, this work programme fosters a competitive and innovative European space sector reinforcing Europe's autonomy in the access and use of space, strengthening the role of Europe as a global actor and promoting international cooperation.

These last years of H2020 Space Programmes are designed to support the market uptake of Copernicus and Galileo, to underpin space business, entrepreneurship, and science and technology development. Besides security aspects, low carbon access to space and digitizing and Europe industry and services transforming are encouraged.

Using CORDIS H2020 project data, we identify all space related projects and build a database with all the relationships between coordinators and participants of space projects. With this information, we first provide a preliminary picture of the type of agents who participate in projects of the space framework programme (universities, private companies…). We rank the agents by number of participations, by the number of times they have played the coordinator role and by the relevance of those participations measured by their weight. Using the ESA broad classification of space activity, we study the interests of agents in each of those technological fields regarding their type. We also use the geographical location of agents, as well as membership in EU-15, EU-13, the EU Big-5 and ESA, and evaluate its relevance. Interests and activity are compared to the average to see how aligned each type of agent is to the H2020 global space activity.

Thanks to the evidence collected in our network database, we analyse how R&D agents cooperate within their type group and if they show any partnership preference. We draw the resulting network and compute its parameters. Then, we filter the network by each of the technological activity fields, draw the resulting sub-network and compute the network parameters in order to detect any differences between technological fields.

Our main results are that Private Research companies lead the R&D project participation and coordination role and Public entities show a low activity as project coordinators. Countries R&D agent type structure can be very different although they get similar influence in the network. Furthermore, most Project coordinators belong to ESA member states, which show the highest alignment with the aggregate participation in R&D projects, followed by states with EU membership.

Network Graphics show the influence of specialization of small agents and the integration function of the network leaders. The “small-world” character of *H2020-Space* network confirms the efficiency of knowledge diffusion among partners. In fact, the network evolution over time confirms this effect and does not show regional, culture or organizational preferences. We find no evidence of homophilic behaviour in the space R&D network.

The chapter is organized as follows. In Section 2, we introduce the *H2020-Space* work programme’s objectives, implementation, and review the relevant network literature. In Section 3, we describe our database on R&D agents’ relationship amid *H2020-Space* projects activity for the period 2014-2019. Section 4 contains the H2020 networks characteristics and parameters and its graphical representation. Finally, Section 5 collects the results, presents the conclusions and propose directions for further research for better understanding the R&D network in the field of space science and technologies.

Knowledge networks and space

Space activities are characterised by a high level of technology, reliability, qualified personnel and investments where cooperation and knowledge sharing are necessary in many space industry projects. All these traits determine that the space industry can be classified as ‘highly analytical’ with respect to other knowledge-based industries (Broekel and Boschma, 2011). When applied to the study of the space industry of the Netherlands, this specific trait was found to bring some important implications in how knowledge networks develop. This is not only driven by technological characteristics of the sector, but also by public industrial policies. For instance, differences in public research intensity also characterize the structure of networks in different sectors (Broekel and Graf, 2012), shifting the role of gatekeepers and brokers (Broekel and Mueller, 2018). The network of the space industry in the Netherlands was characterized by denser collaborative networks, explained by higher levels of trust among agents, lower levels of competition, and high competences. Further, key players in the space knowledge networks were firms and public agencies more frequently, whereas associations are the essential brokers in the case of the akin areas, such as in the aviation industry.

The relationship between space and aviation industry has been the object of study of other works. Agents involved in space usually hold a heritage in aeronautics (Alberti and Pizzurno, 2015). In fact, Guffarth & Barber (2017) observe that in the aerospace industry, civil aeronautics, military aeronautics and space overlap concerning actors and technology and mutually influence each other. Besides, they consider the innovation ability of an economy sector linked to the interplay between actors and the cooperation that enables access, integration and use of external knowledge.

In this cooperation context, we find big space actors counting on specialized SMEs who integrate the whole product and have become the core of the space industry as we can see in Breschi and Cusmano’s (2004) study of the structure of European FPs emerging networks who hold the existence of an oligarchic core whose centrality and connectivity strengths over programmes. Using graph theory approach, they build networks based on the research joint venture projects where the actors (organizations) are members of groups (projects) in an affiliation network.

We supplement the way they apply graph theory analysis with Grandjean & Jacomy (2019) who propose a table of correspondence between the theory and a network graphic analysis. This table results a useful tool for first network architecture interpretations before analysing all network parameters in depth. In those graphic interpretation tips, apart from a gravitational graphic and network evolution over time analysis recommendations, they use global properties including number of nodes and edges, density and the average path length as well as local properties such as the degree, as they define as the simplest centrality measure, and other centrality measures. They observe the advantages of a hierarchy analysis, metrics comparison and metrics combination in the study of a network.

This industry needs experts who have proved their technology readiness levels and commit to cooperate in future developments. This leads to a strong relationship among space agents matching with the European research network, as Barber et al. (2006) conclusion about the solid structure of EU funded project network along first four framework programmes.

Regarding the influence of R&D agents' locations in their activity under H2020 Space Programme, we see how Balland et al. (2019) describe collaborative research considering older members of the European Union EU-15 versus new members EU-13. They analyse network structure and older and newer members' differences in centrality. They also analyse how much more open to the entry of new players is H2020 compared to previous FPs and discuss the influence of the average degree, average path length and the persistence of collaborations. We apply these tools adding up two new groups: (1) ESA member states who had a relevant role in the design of this R&D programme, and (2) the group of the Big-5 EU states (France, Germany, Italy, UK and Spain) who concentrate a high percentage of the space R&D activity under this programme.

H2020 Network is composed of different types of R&D agents as well as Protogeru & Caloghirou & Siokas (2013) hold about EU funded R&D programmes resulting collaboration networks, that may be defined as exploration networks since they are dealing with pre-competitive research. As those tasks are far from the market, they say, EU-funded policy driven networks involve not only companies but also Universities, Research & technology centres and government agencies. Although many of the space projects under H2020 may not be out of the market, they also belong to a pre-competitive research and involve to those agents usually dedicated to low TRLs (Technology Readiness Levels).

Regarding European FP projects data, Protogeru et al. (2013) acknowledge the difficulties to study them at an organization level due to lack of data of organization types, identification of unique companies or missing information or geographical information. However, they identify cross-country collaboration and how they change over time where the linkages among the EU countries where the grand majority (92.3%) of all cross-country connections are. They illustrate the collaboration activity along FP programmes making three groups: (1) the four biggest countries, (2) the rest of EU-15 countries, and (3) new member states. They find linkages among countries remain stable; large countries keep highly interconnected and attract a valuable number of connections with other countries. They include a simulation of an equivalent random network to analyse the small world and scale-free characteristics. "Small World" property is defined as high local clustering and short distances between nodes, while in a "Scale Free" architecture, the degree distribution of network members follows a power-law distribution. They conclude that "*Research Joint Venture networks can be relatively efficient mechanisms for both the creation and diffusion of new technological knowledge and innovation*". We will use this methodology not only for the entire space dataset but also for the different areas of activity.

As this is a network strongly supported by the European institutions, we take into account the contribution of Jackson et al. (2016) where they study the network structure to analyse how social structures may impact social welfare. They highlight that the understanding of externalities, assumed as those situations in which the behaviour of some agents may affect others (positively or negatively), is key for the network formation and the interaction between peers. They argue how some externalities such as the knowledge speciality or technology domain of a given agent may have an effect; for instance, the impact to the network of the decision of one agent (node) when forming or maintaining a relationship (edge) with another agent. The analysis of the cost and benefit to form a relationship may not take into account the benefit of indirect connections. Another externality is the existence of too many connections causing a work overload that may eventually imply the quality of some relationships and the influence of the decisions of others to invest in a relationship. In EU R&D programmes, these externalities turn out to be extremely important.

Jackson et al. (2016) assume that a network is formed by agents with the choice to interact or not and that those agents may not be fully rational. They consider the cost and benefits of a network showing the tension between individual incentives and social welfare efficiency. They apply game theory tools to study how, after a network forms, it translates into costs and benefits and how externalities may affect the behaviour of the network agents. They find that in a Nash equilibrium with peer effects, an agent activity is proportional to the centrality of that agent in the network and the distance in the network influences the decay of the activity. Therefore, the position of a node in a network is important to transmit a given behaviour. Regarding the behaviour of agents, they model learning and influences in a network (rational Bayesian learning). Agents belonging to large networks will share the beliefs and naive learning, where a new belief is born out of the average of the network individuals' beliefs. The influence of others is affected by the tendency to cooperate with similar agents (homophily), causing failures to the knowledge diffusion.

One of the consequences of a R&D network should be the knowledge diffusion but also the growth in size, technology and capability of the involved agents. Guffarth & Barber (2014) study the "Success breeds success" hypothesis where successful regions maintain their position and grow on a larger scale. The analysis includes those network indicators in favour of their hypothesis. They use the Centrality to assess the power and influence of the agents. Regarding the centrality calculations, they pay attention to the quality of connections and the danger to treat all connections with the same weight. Finally, they find a strong correlation between all centralities and conclude that organizations that are powerful in one way are going to be powerful in others.

Data Sources and Database Construction

To analyse the R&D network behaviour between European R&D agents in the field of the space industry, we use *H2020-Space* project data from CORDIS. These data include the calls of the different work programmes (2014-2015; 2016-2017 and 2018-2020). Each work programme splits in different calls for proposals and we extract the space related projects granted in the period 2014-2020. With this information, we build our database that includes projects, and the resulting networks, with start date until January 2, 2020.

The space programme includes the following topics: Applications in Satellite Navigation (GALILEO), Earth Observation (EO), Protection of European assets in and from space (PROTECT), The Competitiveness of European Space Technology (COMPET) and International Cooperation in Space matters (SPACE). For each project, we have information about the topics, start and end date, total cost and EC contribution, type of action, the name of the coordinating agent, coordinator's country, participants and their country. Each project is assigned to a technology field according to the latest ESA classification: EOBS: Earth Observation; SCNC: Science; HFLT: Human Flight; LNCH: Launchers; GSTP: General Support Technology Programmes; NAVI: Navigation and RBEX: Robotic Exploration.

For each project, there is a coordinating agent and one or several participants. In the CORDIS database, there is information on the coordinator's country and other participants' countries. However, there is no information on the actual number of participants, as all agents coming from a given country are aggregated. Since we want to build the agents' network, we need detailed information on the participants and therefore we have collected that information from the project data. Thus, our database NEUS, contains the necessary detailed activity measurements, from agents and countries.

From that information, we define links from the project coordinator to each of the participants; that is, each project in *H2020-Space* from 2014 to 2019 is assigned a star topology where the hub is the project coordinator. These links are the basis of the actual space R&D network that we analyse.

We follow Barber et al. (2006) who suggest the importance of including weights for each edge of the network to understand the network microstructure. For the agents' network, we calculate the weight of each link as the quotient of the project funding over the number of participants. Thus, the funding of the project is used a proxy for the knowledge generated and transmitted through the links created between the coordinator and the participants and therefore the links in projects with more funding are given more weight.

Note that with this link weight definition, the project coordinator gets a remarkably higher influence in the network. As Breschi & Cusmano (2004) point out, the coordinator of each project is in direct contact with the European Joint Undertaking, holds the responsibility for the success of the project, connects with all other participants and acts as intermediary in the knowledge flow, while other members may not have any other connection but the coordinator. These arguments justify the higher allocation of weight to the project coordination.

In our analysis, each project is as a star network, as in Breschi & Cusmano (2004), and our database includes the links and the calculated weights for each project, as relevant information about the implication of agents in H2020 Space R&D Programme. We draw the resulting network using Gephi 0.9.2 software, which also provides several network metrics and their evolution over time.

R&D Agents *H2020-Space* activity

First, we provide a broad picture of the project data with summary statistics of the H2020 Space Programme under the agents' perspective. We are interested in the scope of the space R&D projects and the activity type of the participants in the different technology fields. Later, we build a network with the links among agents participating in the H2020 Space Programme, study the network parameters and obtain some conclusions about knowledge diffusion.

H2020-Space summary statistics

Our database includes 347 projects providing 2,102 links (edges) among participants and the project coordinator. There are 1,258 agents (nodes) where only 241, almost 20%, have been playing the coordinator role (see Annex – Chapter 5). In Table 5.1, we present projects' basic description.

Table 5.1: H2020-Space –Project basic statistics, 2014-2019.

Project Data	
number of projects	347
max. funds (€)	27,999,088
min. funds (€)	71,429
average funds (€)	2,274,841
total funds (€)	789,369,793
standard dev. funds (€)	2,204,125
avg funds per participant (€)	439,142
max. # participants	55
min. # participants	1
avg # part per project	6.1
standard dev. # participants	5.2

Source: Own elaboration using H2020-Space Programme from CORDIS

It is worth highlighting that projects in *H2020-Space* show 6 projects with more than 20 participants and 58 projects with only one agent involved. Regarding funds, there are only 4 projects with total funding over 10 M€ and 41 below 100,000 €.

In order to use the network analysis terminology, we refer to the links between agents as "edges"; to the agents as "nodes"; to the coordinating agent as the "source" and to the participating agents in a project as "targets".

Agents per activity type

Following Barber et al. (2006), we study the network microstructure. First, we classify agents by activity type to analyse each type separately. Agents are classified in the following groups or types:

Description of Activity Type	Code
• Private for-profit entities, excluding Higher or Secondary Education Establishments	(PRC)
• Research Organisations	(REC)
• Higher or Secondary Education Establishments	(HES)
• Public bodies excluding Research Organisations and Secondary or Higher Education Establishments	(PUB)
• Other	(OTH)

Our database includes this classification of agents, with their participation in the *H2020-Space* projects in the period 2014-2019, number of participations, number of projects coordinated and number of projects accomplished by themselves (see Annex – Chapter 5). Table 5.2 presents this information by activity type of the agent.

Table 5.2: H2020-Space – Agents' Project Participation per Activity Type

Agent Activity Type	# Nodes		C. Nodes		# Coord		# Part		#Self		Total Part.	Avg. Part.
PRC	695	55%	150	22%	208	60%	979	47%	48	1,139	48%	1.64
REC	190	15%	35	18%	60	17%	458	22%	0	518	22%	2.73
HES	223	18%	38	17%	49	14%	415	20%	8	456	19%	2.04
PUB	72	6%	7	10%	7	2%	118	6%	1	124	5%	1.72
OTH	78	6%	11	14%	23	7%	132	6%	1	154	6%	1.97
Total	**1,258**	**100**	**241**	**19.2%**	**347**	**100**	**2,102**	**100**	**58**	**2,391**	**100**	**1.90**

Source: Own elaboration using H2020-Space data from CORDIS

The number of existing nodes for each type of agent is 695 for PRC, which represent the 55% of the existing agents in this programme. 223 Higher or Secondary Education Establishments (HES) that participate in H2020 mean 18% and the 190 Research Organisations (REC) follow them with a 15%.

If we focus on those agents/nodes playing the role of project coordinator (C. Nodes: Number of nodes playing the role of Coordinator), we find 150 of 695 PRC have been a project leader once at least. Thus, PRC lead the percentage of project coordinators with 22% over REC and HES with 18% and 17% respectively. Those percentages fall to 10% for Public bodies (PUB) and Other Agents (OTH) get 14%. There is a higher percentage of leaders in PRC than in the other types of agents.

Concerning the number of projects coordinated by each type, PRC is at the top of the ranking with 60% of total projects coordinated by a PRC agent, slightly higher than their population (55. We also may highlight how PUB have only coordinated 2% of projects whilst they are 6% of agents. REC, HES and OTH do not show big differences between the activity type distribution and project coordination role.

Table 5.2 shows the number and percentage of times an agent has participated in a project, distributed by activity type. Note that for 16.7% of the projects (58 out of 347) the coordinator is the only participant, but those 58 participations are very low compared with the 2,102 participations. We see PRC figures at 47%, lower than the expected 55% of number of PRC agents. However, REC and HES increase their share in 4% and 3%

respectively. PUB and OTH keep their percentage close to their share in the activity type distribution.

For some projects the coordinator is the only participant (column # Self). Projects of this kind account for 16.7% of the 347 considered, most of them (82%) belonging to a single PRC.

The total number of participations obtains from adding up the coordination and the participation roles and subtracting the number of times the coordinator is the only participant. These figures give us shares by activity type very similar to the number of participations in projects analysed above.

The average of participations in projects per activity type of agent is calculated as the quotient of the total participations and the number of nodes for each type. REC and HES lead this ranking while PRC gets the lowest rate. The specialisation of companies and the multiple university departments and different research tracks in technological centres may explain those differences. Table 5.3 shows the summary statistics of participation per activity type of agent.

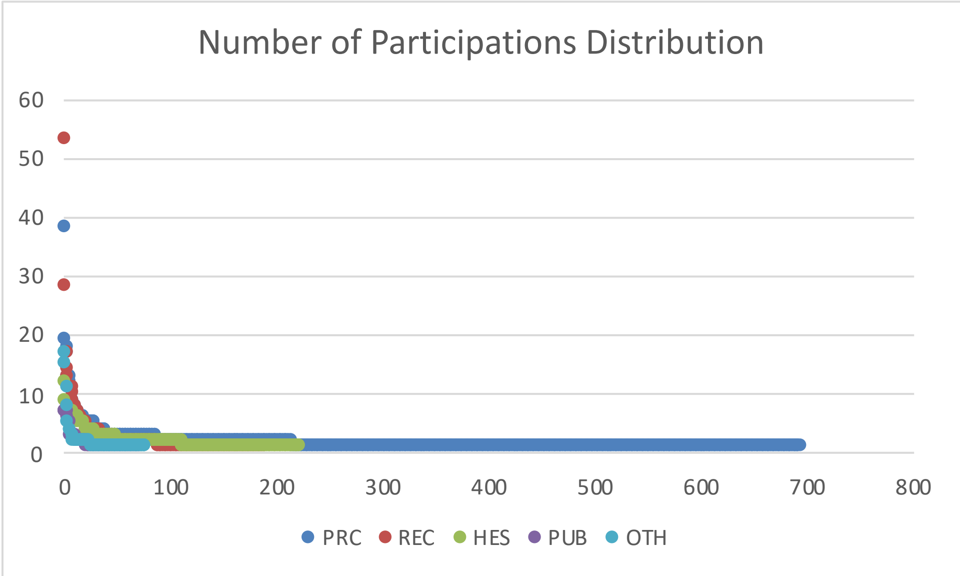
Table 5.3: H2020-Space – Agents' Project Participation summary statistics

Agent Activity Type	Obs	Mean	Std. Dev.	Min	Max
PRC	695	1.6388	2.1807	1	38
REC	190	2.7263	4.8127	1	53
HES	223	2.0448	1.6378	1	12
PUB	72	1.7222	1.5311	1	7
OTH	78	1.9743	2.7396	1	17

Source: Own elaboration using H2020-Space data from CORDIS

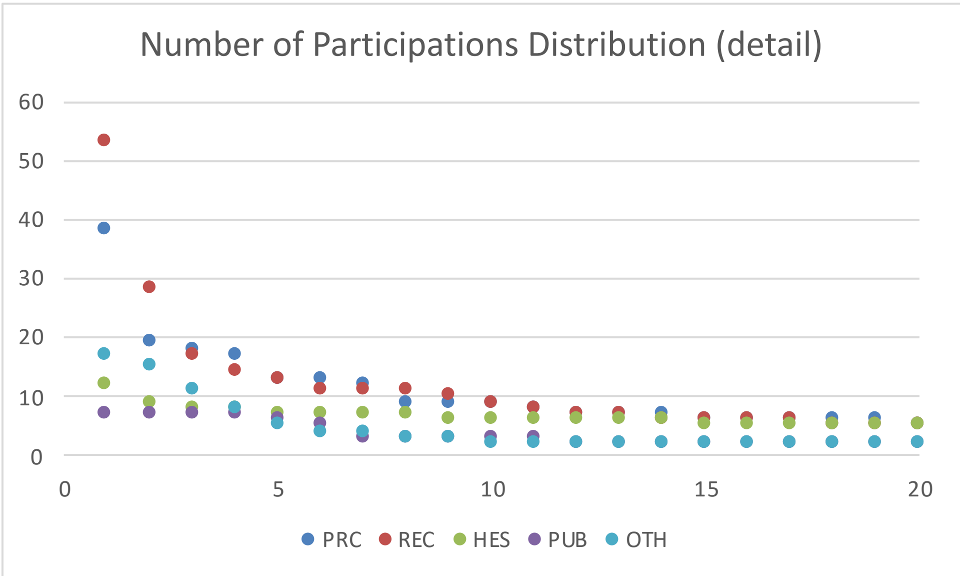
The lowest average corresponds to the PRC type followed by the PUB. Figure 5.1 shows the distribution of participation, by types. PRC and REC groups show a power distribution with few agents with high participation numbers while other types of agents show less concentration of participations.

Figure 5.1a: H2020-Space – Agents' Project Participation distribution, by type



Source: Own elaboration using H2020-Space data from CORDIS

Figure 5.1b: H2020-Space – Agents' Project Participation distribution (detail)



Source: Own elaboration using H2020-Space data from CORDIS

The organizations with the highest number of participations are the German DLR Research Centre with 53 and the French Thales with 38. If we add up all participations by the Thales Group in Europe, we get 71 participations, which is higher than DLR but with the same order of magnitude. See Table 5.4 below.

Table 5.4: H2020-Space – Thales (PRC) Project Participation

AGENT	Country	Participations	Coordinations
TAS	FR	38	14
TAS-IT	IT	19	2
TAS-ES	ES	7	0
TAS-B	BE	6	0
TAS-UK	UK	6	0
TAS-CH	CH	2	0
TAS-D	DE	1	0
Totals		**79**	**16**

Source: CORDIS projects database H2020-Space.

Moreover, if we add up the two largest German Research Organizations, participations are close to Thales's as shown in Table 5.5 below.

Table 5.5: H2020-Space – German top REC Project Participation

AGENT	Country	Participations	Coordinations
DLR	DE	53	11
Fraunhofer	DE	17	1
Totals		**70**	**12**

Source: Own elaboration using H2020-Space data from CORDIS

In Table 5.6 we show a ranking of the top 20 *H2020-Space* participation agents, whereas in Table 5.7 we show a ranking of the top 20 *H2020-Space* participation agents with PRC.

Table 5.6: H2020-Space – Top 20 Project Participation Agents.

AGENT	Participations	Coordinations
DLR	53	11
TAS	38	14
CNRS	28	1
TAS-IT	19	2
AIRBUS	18	5
Fraunhofer	17	1
CNR	17	3
CNES	17	0
AGI	15	5
UKRI	14	0
MPG	13	2
SPACEAPPS	13	6
DEIMOS	13	4
POLITO	12	2
GMV	12	6
CEA	11	2
CSIC	11	2
ON	11	3
FMI	11	1
INAF	10	2

Source: Own elaboration using H2020-Space data from CORDIS

Table 5.7: H2020-Space – Top 20 Project Participation Agents Ranking (With Thales (PRC) consolidated figures)

AGENT	Participations	Coord
TAS-Group	79	16
DLR	53	11
CNRS	28	1
AIRBUS	18	5
Fraunhofer	17	1
CNR	17	3
CNES	17	0
AGI	15	5
UKRI	14	0
MPG	13	2
SPACEAPPS	13	6
DEIMOS	13	4
POLITO	12	2
GMV	12	6
CEA	11	2
CSIC	11	2
ON	11	3
FMI	11	1
INAF	10	2
Pildo Labs	9	3

Source: Own elaboration using H2020-Space data from CORDIS

If we compare the participation and the coordination rankings, we obtain similar positions in the rankings for most agents, with some exceptions such as CNES (France-OTH) with no coordination roles at all, Fraunhofer (Germany-REC) and UKRI (UK – REC) with low coordination and low weight (see Table 5.8).

Table 5.8: H2020-Space – Top 20 Project Participation, Coordination and project weight Agents Ranking (With Thales, PRC, consolidated figures)

AGENT	Participations	AGENT	Coord	AGENT	Weight (M€)
DLR	53	TAS-Group	14	DLR	70.7
TAS	38	DLR	11	TAS	44.0
CNRS	28	SPACEAPPS	6	AGI	23.2
AIRBUS	18	GMV	6	SPACEAPPS	20.5
Fraunhofer	17	AIRBUS	5	ASI	20.4
CNR	17	AGI	5	GMV	16.0
CNES	17	DEIMOS	4	CNRS	15.5
AGI	15	ACO	4	SAF-AE	15.2
UKRI	14	ESA	4	AIRBUS	14.7
MPG	13	UC3M	3	CNES	14.1
SPACEAPPS	13	U LEIDEN	3	DEIMOS	14.0
DEIMOS	13	ISMB	3	CNR	13.5
POLITO	12	GAF AG	3	OU	12.8
GMV	12	Pildo Labs	3	ON	12.3
CEA	11	ESF	3	ESA	11.7
CSIC	11	ON	3	ARIANE	11.5
ON	11	ATOS	3	EUSC	10.5
FMI	11	FORTH	3	TAS-IT	10.4
INAF	10	CNR	3	UK Sp. Ag.	10.2
Pildo Labs	9	POLITO	2	CDTI	10.1

Source: Own elaboration using H2020-Space data from CORDIS

Agents by Technology Field

Next, we analyse the participation of agents in *H2020-Space* projects considering the R&D areas, following the ESA (ESA) Technology Field definition:

Code	Description
• EOBS:	Earth Observation;
• SCNC:	Science;
• HFLT:	Human Flight;
• LNCH:	Launchers;
• GSTP:	General Support Technology Programmes;
• NAVI:	Navigation and
• RBEX:	Robotic Exploration.

In our database, these technological fields are included as part of the information of each project (see Annex – Chapter 5). We are interested in not only the number of participations and the times each agent holds the coordination role but also the corresponding weighted participation in projects and the distribution per R&D field.

In Table 5.9, we present the number and percentages of project coordination role for each type of agent and its distribution by technological field.

Table 5.9: H2020-Space – Agents' Project Coordination by Technology Field

Agent Activity Type	ALL FIELDS		EOBS		GSTP		HMFL		LNCH		NAVI		RBEX		SCNC	
PRC	208	60%	43	54%	89	58%	7	50%	4	44%	55	74%	9	82%	1	17%
REC	60	17%	20	25%	21	14%	2	14%	5	56%	11	15%	0	0%	1	17%
HES	49	14%	10	13%	29	19%	3	21%	0	0%	3	4%	0	0%	4	67%
PUB	7	2%	3	4%	1	1%	1	7%	0	0%	2	3%	0	0%	0	0%
OTH	23	7%	4	5%	13	8%	1	7%	0	0%	3	4%	2	18%	0	0%
Total	**347**	**100**	**80**	**100**	**153**	**100**	**14**	**100**	**9**	**100**	**74**	**100**	**11**	**100**	**6**	**100**

Source: Own elaboration using H2020-Space data from CORDIS

In Table 5.10 below, we can see the leadership of PRC in *H2020-Space* projects, holding the role of project coordinator in 50% of the projects. This leadership is even greater in the fields RBEX and NAVI. As we see in Table 5.10, in the Launchers field, although PRC keeps a high percentage of the activity, the leader in project coordination is the activity type REC. It is worth noting that in the RBEX field, no research, education nor public body leads any project of that area.

Table 5.10: H2020-Space – Agents' Project Participation by Technology Field

Agent Activity Type	ALL FIELDS		EOBS		GSTP		HMFL		LNCH		NAVI		RBEX		SCNC	
PRC	1,139	48%	270	38%	423	46%	33	55%	52	68%	302	60%	51	51%	8	28%
REC	518	22%	203	29%	189	21%	10	17%	16	21%	71	14%	22	22%	7	24%
HES	456	19%	149	21%	197	21%	9	15%	6	8%	65	13%	16	16%	14	48%
PUB	124	5%	45	6%	42	5%	4	7%	-	0%	29	6%	4	4%	-	0%
OTH	154	6%	39	6%	67	7%	4	7%	3	4%	34	7%	7	7%	-	0%
Total	**2,391**		**706**		**918**		**60**		**77**		**501**		**100**		**29**	

Source: Own elaboration using H2020-Space data from CORDIS

Science projects (SCNC) lead by HES. REC and PRC have the same coordination share in that technology field. Public Institutions and Other agents do not have an important presence as coordinator in any technology field other than robotic exploration (RBEX). Total participation shows is quite balanced in most technology fields. Even RBEX has workshares similar to the broad participation (all fields), although the coordination role is biased to PRC. We see also that Science and Launchers fields appear to be of no interest to PUB type agents.

Agents by Country / Location

Next, we decompose the whole network in ESA, EU-15, EU-13 and Out of Europe subnetworks of agents, to analyse each one individually. We build on Balland, Boschma & Ravet (2019) description of collaborative research, taking into account older members of the European Union (EU-15) versus new members (EU-13).

With the project coordination data, we make a first group of all those agents belonging to countries which are state members of the ESA (ESA). Then, we consider those in the EU, those outside the EU and finally the group of those agents outside the EU but cooperating in H2020 programme. We also study the European Big-5 (France, Germany, United Kingdom, Italy and Spain). The results of project coordination are presented in Table 5.11.

Table 5.11: H2020-Space. Agents by location. Project Coordination by Activity Area

Location	ALL		EOBS		GSTP		HMFL		LNCH		NAVI		RBEX		SCNC	
ALL	347		80		[illegible]		14		9		74		11		6	
ESA	338	97%	79	99%	149	97%	14	100%	9	100%	71	96%	11	100%	5	83%
ESA no EU	11	3%	3	4%	4	3%	1	7%	0	0%	3	4%	0	0%	0	0%
EU-28	335	96%	77	96%	148	97%	13	93%	9	100%	69	93%	11	100%	6	100%
EU-13	6	2%	1	1%	3	2%	0	0%	0	0%	1	1%	0	0%	1	17%
EU-13-ESA	8	2%	1	1%	4	3%	0	0%	0	0%	3	4%	0	0%	0	0%
EU-15-ESA	319	92%	75	94%	141	92%	13	93%	9	100%	65	88%	11	100%	5	83%
EUR	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
AMERICA	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
ASIA	3	1%	0	0%	1	1%	0	0%	0	0%	2	3%	0	0%	0	0%
AFRICA	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
OCEANIA	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
Big-5	248	71%	47	59%	112	73%	13	93%	7	78%	58	78%	8	73%	3	50%

Note: EUR: European countries not belonging to the EU or to ESA.

Source: Own elaboration using H2020-Space data from CORDIS

The coordination role is predominantly performed by ESA member states. Moreover, Human Flight, Launchers and Robotic Exploration are 100% headed by ESA members. The distribution in the EU is very concentrated, with a huge difference between EU-15 and EU-13 project coordination figures. Furthermore, there is a high concentration in project coordination in the Big-5, particularly in HMFL, where those 5 countries hold a share of 93% and no other EU-15 country leads any Human Flight project. On the other hand, EOBS activity leadership is more evenly distributed among EU-15.

Table 5.12 covers Participation for each Location by technology field and shows similar shares than in project coordination.

Table 5.12: H2020-Space. Agents by location. Project Participation by Technology Field

Location	ALL		EOBS		GSTP		HMFL		LNCH		NAVI		RBEX		SCNC	
ALL	2,391		706		918		60		77		501		100		29	
ESA	2,249	94%	665	94%	876	95%	59	98%	76	99%	446	89%	100	100%	27	93%
ESA no EU	98	4%	37	5%	32	3%	4	7%	5	6%	17	3%	3	3%	0	0%
EU-28	2,197	92%	644	91%	864	94%	55	92%	72	93%	437	87%	97	97%	28	96%
EU-13	46	2%	16	2%	20	2%	0	0%	1	1%	8	2%	0	0%	1	3%
EU-13-ESA	126	5%	39	6%	46	5%	0	0%	4	5%	31	6%	4	4%	2	7%
EU-15-ESA	2,025	85%	589	83%	798	87%	55	92%	67	87%	398	79%	93	93%	25	86%
EUR	33	1%	11	2%	11	1%	0	0%	0	0%	12	2%	0	0%	1	3%
AMERICA	11	0%	2	0%	3	0%	0	0%	0	0%	6	1%	0	0%	0	0%
ASIA	34	1%	7	1%	4	0%	1	2%	0	0%	22	4%	0	0%	0	0%
AFRICA	13	1%	3	0%	4	0%	0	0%	0	0%	6	1%	0	0%	0	0%
OCEANIA	3	0%	2	0%	0	0%	0	0%	0	0%	1	0%	0	0%	0	0%
EU Big-5	1,479	62%	373	53%	610	66%	42	70%	49	64%	311	62%	79	79%	15	52%

Source: Own elaboration using H2020-Space data from CORDIS

In Tables 5.13 and 5.14, we present the coordination and participation shares by location - indicating geo-political group membership - and activity type of agent.

Table 5.13: H2020-Space – Agents by Location. Project Coordination by Agent's Activity Type

Location	ALL		PRC		REC		HES		PUB		OTH	
ALL	347		208		60		49		7		23	
ESA	338	97%	199	96%	60	100%	49	100%	7	100%	23	100%
ESA no EU	11	3%	3	1%	2	3%	5	10%	0	0%	1	4%
EU-28	335	96%	202	97%	58	97%	44	90%	7	100%	22	95%
EU-13	6	2%	6	3%	0	0%	0	0%	0	0%	0	0%
EU-13-ESA	8	2%	7	3%	0	0%	0	0%	0	0%	1	4%
EU-15-ESA	319	92%	189	91%	58	97%	44	90%	7	100%	21	91%
EUR	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
AMERICA	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
ASIA	3	1%	3	1%	0	0%	0	0%	0	0%	0	0%
AFRICA	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
OCEANIA	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
EU Big-5	248	71%	152	73%	41	68%	29	59%	6	86%	20	87%

Source: Own elaboration using H2020-Space data from CORDIS

Coordination share keeps the same geographical pattern for almost all types of agent, although the Big-5 countries have a lower than the average share of High or Secondary Education Establishments coordinating projects (59% vs 71%). We find the same pattern in Participation figures (Table 5.14).

Table 5.14: H2020-Space – Agents by location. Project Participation by Agent's Activity Type

Location	ALL		PRC		REC		HES		PUB		OTH	
ALL	2,391		1,139		518		456		124		154	
ESA	2,249	94%	1,093	96%	494	95%	419	92%	102	82%	141	92%
ESA no EU	98	4%	37	3%	29	6%	25	5%	1	1%	6	4%
EU-28	2,197	92%	1,072	94%	470	91%	407	89%	105	89%	138	89%
EU-13	46	2%	16	1%	5	1%	13	3%	9	7%	3	2%
EU-13-ESA	126	5%	54	5%	35	7%	23	5%	6	5%	8	5%
EU-15-ESA	2,025	85%	1,002	88%	430	83%	371	81%	95	77%	127	82%
EUR	33	1%	10	1%	5	1%	9	2%	7	6%	4	3%
AMERICA	11	0%	5	0%	1	0%	5	1%	0	0%	0	0%
ASIA	34	1%	11	1%	9	2%	6	1%	2	2%	6	4%
AFRICA	13	1%	3	0%	4	1%	2	0%	4	3%	0	0%
OCEANIA	3	0%	1	0%	0	0%	2	0%	0	0%	0	0%
EU Big-5	1,479	62%	742	65%	298	58%	270	59%	72	58%	97	63%

Source: Own elaboration using H2020-Space data from CORDIS

Although we take Big-5 countries as a group, due to the important role of all of them, in order to compare our study of H2020 to previous analyses of former FPs 2 to 7, we calculate participation percentages for the Big Four (Germany, Italy, UK and France), as in Protogeru et al. (2013). They observe in the FPs 2 to 7 project data that these four countries on average account for 77.2% of total participation in research projects and the rest of EU-15 countries only 19.11%. *H2020-Space*, however, shows a participation of 50% from those four countries while the rest of UE-15 participation rate comes up to 34%.

In Table 5.15 and Table 5.16, we present in more detail the Big-5 figures both regarding coordination and participation roles.

Table 5.15: H2020-Space – Agents by location. Project Coordination by Agent's Type – Big-5 Detail.

Location	ALL		PRC		REC		HES		PUB		OTH	
Big 5	248	71%	152	73%	41	68%	29	59%	6	86%	20	87%
FR	60	17%	44	21%	4	7%	1	2%	1	14%	10	43%
DE	51	15%	20	10%	18	30%	4	8%	1	14%	8	35%
UK	23	7%	7	3%	4	7%	10	20%	2	29%	0	0%
IT	54	16%	35	17%	8	13%	9	18%	0	0%	2	9%
ES	60	17%	46	22%	7	12%	5	10%	2	29%	0	0%

Source: Own elaboration using H2020-Space data from CORDIS

In the coordination breakdown, HES share looks unexpectedly low for France, Germany and UK.

Besides, we also find large differences in Big-5 Agent's activity type structure: France has higher Private Research Companies rate; Research Centres in Germany double the broad coordination rate; Italian Public Bodies do not coordinate a single project while Spanish public bodies reach the highest percentage in our country.

Table 5.16 shows that the Big-5 participation figures (All Types) do not differ substantially from project coordination. We find, however, some differences in the agents' activity type share.

Table 5.16: H2020-Space – Agents by location. Project Participation by Agent's Activity Type – Big-5 Detail.

Location	ALL		PRC		REC		HES		PUB		OTH	
EU Big-5	1,479	62%	742	65%	298	58%	270	59%	72	58%	97	63%
FR	344	14%	200	18%	52	10%	39	9%	7	6%	46	30%
DE	320	13%	117	10%	120	23%	48	11%	12	10%	23	15%
UK	236	10%	100	9%	33	6%	82	18%	19	15%	2	1%
IT	299	13%	170	15%	47	9%	60	13%	7	6%	15	10%
ES	280	12%	155	14%	46	9%	41	9%	27	22%	11	7%

Source: Own elaboration using H2020-Space data from CORDIS

To conclude this section, we observe that the different activity types of agent seem to be complementary in the projects. On the other hand, the differences between technology fields documented in this section suggest that the network characteristics may be different across fields and therefore the knowledge transmission properties will also differ. We address these questions in the next sections.

Misalignment with the aggregate involvement by technology field

In Tables 5.17 and 5.18, we find the share of projects coordinations and participations by technology field (column) for each type of agent (row). We add a row with the totals per technology field. The last column gives for each type of agent the sum of the squares of the differences between the type coordinations or participations in the different fields and the totals per field of the last row. We use this sum as an indicator of the misalignment of a type of agent with the average of participation by field of all agents in H2020 Space Programme.

Table 5.17: H2020-Space – Share of Project Coordinations by Technology Field and Type of Agent.

Coordin.	EOBS	GSTP	HMFL	LNCH	NAVI	RBEX	SCNC	Misalignment
PRC	21%	43%	3%	2%	26%	4%	0%	0,004
REC	33%	35%	3%	8%	18%	0%	2%	0,024
HES	20%	59%	6%	0%	6%	0%	8%	0,053
PUB	43%	14%	14%	0%	29%	0%	0%	0,146
OTH	17%	57%	4%	0%	13%	9%	0%	0,030
All Types	23%	44%	4%	3%	21%	3%	2%	-

Source: Own elaboration using H2020-Space data from CORDIS

With the proposed measure of misalignment of each type of agent, we see how private companies are nearer to the aggregate than other types of agents, both in coordination and participation while public and private research bodies amplify their activity in EOBS and put less effort in NAVI and GSTP, respectively. Note that a large misalignment in coordination corresponds to a high specialization in the leadership of a few fields, while a low misalignment is associated to a wider scope of technological leadership.

Table 5.18: H2020-Space – Share of Project Participations by Technology Field and Type of Agent.

Particip	EOBS	GSTP	HMFL	LNCH	NAVI	RBEX	SCNC	Misalignment
PRC	24%	37%	3%	5%	27%	4%	1%	0.008
REC	39%	36%	2%	3%	14%	4%	1%	0.038
HES	33%	43%	2%	1%	14%	4%	3%	0.015
PUB	36%	34%	3%	0%	23%	3%	0%	0.029
OTH	25%	44%	3%	2%	22%	5%	0%	0.001
All Types	30%	38%	3%	3%	21%	4%	1%	

Source: Own elaboration using H2020-Space data from CORDIS

Table 5.19: H2020-Space – Share of Project Participations by Technology Field and Location.

Location	EOBS	GSTP	HMFL	LNCH	NAVI	RBEX	SCNC	Misalignment
ALL	30%	38%	3%	3%	21%	4%	1%	0
ESA	30%	39%	3%	3%	20%	4%	1%	0.001
ESA no EU	38%	33%	4%	5%	17%	3%	0%	0.012
EU-28	29%	39%	3%	3%	20%	4%	1%	0.001
EU-13	35%	43%	0%	2%	17%	0%	2%	0.009
EU-13-ESA	31%	37%	0%	3%	25%	3%	2%	0.003
EU-15-ESA	29%	39%	3%	3%	20%	5%	1%	0.001
EUR	31%	31%	0%	0%	34%	0%	3%	0.027
AMERICA	18%	27%	0%	0%	55%	0%	0%	0.142
ASIA	21%	12%	3%	0%	65%	0%	0%	0.273
AFRICA	23%	31%	0%	0%	46%	0%	0%	0.077
OCEANIA	67%	0%	0%	0%	33%	0%	0%	0.304
Big-5	25%	41%	3%	3%	21%	5%	1%	0.003
FR	24%	48%	2%	3%	17%	6%	1%	0.015
DE	28%	44%	4%	5%	15%	4%	1%	0.008
UK	33%	41%	1%	4%	12%	9%	0%	0.012
IT	22%	36%	6%	1%	29%	3%	2%	0.016
ES	22%	35%	1%	4%	31%	5%	2%	0.018

Source: Own elaboration using H2020-Space data from CORDIS

So far, PRC agents lead coordination and participation and have a wider scope of technological interests. We are also interested in the degree of specialization or misalignment by location. Agents in the EU and other ESA members are better aligned. There are big differences in the Big-5 agents share per country; although they, as a group, are aligned with the aggregate distribution, they do not hold the same technological interests (e.g. Spain and Italy are more specialized in NAVI, and France and Germany in GSTP).

Agents Network

Next, with the data set previously described, we build a network considering each node as an agent, and each link from the project coordinator to each of the participating agents as a network edge. In addition, we use the project participation weight, defined as the total project funds divided over the number of non-coordinating participants. Thus, the coordinator of one project accumulates the weights of all the edges, equivalent to the total funds of the project.

First, we analyse the cooperation pattern among types of agents. We characterize the agents' network by its global metrics, which allow us to compare networks across multiple dimensions. Some of these metrics provide information on the network size: nodes, edges, percentage nodes, and edges/nodes ratio. Other characteristics of the network are given by the metrics: Average Degree, Average Weighted Degree, Average Participation Weighted degree, Diameter, Radius, Average Path length, Density, Modularity, Number of Communities, Number of triangles, Number of paths (Length 2), Value of Clustering Coefficient and Number of Weakly Connected Components. Lastly, we also provide metrics dealing with node characteristics: Average Clustering Coefficient, Eigenvector centrality and triangles / nodes ratio.

Cooperation by type of agent

In this section, we study the degree of complementarity of the different activity type agents. If the types of agents were highly complementary, we would observe that projects contain several types of agents; if not, projects would group the same type. In Table 5.20, we present the number and share on the total links generated by the coordinated (participated) projects by each type of agent. We can see the frequency of the match between a coordinator and participant of the same type and of different type.

Table 5.20: H2020-Space – Cooperation in projects by Type of Agent.

Coordination (Participation)	Coordinator	Participant	number of links	Relative % of Links
13%	HES	HES	102	37%
(19%)	HES	REC	69	25%
	HES	PRC	81	29%
	HES	PUB	6	2%
	HES	OTH	17	6%
25%	REC	HES	102	20%
(22%)	REC	REC	138	27%
	REC	PRC	193	37%
	REC	PUB	49	9%
	REC	OTH	35	7%
49%	PRC	HES	159	15%
(48%)	PRC	REC	175	17%
	PRC	PRC	594	58%
	PRC	PUB	43	4%
	PRC	OTH	62	6%
2%	PUB	HES	15	29%
(5%)	PUB	REC	15	29%
	PUB	PRC	17	33%
	PUB	PUB	3	6%
	PUB	OTH	2	4%
11%	OTH	HES	37	16%
(6%)	OTH	REC	61	27%
	OTH	PRC	94	42%
	OTH	PUB	17	8%
	OTH	OTH	16	7%
		totals	2,102	

Source: Own elaboration using H2020-Space data from CORDIS

For all types of coordinator, a very frequent partner is a PRC. HES cooperates with a higher percentage of other Higher or Secondary Education establishments, although they also have a high rate of cooperation with PRCs. Note that the types seem highly complementary, independently of the type of the coordinator.

In Table 5.21, we rank the cooperation between pairs of types of agents. In the third column, we show the percentage of links between each pair of types of agents and we see how the pair PRC-PRC leads the ranking. However, they are the majority of the participating agents (55%) so we calculate in the last column, a relative percentage of cooperation of those links over the full participation of the involved type of agents.

Table 5.21: H2020-Space. Cooperation in projects by Type of Agent. Ranking.

Cooperation Ranking		Links	% of links (over 2102)	Tot. Part. Of Involved Ag.	Rel. %
PRC	PRC	594	28%	1,418	42%
REC	PRC	368	18%	2,255	16%
HES	PRC	240	11%	1,585	15%
HES	REC	171	8%	1,004	17%
PRC	OTH	156	7%	1,759	9%
REC	REC	138	7%	837	16%
HES	HES	102	5%	167	61%
REC	OTH	96	5%	1,178	8%
REC	PUB	64	3%	1,004	6%
PRC	PUB	60	3%	1,585	4%
HES	OTH	54	3%	508	11%
HES	PUB	21	1%	334	6%
PUB	OTH	19	1%	508	4%
OTH	OTH	16	1%	341	5%
PUB	PUB	3	0%	167	2%

Source: Own elaboration using H2020-Space data from CORDIS

Table 5.22: H2020-Space – Total Participations by Type of Agent.

TYPE	Total participations
PRC	1,418
REC	837
HES	167
PUB	167
OTH	341

Source: Own elaboration using H2020-Space data from CORDIS

Note that the pair REC-PRC is relatively more frequent and that PRC is present in the most frequent cooperation pairs. This indicates the complementarity of the types of agents to carry out the projects. However, we must highlight the importance of PRC-PRC cooperation, both in absolute and relative terms and also the HES-HES match, most probably associated to former traditional cooperation in basic research among Universities. To check the hypothesis of complementarity we run a regression of participation of a type of agent as a function of the type of the coordinator. Table 5.23 presents the results.

Table 5.23. OLS regression of Participation over Coordinator type.

Participation	**PRC**	**HES**	**REC**	**PUB**
coorprc	0.575	0.154	0.169	0.042
	(0.000)	(0.000)	(0.000)	(0.000)
coorhes	0.294	0.371	0.251	0.022
	(0.000)	(0.000)	(0.000)	(0.116)
coorrec	0.373	0.197	0.267	0.095
	(0.000)	(0.000)	(0.000)	(0.000)
coorpub	0.327	0.288	0.288	0.058
	(0.000)	(0.000)	(0.000)	(0.071)
Number of obs	2102	2102	2102	2102
F(4, 2098)	433.55	138.63	124.96	31.76
Prob > F	0.0000	0.0000	0.0000	0.0000
Adj R-squared	0.4515	0.2075	0.1909	0.0553

Note: p-values in parentheses

Source: Own elaboration using H2020-Space data from CORDIS

The coefficients give us the probability of each type of agent participating in a project for each type of coordinator. For PRC the highest probability corresponds to a coordinator of the same type (PRC) but the rest of the coefficients are quite high also. For PRC, HES and REC participation, we do not reject the hypothesis of complementarity with all the types.

Note that PUB has a different behaviour, it is not likely to be selected by a coordinator of the same type or a HES (the coefficients are not significant at 5%). For PUB we reject the hypothesis of complementarity with PUB or HES, but it is complementary with PRC and HES.

Next, we calculate the homophilic index, as a measure of in-group and out-group preference:

HI = (external links - internal links) / (external + internal links)

If the index takes value -1, this means complete homophily: the coordinator only has links with other institutions of the same type. If the index takes value 1, this means complete heterophily: all the links are to a different type. Finally, an index of 0 means that there is an equal number of external and internal links, that is, absence of heterophily and homophily. Table 5.24 presents the aggregate homophily index and disaggregated by type of coordinator.

Table 5.24. Homophily index.

TYPE	Internal	External	Homophily index
PRC	594	439	-0.150
REC	138	379	0.466
HES	102	173	0.258
PUB	3	49	0.885
Aggregate	837	1040	0.108

Source: Own elaboration using H2020-Space data from CORDIS

PUB shows a clear heterophily, and REC a moderate level. PRC has a very low level of homophily

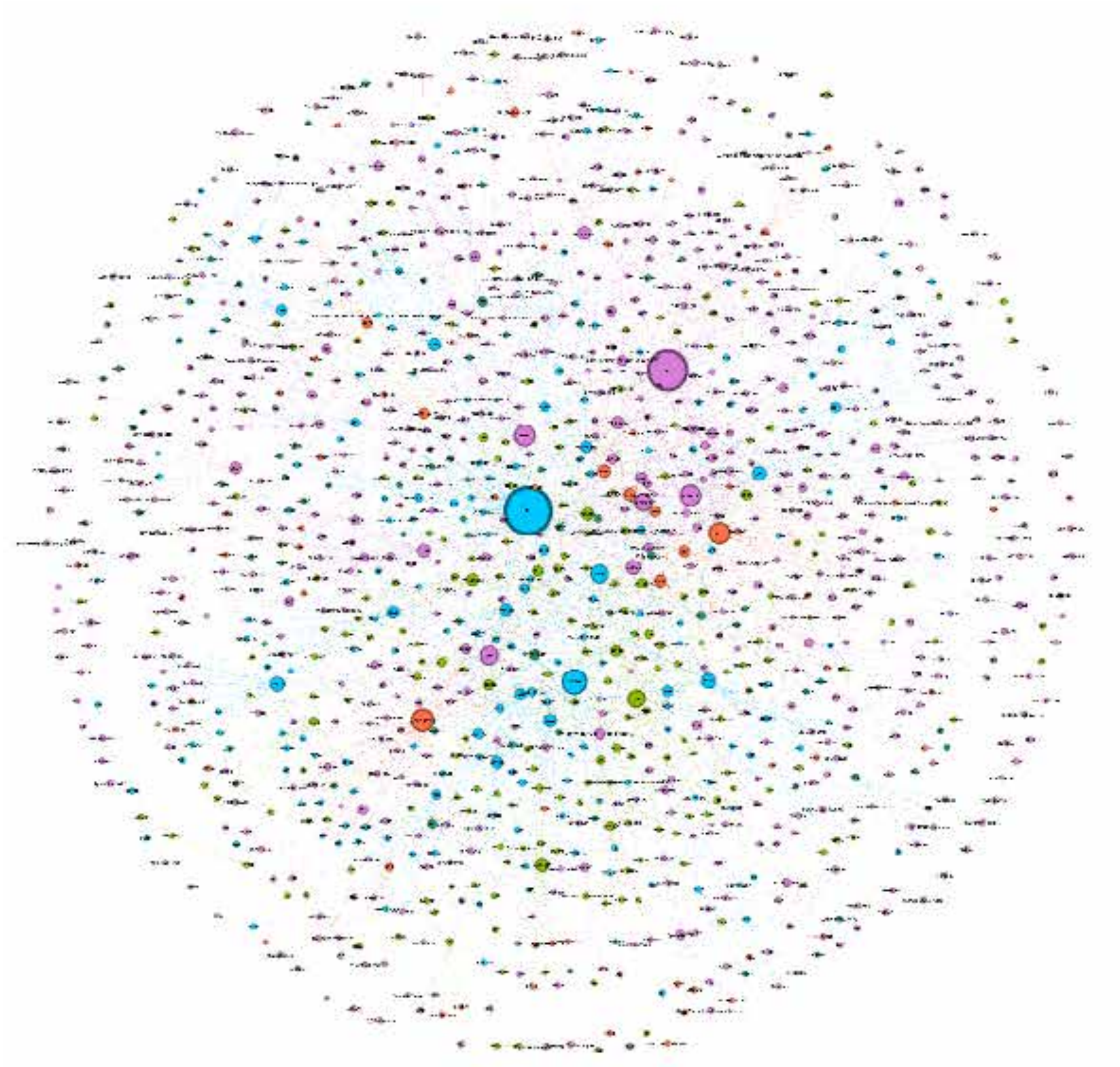
Network by Technology Field and Type of Agent.

In the previous sections, we have presented evidence on the heterogeneity of agent's interests by technology field and agent activity type. This analysis justifies that we examine in this section not only the aggregate *H2020-Space* network but also by technology field and type of agent.

Although the funds go from the project coordinator to the participants, to study the evolution of this R&D network, the transmission of knowledge and innovation adoption, we model it as an undirected graph, implying that knowledge can be transmitted in both directions.

In Figure 5.2a-b, we present the aggregate network formed by R&D agents in *H2020-Space*.[26] The size of the nodes in the figure is proportional to their degree, defined as the number of edges, a measure of the connectivity of a given R&D agent with others.

Figure 5.2a: H2020-Space – Agents Network by Activity Type:
PRC (Rose), REC (Blue), HES (Green), PUB (Dark Green) and OTH (Orange).

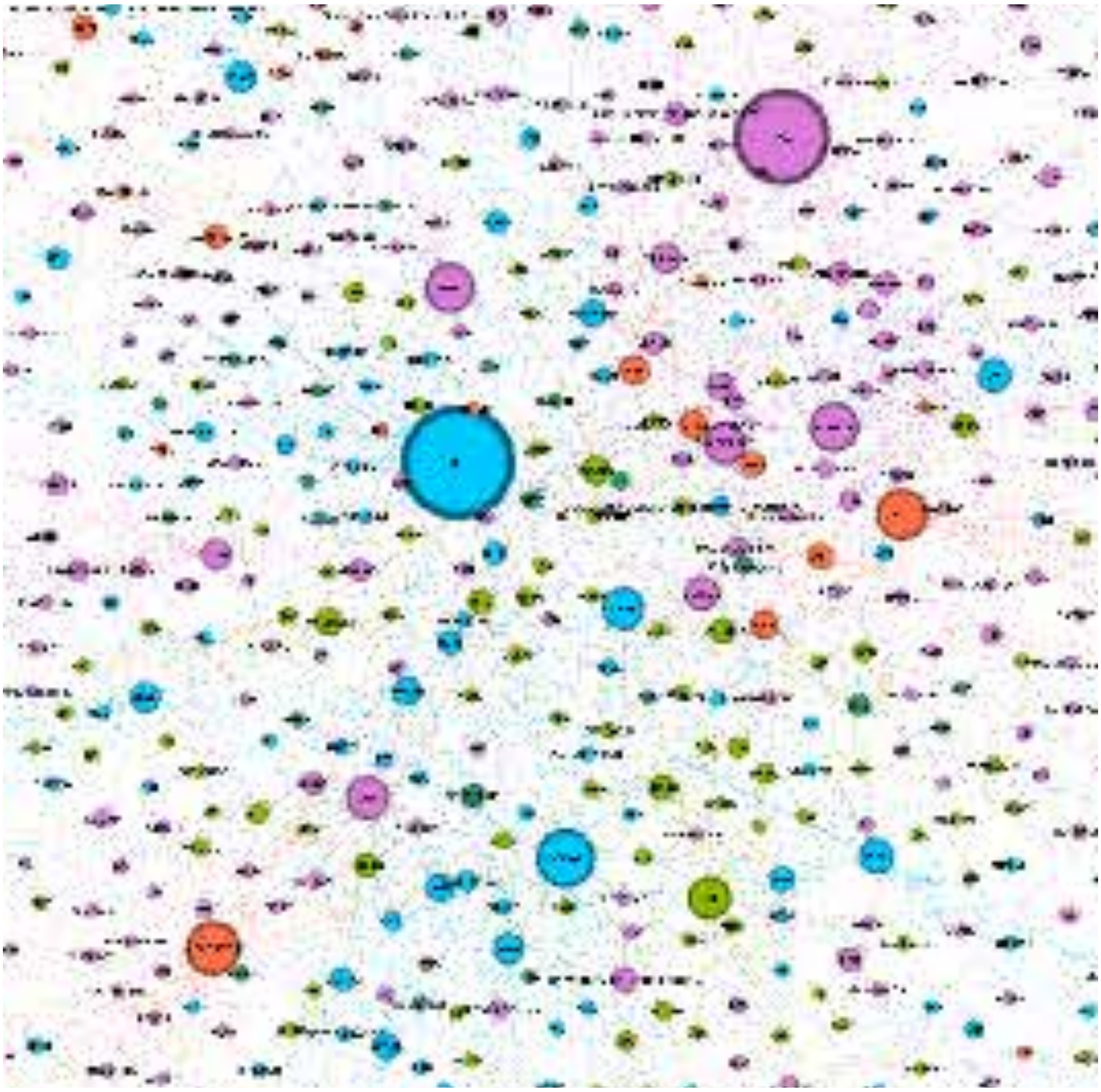


Source: Own elaboration using H2020-Space data from CORDIS

[26] We represent the aggregate network with a Frutcherman Reingold graphic generated with Gephi 0.9.2 software using the data from *H2020 Space*.

Figure 5.2a-b shows the connectivity generated by the H2020 Space Programme 2014-2019. There is a high percentage of private entities PRC (rose), two big players (DLR and Thales) of different type, a few agents with a large size and most of the others with a low participation and low influence in the network.

Figure 5.2b: H2020-Space – Agents Network per Activity Type. Detail

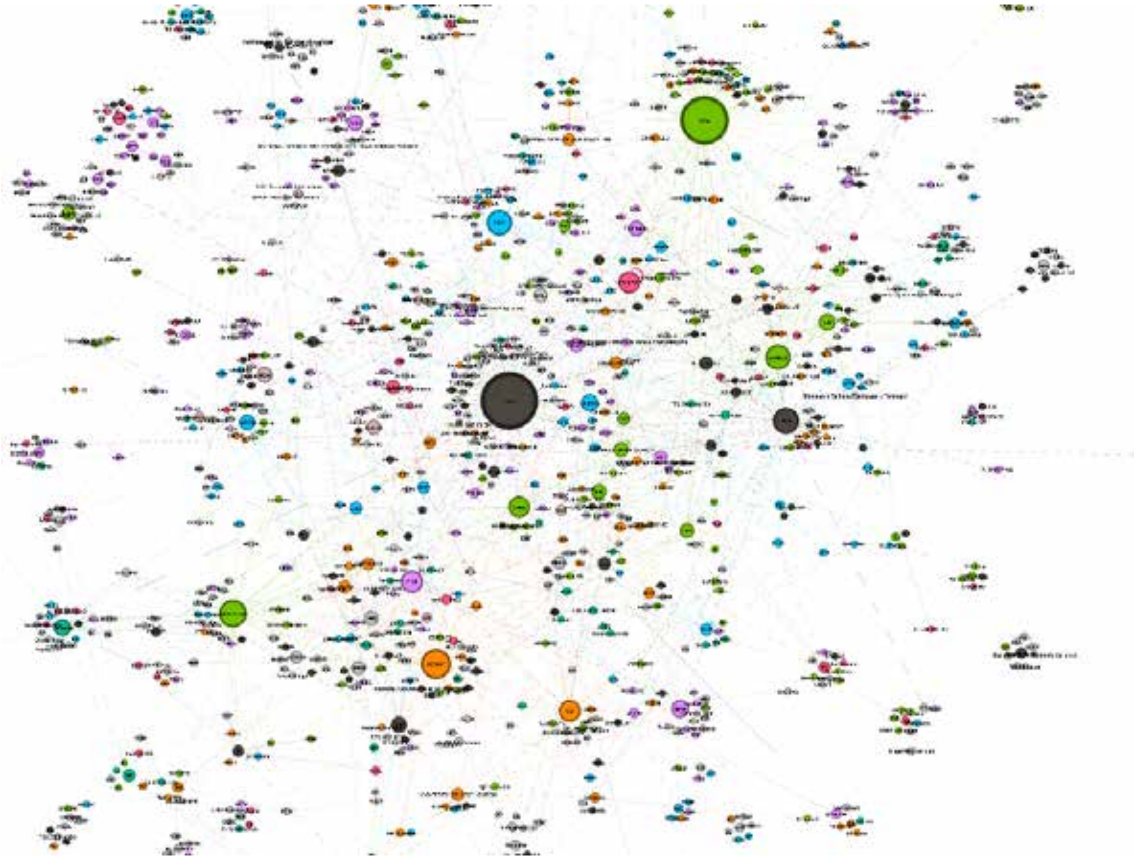


Source: Own elaboration using H2020-Space data from CORDIS

In Figure 5.3a, we use a gravitational representation in order to analyse the influence of geographic proximity. This is an important issue and indeed the Monitoring Flash of the EC (2018) detected that geographical and cultural proximities between participants in the Horizon 2020 Programme played an important role in shaping the structure of the H2020 collaboration network. However, we find no apparent geographical or cultural influence in project cooperation. We can see as many links between countries of different geographical areas and cultures as we can see links from the near areas and similar cultures.

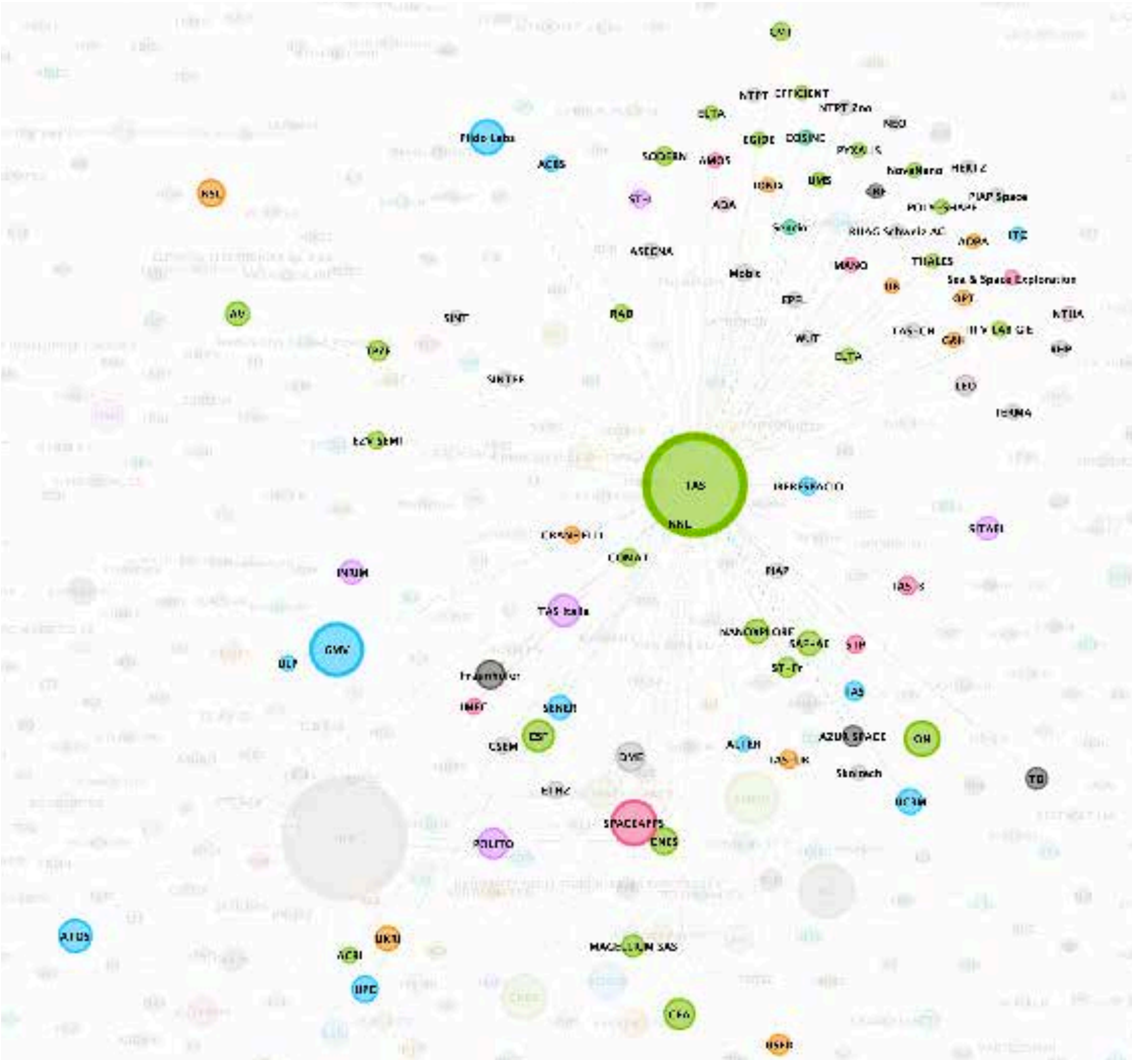
In Figures 5.3b and 5.3c we present the sub-networks of the two biggest agents (TAS and DLR). Note that they have some coincidences in participants, mostly the larger ones, but have also their own set of collaborators. The influence of specialization of small agents and the integration function of the big players seem to be the main drivers of the shape of *H2020-Space* cooperating network.

Figure 5.3a: H2020-Space – Agents Network per Activity Type. Gravitational representation. Colours per Country. Detail.



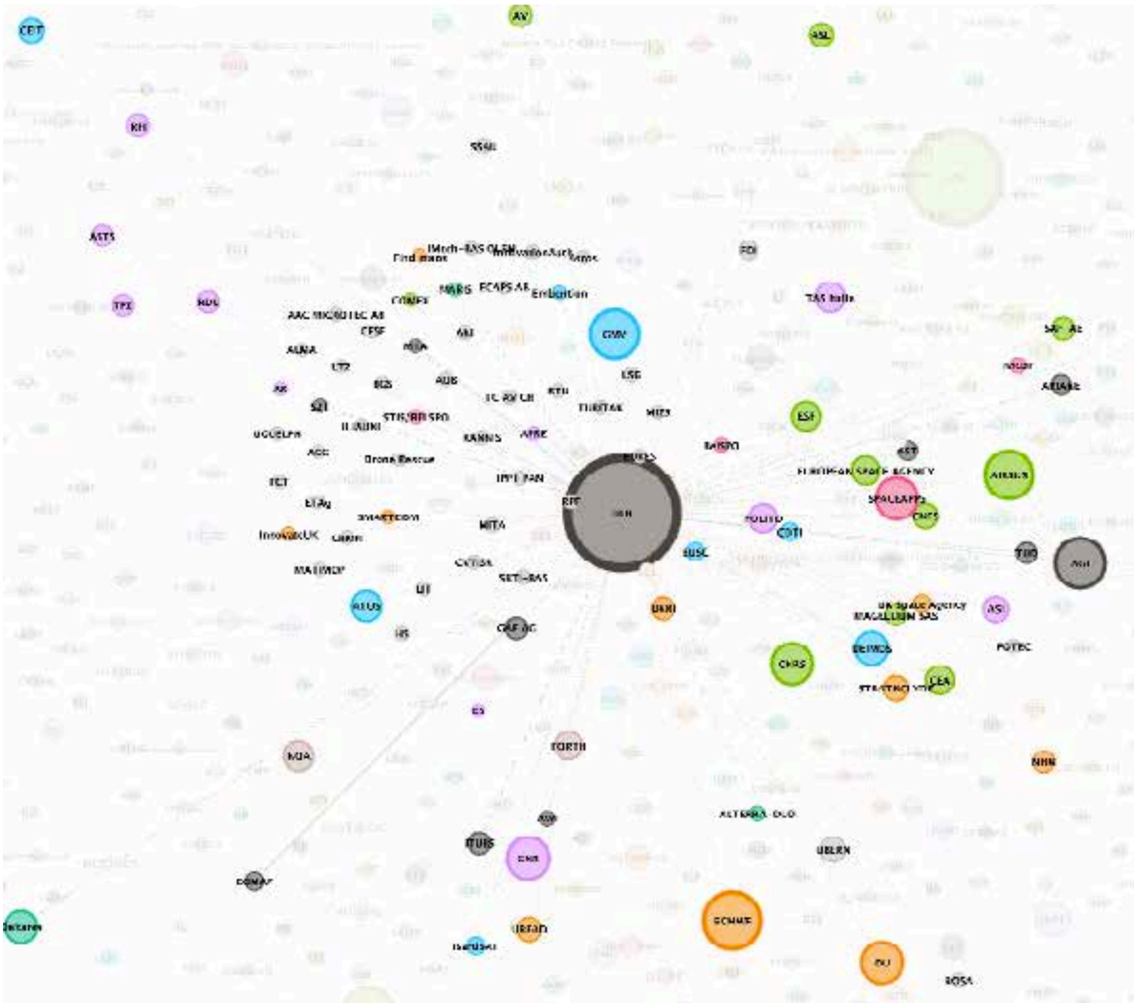
Source: Own elaboration using H2020-Space data from CORDIS

Figure 5.3b: H2020-Space – Agents Network per Activity Type. Gravitational representation. Colours per Country. Detail TAS.



Source: Own elaboration using H2020-Space data from CORDIS

Figure 5.3c: H2020-Space – Agents Network per Activity Type. Gravitational representation. Colours per Country. Detail DLR.



Source: Own elaboration using H2020-Space data from CORDIS

In Table 5.25, we show the global metrics for the space Innovation & Research network generated by *H2020-Space* projects.

Table 5.25: H2020-Space – Agents' Network Global Metrics per Technology Field

AGENTS' Network	ALL	EOBS	GSTP	HMFL	LNCH	NAVI	RBEX	SCNC
Network Size								
nodes	1,258	447	543	54	65	353	52	28
edges	2,102	634	797	51	69	437	89	25
% nodes	100%	36%	43%	4%	5%	28%	4%	2%
Total Project funds (M€)	789.4	195.8	337.7	24.9	37.9	142.0	39.0	12.1
% of total funds	100%	25%	43%	3%	5%	18%	5%	2%
Network overview								
Average Degree	1.671	1.418	1.468	0.944	1.062	1.238	1.712	0.893
Av. Weighted Deg (M€)	1.233	0.863	1.221	0.875	1.109	0.798	1.499	0.849
Diameter	12.00	9.00	9.00	4.00	6.00	11.00	5.00	3.00
Average Path length	4.43	4.46	4.18	2.30	3.31	4.97	..79	1.90
Density	0.003	0.006	0.005	0.036	0.033	0.007	0.066	0.066
Modularity	0.668	0.683	0.679	0.703	0.690	0.799	0,468	0.593
Number of Communities	63	25	50	12	7	24	6	6
Number of triangles	659	111	169	2	4	48	29	0
Number of paths (Length 2)	38,889	7,443	11,063	236	375	2,890	981	91
Value of Clustering Coefficient	0.051	0.045	0.046	0.025	0.032	0.050	0.089	0.000
Number of Weakly Connected Components	44	9	33	10	3	11	1	5
Node Overview								
Average Clustering Coefficient	0.175	0.177	0.166	0.277	0.238	0.177	0.497	0.000
Eigenvector centrality	0.025	0.016	0.015	0.004	0.004	0.032	0.001	0.003

Source: Own elaboration using H2020-Space data from CORDIS

For each technology field, the number and percentage of nodes, the project funds and the percentage of funds per field gives information on its relevance in the aggregate network. Concerning the number of nodes ***(n)*** and edges ***(e)***, GSTP, EOBS and NAVI are the most relevant fields. General support technology programmes have the highest relevance in terms of funds and is the only in those three fields where the percentage of nodes is not lower than the project funds share.

The average degree (***d***) of a network is the average number of links that a node has (total number of links over the number of nodes: ***2e/n***)).[27] There are differences among the most relevant fields. While the general support technology programmes and earth observation areas have a high average degree (1.47 and 1.42, respectively), navigation area has a lower one (1.24). The RBEX cooperation rate is the highest of all.

We use the average weighted degree to consider the intensity of the links between the coordinator and participants. RBEX, GSTP and LNCH hold the highest figures so we may infer the relevant size of projects in those fields.

The network diameter provides information about how far the most distant nodes are and is computed as the longest of all the shortest paths between any pair of nodes in the graph. NAVI, GSTP y EOBS get the highest diameter values because of the high number of participants and projects. NAVI holds the highest diameter (11).

The average path length is the average of the shortest paths between all pairs of nodes. It tells us how wide a network is and complements the information provided by the network diameter. In fact, NAVI has an average path length longer than GSTP and EOBS even though they hold similar diameters. It is surprising how a technology field like Navigation, focused on a single subject, shows less relationship rates among agents than other fields covering many more subjects such as EOBS and GSTP.

The density is defined as the number of actual connections over the number of potential connections e/(n(n-1)/2)=2e/(n(n-1)). Complete networks have a density of 1. The closer to 1, the more connected are technological agents overall and the higher the chances that knowledge can be spread throughout the network and innovations adopted. The density is very low for all fields. However, SCNC, RBEX, HFLT and LNCH get better results than the others do. They also have a lower average path length.

Modularity measures the intensity of fragmentation of a network into groups (clusters, modules). RBEX has the lowest modularity, followed by SCNC. Thus, Robotic

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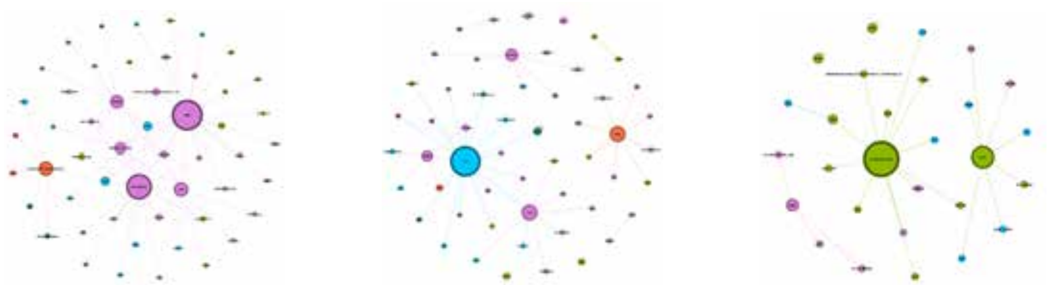
[27] In a random network in which any two nodes connect with probability *p*, the expected value for the average degree would be *p(n-1)*.

Exploration, holding high average degree, low diameter, low average path length and high density added to this low modularity, ratifies the highest cohesion among agents participating in this technical field.

The number of communities classifies nodes into communities using their similarity. SCNC, RBEX and LNCH show the lowest number of communities, while GSTP holds the highest number of communities of all activity areas. This is probably due to the broader diversity of subjects.

The number of triangles informs how many agents work with common co-operators, closing the cooperation among each 3 agents. The whole network has a high number of triangles (569 triangles over 1258 nodes (0,52), while there are disparities among the technology fields. We find RBEX has 29 triangles over 52 nodes, HMFL 2 triangles over 51 nodes and SCNC no triangles at all (see Figure 5.4).

Figure 5.4: H2020-Space – RBEX, HMFL & SCNC – Agents Network by Type.



RBEX HMFL SCNC

Source: Own elaboration using H2020-Space data from CORDIS

The "number of paths" indicator, gives the number of possible (direct and indirect) connections between two agents through project relationships. Although we can connect one agent to another through a path, they may not have had any type of direct cooperation. Technology fields GSTP, RBEX and EOBS get the highest number of paths per node while SCNC has the lowest number of paths, both in absolute terms and relative to the number of nodes.

The clustering coefficient of a node is the ratio of existing links connecting a node's neighbours to each other (triangles) to the maximum possible number of such links. It takes values between 0 and 1. The clustering of the network is the average of the clustering coefficients of all the nodes. High clustering is expected in “small-world” networks. This is one of the most relevant network features for innovation diffusion; high clustering and short path lengths characterize small-world networks. Human social networks are usually small-worlds (Milgram, 1967, and Travers & Milgram, 1969), as well as the collaboration networks of scientific authors (Newman, 2001).

A high level of clustering means that knowledge transmits easily to the close neighbourhood, but short path lengths mean that information can be spread through the entire network very rapidly. We will check this network feature later, when we compare our network to a randomly generated network, considering the degree distribution, clustering and distances between nodes.

The number of weakly connected components is useful to evaluate how fragile a network is; more precisely, what would be the effect of an agent removal. A component is a group of connected pairs of nodes that are disconnected from the rest of the network. The robustness of a network is a consequence of this type of connectivity. In our network, we find a very low rate of weakly connected components over the number of agents. In order to evaluate the different fields, we calculate this rate for each area.

Table 5.26: H2020-Space – Agents' Network connectivity per Technology Field

AGENTS' Network	ALL	EOBS	GSTP	HMFL	LNCH	NAVI	RBEX	SCNC
Number of Agents (nodes)	1258	447	543	54	65	353	52	28
N. of Weakly Conn. Comp.	44	9	33	10	3	11	1	5
Rate (N. w. conn. Comp / nodes)	0,035	0,020	0,061	0,185	0,046	0,031	0,019	0,179

Source: Own elaboration using H202- Space data from CORDIS

HMFL and SCNC fields have high rates compared to the rest. We can confirm such network fragility if we look at the network graphic for HMFL and SCNC compared to RBEX where we are able to see the effect of an agent removal. See Figure 4.

Next, we focus on some network parameters under the point of view of the nodes of the network. The average clustering coefficient, defined as the average of the frequency of triangles in the network, provides information about the knowledge flow rate. In Table

5.27, SCNC technology field shows no clustering while RBEX has a very high coefficient, doubling the other areas, all of them almost at the average.

We use triangles, which is the number of closed triplets of nodes in their own network, to calculate the clustering coefficient. We may compute the total number of triangles over the number of agents in order to compare the connectivity of the technology fields. We see how HMFL, LNCH and SCNC show the lowest clustering.

Table 5.27: H2020-Space – Agents' Network Triangles per Activity Area

AGENTS' Network	ALL	EOBS	GSTP	HMFL	LNCH	NAVI	RBEX	SCNC
Number of Agents (nodes)	1258	447	543	54	65	353	52	28
Number of triangles	659	111	169	2	4	48	29	0
# Triangles / nodes	0.524	0.248	0.311	0.037	0.062	0.136	0.558	0.000

Source: Own elaboration using H2020-Space data from CORDIS

Table 5.27 show that many agents participate in several fields as the sum of the nodes of each subnetwork (1542) is larger than the existing nodes in the whole network. We also see, however, that triangles formed in the whole network are much higher than the sum of triangles formed in the subnetworks (287) showing connections between agents in different fields. University departments, company subsidiaries or different laboratories in a technological centre may explain such occurrence.

Lastly, we analyse the eigenvector centrality, a coefficient that provides information about the importance of the connections of the nodes in a network. A node with high centrality indicates a high proportion of connections to the most influential nodes of the network. Although we should expect a positive correlation of eigenvector centrality with other coefficients related to connection properties, we see a singularity in RBEX field caused by the small size and short path length added to a low modularity.

Table 5.28: H2020-Space – Agents' Network Eigenvector centrality by Technology Field (RBEX singularity)

AGENTS' Network	ALL	EOBS	GSTP	HMFL	LNCH	NAVI	RBEX	SCNC
Eigenvector centrality	0,025	0,016	0,015	0,004	0,004	0,032	0,001	0,003
Average Degree	1,671	1,418	1,468	0,944	1,062	1,238	1,712	0,893
Av. Weighted Pr. Part. Deg (M€)	1,233	0,863	1,221	0,875	1,109	0,798	1,499	0,849
Triangles / nodes	0,346	0,221	0,227	0,037	0,062	0,113	0,365	0,000
Average Degree	1,671	1,418	1,468	0,944	1,062	1,238	1,712	0,893
Av. Weighted Pr. Part. Deg (M€)	1,233	0,863	1,221	0,875	1,109	0,798	1,499	0,849
Average Path length	4,429	4,46	4,18	2,30	3,31	4,97	2,79	1,90
Density	0,003	0,006	0,005	0,036	0,033	0,007	0,066	0,066
Modularity	0,668	0,683	0,679	0,703	0,690	0,799	0,468	0,593

Source: Own elaboration using H2020-Space data from CORDIS

Efficiency of the H2020-Space Network

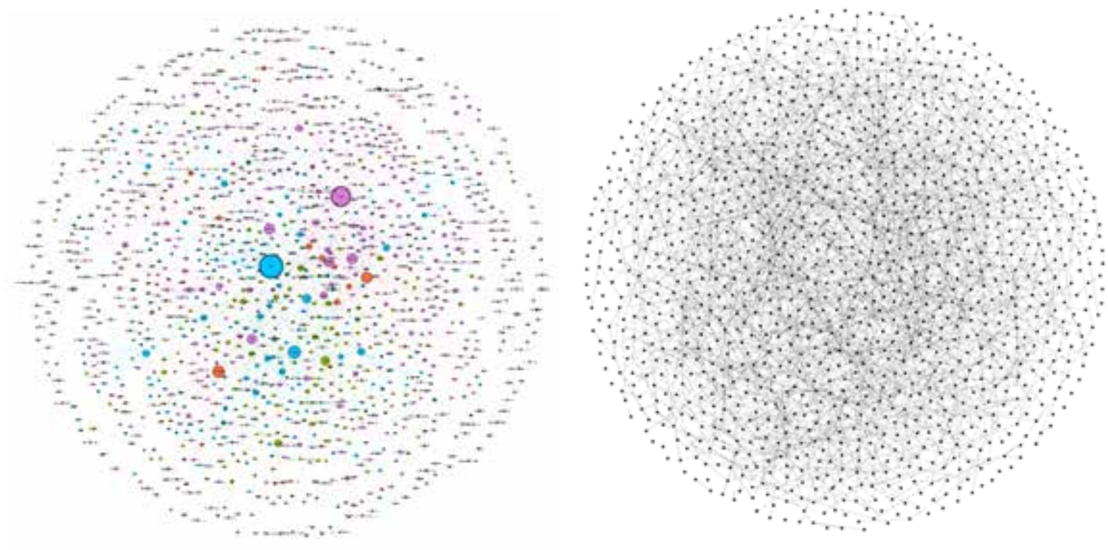
After the analysis of the network global metrics, we are in a position to evaluate the efficiency of the network. We are interested in how adequate the network is for the knowledge and technology diffusion. Protogeru et al. (2013) consider that a network showing "small-world" characteristics is "relatively efficient mechanism for both the creation and diffusion of new technological knowledge and innovation".

Small-world usually refers to the need of only six steps to reach any node of a network. However, other conditions can make knowledge diffusion effective. Watts (1999) defines some characteristics for a world where every node almost connects to every other.

Protogeru et al. (2013) and Breschi and Cusmano (2004) hold that two basic concepts are frequently related to the global topology of large networks are scale-free and small-world characteristics. A scale-free network architecture means we have a small number of nodes with high degree and the majority have low degrees. That is, the degree distribution follows a power distribution. Networks with a 'small world' property show high clustering and short distances between nodes. Following Watts (1999), they identify the presence of the "small world" behaviour using the combination of the clustering coefficient and the characteristic path length. In order to agree if a network behaves as a "small world", they compare the values of those two metrics with the values of the metrics belonging to a random network generated with the same number of nodes and similar average degree.

We generate a random network with the same number of nodes (1,258) than the *H2020-Space* network and a wiring probability (0,026) which gives us a similar number of links among nodes. Then, we compare their metrics and see if the R&D agents' network is efficient regarding knowledge and innovation diffusion. Figure 5.5 shows the differences between a random network and the *H2020-Space* network.

Figure 5.5: H2020-Space – Agents Network per Activity Type vs Random Network.

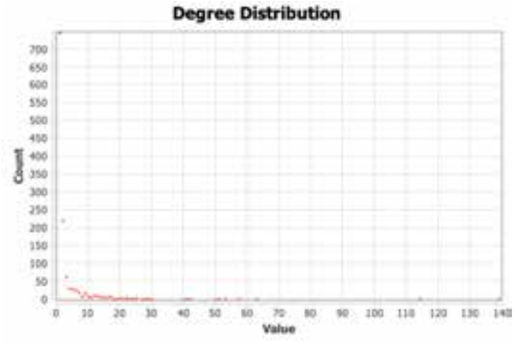


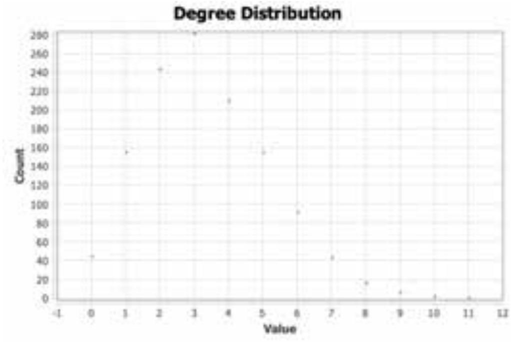
Agents Network *Random Network*

Source: Own elaboration using H2020-Space data from CORDIS

From the degree distribution, there is some evidence that our network follows a power-law distribution, matching also with "Scale Free" architecture properties.

Figure 5.6: H2020-Space vs Random Network – Degree distribution.





H2020 Degree distribution *Random Degree distribution*

Source: Own elaboration using H2020-Space data from CORDIS

Table 5.29 contains the global network metrics of our network and those belonging to the randomly generated network.

Table 5.29: H2020-Space vs Random Network – Global Network Metrics.

Global Network Metrics	AGENTS' Network (ALL AREAS)	RANDOM Network
nodes	1,258	1,258
edges	2,102	2,107
% nodes	100%	100%
Network overview		
Average Degree	1.671	1.675
Average Weighted Degree	N/A	N/A
Diameter	12	14
Average Path length	4.429	5.958
Density	0.003	0.003
Modularity	0.668	0.578
Number of Communities	63	69
Number of triangles	659	6
Number of paths (Length 2)	38,889	7,138
Value of Clustering Coefficient	0.051	0.003
Number of Weakly Connected Components	44	49
Node Overview		
Average Clustering Coefficient	0.175	0.002
Eigenvector centrality	0.0253	0.2063
triangles / nodes	0.346	0.005

Source: Own elaboration using H2020-Space data from CORDIS

Our network has higher clustering with a higher number of triangles. Even though we have a similar average path length, our network gets a much higher number of paths (length 2) compared to the randomly generated network so there is a better connection between nodes than the equivalent random network. Thus, we may expect that the H2020 Space Programme to favour a collaboration network where knowledge diffusion is encouraged.

We calculate in Table 5.30 the ratios of those metrics: Average Path Length (L), Culstering Coefficient (C) and number of paths of Length 2 (P(L=2)) over the Random network ones (Lr); (Cr) and (Pr(L=2)).

Table 5.30: "Small World" metrics ratios.

Small World ratios	Agents' Network (ALL AREAS)
L/Lr	0,74
C/Cr	20,16
P(L=2)/Pr(L=2)	5,45

Source: Own elaboration using H2020-Space data from CORDIS

However, if we perform the same exercise with the activity fields (see Annex – Chapter 5 for a complete presentation of the Degree Distribution graphics), we find differences in network behaviour. Table 5.31 presents the main network parameters compared related with the "small world" performance.

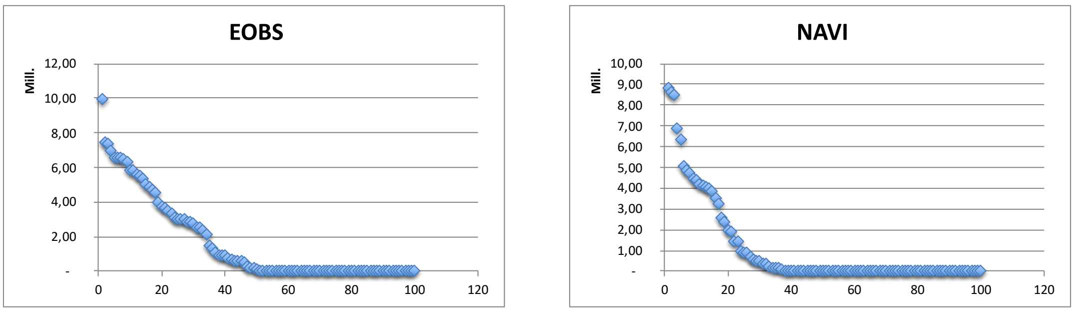
Table 5.31: H2020-Space vs Random Network metrics.

Agents' Network	EOBS	Rnd	GSTP	Rnd	HMFL	Rnd	LNCH	Rnd	NAVI	Rnd	RBEX	Rnd	SCNC	Rnd
nodes	447	447	543	543	54	54	65	65	353	353	52	52	28	28
edges	634	617	797	742	51	53	69	64	437	433	89	87	25	26
% nodes	36%		43%		4%		5%		28%		4%		2%	
Network overview														
Av. Degree	1.418	1.380	1.468	1.366	0.944	0.981	1.062	0.985	1.238	1.227	1.712	1.673	0.893	0.929
Diameter	9	15	9	15	4	10	6	19	11	14	5	6	3	8
Av.Path Lgth	4.46	5.93	4.18	6.09	2.30	4.23	3.31	7.37	4.97	5.98	2.79	3.11	1.90	3.91
Density	0.006	0.006	0.005	0.005	0.036	0.037	0.033	0.031	0.007	0.007	0.066	0.066	0.066	0.069
Modularity	0.683	0.642	0.679	0.638	0.703	0.678	0.690	0.700	0.799	0.672	0.468	0.443	0.593	0.586
N. Comm.	25	47	50	59	12	12	7	14	24	50	6	8	6	8
N. triangles	111	5	169	3	2	1	4	2	48	2	29	7	0	1
N Paths (L2)	7,443	1,684	11,063	2,049	236	86	375	114	2,890	554	981	305	91	41
Clustering Cf.	0.045	0.009	0.046	0.044	0.025	0.035	0.032	0.053	0.050	0.006	0.089	0.069	0.000	0.073
N Weak C.C.	9	32	33	42	10	8	3	7	11	38	1	4	5	
Node Overview														
Av Clust. Cf	0.177	0.009	0.166	0.003	0.277	0.064	0.238	0.057	0.177	0.003	0.497	0.056	0.000	0.094
Eigen. Centr	0.016	0.079	0.015	0.102	0.004	0.008	0.004	0.012	0.032	0.057	0.001	0.006	0.003	0.005
trgles / nodes	0.221	0.011	0.227	0.006	0.037	0.019	0.062	0.031	0.113	0.006	0.365	0.135	0.000	0.036

Source: Own elaboration using H2020-Space data from CORDIS

If we look to each area, we see how the number of paths of length 2 and the Average Clustering Coefficient are higher than in the random network in all areas but SCNC. So, we may reject the "small world" hypothesis for SCNC even though the degree shows a power distribution (Figure 5.7b). Furthermore, EOBS and NAVI get the highest differences in clustering to the random equivalent networks but their degree distributions are not the most power distribution shaped of all areas.

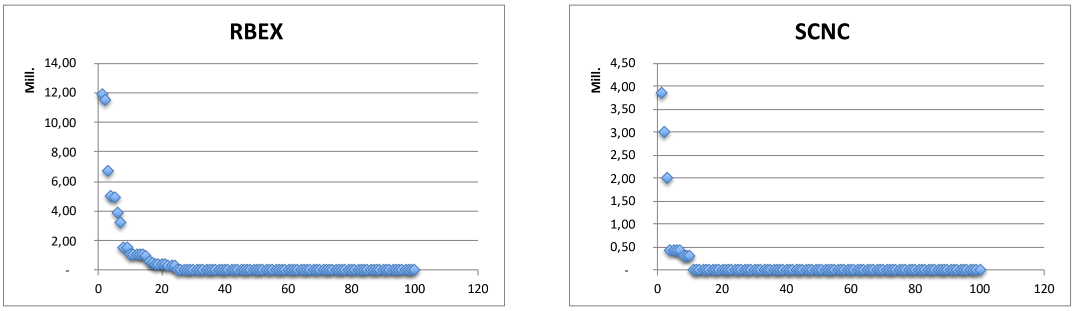
Figure 5.7a: H2020-Space EOBS & NAVI Degree Distribution.



Source: Own elaboration using H2020-Space data from CORDIS

It is worth highlighting RBEX network, with an Average Clustering Coefficient much higher than the other areas and a very clear degree power distribution (Figure 7b).

Figure 5.7b: H2020-Space RBEX & SCNC Degree Distribution.



Source: Own elaboration using H2020-Space data from CORDIS

In Table 5.32 we collect the small-world ratios for all fields, finding EOBS, NAVI and RBEX as the fields with better "small-world" characteristics and so, with most expected knowledge diffusion performance among the *H2020-Space* R&D cooperation network.

Table 5.32: "Small World" metrics ratios

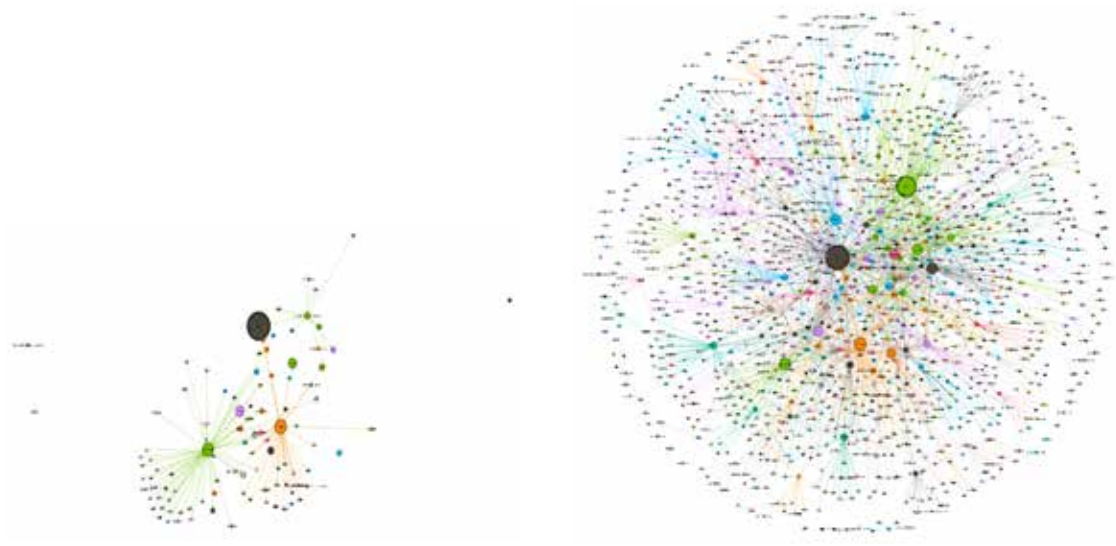
Small World	ALL	EOBS	GSTP	HMFL	LNCH	NAVI	RBEX	SCNC
L/Lr	0,74	0,75	0,69	0,54	0,45	0,83	0,90	0,49
C/Cr	20,16	5,03	1,04	0,73	0,61	9,01	1,29	0,00
P(L=2)/Pr(L=2)	5,45	4,42	5,40	2,74	3,29	5,22	3,22	2,22

Source: Own elaboration using H2020-Space data from CORDIS

Agents' Network Dynamics

In order to evaluate the evolution of the *H2020-Space* network, we build accumulative networks from 2014 to January 2020. First, we analyse the resulting accumulative network graphics for each year. We use the same Frutcherman Reingold graphic generated with Gephi than in the previous section, with the same country colour code and the degree as the agents' size. In this way, we can clearly see how the most prominent network leaders extend their influence with other coming agents and promote their relationships with other network leaders. This growing standard seems to hold along the programme and does not show preferences by country of origin, agent size or type. This absence of homophily contributes to a better knowledge and technology diffusion.

Figure 5.8: H2020-Space – Agents Network. 2014-2020

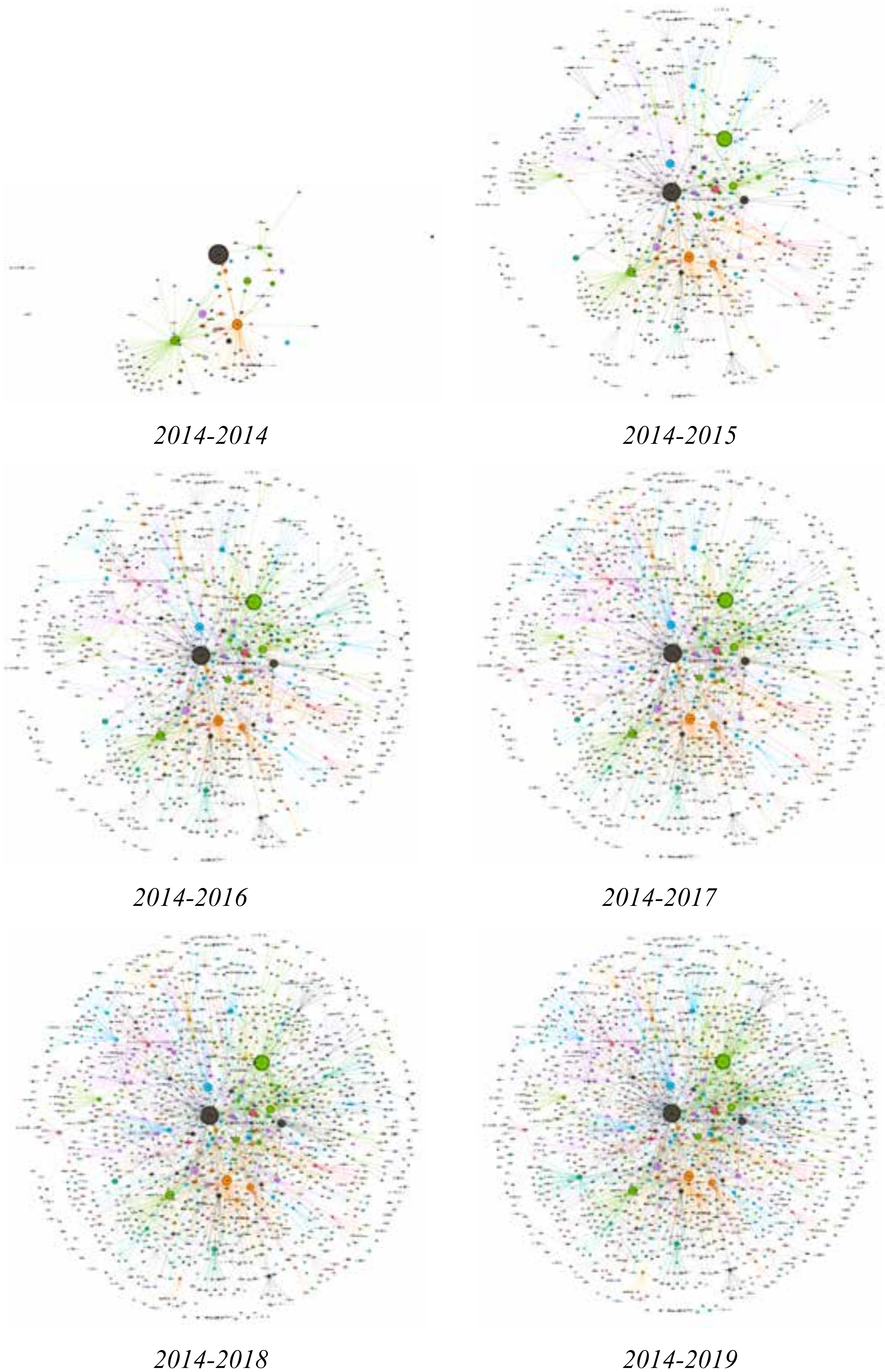


2014-2014 2014-2020

Source: Own elaboration using H2020-Space data from CORDIS

In Figure 5.8, we show the evolution from 2014 to 2020 of the *H2020-Space* R&D network. In Figure 5.9 we see the changes year by year.

Figure 5.9: H2020-Space – Agents Network Evolution. 2014-2019



Source: Own elaboration using H2020-Space data from CORDIS

When we compute the network parameters, we find a clear evolution in time towards network growth in size and relationships among R&D agents.

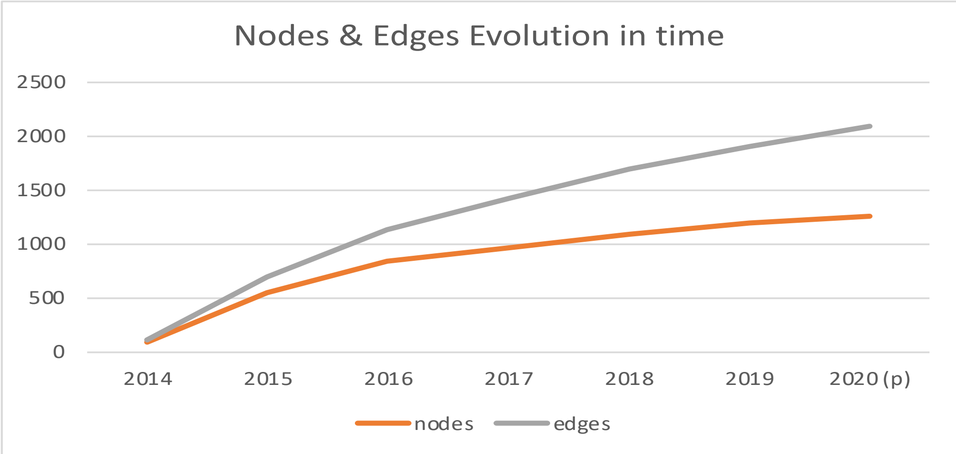
Table 5.33: H2020-Space – Agents' Network Global Metrics Dynamics

AGENTS' Network	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020(p)**
Network Size							
nodes	101	560	842	974	1,102	1,195	1,258
edges	110	699	1,141	1,428	1,701	1,905	2,102
% nodes	8%	45%	67%	77%	88%	95%	100%
Network overview							
Average Degree	1.089	1.248	1.355	1.466	1.544	1.594	1.671
Diameter	5	10	10	10	9	12	12
Average Path length:	2.727	4.472	4.600	4.580	4.472	4.479	4.429
Density:	0.022	0.004	0,003	0.003	0.003	0.003	0.003
Modularity:	0.535	0.754	0,726	0.710	0.694	0.692	0.668
Number of Communities:	8	63	71	66	63	66	63
Number of triangles:	5	98	204	299	406	505	659
Number of paths (Length 2):	2,254	8,335	14,400	19,874	24,707	33,180	38,889
Value of Clustering Coefficient:	0.007	0.035	0,043	0.045	0.049	0.046	0.051
Number of Weakly Connected Components:	6	49	51	47	44	46	44
Node Overview							
Average Clustering Coefficient:	0.557	0.244	0.149	0.152	0.164	0.171	0.175
Eigenvector centrality	0.003	0.018	0.024	0.025	0.025	0.027	0.025

Source: Own elaboration using H2020-Space data from CORDIS

The number of involved participants grows rapidly, reaching 88% of the current participants in 2018. The number of links growth is higher than the number of nodes; in fact, the network density stabilization from 2016, tells us about the evolution of relationships, as it is defined as the number of connections found over the total number of potential connections. The number of paths of length 2 between agents over the number of nodes increases from 22.3 to 30.9. Besides, the relative number of triangles in the network over the number of nodes grows over time from 0.05 in 2014 to 0.51 in 2020, common co-operators rate raises considerably. This rate, added to the increasing average degree, shows how this programme boosts relationships between agents through R&D projects.

Figure 5.10: H2020-Space – Agents Network Nodes & Edges Evolution over time.



Source: Own elaboration using H2020-Space data from CORDIS

Regarding the network diameter and the average path length, although they increase from 5 to 10 and from 2.7 to 4.5, respectively, in only one year, they become stable afterwards even though the number of involved agents raises rapidly. This effect may appear if relations among previous participants increase or if the newcomers contact the network through a very well-connected agent. Considering the evolution in the number of triangles, it seems to be a combination of both effects.

Modularity and the number of communities are also stable since 2015. Thus, accounting for the activity areas' characteristics, we conclude agents found their own organization regarding partnerships or specialties from the very beginning of this programme.

The clustering coefficient increases under those network growth rates and a high growth rate of paths between agents may imply a rising knowledge transmission. Moreover, the relatively low number of weakly connected components will ease such knowledge transmission in this solid network structure. The average clustering coefficient decreases the first year and becomes stable afterwards, even though the number of involved agents increases. This fact together with the triangles growth over time help to confirm the network knowledge diffusion described above.

Regarding eigenvector centrality figures, they are stable since 2016. As a measure of the importance of the connections of the nodes in a network, these figures seem to support the idea of a structured network based on a few leaders and increasing relationships among R&D agents.

Conclusions

We have studied the *H2020-Space* project data under the point of view of the participating agents' types and the area of activity. We use CORDIS classification and ESA areas of activity breakdown. We find PRC (Private Research Companies) leading the R&D project participation and coordination roles. Even though their participation rates add up to 55% of the projects, PRC lead 60% of them in the role of coordinator. We see a higher percentage of coordinators in PRC (22%) compared to REC (18%) and HES (17%). Public entities (PUB) show a low coordination percentage (2%) even though their participation amounts to 6%.

We conclude that participation and coordination rankings are very similar, and we find very different agent types in the top positions. In fact, this provides evidence that the agent type structure is very different among countries. The detail in the European Big-5 countries tells us how different the R&D agent type structure can be. French leaders are typically PRC while German ones are REC.

These differences also appear in the activity by area but, if we measure the alignment with the aggregate activity of the Big-5 countries together, we see a great deal of alignment for these countries. Besides, we find differences among countries' involvement in *H2020-Space* projects depending on their implication in ESA activities: Project coordinators belong to ESA member states, which show the highest alignment with the aggregate participation in R&D projects, followed by states with EU membership.

In addition, we see how PRC and OTH show a great deal of alignment with the aggregate share by activity area, while REC does not get a close result in areas such as NAVI and EOBS, those activity areas more connected with the market.

Another important issue for network formation is to make inferences about coordinators' preferences. We see how PRC chooses mainly PRC partnership and HES also chooses other HES as their preferred partners. All others look for PRC to work with, as absolute and relative cooperation figures show.

The Network Graphic analysis shows that the influence of specialization of small agents and the integration function of the bigger ones seem to be the main drivers of the shape of *H2020-Space* cooperating network.

When we analyse the network metrics and compare the activity areas, we confirm GSTP, EOBS and NAVI as the most participated ones but with different characteristics. GSTP, an activity with a high technical diversity, holds the highest number of communities of all activity areas. NAVI, with a low average degree and the largest diameter, has the largest distance between two nodes and shows less relationship rates among agents than other areas covering much more subjects such as EOBS and GSTP. RBEX shows the highest cohesion among agents participating in this technical field, as this network has a high average degree, a low diameter, a low average path length, a high density and a low modularity. SCNC, however, although it has a low modularity, has no clusters at all, showing a star shaped network for each of the communities. That means no direct communication among most of the participating partners.

The whole network, with degree power distribution, high number of paths of length 2 and a high average clustering coefficient compared to an equivalent randomly generated network, confirms the efficiency of the knowledge diffusion among partners. However, we find differences among activity areas: on the one hand, RBEX, with an average clustering coefficient difference with an equivalent random network much higher than the other areas and, on the other, SCNC network, with no clustering, which excludes the "small-world" hypothesis, although it shows a degree power distribution.

In addition, the dynamics of the network put some additional light over the question of the EU objectives achievement concerning R&D cooperation among companies, universities and research centres. The R&D network grows dragged by several leaders who extend their activity to programme newcomers through project cooperation. They do not show regional, culture or organizational type preferences and do not fall into a homophilic behaviour, supporting the interaction among leaders' partners as triangles formed among them (clustering).

Our main purpose was to analyse the H2020 network from a global perspective to check whether its features encourage knowledge transmission. An interesting question, that we leave for further research is the study of agents' network local parameters to determine the importance and network roles of each type of agent. Likewise, the study of the participation and coordination role of countries, considered as the addition of all agents' participations, may provide useful information of the most successful national R&D policies in space and the best R&D structure to achieve outstanding outcomes in terms of participation and significance in the network. Finally, apart from the number of agents belonging to a given country, such study may show the influence, relative effort and leadership of that country in H2020 Space Programme.

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Chapter 6

Conclusions

Chapter 6. Conclusions

Space exploration and exploitation produces a notable impact into our society and has potential to further influence in the near future. The economic approach to analyse this technological and innovative industrial sector shows how public and private organizations interact to solve the difficulties that outer space activity implies and to take benefit from them. Since the early cooperation in space, after the cold war context, huge technological achievements have arisen. Their benefits to the society are not only the use of those developments produced under the space industry umbrella but also the surging economic activity in the downstream perimeter of space and in related areas such as tourism (Spector and Higham, 2019).

Risk and uncertainty of the new technological developments are covered with different funding sources, usually linked to the technology readiness level where fundamental research and more complex developments funding needs public intervention to eliminate the market failures associated to knowledge spill-overs and intergenerational externalities. Complexity and time-consuming developments make long term international cooperation essential. As argued in the configuration of the Space Sector and in the empirical chapters, public goods and club goods are typically generated by technology and innovation that is collaboratively produced in alliances and cooperative instances. Public intervention is also needed to solve the conflicts of interests that emerge when property rights are ill-defined and when there is the possibility of rivalry and no exclusion in the access to resources in the outer space (Béal et al., 2020; Grzelka and Wagner, 2019). In this respect, the tragedy of the commons in space and the negative externalities that arise such as the space debris, the limited available orbits and their associated electromagnetic bandwidth are still challenges to be solved with the help of the Space Economics. The contribution made by Economics is qualified as 'relatively thin' in Grzelka and Wagner (2019, p. 320). Pomeroy (2018) defines the corpus of literature as being driven by a 'eclectic, multidisciplinary research agenda'. The presentation of the main features of the economic properties of space resources and services done in this thesis is expected to provide new insights to progress in this respect.

However, multidisciplinary approaches are crucial to gain insights about the complex space exploration and exploitation (Weinzierl, 2018).

Once the public sector initiated the Space activity, the promotion of technology based private organizations participation has been a habit in the Space missions where, the cooperation in the necessary research, development and innovation to answer to the institutions' demands is been notable. Public agencies, big private enterprises, SMEs, technological centres, and higher education institutions are the high technology profile players of a dense cooperating R&D network for space, with high levels of trust among agents, lower levels of competition and high competences. Besides, the European citizenship has a broad positive opinion of space due to its influence in technological developments and the benefits of their daily basis usage. We may expect, thus, an impact on the national investment in space related activity. However, states policies are not so clear, and we find they are up to so many parameters such as the existing industrial capacity and the subsector specialties, the science literacy of the population, the industrial development preferences or even national security, non-dependence attitudes and cooperation and supranational participation strategies.

Europe in space, with the aim to enhance innovation, promote sustainability, digitalization, impulse economic growth and foster Europeans' quality of life is currently structured as a private-public-partnership where the *European Space Agency* (ESA), the *European Union* (EU), the *Space Council*, several national agencies and public research establishments and higher education institutions cooperate with private companies, research centres and universities in the development of technologies, the space missions accomplishment, contribute to the national defence, working for prosperity and looking after the European autonomy in space.

The European space sector is described by *Eurospace*, the main representative of the European space industry, as very concentrated and, at the same time, highly fragmented. ESA gathers grate part of the member states effort under a fair geographical return that ensures the benefits from ESA contracts. EU funds R&D activities under the framework programs space related project calls and National Agencies cooperate with other agencies to complete their space national programs. However, Europe needs to grow, to be globally competitive in space, to reinforce its autonomy in upstream, downstream and applications sectors, its technological independence and security. This European space sector enhancement track shall be developed counting up with all agents. On the one side, the public institutions support to space in terms of low technology readiness level products development funding, where universities and start-ups will play a key role, and the public purchase dedicated to innovative products where major private companies and SMEs will be able to put in place their latest technologies and to take a new step forward in their global position in the space market. On the other, we will find those initiatives surging from the market demand, switching those technological developments to daily use products that have been adopted by the final users and so, they will be set upon new requirements such as serial manufacturing techniques, cost improvements and supply chain development, aspects that contribute to the growth and competitiveness of the space industry.

In order to study the influence and the willingness of countries to cooperate through an intergovernmental institution, we have modelled the decision to contribute to ESA and how much to contribute as a function of the costs and benefits of the decision. According to our model, the variables that positively affect contributions are the level of technological development of a country, the space industry capacity, the potential free-riding behaviour associated to spillovers and the misalignment between the technological preferences of the country and those of ESA. In doing this research, we faced the problems derived from the lack of definition in the sector and the difficulties of finding suitable data. Doing empirical research on space economics is a challenging task. The main problems are the scarcity of harmonized data, the existence of lags between the initial investments and realised outcomes, and, as the OECD points out, the evolving nature of the space economy itself and its increased connections with other economic sectors (OECD, 2012).

Our findings, using an empirical approach with a data panel built with data coming from ESA annual reports, the World Bank and CORDIS framework programs database, tell us that institutional factors such as being a member of the EU or having a national space agency are associated with a higher probability of being a member of the agency and a higher probability of contributing to ESA. Also, the general expenditure in R&D and the rate of researchers over the population of a country influences the decision to contribute, the level of the total contribution and specially the optional part of the contribution to ESA. We find also that the sectorial alignment with ESA preferences is an important factor for contributions. Our hypothesis about that the space industry capacity would allow a country to benefit from the geo-return rule, tell us that this variable is weakly significant for the probability of contributing and non-significant for the level of contributions. We were not able either to capture the potential free-riding effect of spillovers and therefore, we could not confirm nor reject the lower contribution hypothesis.

The role of the UE in the cooperation encouraging have been characterized in this thesis using the H2020 Space R&D program project data. First, we have built a network based on the countries with agents that have joined this program in the period 2014-2019 and we have compared it to previous or more general programs obtaining that the space program shows remarkable international cooperation outside Europe and much larger than in the broader framework programmes. *H2020-Space* network metrics show it is a more open network, the participation of small countries is higher and the connection path between countries is shorter than in previous FPs and the full Horizon 2020 programme. Our network evaluation using network analysis methods concludes that France leads space research in Europe regarding network launching, coordination and weighted participation in projects, while Germany is leading the broader framework program. The consideration of the weight of the links of the network based on the funding needs of projects and the role played in them (coordinator or participant) allow us to enrich the analysis. In this network, individual countries' own interests do not seem to be the only drivers of the Space R&D activity, even for the Big-5. We find asymmetries in the Space research effort of some countries, compared to Horizon 2020 full program, pointing to a specialization in Space research. This effort has a direct relationship with the condition of ESA membership.

Also, following social networks applied to countries cooperation literature, we have normalized network metrics over population, so we have seen how small countries such as Cyprus, Norway or Finland are making a considerably higher effort than other countries in space research and also shows how the countries' relative efforts change the ranking in favour of Spain and Italy over France and Germany. The network architecture, as the metrics from the network theory say, shows that it has small-world properties, facilitating the creation and the transmission of technological knowledge between countries, contributing to a larger research base.

Lastly, regarding this countries' network, we have defined a country's success index based on its ability to lead *H2020-Space* projects, normalized by its population. This index is neither correlated with the country R&D agents type composition nor with the technology areas of their interest. Previous effort in R&D, however, is correlated with the success rate and "success breads success" hypothesis is also proved with the program participation growth rates.

Following the *H2020-Space* network study where a deeper analysis taking into account the agents which conform a country by aggregation of their participation in projects, we also have studied the *H2020-Space* project data under the point of view of the participating Agents. First, we group them by type of agent under the Cordis classification: Private Research Companies (PRC), Secondary Education Institutions (HES), Research Organizations (REC), Public Bodies excluding REC and Others (OTH). From our study we conclude that PRC lead the R&D project participation and coordination roles and chooses mainly PRC partnership as all other types of agents do but Higher and Secondary Education Institutions (HES), that also chooses other HES as their preferred partners. We also find that agent type structure participation is very different among countries.

Besides, we find differences among agents by their countries' involvement in H2020 Space projects depending on their implication in ESA activities: Project coordinators belong to ESA member states which show the highest alignment with the aggregate participation in R&D projects, followed by states with EU membership.

The H2020 Space Agents' Network Graphic analysis shows that the influence of specialization of small agents and the integration function of the bigger ones seem to be the main drivers of the shape of *H2020-Space* cooperating network.

The whole network, with degree power distribution, high number of paths of length 2 and a high average clustering coefficient compared to an equivalent randomly generated network, confirms the efficiency of the knowledge diffusion among partners. As we did previously with the countries' network, we have made a breakdown of the network by technology field. This exercise, as well as in the case of type of agent distribution, shows a large variety of interest in technology field distributions. Also, we find differences among activity areas such as Robotic Exploration, with an average clustering coefficient difference with an equivalent random network much higher than the other areas and the Science network, with no clustering, which excludes the "small-world" hypothesis.

Same as in the case of countries, the R&D network dynamics show its growth dragged by several leaders who extend their activity to program newcomers through project cooperation. They do not show regional, culture or organizational type preferences and do not fall into a homophilic behaviour, supporting the interaction among leaders' partners as triangles formed among them (clustering).

There are many questions open that would deserve further consideration. We start with the presentation of possible extensions to the research presented in the empirical part of this thesis and continue with some general questions.

The ESA contribution analysis may be enhanced by a more detailed and extended over time country data collection. Moreover, an analysis based on companies and their aggregation can put more light on the specific space industrial capacity of a country and of the whole Europe. Also, on the bidirectional effect of contributions to the global public good and the country's space industry development. With such a disaggregation of data we may analyse the resulting network and the cooperation behind it, as we have made with the H2020 Space program and include the influences of externalities in both, ESA activities and *H2020-Space* projects.

Once we have evidence that the space R&D activity networks promote the knowledge and technology diffusion, it may be worthy of further research to check its transfer to the market. Satellites in orbit disaggregated by technology, outer space missions participation or downstream software applications created upon space data, can help us to evaluate the effect of technology diffusion into the industrial development, technology field interest and economical return for the involved countries.

Moreover, this effect of technology transfer to the market could be matched to both, the contributions to ESA and the effort in space R&D under the EU framework programs, the evolution over time and the computation of the time-to-market of each of the specialties or technology fields considered. The combination of development periods and economical return shall be a useful tool for countries' investments in space industry decisions and big companies' strategic plans. The results may be also valuable in order to improve people's attitude to high technology investments and, particularly, in the space sector.

The continuous existence of technological risk, uncertainties on property rights and other legal issues in outer space such as the space debris, the limited orbits and their associated communications bandwidth are market failures that call for public intervention. An analysis of other national and international public institutions other the ones studied in this thesis, ESA and UE, may give us the chance to design the best policies, cooperation agreements and funding schemes to boost the knowledge-based organisations, the industrial capacity and the private companies' competitiveness of a country or an alliance of them and to contribute to the Space Economy growth.

In the network study worked out in this thesis, we have followed not only those methods used in the social networks' literature but also the improvements that several authors propose in their conclusions and future research suggestions. The edges weight consideration, which shows differences in metrics and rankings among countries and give us a more reliable picture of the role of countries in the network. We have been able to see how France leads the space R&D activity in Europe over Germany and that the UK has not been the expected kind of player in favour of Italy and Spain.

Also, the use of countries' population to normalise network metrics such as degree, weighted degree and eigenvector centrality, gives us a different network ranking based on the effort of a given country over their population and thus, the interest in space technologies and the intensity of their contributions to space R&D and, consequently, to their space industry development. We consider these methods worthy enough to be used in the future research we propose. They may be useful for a country's Space Policy design and budget allocation tasks.

Besides, our technology field breakdown of the *H2020-Space* project activity have also given us the image of each of them and how cooperation differs from those fields more related to science or technological developments to those more focused in a final product such as navigation, with Galileo global positioning system as a clear example of a final product, robotic exploration, with space probes used in outer space missions, communications and earth observation, where broadcast and observation satellites are the objectives of these fields.

All those tools and methods have proved to be truly useful for the cooperation analysis and to find singularities and externalities that may be worth to be studied in the future or to follow their evolution over time and to study the effect on them of any policy variation or a breakthrough technology arrival. As the exploration and exploitation of space resources becomes a feasible and profitable activity in technological and economic terms, there would be more pressing demands to a clear definition and allocation of property rights. New profitable activities are expected to emerge, with space tourism being one of the most attractive for the popular media. We expect that public awareness of the space will thus increase in the future and that citizens will better understand its potential benefits.

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Annexes

Annex for Chapter 3

In this Annex we explain the data collection process taken from ESA annual reports, CORDIS Framework Programmes database and the resulting variables compendium we use for our computing.

We also include additional graphics concerning the evolution of states contributions to ESA and national technology field preferences.

Data Sources

ESA Annual Reports

Our sample spans the period 1997-2016. Over the years, ESA has changed the structure of the annual reports and the information they provide. We have used the data from the financial reports and also from the description of activities in those reports. In the years with incomplete information, we use alternative sources and completed missing magnitudes using the available data.

- For the years 1991, 2003 to 2010, and 2013, the shares of technological fields were not reported, and we compute them as the quotient of the actual cost per field over total expenses. For the year 2008, data are taken from the European Space Policy and Programmes Handbook (2008).

- ESA annual reports do not provide a country activity breakdown by field, and we are only able to get the participation of countries in the Science (SCNC) field (as defined by ESA) as part of the mandatory contribution. Mandatory contribution is used for the Agency's general expenses and Science activity so we may infer the resulting SCNC activity for each country is equal to their mandatory contribution share. 2010 and 2013 missing data are completed by their corresponding linear interpolations.

European Commission's Framework Programmes

For the other technology fields, we use European R&D programmes activity. First, we select all projects connected with a space activity using keywords for each of the technology fields such as "Space", "Spacecraft", "Moon", "Mars", "Satellite", "SAT", "Earth Observation", "Navigation", "NAV", "GNSS", GMES", "Galileo", "ESA", "Launch", "Rocket", "Orbit", "LEO" from Low Earth Orbit, "Geostationary", "GEO" from Geostationary Orbit, "Human Flight", "Manned Flight", "Robotic Exploration" and "Communication". Each project title and description are revised in order to discard projects not associated with the outer space activity and to classify them by the relevant technology fields. Moreover, those calls directly focused on space have been used to select projects and as a tool to classify them properly.

Table A3.1: Number of Space related projects from R&D Programmes.

Framework Programme	FP4	FP5	FP6	FP7	H2020
Number of Space Projects	96	70	199	276	367
Total Projects	14,526	17,204	10,082	25,778	30,562
Percentage	0.7%	0.4%	2.0%	1.1%	1.2%

(*) Projects registered in H2020 up to 16th October 2020.

From each project, we use the ID number, the start date, the ending date, the funding and the assigned technology field. In the organization's database for each framework programme, we have a list of the organizations participating in each project specifying the role and the country of origin. First, we complete such list with the project funding, the start date, the ending date and the technology field. Then, we create a database for each framework programme where, for each participation of an organization in a project we collect information on the number of participants and the number of days of activity for each project and year. Later, we calculate the share of funding corresponding to each organization in a given project as the total funds over the number of participants. When an organization holds the role of coordinator, as this organization is in contact with all the others and has access to all the developments and knowledge, we assign it the complete funding. Those funds are distributed by year following the start date and the days the project lasts.

The resulting aggregation of the assigned funds to each organization of each country and each year, is collected for each technology field. Then, we collect all individual FP data in order to get the complete participation of each country from 1997 to 2016 in space related projects belonging to European R&D Framework Programmes. We then extract the data of those countries (i) involved in ESA activity,[28] and we calculate for each country the share of the technology fields. We use those proportions to define the technology profile of countries.

Variables compendium

I the Table A3.2 below, we name the different variables used in chapter 3 and include a short description, the source and the website link when applicable.

Table A3. 2: Description of variables with link to the original source of information

VARIABLE	LABEL	DESCRIPTION	UNITS	SOURCE	LINK
Countries	Countries	Code / Country / Country number (1-33)	String	Sample selection to cover EU-28 and ESA member/partnership as represented in Figure X1	N/A
EU membership	EU	EU Membership	binary	EU Information about accession year	https://europa.eu/european-union/about-eu/countries_en#tab-0-1
Space agency	SpAg	Space Agency	binary	United Nations – Office for Outer Space Affairs	https://www.unoosa.org/oosa/en/ourwork/space-agencies.html
ESA membership	ESA	ESA Membership	binary	ESA Reports. Information about ESA membership.	https://www.esa.int/About_Us/ESA_Publications/ESA_Publications_Annual_Report
States Contribution - Mandatory	X	Yearly mandatory contribution of ESA member states dedicated to ESA general expenses support and Science programmes.	M€	ESA Reports	

[28] As we may find countries with a significant participation in the FPs but very little or even no activity or contribution to ESA optional programmes, we multiply it also by the yearly country contribution rate $(Y_i)_t / \Sigma(Y_i)_t$.

VARIABLE	LABEL	DESCRIPTION	UNITS	SOURCE	LINK
States Contribution - Optional	Y	Optional contribution of member states and cooperating states dedicated to ESA optional programmes.	M€	ESA Reports	
States Contribution - Total	T	Total contribution of countries to ESA	M€	ESA Reports	
States Contribution - Dummy	Cd	Dummy variable of contribution to ESA. Value 1 if any contribution is made in a given year.	binary	ESA Reports	
Broad Technological and Industrial capacity	A	Gross Domestic Expenditure on R&D - million current PPP $	M$ PPP	WB	https://data.worldbank.org/indicator/GB.XPD.RSDV.GD.ZS?view=chart
Broad Technological and Industrial capacity - Dummy	Ad	Dummy variable of a minimum expense in R&D. Set to the higher of 20% of the average of the participating countries.	binary	WB	https://data.worldbank.org/indicator/NY.GDP.MKTP.CD
Space Industry Capacity	G	Civil Gross domestic expense in R&D for Space programmes	M$ PPP	OECD & ESA Reports	https://stats.oecd.org/viewhtml.aspx?datasetcode=MSTI_PUB&lang=en
Space Industry Capacity Normalized by Population	Gn	Ratio G/P	€/Pop	WB	https://www.esa.int/About_Us/ESA_Publications/ESA_Publications_Annual_Report https://data.worldbank.org/indicator/NY.GDP.MKTP.CD
Participation in Science technology field ESA projects	f1_SCNC	Country participation in Science technology field ESA programmes	M€	ESA Reports	https://www.esa.int/About_Us/ESA_Publications/ESA_Publications_Annual_Report
Participation in Communications technology field ESA projects	f2_COMM	Country participation in Communications technology field ESA programmes	M€	CORDIS & ESA Reports	https://data.europa.eu/euodp/data/dataset/cordisH2020projects
Participation in Earth Observation technology field ESA projects	f3_EOBS	Country participation in Earth Observation technology field ESA programmes	M€	CORDIS & ESA Reports	https://data.europa.eu/euodp/es/data/dataset/cordisfp7projects

VARIABLE	LABEL	DESCRIPTION	UNITS	SOURCE	LINK
Participation in General Support Technology Programmes technology field ESA projects	f4_GSTP	Country participation in General Support Tecnology Programmes technology field ESA programmes	M€	CORDIS & ESA Reports	https://data.europa.eu/euodp/es/data/dataset/cordisfp6projects https://data.europa.eu/euodp/es/data/dataset/cordisfp5projects
Participation in Human FLight technology field ESA projects	f5_HMFL	Country participation in Human Flight technology field ESA programmes	M€	CORDIS & ESA Reports	https://data.europa.eu/euodp/es/data/dataset/cordisfp4projects
Participation in Launchers technology field ESA projects	f6_LNCH	Country participation in Launchers technology field ESA programmes	M€	CORDIS & ESA Reports	https://data.europa.eu/euodp/es/data/dataset/cordis-fp3
Participation in Navigation technology field ESA projects	f7_NAVI	Country participation in Navigation technology field ESA programmes	M€	CORDIS & ESA Reports	https://data.europa.eu/euodp/es/data/dataset/cordis-2
Participation in Robotic Exploration technology field ESA projects	f8_RBEX	Country participation in Robotic Exploration technology field ESA programmes	M€	CORDIS & ESA Reports	https://data.europa.eu/euodp/es/data/dataset/fp1-cordis
Misalignment with ESA technology fields activity share	W	Aggregation of squared differences of technology field activity share to ESA global figures.	Dimensionless	CORDIS & ESA Reports	
Alignment with ESA technology fields activity share	IW	Inverse of Misalignment with ESA technology fields activity share	Dimensionless	CORDIS & ESA Reports	
Population	P	Population	Mpop	WB	https://data.worldbank.org/indicator/SP.POP.TOTL?view=chart
Spillovers	S	Number of Researchers over Population (MPax)	Researchers / Mpop	WB	https://data.worldbank.org/indicator/SP.POP.SCIE.RD.P6?view=chart
Gross Domestic Product	GDP	Gross Domestic Product	M$ PPP	WB	https://data.worldbank.org/indicator/NY.GDP.MKTP.CD

Additional graphics for Chapter 3

Graph A3.1: Evolution of mandatory and voluntary contributions (M €) for a selection of countries not members / associated by 2000 (1997-2016)

Source: ESA. Own construction from ESA dataset.

Graph A3.2: National revealed preferences in the technology fields for selected countries (1997-2016)

Source: ESA. Own construction from ESA dataset.

Annex for Chapter 4

(a) H2020 vs *H2020-Space* projects

There are some projects in the H2020 programme with a very high number of participants, but 99% of projects in space and in the full programme have less than 27 participants from up to 17 different countries. If we eliminate the projects with more than 27 participants and compute the same metrics (see Table A4.1), we find that space gets almost the same figures whilst the full programme shows less cooperation average and the Countries over Agents participation averages ratio is much higher.

Table A4.1: full H2020 vs H2020-Space Projects. 2014-2020(p). Only 99% of projects with less participants considered.

Project Participation metrics (99% of projects with less participants)	**H2020**	***H2020-Space***
Number of Projects	26,352	343
Number of individual projects	17,117	58
Individual projects percentage	65.0 %	16.9 %
Average participation agents	3.08	6.33
Average participation countries	2.53	4.15
Countries over agents ratio	0.822	0.656

(b) Countries with *H2020-Space* internal activity

There are some projects where we find participants who belong to the same country and even though there is a strong correlation between countries' Total participation and External participation, we will take into account, the effect of country self-cooperation in R&D projects and single organization accomplished projects. We find some countries with substantial differences. In Table A4.2 we show all countries with internal activity in the space framework programme and we calculate those differences and their percentage over their total participation. We see that all but one (CY) of the countries involved are ESA member states. Those, other than the European big 5, showing higher percentages of times their own agents cooperate in R&D projects are NO, EL, PT, SI, SE and CZ. Regarding the weighted participation, PT, SI and SE show better figures than NO and EL.

Table A4.2: H2020-Space Countries with internal activity. Total Participation vs External Cooperation. Ranked by Total External Weighted Participation vs total weighted participation difference in percentage.

Ctry.	Location Group	Total # Part	Ext # Part.	Diff %	Total Part Weight (€)	Total Part Weight (Ext) (€)	Diff %
FR	EU-15-ESA	344	245	29%	283,784,676	238,894,594	16%
SI	EU-13-ESA	16	14	13%	6,395,660	5,404,067	16%
FI	EU-15-ESA	35	31	11%	21,869,481	18,842,846	14%
IT	EU-15-ESA	299	232	22%	193,169,195	166,536,678	14%
ES	EU-15-ESA	280	219	22%	208,988,946	183,412,675	12%
DE	EU-15-ESA	320	271	15%	256,719,935	227,646,992	11%
PT	EU-15-ESA	52	45	13%	35,170,861	31,669,746	10%
SE	EU-15-ESA	37	32	14%	22,066,572	19,772,123	10%
NO	ESA	39	32	18%	32,583,634	29,679,015	9%
EL	EU-15-ESA	76	63	17%	58,337,316	53,955,395	8%
UK	EU-15-ESA	236	196	17%	150,763,571	138,977,393	8%
AT	EU-15-ESA	55	51	7%	25,701,600	23,934,911	7%
CZ	EU-13-ESA	32	27	16%	10,674,832	9,901,009	7%
NL	EU-15-ESA	101	91	10%	54,336,756	51,451,176	5%
CH	ESA	56	53	5%	30,192,387	29,082,373	4%
CY	EU-13	10	9	10%	5,421,992	5,261,692	3%
BE	EU-15-ESA	139	132	5%	78,707,798	76,746,463	2%

(c) *H2020-Space* projects Countries' ranking

In Table A4.3 we show the countries list ranked by number of agents with total number of participations, weighted participation and percentage of internal cooperation.[29]

Table A4.3: Countries ranking by # Agents & H2020-Space participation figures.

Country	Location Group	# agents	Total # Part	Internal %	Total Weight Part	Internal Weight %
IT	EU-15-ESA	151	299	22%	193,169,195	14%
FR	EU-15-ESA	146	344	29%	283,784,676	16%
ES	EU-15-ESA	134	280	22%	208,988,946	12%
DE	EU-15-ESA	130	320	15%	256,719,935	11%
UK	EU-15-ESA	107	236	17%	150,763,571	8%
BE	EU-15-ESA	70	139	5%	78,707,798	2%
NL	EU-15-ESA	59	101	10%	54,336,756	5%
EL	EU-15-ESA	43	76	17%	58,337,316	8%
PT	EU-15-ESA	38	52	13%	35,170,861	10%
AT	EU-15-ESA	37	55	7%	25,701,600	7%
CH	ESA	34	56	5%	30,192,387	4%
PL	EU-13-ESA	29	38	-- %	12,799,053	-- %
SE	EU-15-ESA	26	37	14%	22,066,572	10%
NO	ESA	25	39	18%	32,583,634	9%
CZ	EU-13-ESA	24	32	16%	10,674,832	7%
RO	EU-13-ESA	20	22	-- %	6,093,363	-- %
DK	EU-15-ESA	15	32	-- %	10,140,590	-- %
FI	EU-15-ESA	14	35	11%	21,869,481	14%
IE	EU-15-ESA	12	16	-- %	6,172,282	-- %
SI	EU-13-ESA	11	16	13%	6,395,660	16%
CY	EU-13	9	10	10%	5,421,992	3%
HU	EU-13-ESA	9	9	-- %	2,630,829	-- %
LT	EU-13	8	11	-- %	2,834,372	-- %
IL	ASIA	8	10	-- %	6,143,381	-- %
RS	EUR	8	10	-- %	2,688,156	-- %
BG	EU-13	7	10	-- %	4,366,187	-- %
EE	EU-13-ESA	6	9	-- %	2,272,142	-- %
TR	EUR	6	8	-- %	1,631,429	-- %
LV	EU-13	4	6	-- %	748,948	-- %
SK	EU-13	4	5	-- %	602,854	-- %
UA	EUR	4	5	-- %	799,893	-- %
KR	ASIA	4	4	-- %	869,204	-- %
RU	EUR	4	5	-- %	1,234,671	-- %

[29] See also Annex – Chapter 4 (b).

Country	Location Group	# agents	Total # Part	Internal %	Total Weight Part	Internal Weight %
US	AMERICA	4	5	-- %	2,092,605	-- %
IN	ASIA	4	5	-- %	1,112,142	-- %
LU	EU-15-ESA	3	3	-- %	886,558	-- %
CA	ESA	3	3	-- %	1,321,334	-- %
AU	OCEANIA	3	3	-- %	833,018	-- %
ZA	AFRICA	3	3	-- %	625,472	-- %
BR	AMERICA	3	5	-- %	832,903	-- %
MT	EU-13	2	2	-- %	685,136	-- %
IS	EUR	2	3	-- %	440,206	-- %
XK	EUR	2	2	-- %	212,673	-- %
SN	AFRICA	2	4	-- %	1,510,327	-- %
HR	EU-13	2	2	-- %	301,400	-- %
TN	AFRICA	2	2	-- %	470,970	-- %
MA	AFRICA	2	2	-- %	215,427	-- %
JP	ASIA	2	3	-- %	496,816	-- %
AI	AMERICA	1	1	-- %	325,867	-- %
MD	ASIA	1	1	-- %	106,336	-- %
ME	EUR	1	1	-- %	106,336	-- %
MK	EUR	1	1	-- %	106,336	-- %
TG	AFRICA	1	1	-- %	260,288	-- %
PS	ASIA	1	1	-- %	106,336	-- %
TW	ASIA	1	2	-- %	324,404	-- %
GE	ASIA	1	1	-- %	28,571	-- %
MY	ASIA	1	1	-- %	160,300	-- %
TH	ASIA	1	2	-- %	247,747	-- %
VN	ASIA	1	2	-- %	247,747	-- %
EG	AFRICA	1	1	-- %	106,336	-- %
CN	ASIA	1	2	-- %	324,404	-- %

(d) EU-15 *H2020-Space* Project coordination ranking

Table A4.4: EU-15 Countries H2020-Space Weighted Project Coordination (€) and Weighted Project Participation (€) ranked by Population

Country	Population (2019)	Project coordination (weighted participation €)	Total Participation (weighted participation €)
DE	83,132,799	146,323,285	256,719,935
FR	67,059,887	165,582,978	283,784,676
UK	66,834,405	70,456,429	150,763,571
IT	60,297,396	95,944,747	193,169,195
ES	47,076,781	111,591,059	208,988,946
NL	17,332,850	25,567,973	54,336,756
BE	11,484,055	37,288,245	78,707,798
EL	10,716,322	37,861,372	58,337,316
SE	10,285,453	8,437,286	22,066,572
PT	10,269,417	21,734,771	35,170,861
AT	8,877,067	6,462,885	25,701,600
DK	5,818,553	2,047,657	10,140,590
FI	5,520,314	10,755,347	21,869,481
IE	4,941,444	1,599,924	6,172,282
LU	619,896	0	886,558

(e) *H2020-Space* Network metrics (w/o internal activity)

Table A4.5. Research and Innovation Network 2017-2020 (partial) with 2020(p) Scenario without internal activity.

Global Properties Countries Network	**…**	**2017**	**2018**	**2019**	**2020 (p)**	**2020 (p) External Activity only**
Nodes	…	61	61	61	61	61
Edges	…	249	287	338	347	249
NETWORK OVERVIEW						
Average Degree	…	4.082	4.705	5.541	5.689	5.295
Average Weighted Degree (# projects)	…	24.525	27.820	33.705	34.459	27.213
Diameter	…	3	3	3	3	3
Average Path length:	…	2.185	2.153	2.080	2.067	2.067
Density:	…	0.117	0.131	0.145	0.149	0.136
Modularity:	…	0.073	0.077	0.072	0.063	0.050
Number of Communities:	…	5	5	3	3	3
Number of triangles:	…	393	519	659	698	698
Number of paths (Length 2):	…	2,998	3,612	4,489	4,715	4,715
Value of Clustering Coefficient:	…	0.393	0.431	0.440	0.444	0.444
Number of Weakly Connected Components:	…	3	2	1	1	1
NODE OVERVIEW						
Average Clustering Coefficient:	…	0.687	0.719	0.777	0.785	0.842
Eigenvector centrality	…	1.19E-3	0.74E-3	1.02E-3	1.06E-3	0.94E-3

(f) *H2020-Space* network degree vs weighted degree graphics.

Figure A4.1: H2020-Space Degree & Weighted degree correlation.

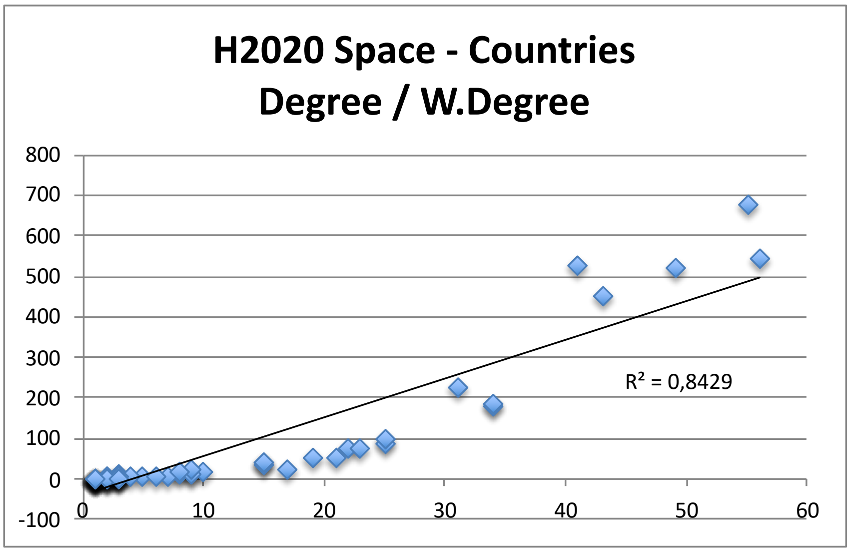
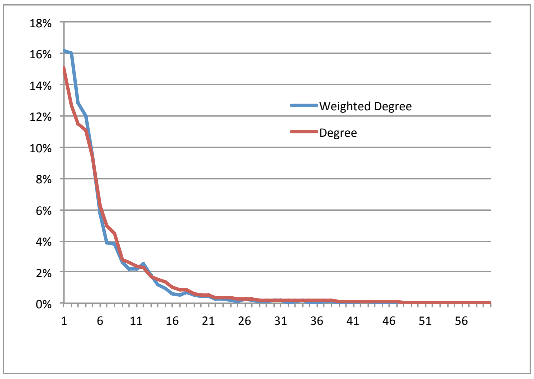
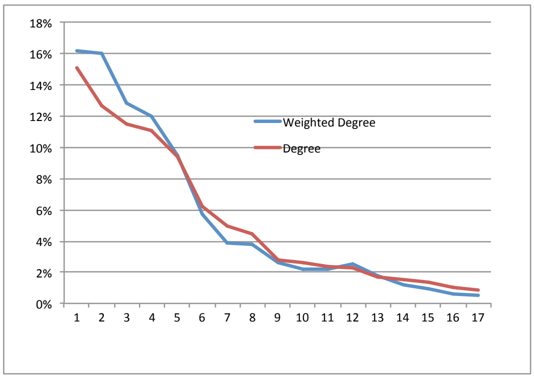


Figure A4.2: Degree & Weighted Degree Distribution



Degree and Weighted degree distributions



Degree and Weighted degree distributions (detail highest degrees)

(g) *H2020-Space* network degree vs weighted degree data.

Table A4.6. Countries Degree and Weighted degree data. Ranked by degree.

Code	Country name	Location group	p-2019 (M)	Degree	Weighted Degree	Degree / Pop	W.Degree / Pop
DE	Germany	EU-15-ESA	83.13	59	582	0.71	7.00
FR	France	EU-15-ESA	67.06	56	709	0.84	10.57
IT	Italy	EU-15-ESA	60.30	49	520	0.81	8.62
UK	United Kingdom	EU-15-ESA	66.83	43	451	0.64	6.75
ES	Spain	EU-15-ESA	47.08	41	528	0.87	11.22
EL	Greece	EU-15-ESA	10.72	38	186	3.55	17.36
NL	Netherlands	EU-15-ESA	17.33	35	187	2.02	10.79
BE	Belgium	EU-15-ESA	11.48	31	227	2.70	19.77
NO	Norway	ESA	5.35	25	87	4.67	16.27
PT	Portugal	EU-15-ESA	10.27	25	100	2.43	9.74
CH	Switzerland	ESA	8.57	24	75	2.80	8.75
AT	Austria	EU-15-ESA	8.88	23	77	2.59	8.67
SE	Sweden	EU-15-ESA	10.29	21	54	2.04	5.25
FI	Finland	EU-15-ESA	5.52	19	51	3.44	9.24
CY	Cyprus	EU-13	1.20	17	24	14.18	20.02
CZ	Czech Republic	EU-13-ESA	10.67	16	43	1.50	4.03
DK	Denmark	EU-15-ESA	5.82	16	35	2.75	6.02
PL	Poland	EU-13-ESA	37.97	15	42	0.40	1.11
IE	Ireland	EU-15-ESA	4.94	10	17	2.02	3.44
BG	Bulgaria	EU-13	6.98	9	12	1.29	1.72
IL	India	ASIA	9.05	9	14	0.99	1.55
LT	Lithuania	EU-13	2.79	9	12	3.23	4.31
RO	Romania	EU-13-ESA	19.36	9	22	0.46	1.14
SI	Slovenia	EU-13-ESA	2.09	9	21	4.31	10.06
HU	Hungary	EU-13-ESA	9.77	8	10	0.82	1.02
LV	Latvia	EU-13	1.91	6	7	3.14	3.66
EE	Estonia	EU-13-ESA	1.33	5	9	3.77	6.78
TR	Turkey	EUR	83.43	4	8	0.05	0.10
US	United States	AMERICA	328.24	4	5	0.01	0.02
HR	Croatia	EU-13	4.07	3	3	0.74	0.74
IN	India	ASIA	1,366.42	3	5	0.00	0.00
KR	South Korea	ASIA	51.71	3	4	0.06	0.08
LU	Luxembourg	EU-15-ESA	0.62	3	3	4.84	4.84
RS	Serbia	EUR	6.94	3	10	0.43	1.44
SK	Slovak Republic	EU-13	5.45	3	5	0.55	0.92
SN	Senegal	AFRICA	16.30	3	4	0.18	0.25
UA	Ukraine	EUR	44.39	3	5	0.07	0.11
ZA	South Africa	AFRICA	58.56	3	3	0.05	0.05

Code	Country name	Location group	p-2019 (M)	Degree	Weighted Degree	Degree / Pop	W.Degree / Pop
AU	Australia	OCEANIA	25.36	2	3	0.08	0.12
BR	Brazil	AMERICA	211.05	2	5	0.01	0.02
CA	Canada	ESA	37.59	2	3	0.05	0.08
IS	Iceland	EUR	0.36	2	3	5.54	8.30
JP	JAPAN	ASIA	126.26	2	3	0.02	0.02
MT	Malta	EU-13	0.50	2	2	3.98	3.98
RU	Russian Fed.	EUR	144.37	2	5	0.01	0.03
TH	Thailand	ASIA	69.63	2	2	0.03	0.03
VN	Vietnam	ASIA	96.46	2	2	0.02	0.02
AI	Anguilla	AMERICA	0.01	1	1	67.25	67.25
CN	China	ASIA	1,397.72	1	2	0.00	0.00
EG	Egypt	AFRICA	100.39	1	1	0.01	0.01
GE	Georgia	ASIA	3.72	1	1	0.27	0.27
MA	Morocco	AFRICA	36.47	1	2	0.03	0.05
MD	Maldives	ASIA	0.53	1	1	1.88	1.88
ME	Montenegro	EUR	0.62	1	1	1.61	1.61
MK	North Macedonia	EUR	2.08	1	1	0.48	0.48
MY	Malaysia	ASIA	31.95	1	1	0.03	0.03
PS	Palestine	ASIA	4.12	1	1	0.24	0.24
TG	Togo	AFRICA	8.08	1	1	0.12	0.12
TN	Tunisia	AFRICA	11.69	1	2	0.09	0.17
TW	Taiwan	ASIA	23.77	1	2	0.04	0.08
XK	Kosovo	EUR	1.79	1	2	0.56	1.11

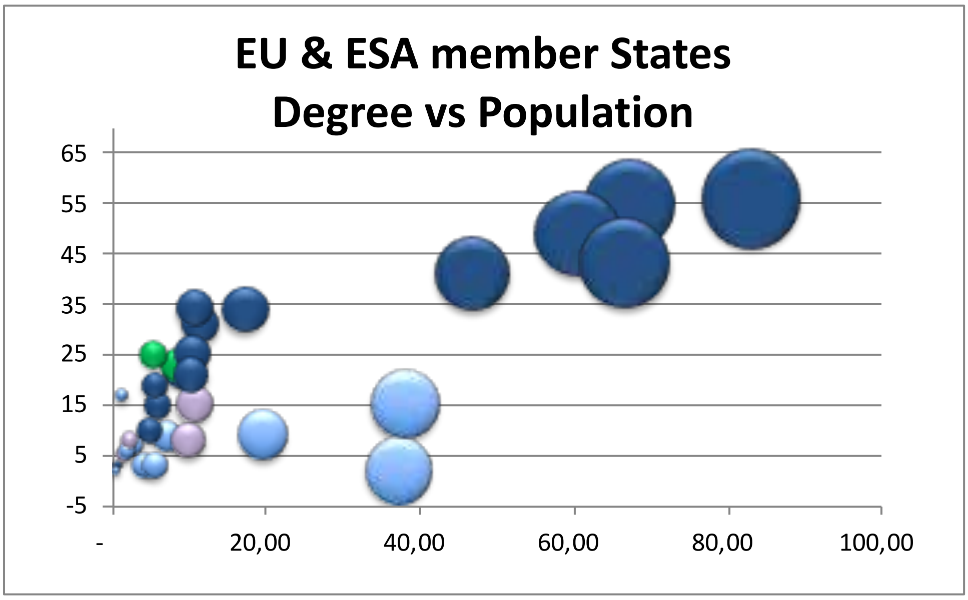
The next double ranking compares Degree and Degree over population. We have highlighted Big-5 (Germany, France, Italy, UK and Spain) in red. The result is a really different map where Cyprus and Malta, even though they are not ESA member states, get a very high result and Big-5 have the lowest ratio on EU-15 and most of ESA member states. Only Poland, Romania and Canada get a worse position.

Table A4.7: EU and ESA member States H2020-Space Degree and Degree over population rankings comparison.

Degree Ranking			**Degree/Population Ranking**		
DE	EU-15-ESA	59	**CY**	EU-13	14.18
FR	EU-15-ESA	56	**LU**	EU-15-ESA	4.84
IT	EU-15-ESA	49	**NO**	ESA	4.67
UK	EU-15-ESA	43	**SI**	EU-13-ESA	4.31
ES	EU-15-ESA	41	**MT**	EU-13	3.98
EL	EU-15-ESA	38	**EE**	EU-13-ESA	3.77
NL	EU-15-ESA	35	**EL**	EU-15-ESA	3.55
BE	EU-15-ESA	31	**FI**	EU-15-ESA	3.44
NO	ESA	25	**LT**	EU-13	3.23
PT	EU-15-ESA	25	**LV**	EU-13	3.14
CH	ESA	24	**CH**	ESA	2.80
AT	EU-15-ESA	23	**DK**	EU-15-ESA	2.75
SE	EU-15-ESA	21	**BE**	EU-15-ESA	2.70
FI	EU-15-ESA	19	**AT**	EU-15-ESA	2.59
CY	EU-13	17	**PT**	EU-15-ESA	2.43
DK	EU-15-ESA	16	**SE**	EU-15-ESA	2.04
CZ	EU-13-ESA	16	**IE**	EU-15-ESA	2.02
PL	EU-13-ESA	15	**NL**	EU-15-ESA	2.02
IE	EU-15-ESA	10	**CZ**	EU-13-ESA	1.50
SI	EU-13-ESA	9	**BG**	EU-13	1.29
LT	EU-13	9	**ES**	EU-15-ESA	0.87
BG	EU-13	9	**FR**	EU-15-ESA	0.84
RO	EU-13-ESA	9	**HU**	EU-13-ESA	0.82
HU	EU-13-ESA	8	**IT**	EU-15-ESA	0.81
LV	EU-13	6	**HR**	EU-13	0.74
EE	EU-13-ESA	5	**DE**	EU-15-ESA	0.71
LU	EU-15-ESA	3	**UK**	EU-15-ESA	0.64
HR	EU-13	3	**SK**	EU-13	0.55
SK	EU-13	3	**RO**	EU-13-ESA	0.46
MT	EU-13	2	**PL**	EU-13-ESA	0.40
CA	ESA	2	**CA**	ESA	0.05

(h) *H2020-Space* network degree over population graphics.

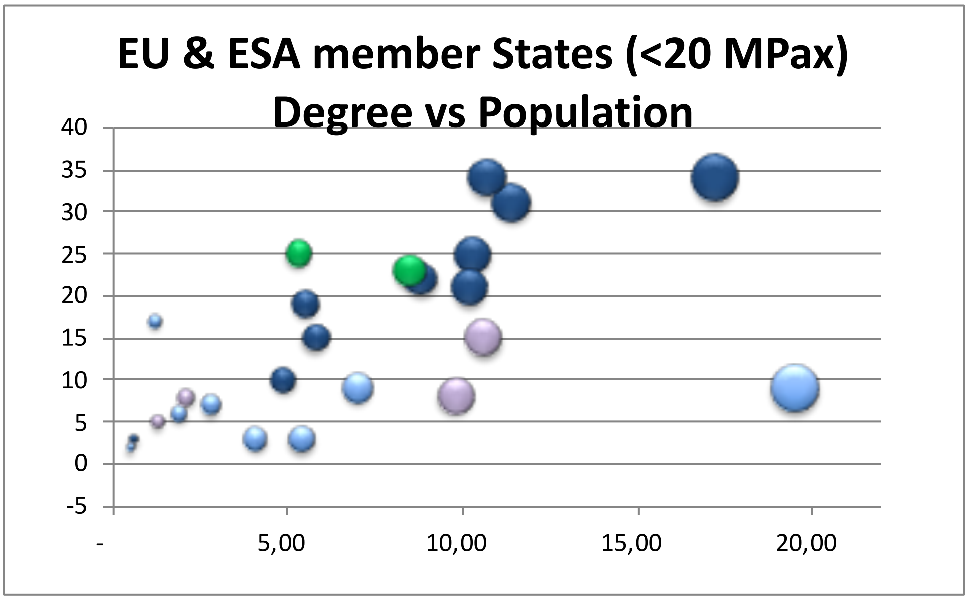
Figure A4.3: H2020-Space Degree vs Population



(EU & ESA member States)

If we focus on small countries, those with less than 20 million people, we obtain the same result and even with a higher difference in countries of the same population in favour of EU-15 and ESA member states.

Figure A4.4: H2020-Space Degree vs Population



(EU & ESA member States) (Detail countries with less than 20 million people)

(i) National space agencies

National Space Agencies:

- Denmark: Denmark's national space strategy published by the Danish government in 2016, recognising the previous lack of a strategy in space. With this new strategy, they "aim to help businesses, researchers and public authorities to harvest the potential of the sector". However, it seems too soon to get results from this renewed Danish Space Agency.

- Romania: Although Romania has a space agency as the coordinator of Romania's national and international space activities since 1995, there is no big difference between Romania's ranking in H2020 full programme and European cooperation R&D in space, keeping a low position both in absolute and relative to population figures.

- Spain: Even though Spain is in that list with the Spanish office for the industry technological development, it is not an actual National Agency. However, Spain has a long history in space activities with an Aerospace national research institute, founded in 1942, cooperating with almost all worldwide space actors and participating in the most relevant space missions.

- Luxembourg: It seems to make a great effort in a normalized R&D activity measure. We should bear in mind in the next future, the lately setup (September 2018) of a business focused agency (Luxembourg Space Agency - LSA) with the goal of promoting the space industry economic development through financial solutions, education and research infrastructure. Luxembourg, in 2018, held a real high commercial space activity of 2% of GDP.

- Similarly, other European countries without a national space agency hold space research institutes participating in R&D projects and space missions and/or offices devoted to the coordination and promotion of space activities:

    - Austrian Office called The Aeronautics and Space Agency (ALR) belonging to the FFG (Austrian Research and Promotion Agency) (1972)
    - Belgian Institute for Space Aeronomy R&D institute (1964)
    - Bulgarian Space Research and Technology Institute R&D institute (1987)
    - Greek Institute for Space applications and remote sensing (1955)
    - Lithuania Space Association (2007)
    - The Netherlands Institute for Space Research (1983)
    - Portugal FCT Space Office (2009) and Portugal Space (2019)
    - Hungarian Space Office (1972)
    - Poland Space Agency (2014)
    - Swedish National Space Agency (1972).

(j) Success Index rating

Table A4.8. Success index ranking.

Country name		Location Group	Pop - 2019	# agents	# coordinators	Success INDEX
AI	Anguilla	AMERICA	14,869	1	0	0.000
EE	Estonia	EU-13-ESA	1,326,590	6	0	0.000
LU	Luxembourg	EU-15-ESA	619,896	3	0	0.000
MT	Malta	EU-13	502,653	2	0	0.000
IS	Iceland	EUR	361,313	2	0	0.000
RS	Serbia	EUR	6,944,975	8	0	0.000
RO	Romania	EU-13-ESA	19,356,544	20	0	0.000
MD	Maldives	ASIA	530,953	1	0	0.000
ME	Montenegro	EUR	622,137	1	0	0.000
XK	Kosovo	EUR	1,794,248	2	0	0.000
SK	Slovak Republic	EU-13	5,454,073	4	0	0.000
SN	Senegal	AFRICA	16,296,364	2	0	0.000
MK	North Macedonia	EUR	2,083,459	1	0	0.000
TN	Tunisia	AFRICA	11,694,719	2	0	0.000
CA	Canada	ESA	37,589,262	3	0	0.000
AU	Austrialia	OCEANIA	25,364,307	3	0	0.000
TG	Togo	AFRICA	8,082,366	1	0	0.000
PS	Palestine	ASIA	4,123,983	1	0	0.000
TR	Turkey	EUR	83,429,615	6	0	0.000
UA	Ukraine	EUR	44,385,155	4	0	0.000
KR	South Korea	ASIA	51,709,098	4	0	0.000
TW	taiwan	ASIA	23,773,876	1	0	0.000
ZA	South Africa	AFRICA	58,558,270	3	0	0.000
RU	Russian Federation	EUR	144,373,535	4	0	0.000
GE	Georgia	ASIA	3,720,382	1	0	0.000
US	United States	AMERICA	328,239,523	4	0	0.000
MA	Morocco	AFRICA	36,471,769	2	0	0.000
MY	Malaysia	ASIA	31,949,777	1	0	0.000
BR	Brazil	AMERICA	211,049,527	3	0	0.000
JP	JAPAN	ASIA	126,264,931	2	0	0.000
TH	Thailand	ASIA	69,625,582	1	0	0.000
VN	Vietnam	ASIA	96,462,106	1	0	0.000
EG	Egypt	AFRICA	100,388,073	1	0	0.000
IN	India	ASIA	1,366,417,754	4	0	0.000
CN	China	ASIA	1,397,715,000	1	0	0.000

Source: Own construction from H2020-Space data from CORDIS database.

(k) 2014-2019 Networks. Global countries' network evolution over time.

Figure A4.5: 2014 Network

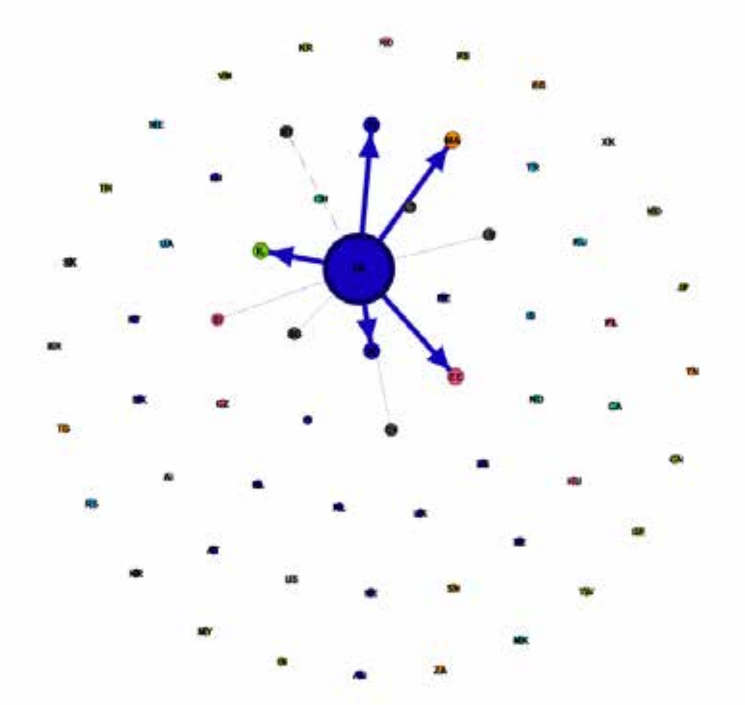


Figure A4.6: 2015 Network

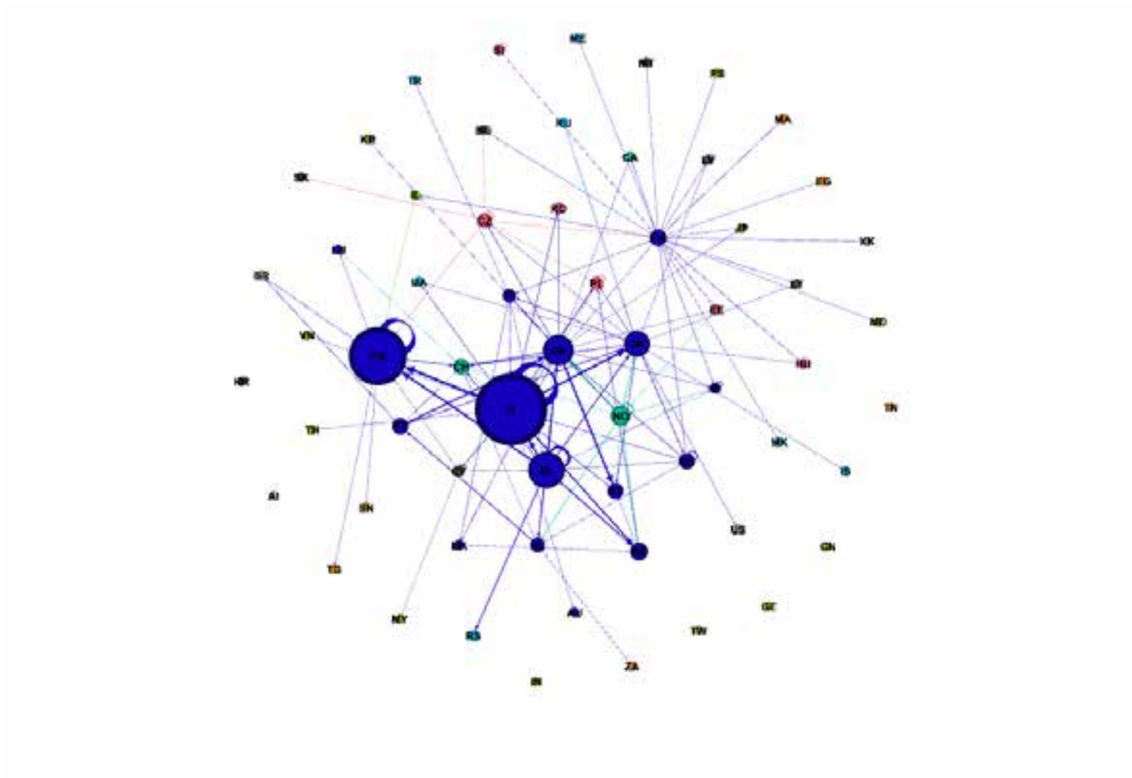


Figure A4.7: 2016 Network

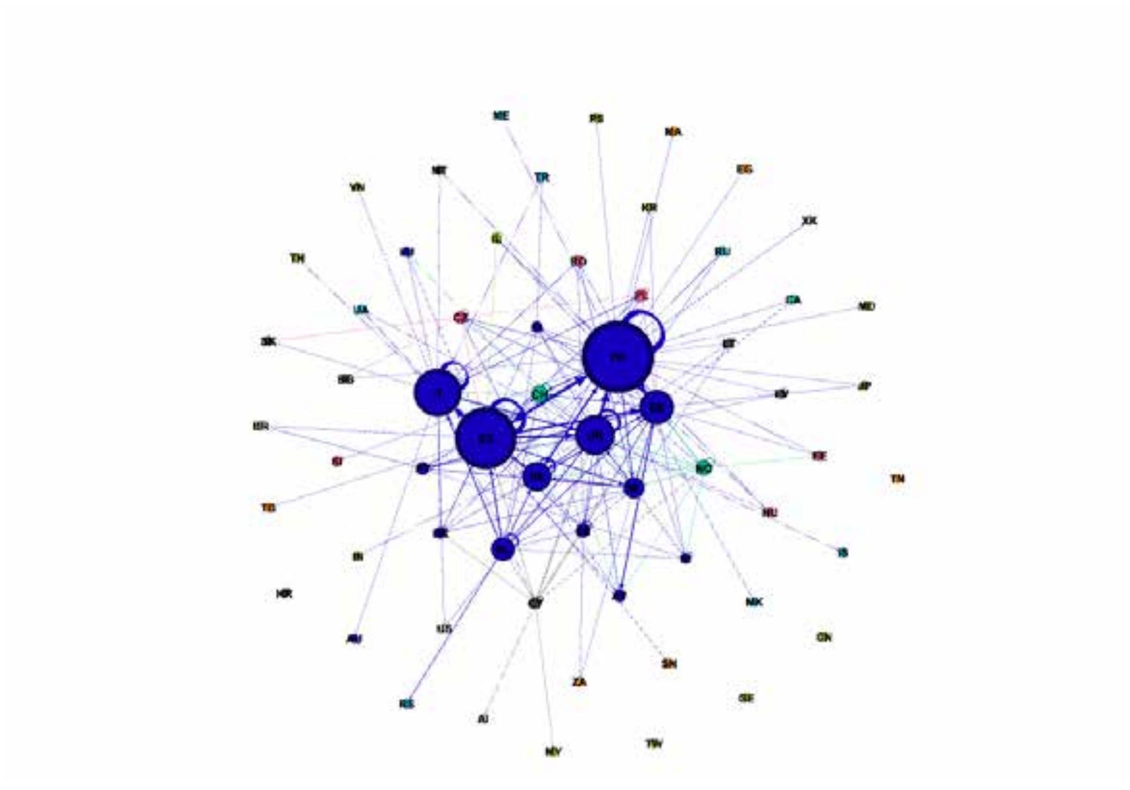


Figure A4.8: 2017 Network

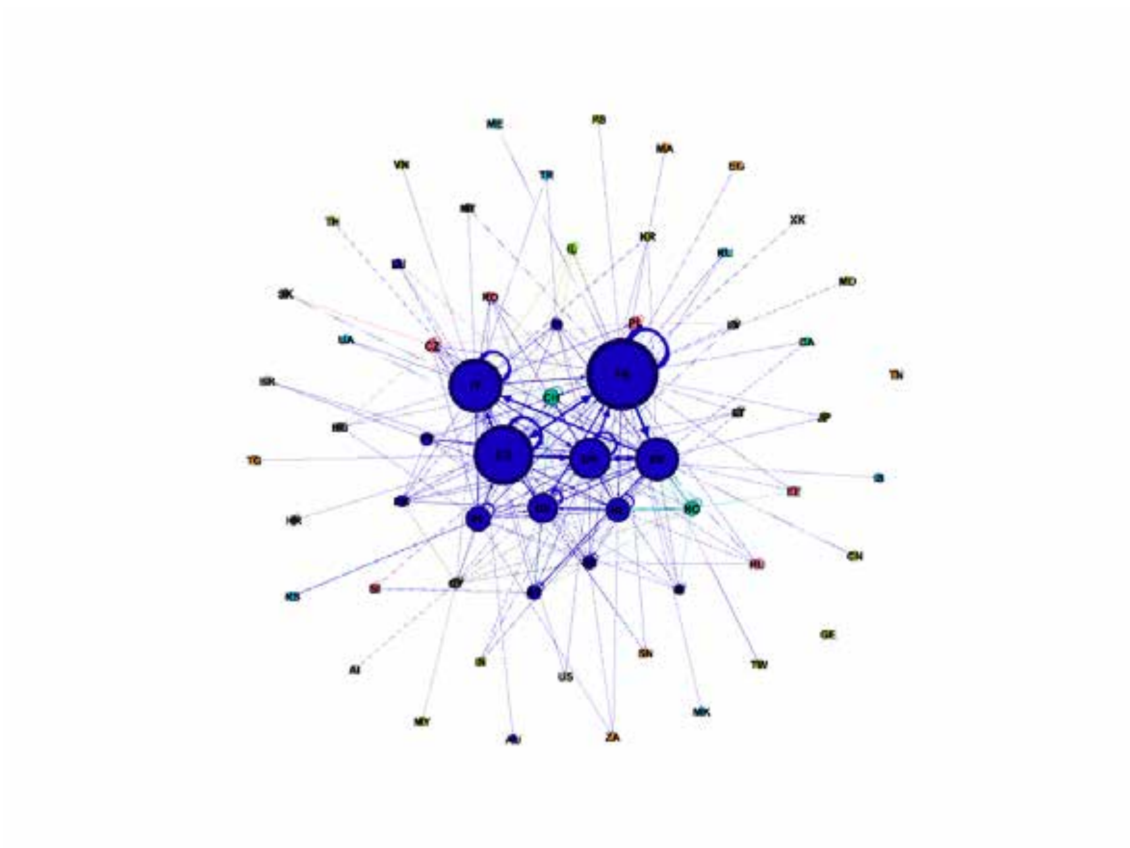


Figure A4.9: 2018 Network

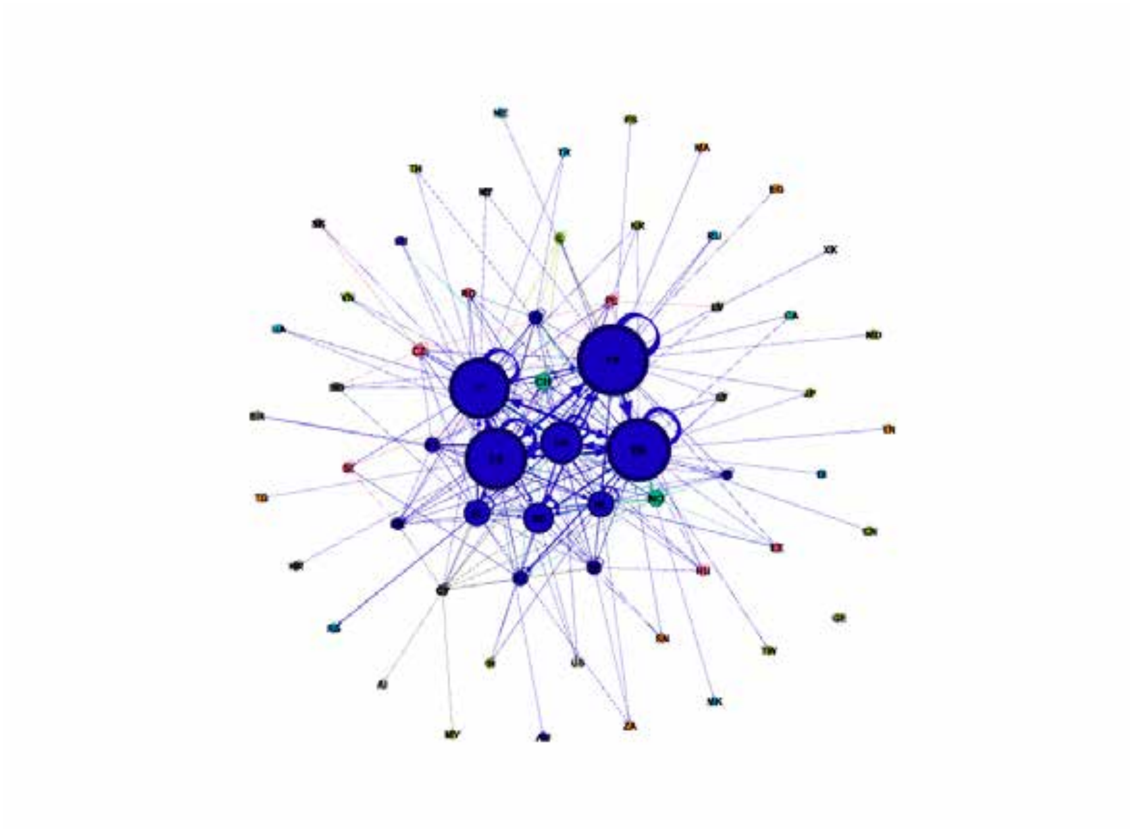
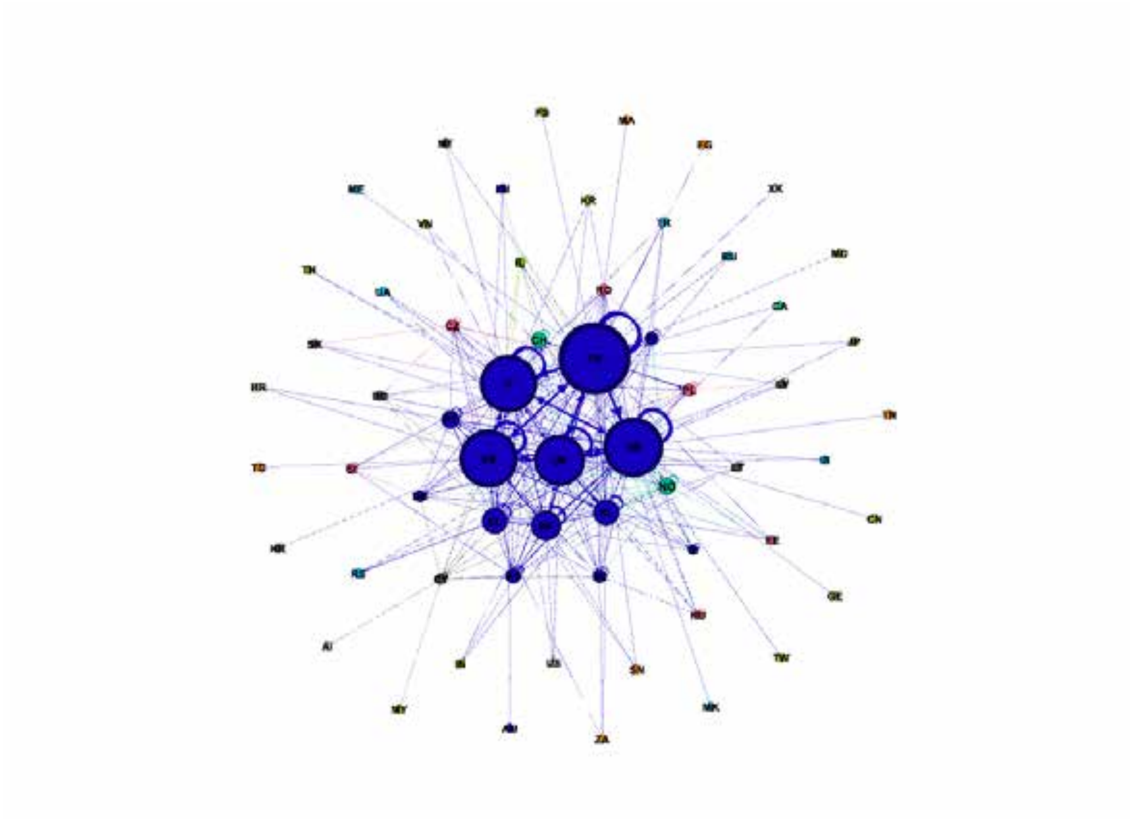


Figure A4.10: 2019 Network



(l) Big-5 European countries 2019 Networks.

Figure A4.11: DE 2019 Network

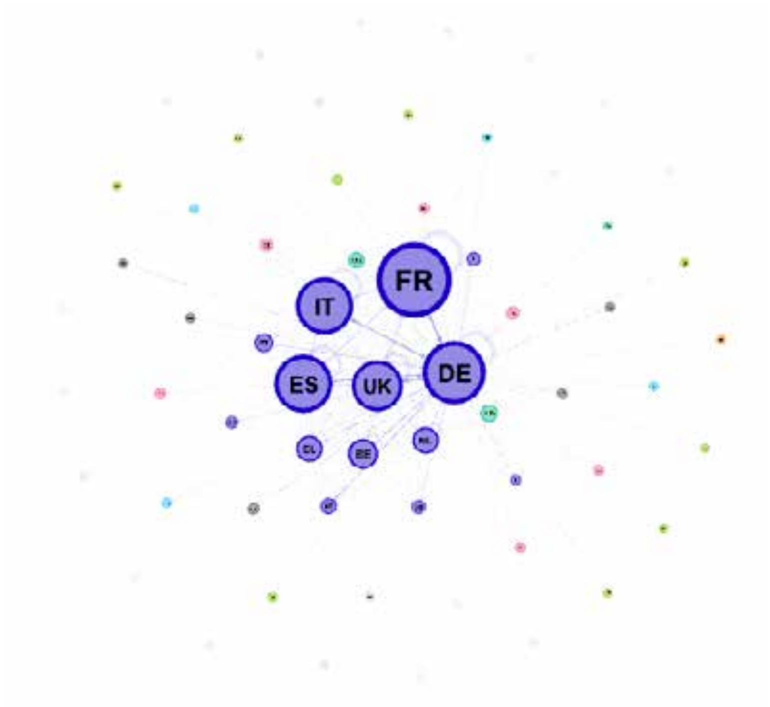


Figure A4.12: ES 2019 Network

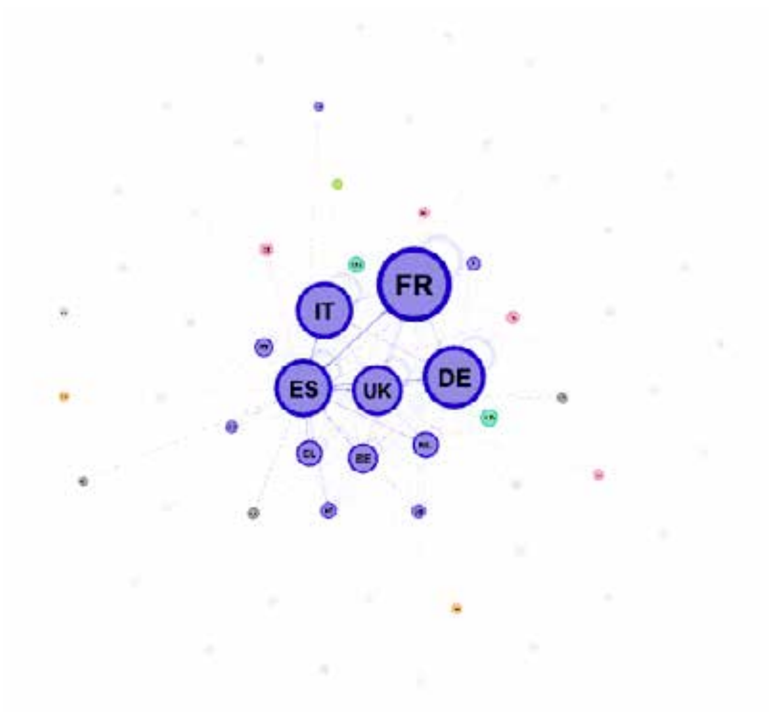


Figure A4.13: FR 2019 Network

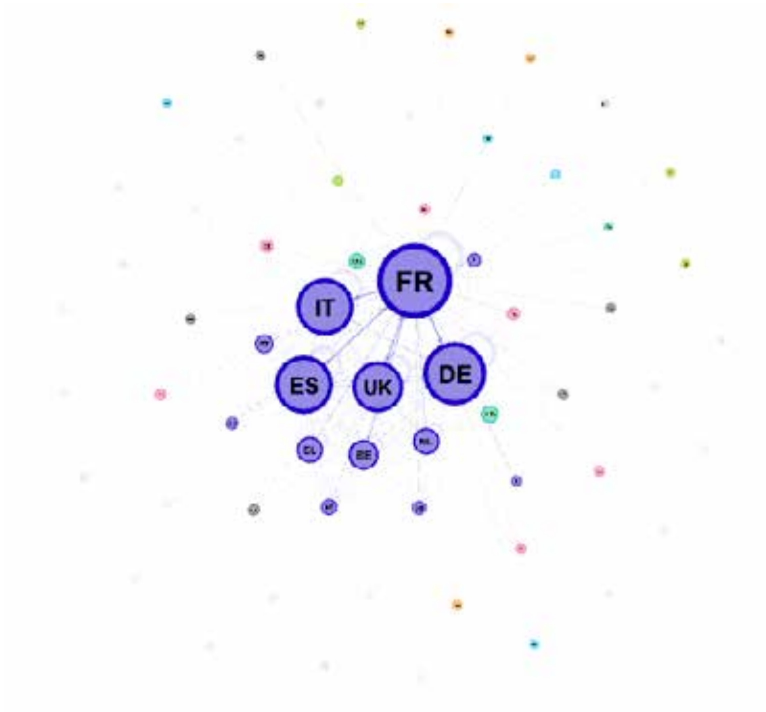


Figure A4.14: IT 2019 Network

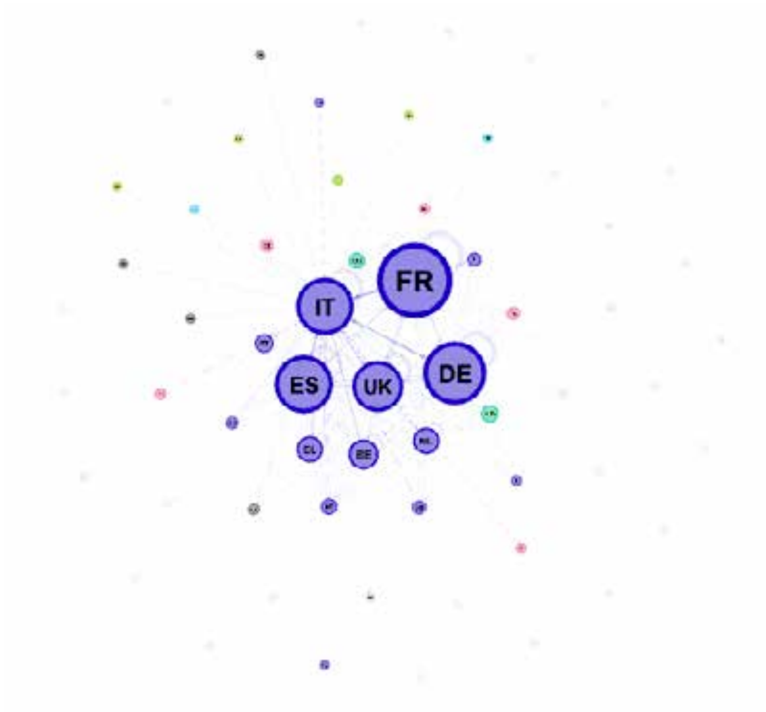
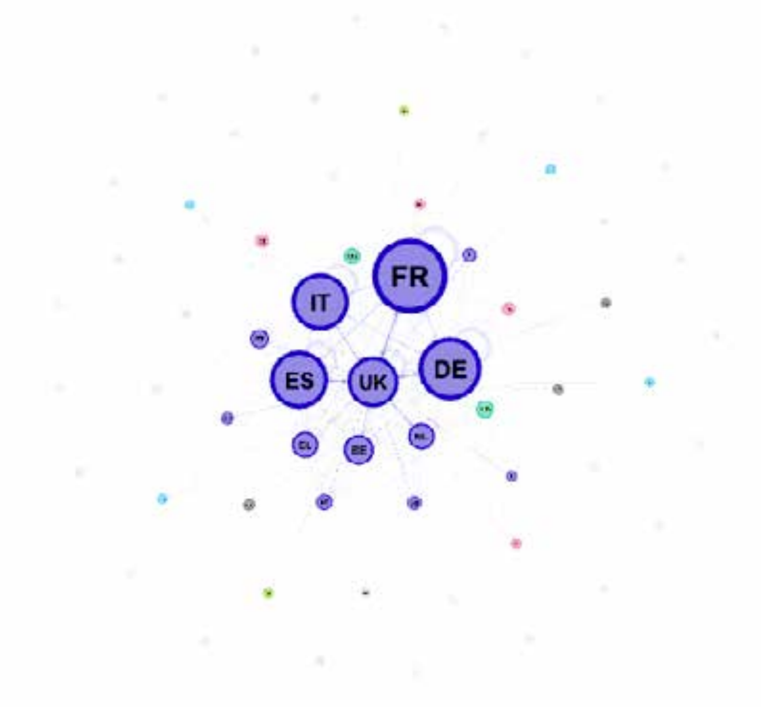


Figure A4.15: UK 2019 Network



Annex for Chapter 5

1. CORDIS - EU research projects under Horizon 2020 (2014-2020).
    a. Project data table (CORDIS). Extract.
    b. Agents Data table. Extract.
    c. Project Links table. Extract.
2. Agents' Network Graphics.
    a. Area of Activity and Type of Agent.
    b. Area of Activity and Country.
    c. Agents Network Evolution over Time
3. Agents Network degree distributions per Activity Area
4. Agents Network metrics per Area vs Random Networks.
5. Agents' Project participation metrics - *Horizon 2020* (2014-2020)
6. CORDIS Dataset - EU research projects under *Horizon 2020* (2014-2020)

CORDIS - EU research projects under *Horizon 2020* (2014-2020)

This dataset contains projects and organisations funded by the European Union under the Horizon 2020 framework programme for research and innovation from 2014 to 2020.

The file 'H2020 Projects' contains the public grant information for each project, including the following information: Record Control Number (RCN), project ID (grant agreement number), project acronym, project status, funding programme, topic, project title, project start date, project end date, project objective, project total funds, EC max contribution (commitment), call ID, funding scheme (type of action), coordinator, coordinator country, participants (ordered in a semi-colon separated list), participant countries (ordered in a semi-colon separated list).

The participating organisations are listed in the file 'H2020 Organisations' which includes: project Record Control Number (RCN), project ID, project acronym, organisation role, organisation ID, organisation name, organisation short name, organisation type, participation ended (true/false), EC contribution, organisation country.

The periodic or final report summaries (or publishable summaries) from the projects have been included since September 2018.

The lists of publications and deliverables from the projects have been included since May 2019.

Reference data (programmes topics, funding schemes (types of action), organisation types and countries) can be found in this dataset:
https://data.europa.eu/euodp/en/data/dataset/cordisref-data
CORDIS datasets are produced monthly. Therefore, inconsistencies may occur between what is presented on the CORDIS live website and the datasets.
Horizon 2020 principal investigators and MSCA researchers were last extracted on November 2018.

Project Data. CORDIS Database. (Extract)

Pr Id	Coord. (Source)	Crd. Ctry	PARTICIPANTS (TARGETS)	Part. Ctr.	Start Date	H.id	Acr	Total Funds	N. P.	Field	N. P.C.
1	"NATIONAL CENTER FOR SCIENTIFIC RESEARCH ""DEMOKRITOS"""	EL	KYSTVERKET VEST;SINTEF OCEAN AS;FUNDO REGIONAL PARA A CIENCIA E TECNOLOGIA;HELLENIC CENTRE FOR MARINE RESEARCH;DIRECAO-GERAL DE POLITICA DO MAR;EUROPEAN UNION SATELLITE CENTRE;MINISTERIO DEL INTERIOR;NATIONAL OBSERVATORY OF ATHENS	NO;PT;EL;ES	2017-01-01	730098	MARINE-EO	4,865,093	8	EOBS	4
2	ACADEMY OF ATHENS	EL	THE PROVOST, FELLOWS, FOUNDATION SCHOLARS & THE OTHER MEMBERS OF BOARD OF THE COLLEGE OF THE HOLY & UNDIVIDED TRINITY OF QUEEN ELIZABETH NEAR DUBLIN; FACHHOCHSCHULE NORDWESTSCHWEIZ;MET OFFICE;UNIVERSITE PARIS-SUD;UNIVERSITY OF NORTHUMBRIA AT NEWCASTLE;CONSIGLIO NAZIONALE DELLE RICERCHE;UNIVERSITA DEGLI STUDI DI GENOVA;CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS	IE;CH;UK;FR;IT	2015-01-01	640216	FLARECAST	2,416,651	8	GSTP	5
3	ACORDE TECHNOLOGIES SA	ES	ACORDE TECHNOLOGIES SA	ES	2014-10-01	651137	GLAD	71,429	1	NAVI	1
4	ACORDE TECHNOLOGIES SA	ES	CENTRE TECNOLOGIC DE TELECOMUNICACIONS DE CATALUNYA;TECHNISCHE UNIVERSITAET MUENCHEN;ALPHA CONSULTANTS S.R.L.;DRAXIS ENVIRONMENTAL S.A.;UNIVERSITAT POLITECNICA DE CATALUNYA;STICHTING WAGENINGEN RESEARCH	ES;DE;IT;EL;NL	2016-01-01	687367	AUDITOR	1,157,736	6	NAVI	5
346	WATER INSIGHT BV	NL	BIO-LITTORAL;STICHTING HZ UNIVERSITY OF APPLIED SCIENCES;THE UNIVERSITY OF STIRLING;CONSIGLIO NAZIONALE DELLE RICERCHE;GEONARDO ENVIRONMENTAL TECHNOLOGIES LTD;UNIVERSITE DE NANTES;UNIVERSIDAD DE VIGO	FR;NL;UK;IT;HU;ES	2017-11-01	776348	CoastObs	2,306,911	7	EOBS	6
347	ZERO 2 INFINITY SL	ES	ZERO 2 INFINITY SL	ES	2015-03-01	663486	HELIUM	71,429	1	GSTP	1

Agents Data. (Extract)

ID	SHORT	Ctry	Loc.	Typ	C.	N P.	Pr. W. Deg. coord k€	Prt. W. Deg. Rºk€	EOBS k€	GSTP k€	HM FL k€	LN CH k€	NA VI k€	RB EX k€	SC NC k€
"ABBIA ""GNSS TECHNOLOGIES"" SARL"	ABBIA	FR	EU-15-ESA	PRC	0	1	0	260	0	0	0	0	260	0	0
"INSTITUTUL NATIONAL DE CERCETARE-DEZVOLTARE AEROSPATIALA ""ELIE CARAFOLI""-INCAS BUCURESTI"	ELIE CARAFOLI	RO	EU-13-ESA	REC	0	1	0	290	0	0	0	289	0	0	0
"NATIONAL CENTER FOR SCIENTIFIC RESEARCH ""DEMOKRITOS"""	DEMOKRITOS	EL	EU-15-ESA	REC	1	1	4,865	5,037	4,865	0	172	0	0	0	0
52IMPACT BV	52IMPACT	NL	EU-15-ESA	PRC	0	1	0	332	332	0	0	0	0	0	0
A D D L	ADDL	FR	EU-15-ESA	PRC	0	1	0	1,248	0	1,248	0	0	0	0	0
A-ETC SRO	A-ETC s.r.o.	CZ	EU-13-ESA	PRC	0	1	0	333	0	333	0	0	0	0	0
A.T.I. TRASPORTI INTERURBANI SPA	A.T.I. Trasporti Interurbani	IT	EU-15-ESA	PRC	0	1	0	170	0	0	0	0	170	0	0
AAC MICROTEC AB	AAC MICROTEC AB	SE	EU-15-ESA	PRC	0	1	0	696	0	696	0	0	0	0	0
...															
ZERO 2 INFINITY SL	Z2I	ES	EU-15-ESA	PRC	1	1	71	71	0	71	0	0	0	0	0
ZILINSKA UNIVERZITA V ZILINE	UNIZA	SK	EU-13	HES	0	1	0	154	0	0	0	0	154	0	0

Project Links. (Extract)

C. Src	C. Trgt	Source	Target	Start Date	Acr.	Total k€ Funds	AREA	Loc. S	Loc. T	N. P.	Funds / part k€	self	Type Coord	Type Partic	Project Id
EL	EL	"NATIONAL CENTER FOR SCIENTIFIC RESEARCH ""DEMOKRITOS"""	NATIONAL OBSERVATORY OF ATHENS	2017-01-01	MARINE-EO	4,865	EOBS	EU-15-ESA	EU-15 - ESA	8	608	0	REC	REC	1
EL	NO	"NATIONAL CENTER FOR SCIENTIFIC RESEARCH ""DEMOKRITOS"""	SINTEF OCEAN AS	2017-01-01	MARINE-EO	4,865	EOBS	EU-15-ESA	ESA	8	608	0	REC	OTH	1
EL	NO	"NATIONAL CENTER FOR SCIENTIFIC RESEARCH ""DEMOKRITOS"""	KYSTVERKET VEST	2017-01-01	MARINE-EO	4,865	EOBS	EU-15-ESA	ESA	8	608	0	REC	PUB	1
EL	ES	"NATIONAL CENTER FOR SCIENTIFIC RESEARCH ""DEMOKRITOS"""	EUROPEAN UNION SATELLITE CENTRE	2017-01-01	MARINE-EO	4,865	EOBS	EU-15-ESA	EU-15 - ESA	8	608	0	REC	PUB	1
EL	PT	"NATIONAL CENTER FOR SCIENTIFIC RESEARCH ""DEMOKRITOS"""	FUNDO REGIONAL PARA A CIENCIA E TECNOLOGIA	2017-01-01	MARINE-EO	4,865	EOBS	EU-15-ESA	EU-15 - ESA	8	608	0	REC	REC	1
EL	ES	"NATIONAL CENTER FOR SCIENTIFIC RESEARCH ""DEMOKRITOS"""	MINISTERIO DEL INTERIOR	2017-01-01	MARINE-EO	4,865	EOBS	EU-15-ESA	EU-15 - ESA	8	608	0	REC	PUB	1
EL	PT	"NATIONAL CENTER FOR SCIENTIFIC RESEARCH ""DEMOKRITOS"""	DIRECAO-GERAL DE POLITICA DO MAR	2017-01-01	MARINE-EO	4,865	EOBS	EU-15-ESA	EU-15 - ESA	8	608	0	REC	PUB	1

EL	EL	"NATIONAL CENTER FOR SCIENTIFIC RESEARCH ""DEMOKRITOS"""	HELLENIC CENTRE FOR MARINE RESEARCH	2017-01-01	MARINE-EO	4,865	EOBS	EU-15-ESA	EU-15 - ESA	8	608	0	REC	REC		1
EL	FR	ACADEMY OF ATHENS	UNIVERSITE PARIS-SUD	2015-01-01	FLARECAST	2,416	GSTP	EU-15-ESA	EU-15 - ESA	8	302	0	HES	HES		2
EL	IT	ACADEMY OF ATHENS	UNIVERSITA DEGLI STUDI DI GENOVA	2015-01-01	FLARECAST	2,416	GSTP	EU-15-ESA	EU-15 - ESA	8	302	0	HES	HES		2
…NL	**FR**	**WATER INSIGHT BV**	**BIO-LITTORAL**	**2017-11-01**	**CoastObs**	**2,306**	**EOBS**	**EU-15-ESA**	**EU-15 - ESA**	**7**	**329**	**0**	**PRC**	**PRC**	**346**	
ES	ES	ZERO 2 INFINITY SL	ZERO 2 INFINITY SL	2015-03-01	HELIUM	71	GSTP	EU-15-ESA	EU-15 - ESA	1	71	1	PRC	PRC	347	

Agents' Network Graphics

Graphics by Area of Activity and Type of Agent.

The chosen colour code follows:

PRC (Rose), REC (Blue), HES (Green), PUB (Dark Green) and OTH (Orange).

Figure A5.1: H2020-Space – EOBS – Agents Network per Agent Type.

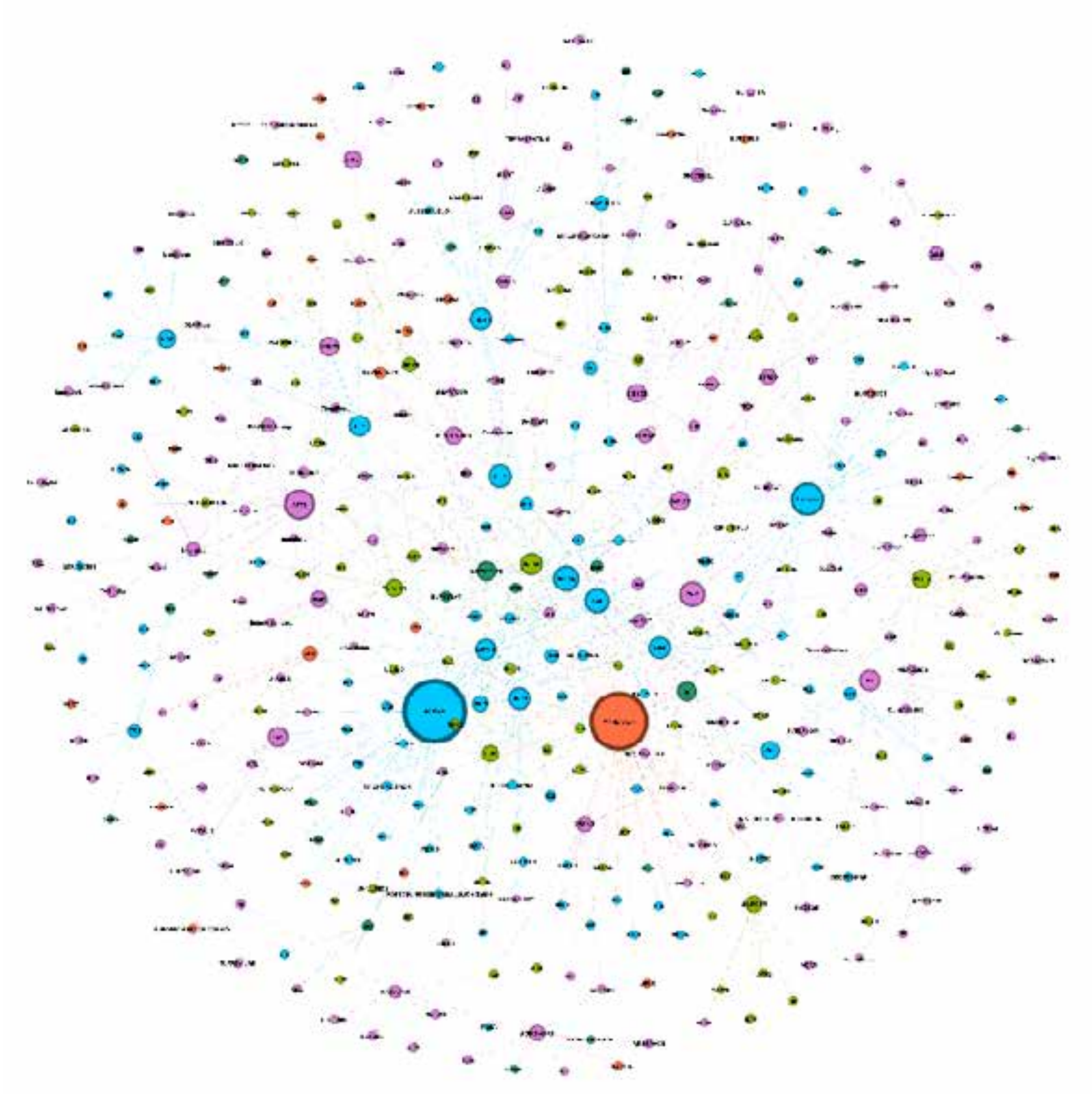


Figure A5.2: H2020-Space – GSTP – Agents Network by Agent Type.

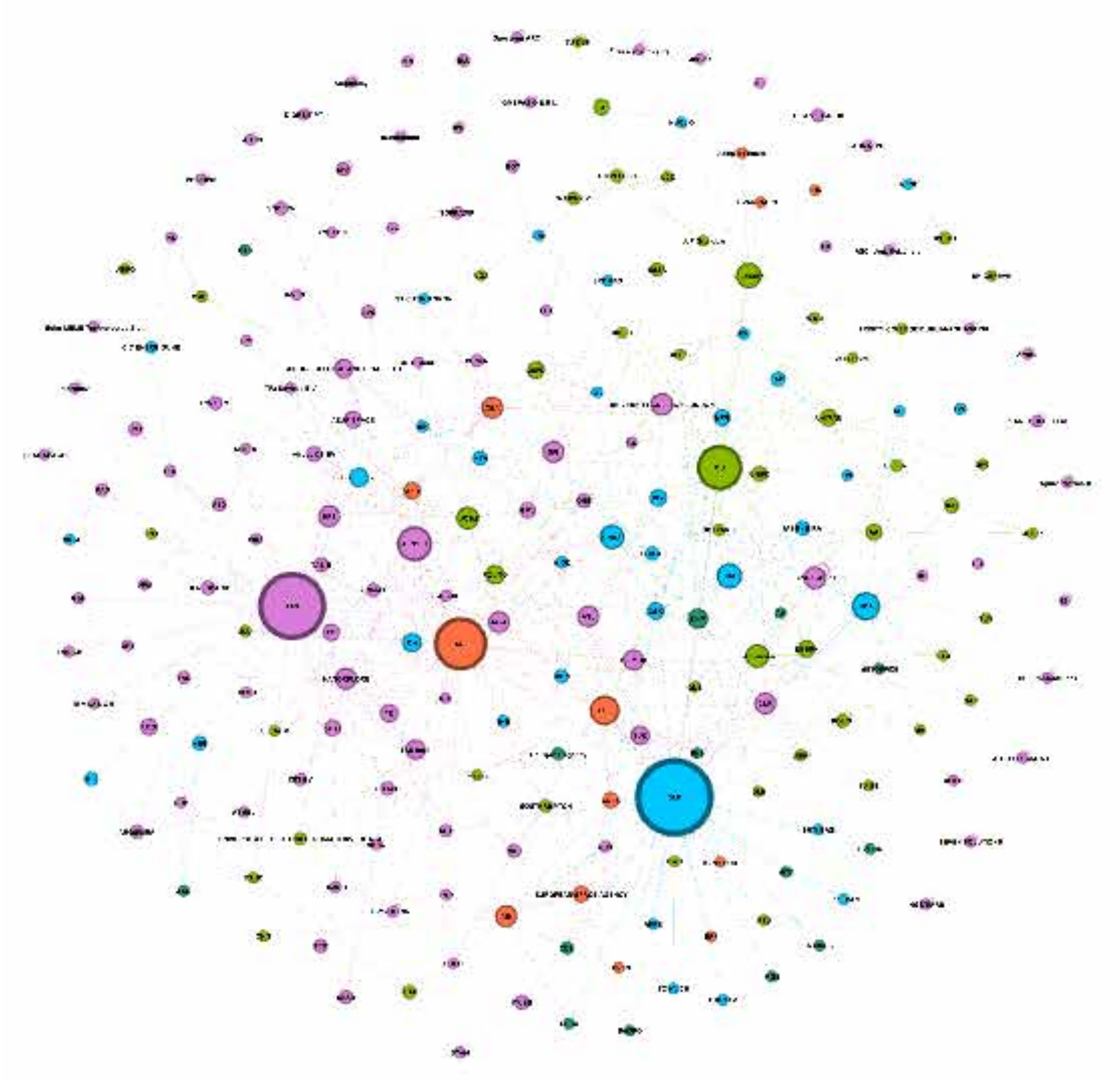


Figure A5.3: H2020-Space – HMFL – Agents Network by Agent Type.

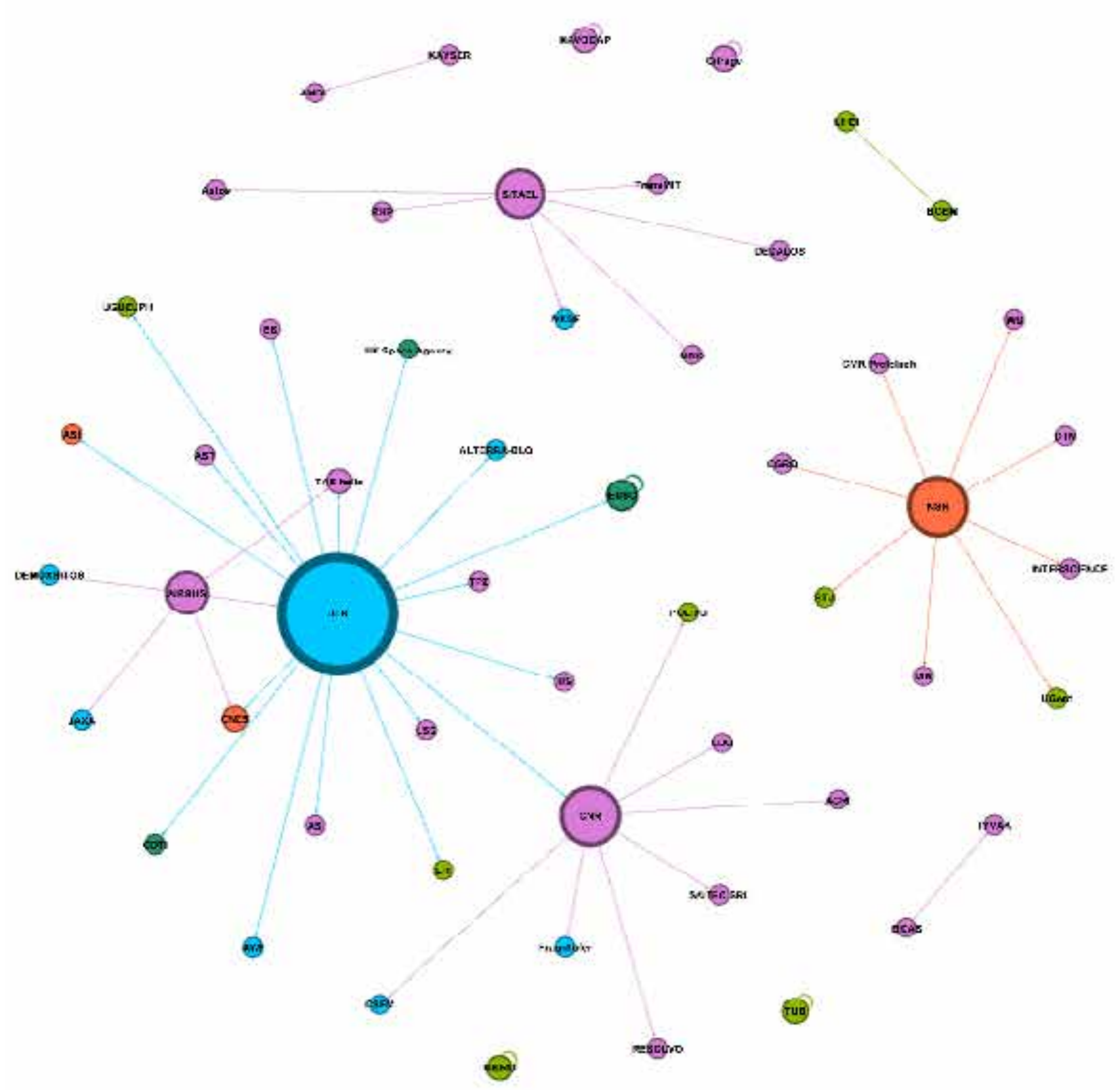


Figure A5.4: H2020-Space – LNCH – Agents Network by Agent Type.

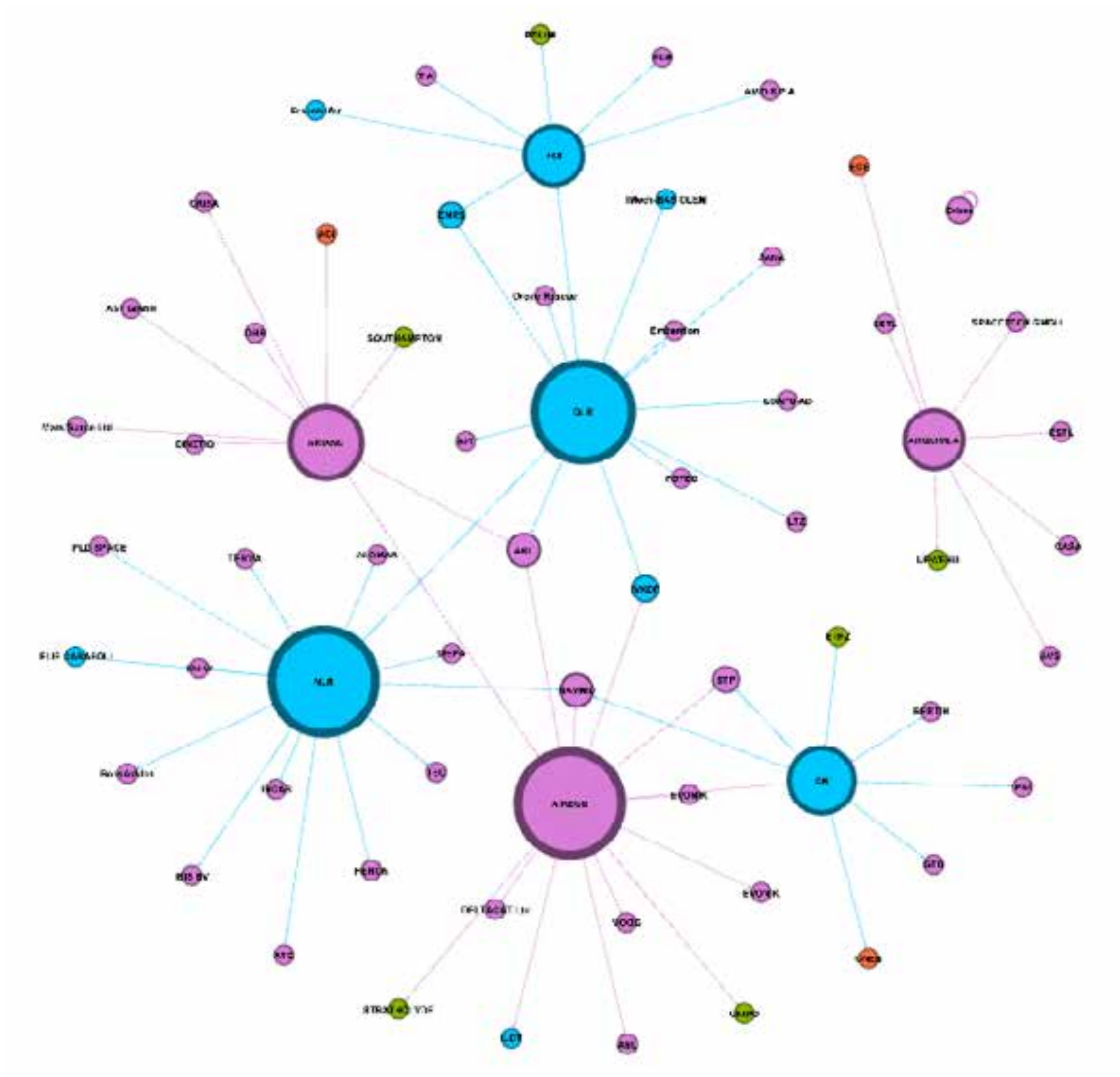


Figure A5.5: H2020-Space – NAVI – Agents Network by Agent Type.

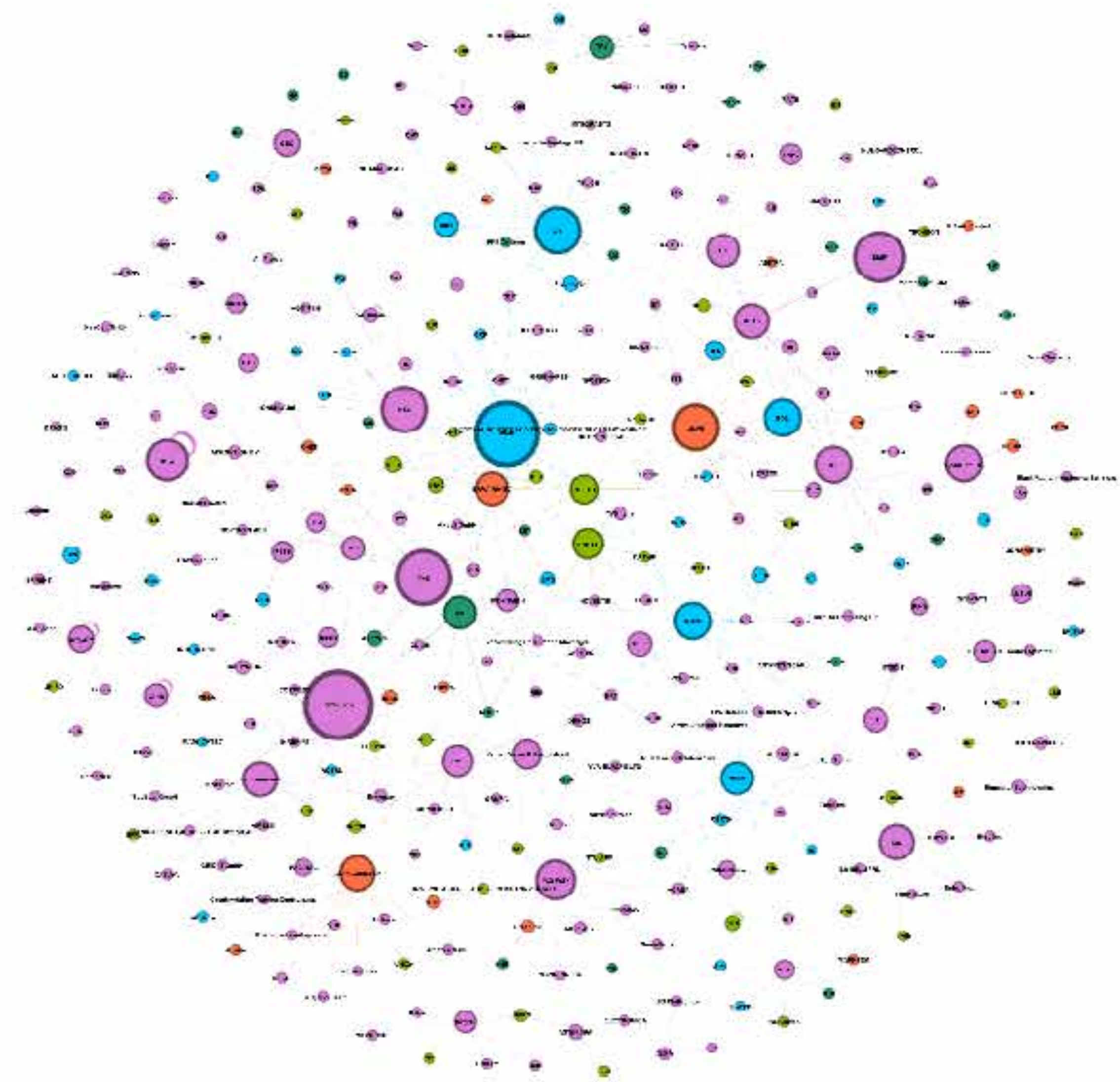


Figure A5.6: H2020-Space – RBEX – Agents Network by Agent Type.

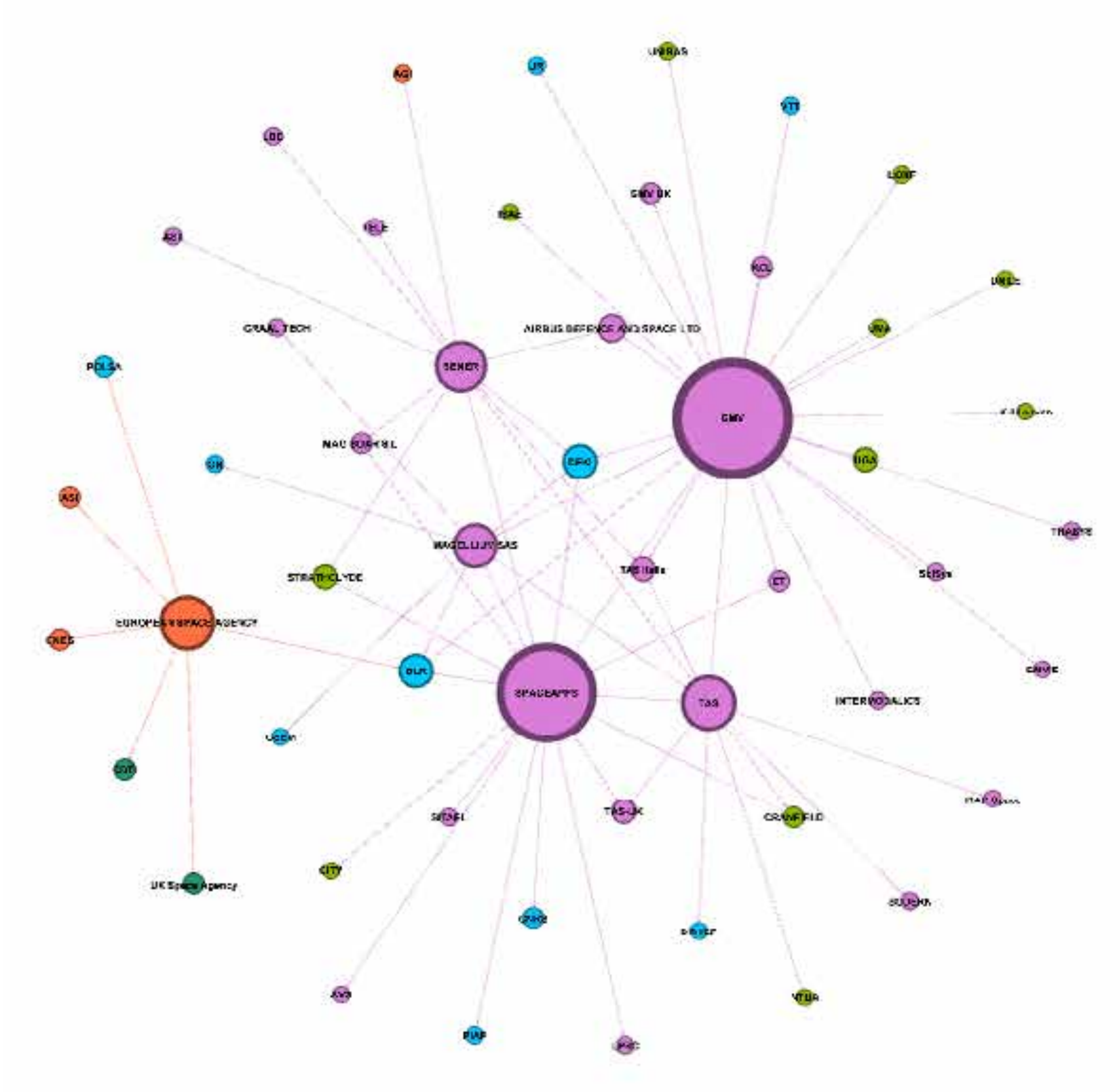
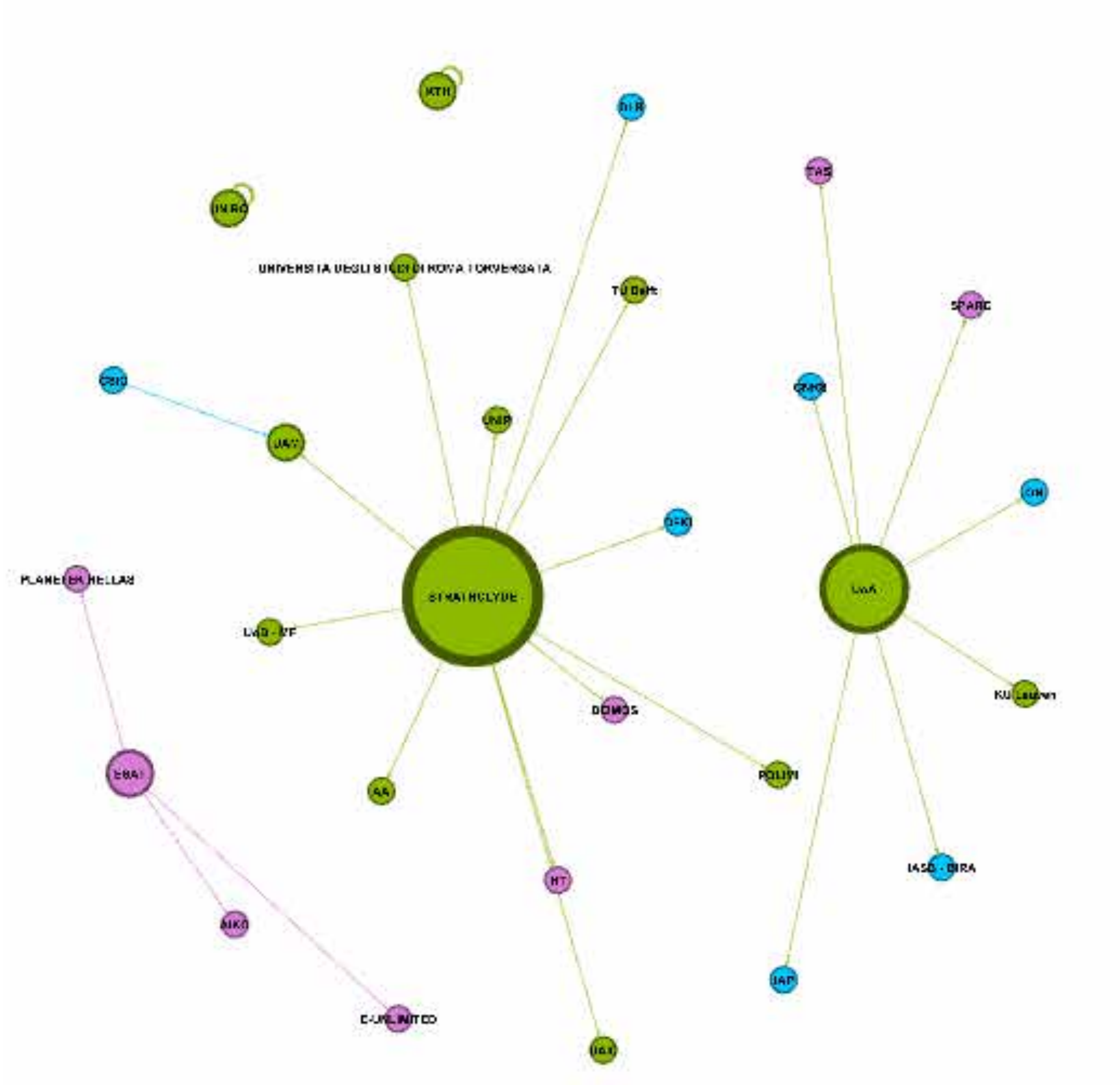


Figure A5.7: H2020-Space – SCNC – Agents Network by Agent Type.



Graphics by Area of Activity and Country.

The colour code:

Germany: Brown; France: Light Green; UK: Orange; Italy: Purple; Spain: Blue; Belgium: Red; Netherlands: Dark Green and Others: Grey.

Figure A5.8: H2020-Space – Agents Network by Country.

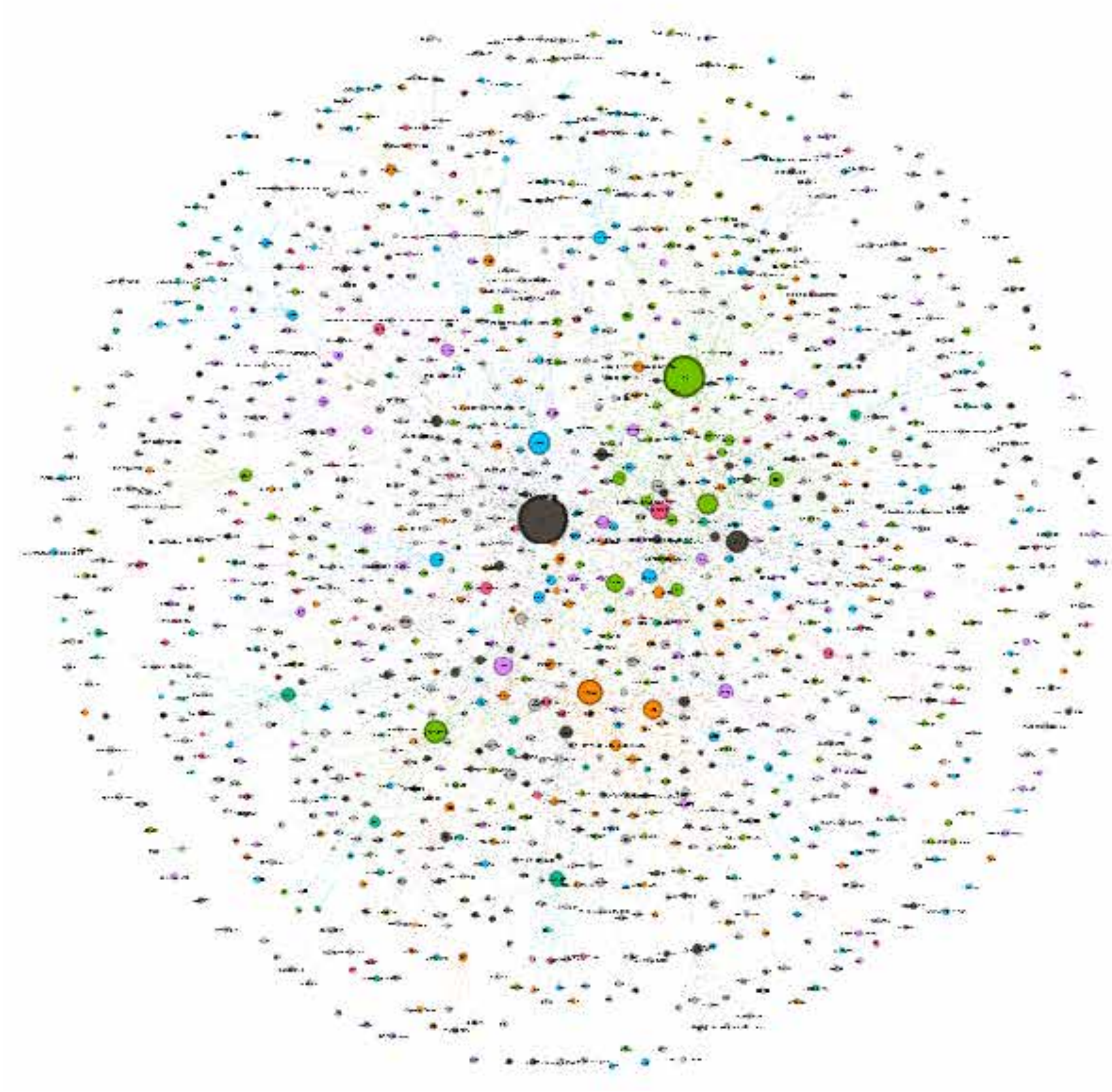


Figure A5.9: H2020-Space – EOBS – Agents Network by Country.

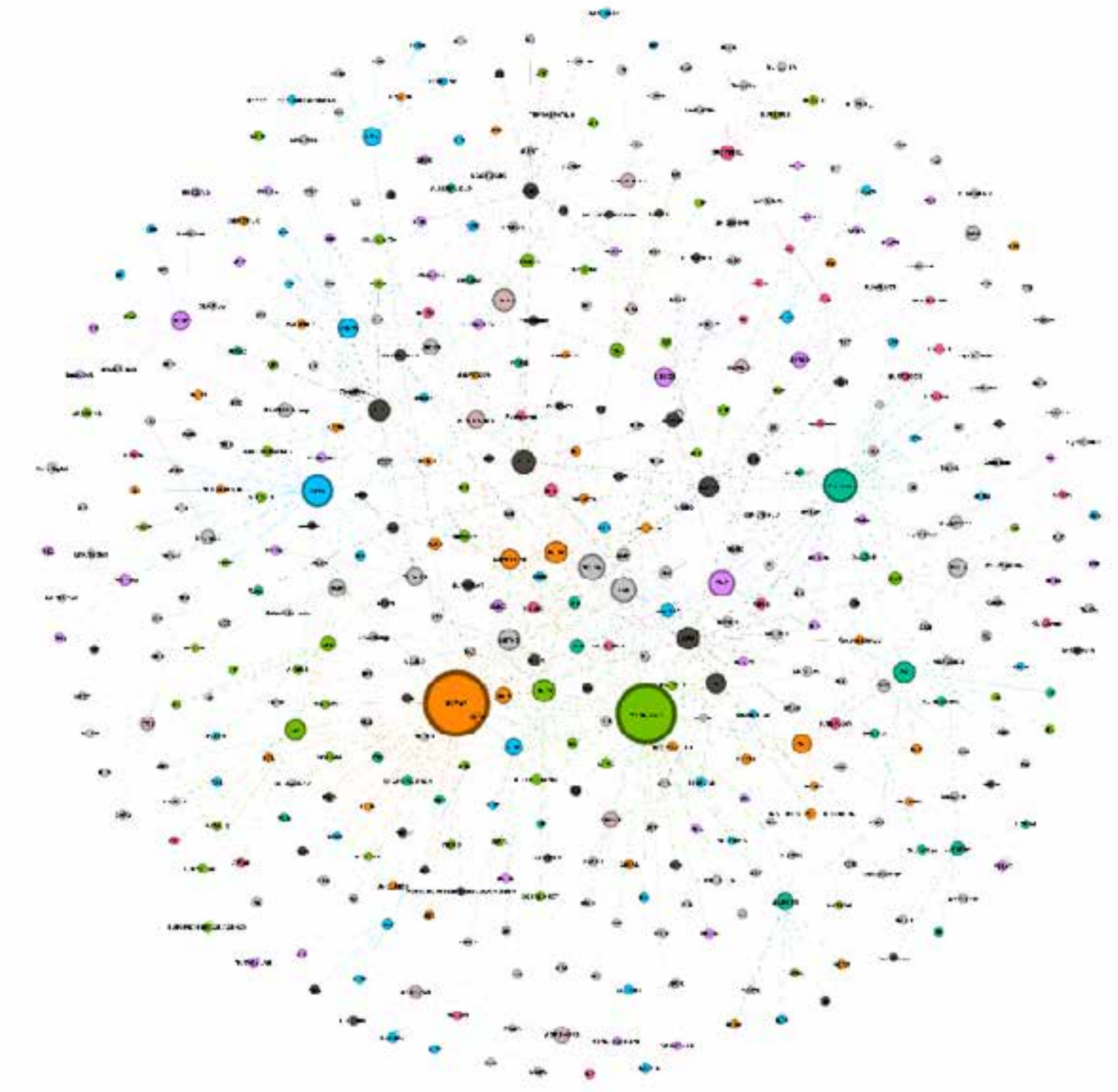


Figure A5.10: H2020-Space – GSTP – Agents Network by Country.

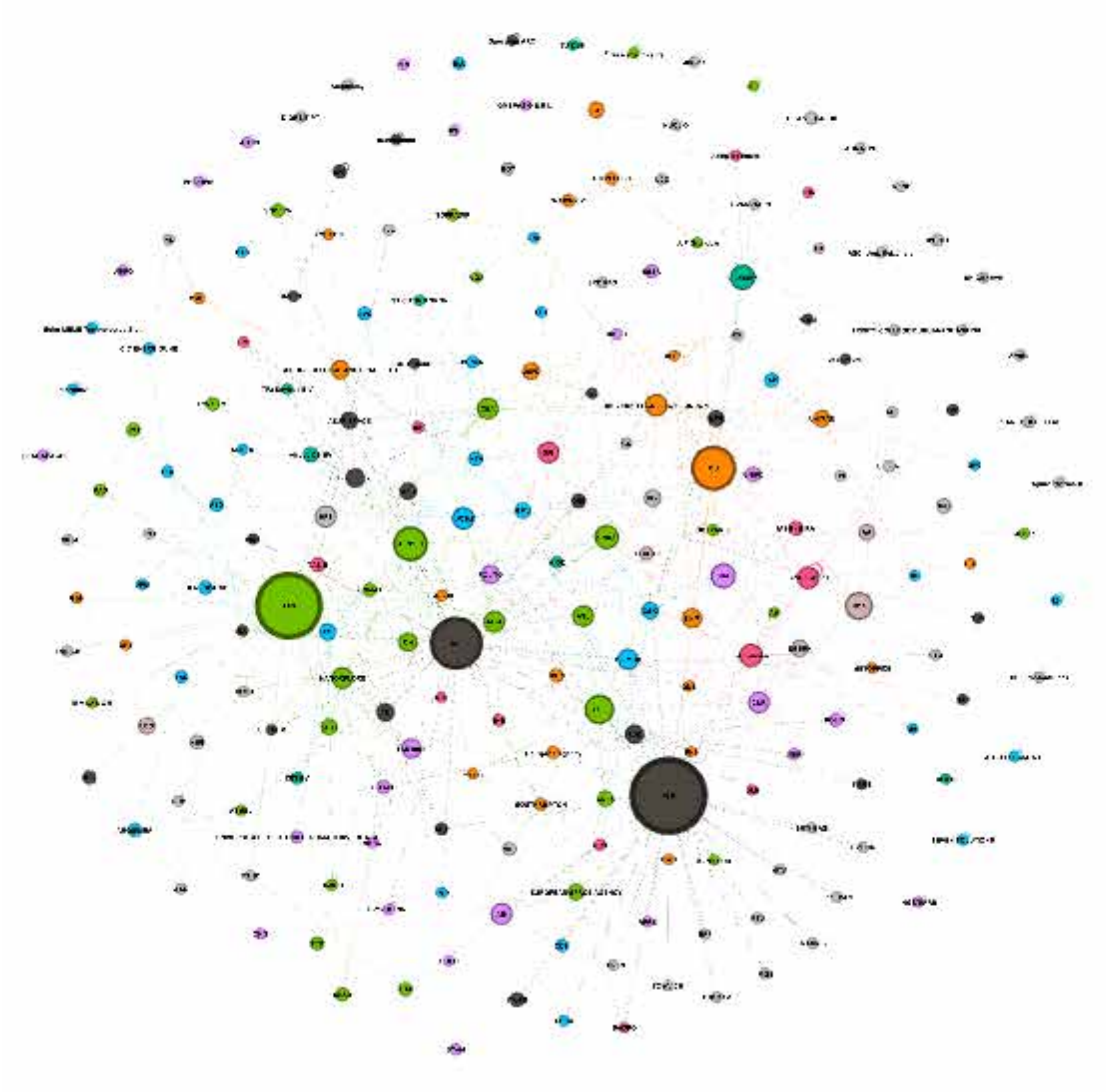


Figure A5.11: H2020-Space – HMFL – Agents Network by Country.

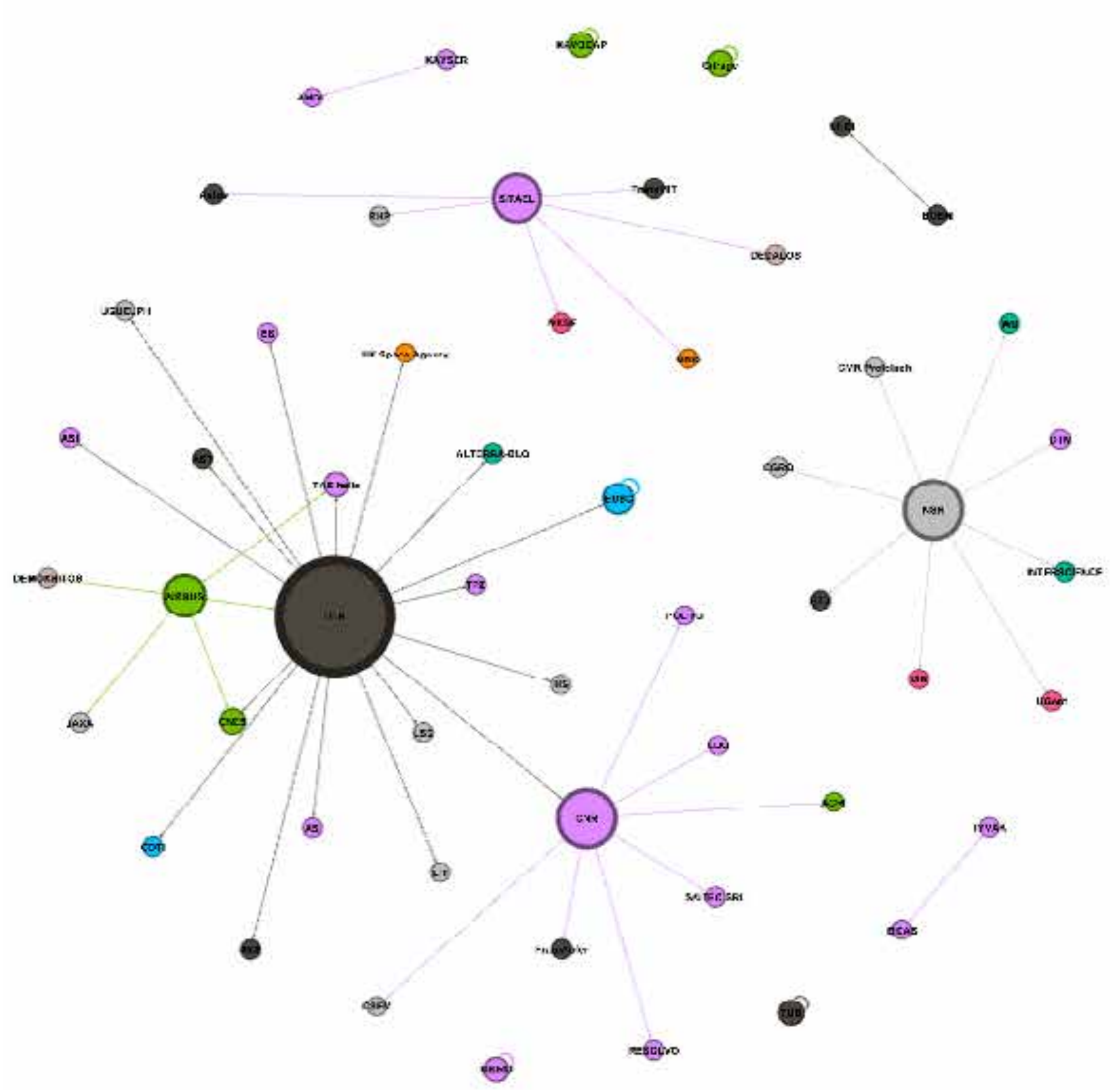


Figure A5.12: H2020-Space – LNCH – Agents Network by Country.

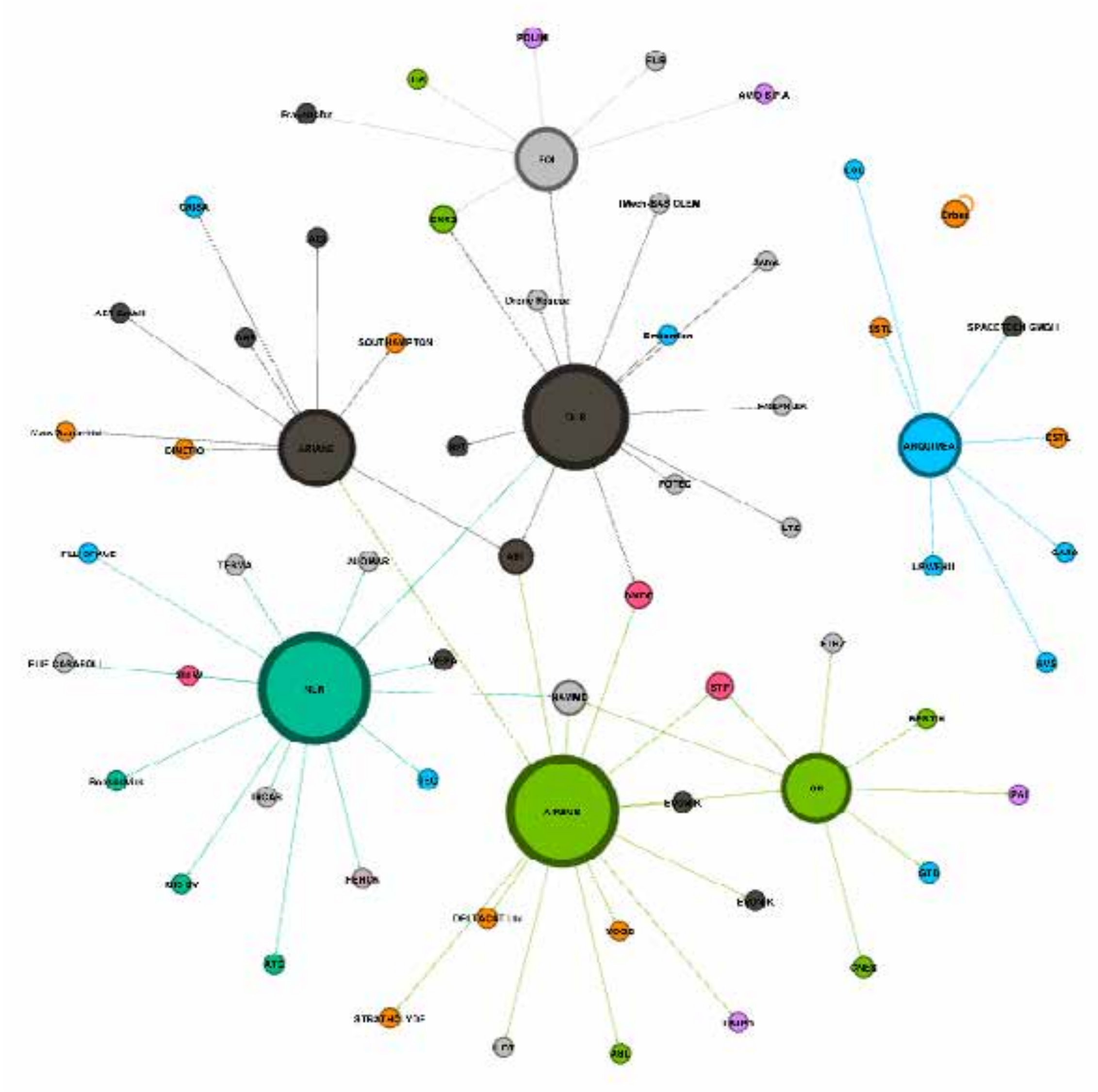


Figure A5.13: H2020-Space – NAVI – Agents Network by Country.

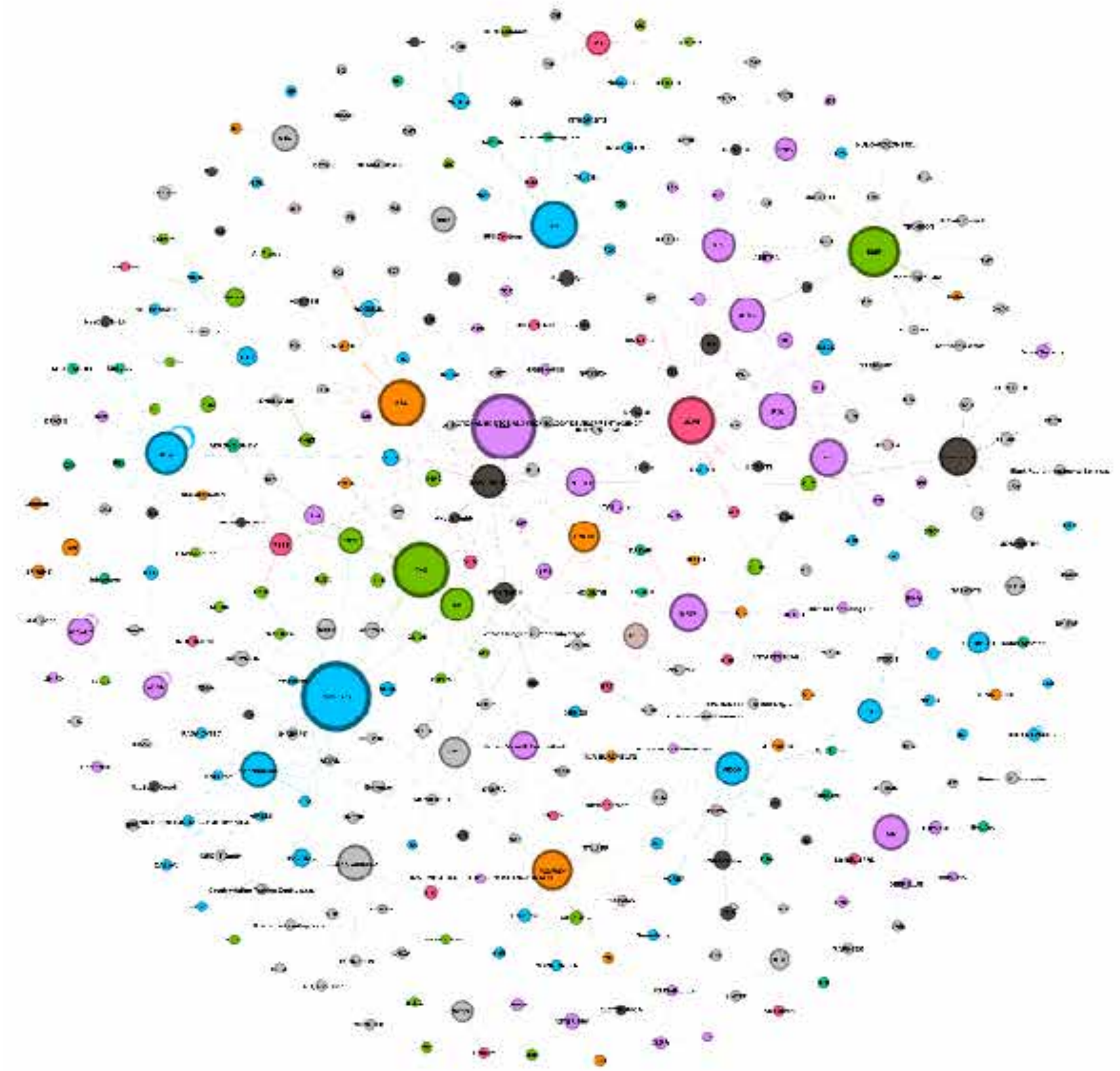


Figure A5.14: H2020-Space – RBEX – Agents Network by Country.

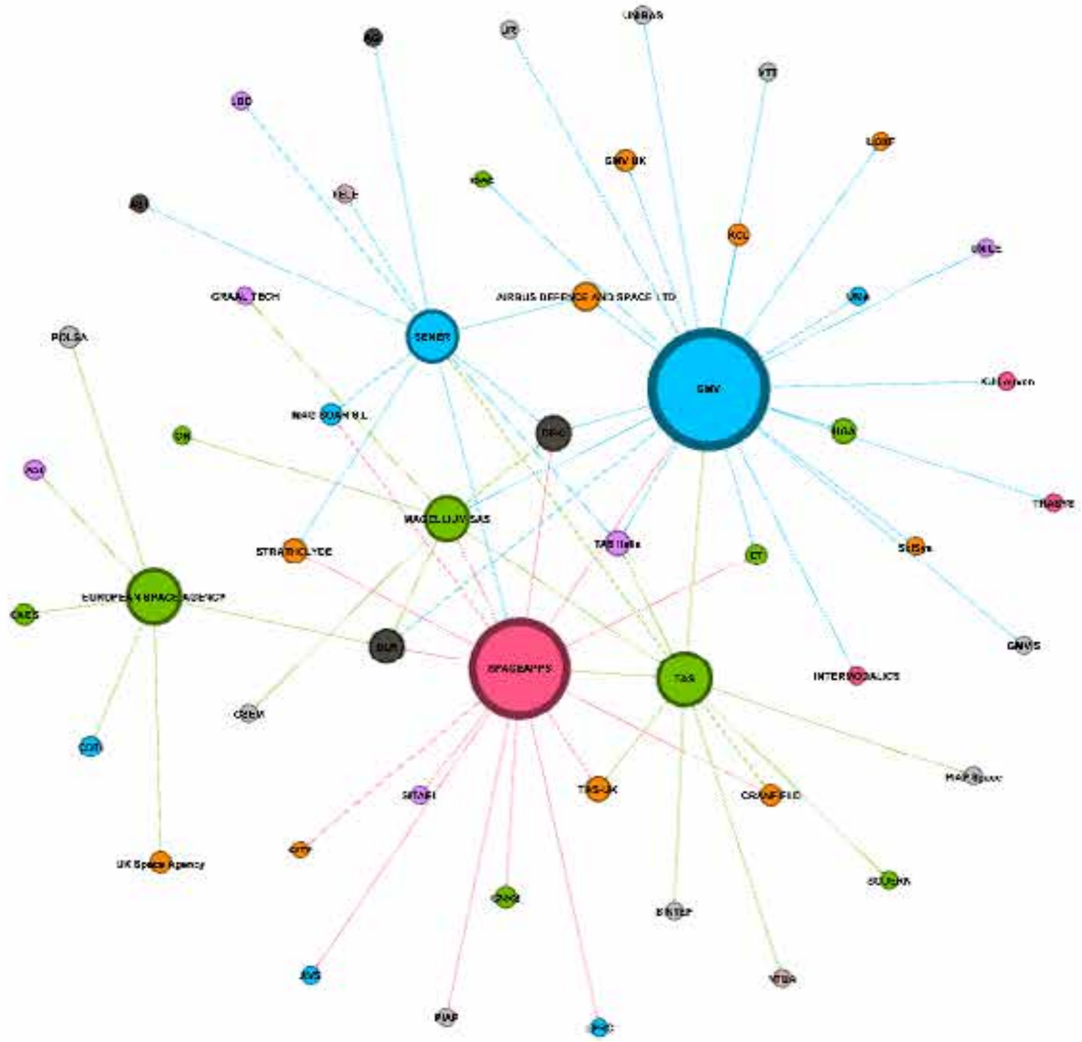
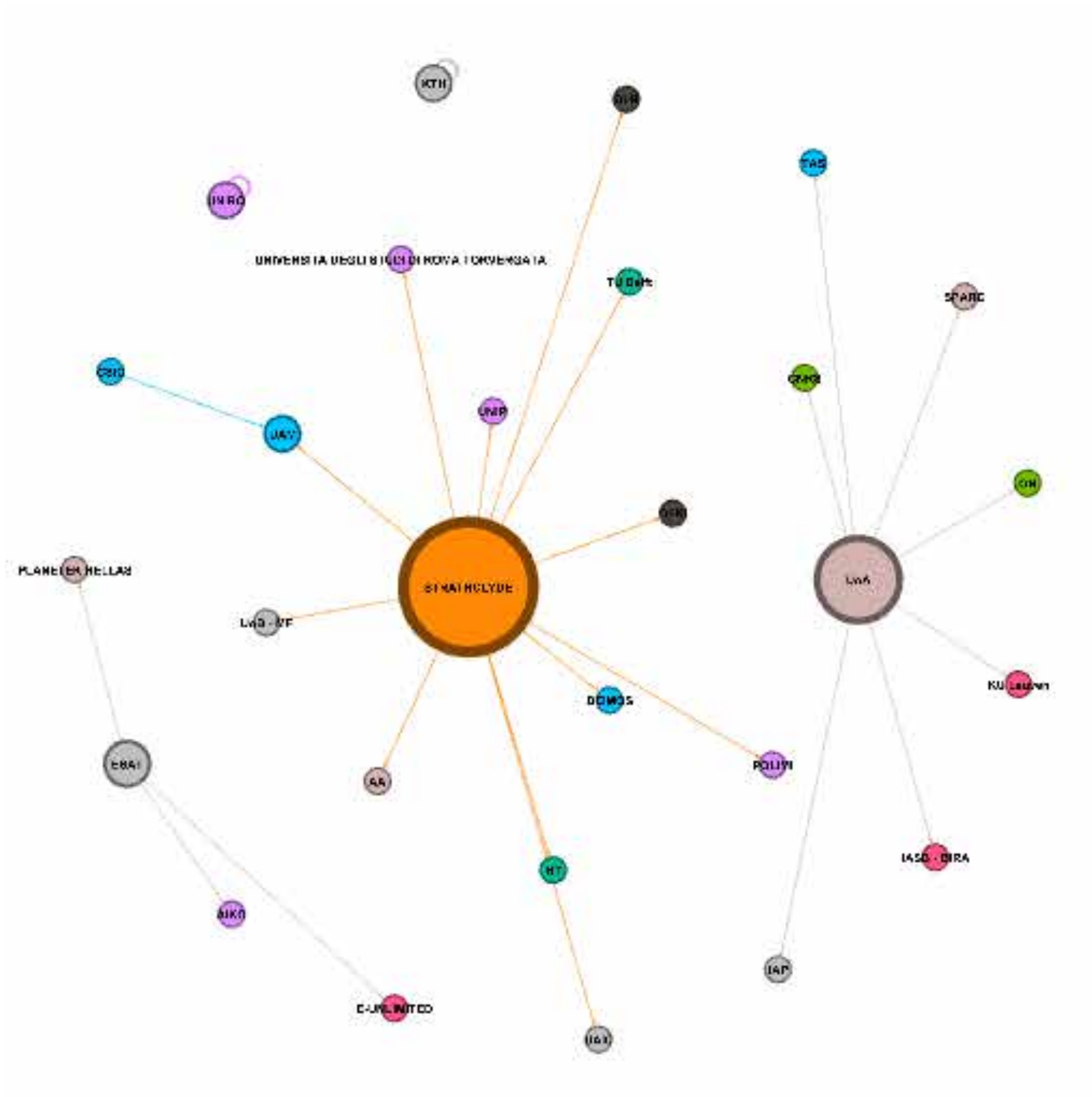


Figure A5.15: H2020-Space – SCNC – Agents Network by Country.



H2020-Space - Agents Network Evolution over Time.

Figure A5.16: H2020-Space – Agents Network. 2014-2014

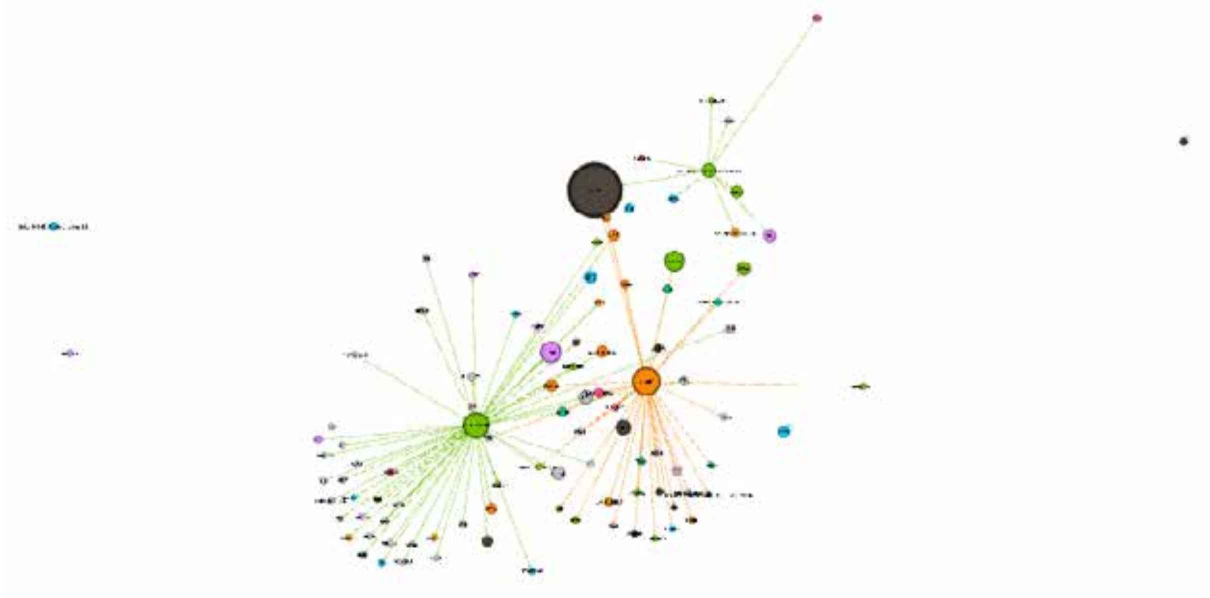


Figure A5.17: H2020-Space – Agents Network. 2014-2015

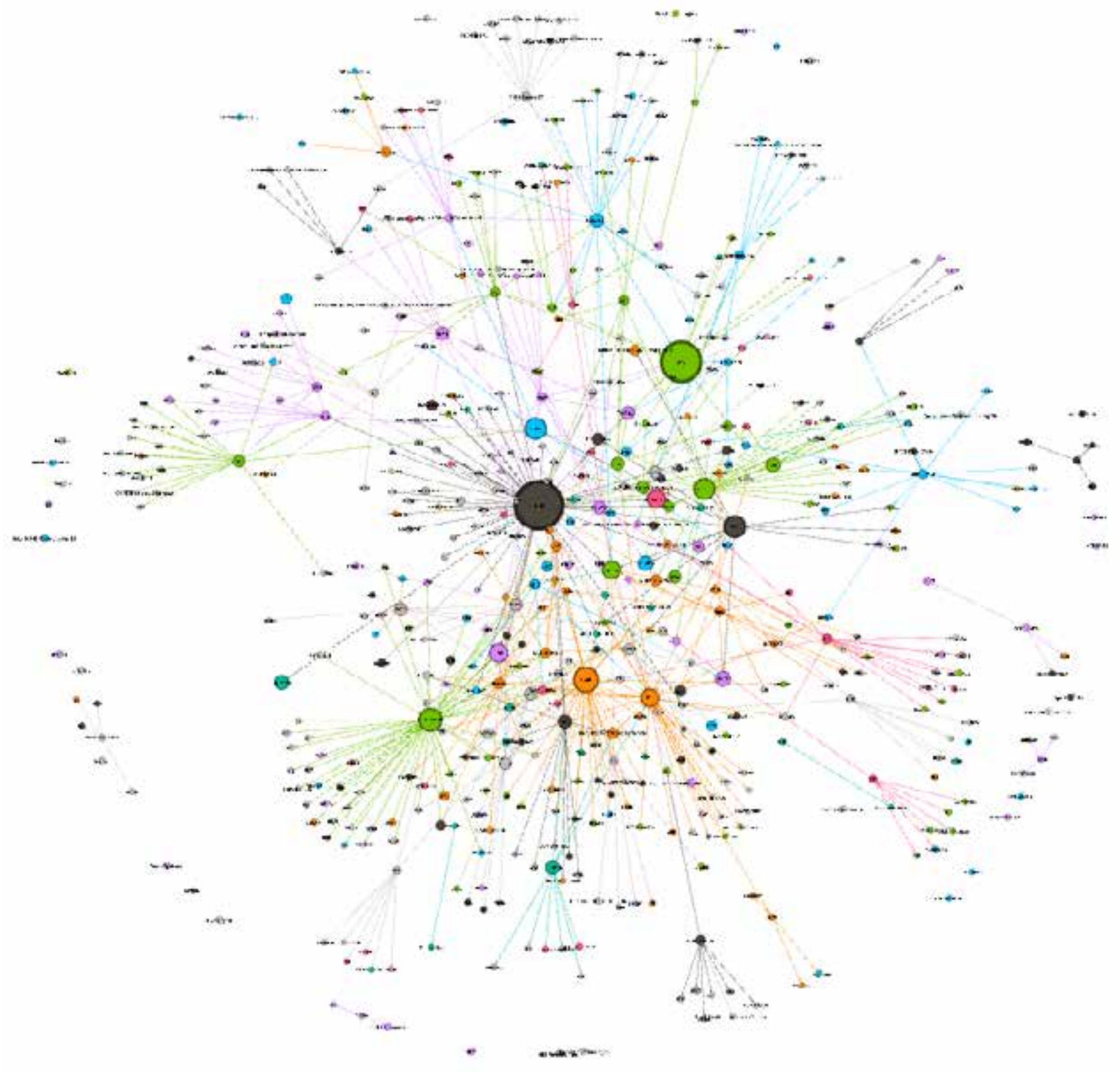


Figure A5.18: H2020-Space – Agents Network. 2014-2016

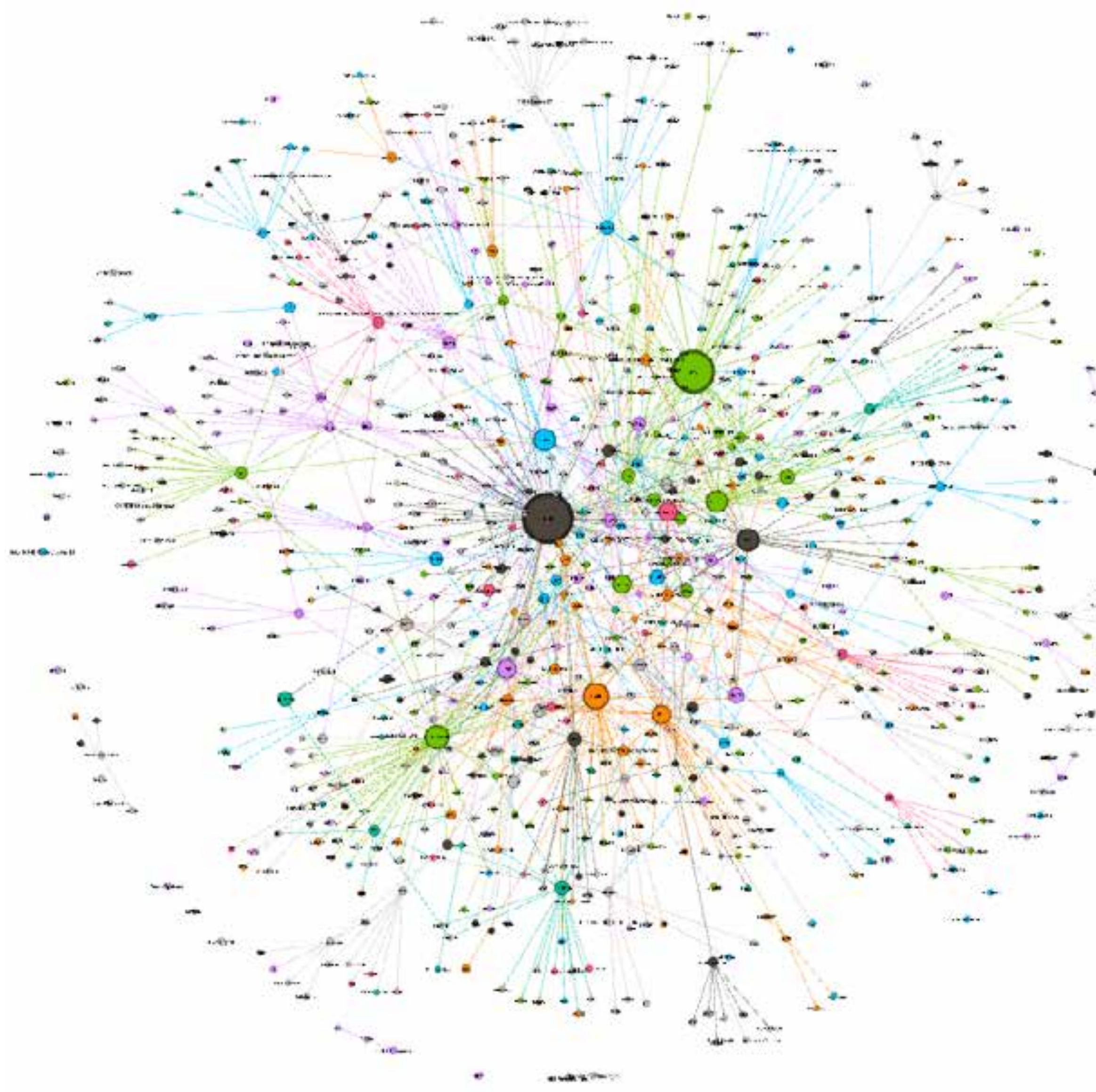


Figure A5.19: H2020-Space – Agents Network. 2014-2017

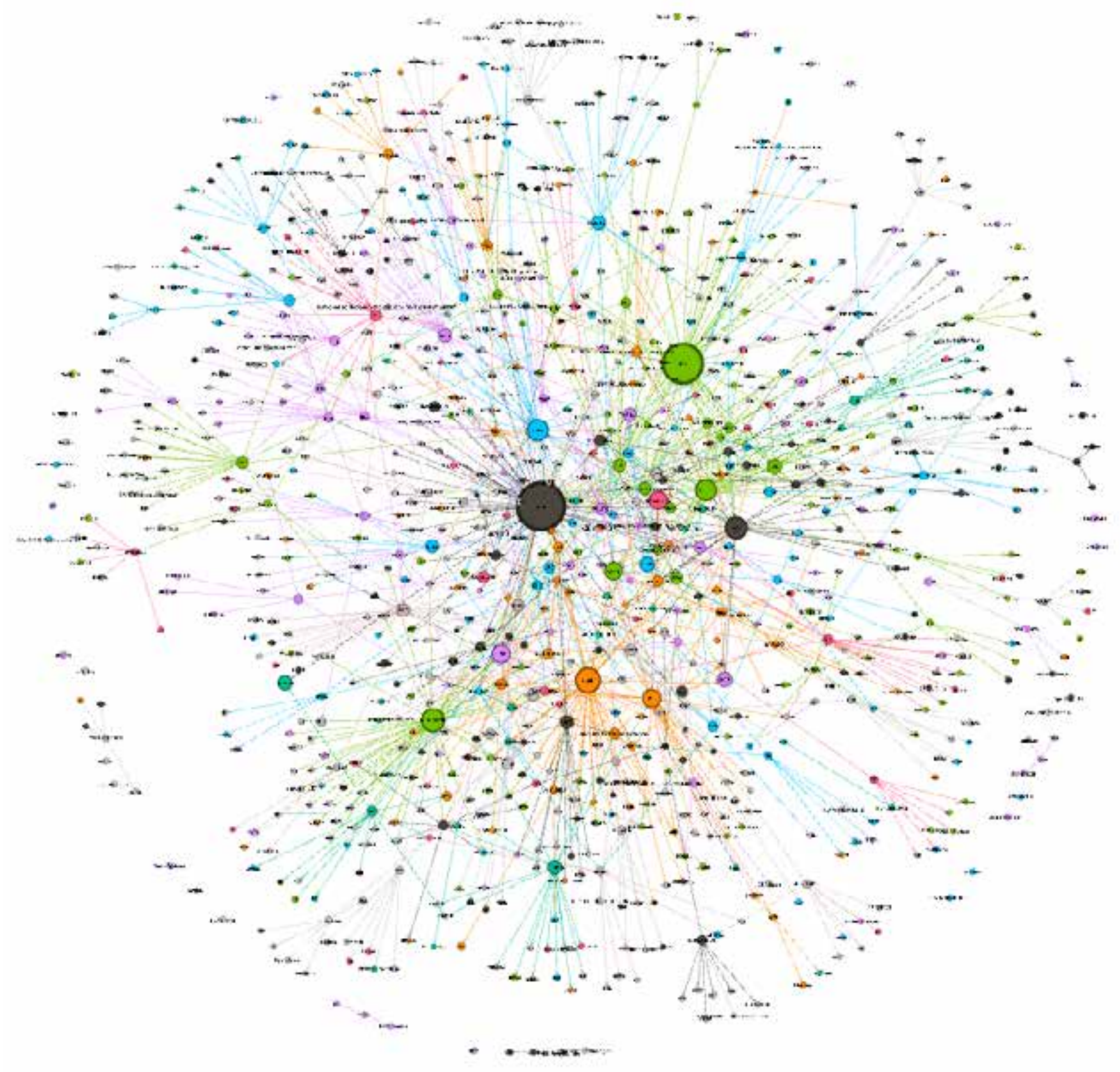


Figure A5.20: H2020-Space – Agents Network. 2014-2018

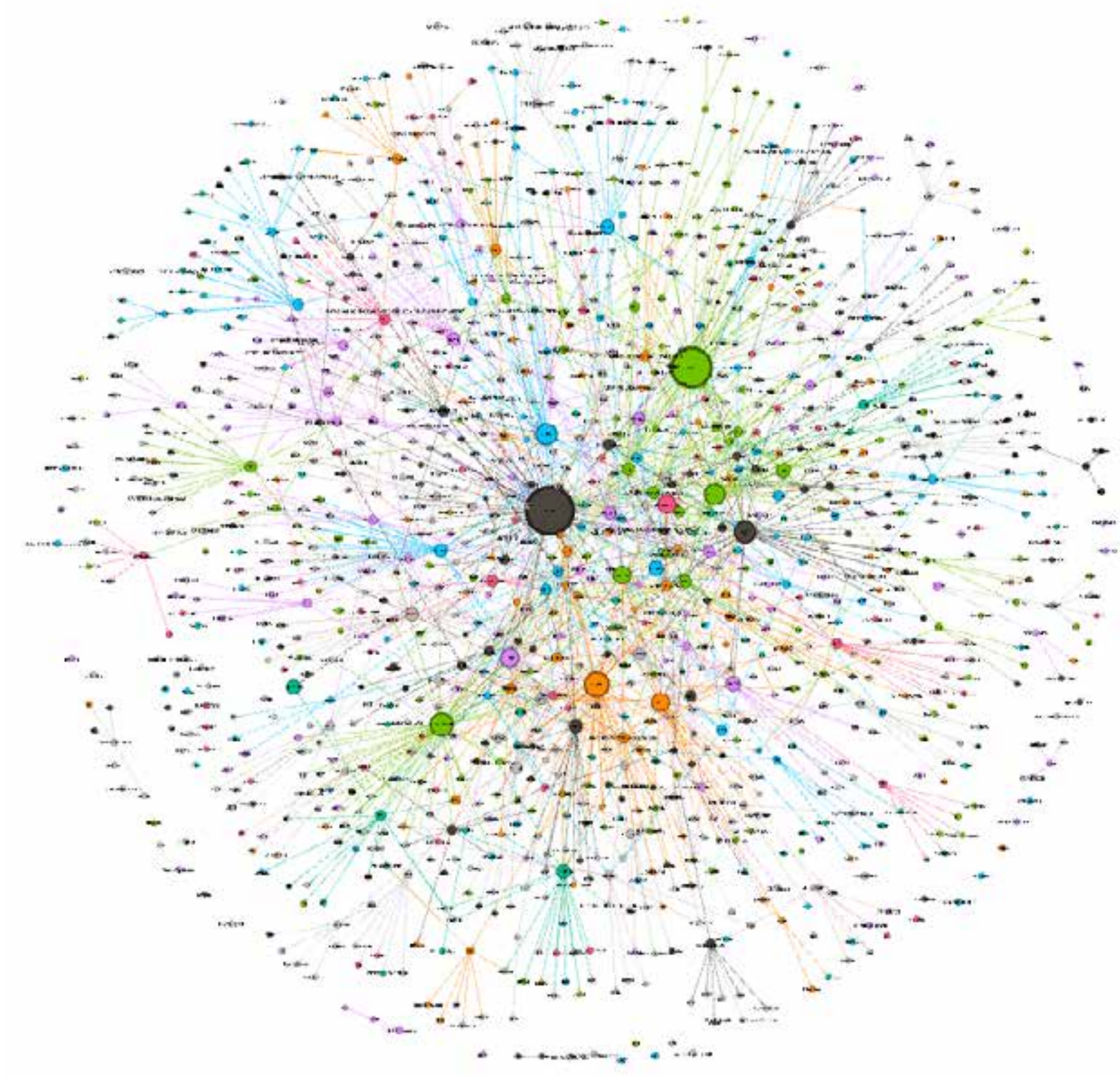


Figure A5.21: H2020-Space – Agents Network. 2014-2019

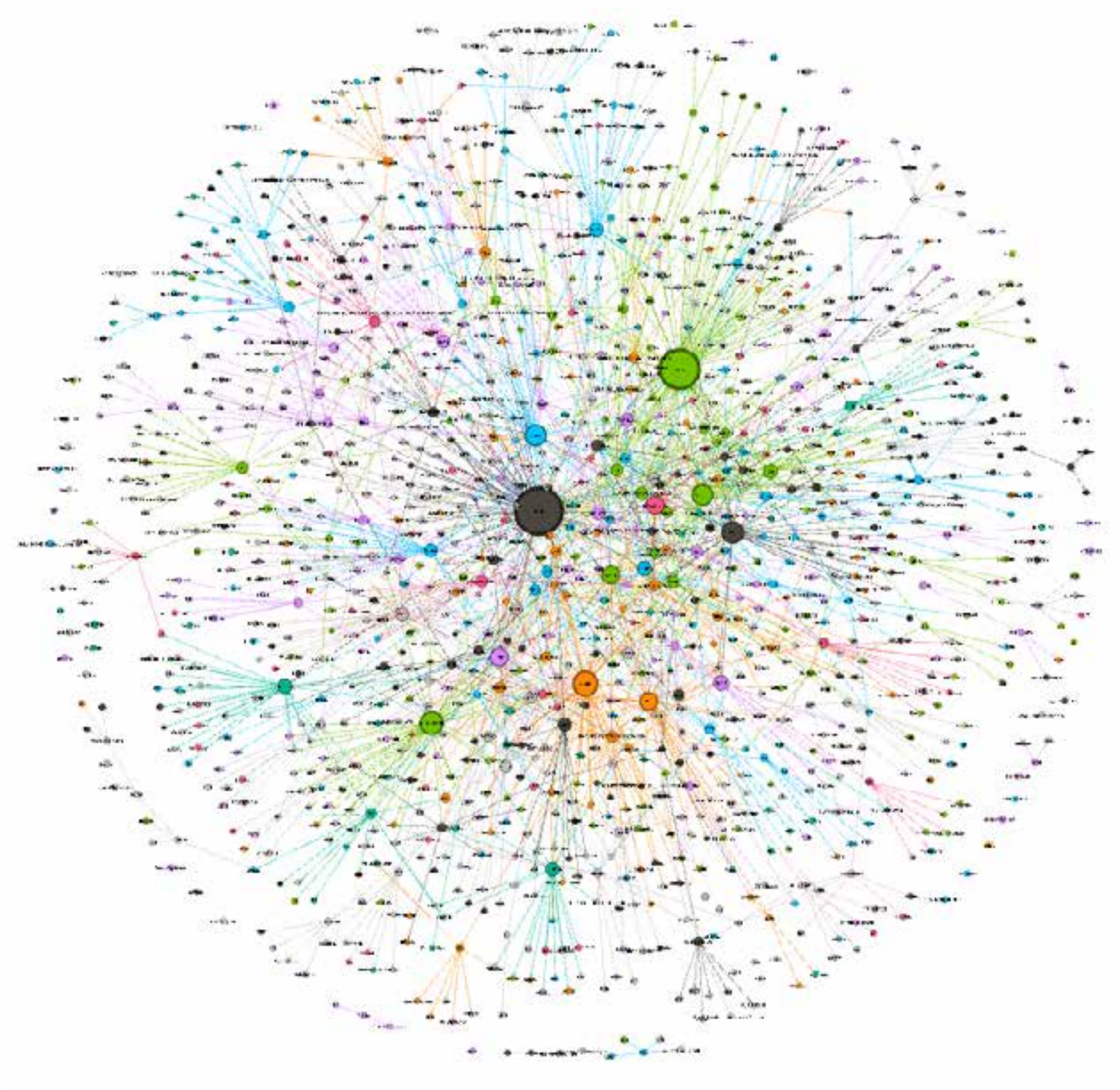
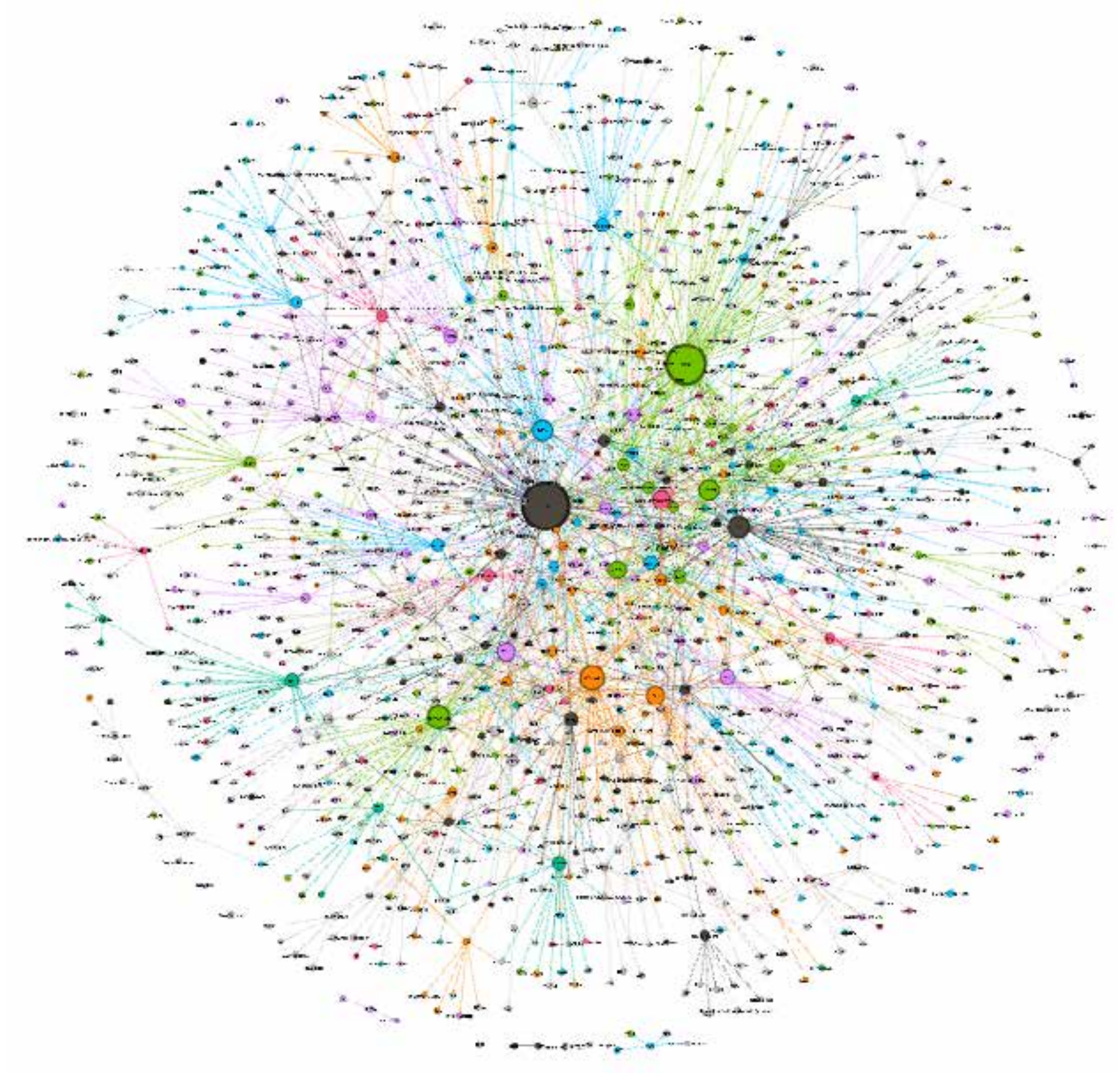
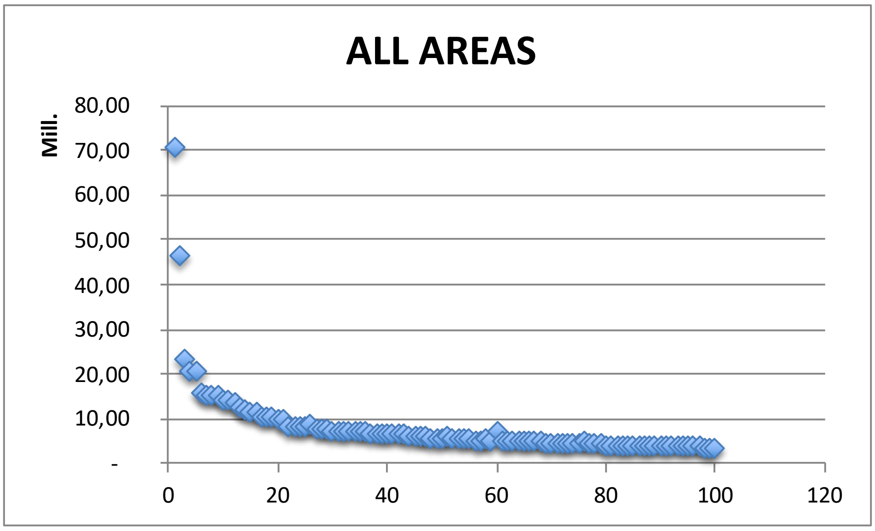
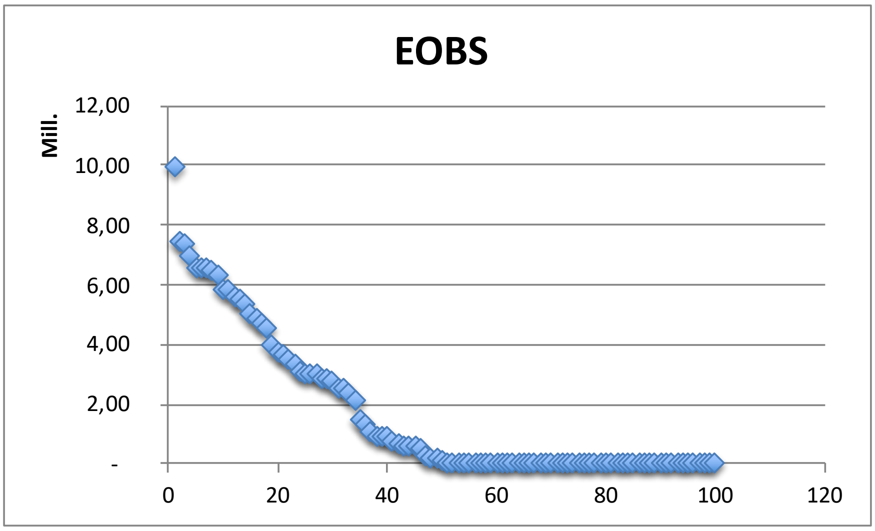


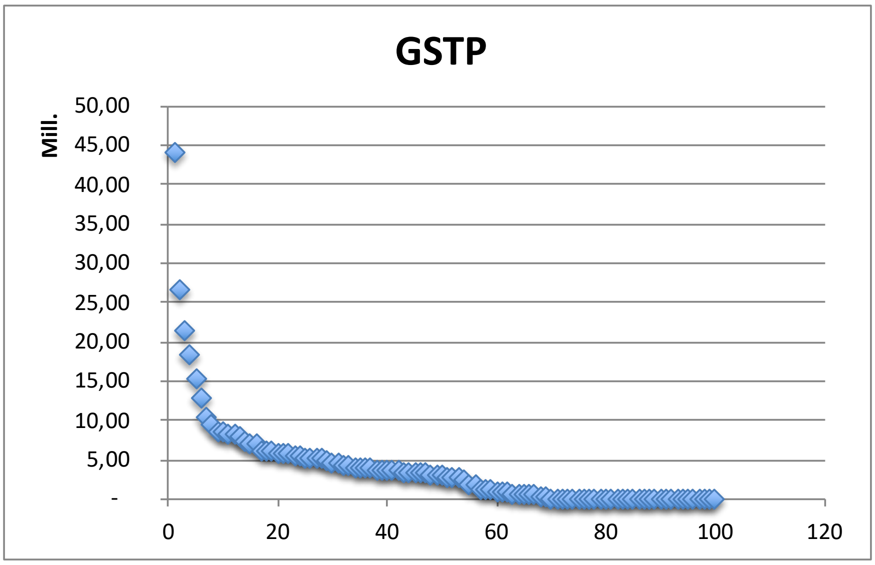
Figure A5.22: H2020-Space – Agents Network. 2014-2020

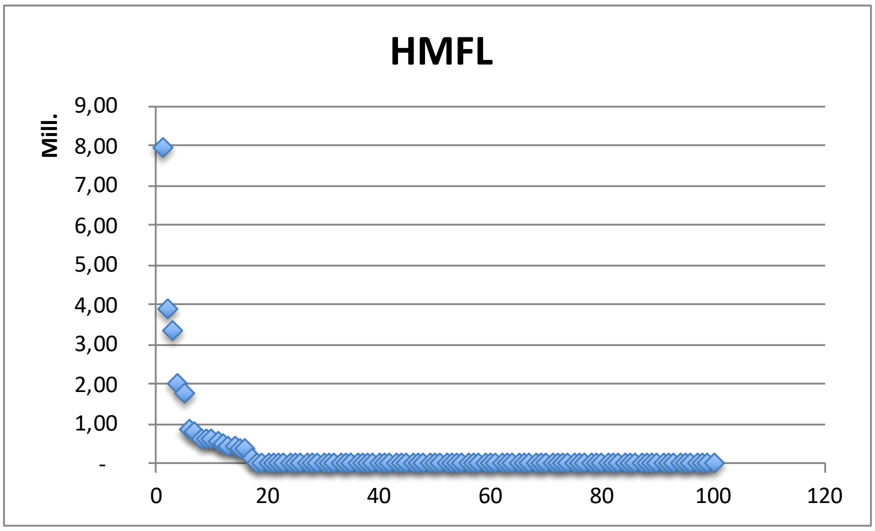


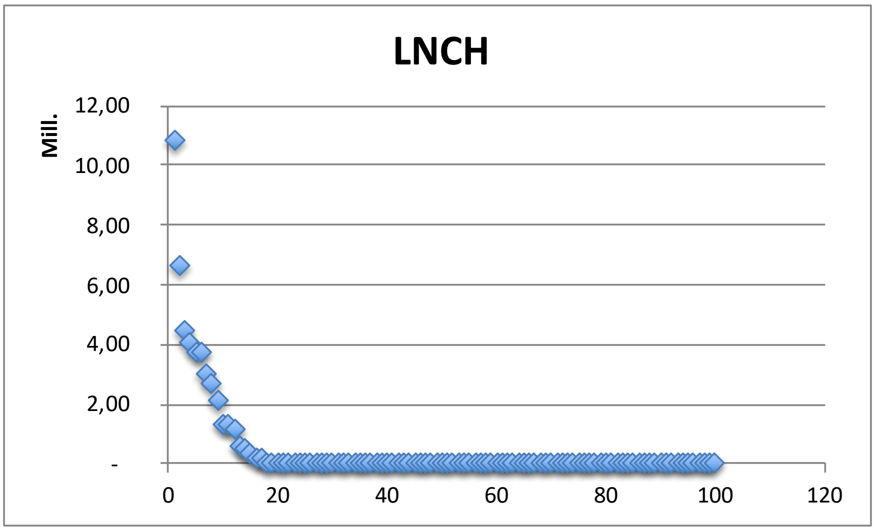
Agents Network Degree distribution by Activity Area.

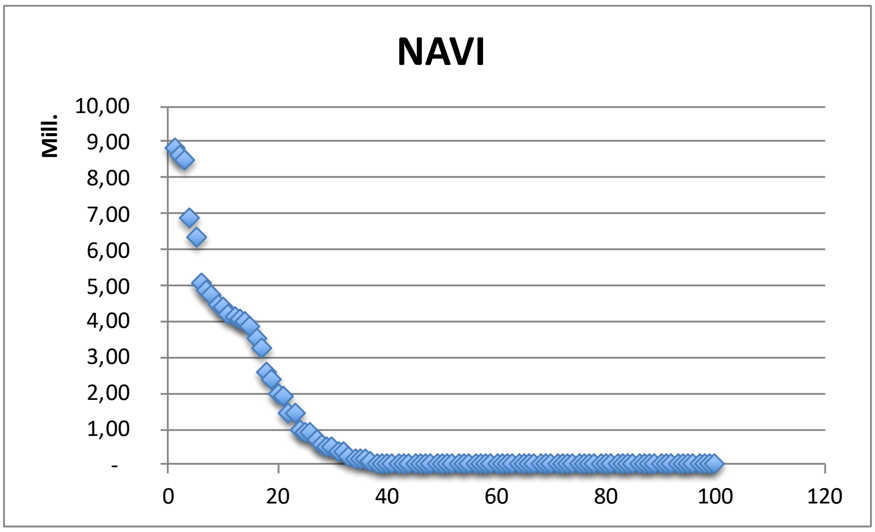


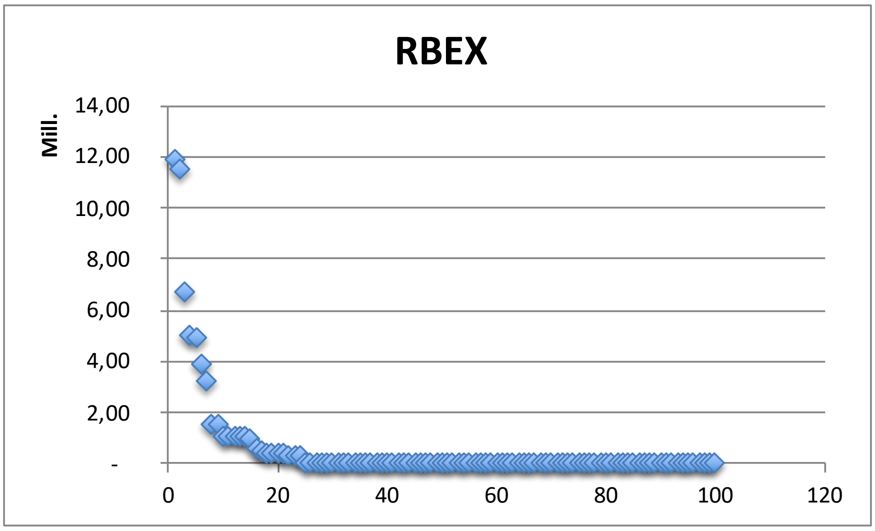


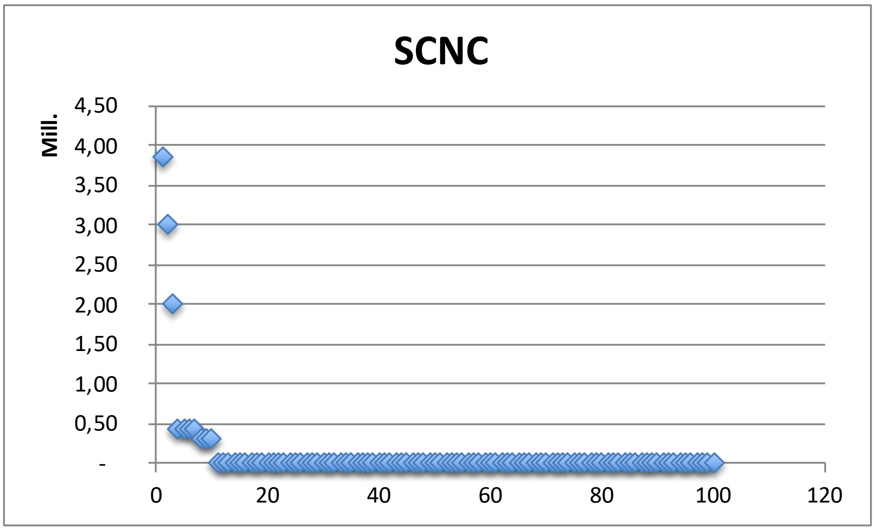



HMFL
Mill.
9,00
8,00
7,00
6,00
5,00
4,00
3,00
2,00
1,00
-
0
20
40
60
80
100
120


LNCH
Mill.
12,00
10,00
8,00
6,00
4,00
2,00
-
0
20
40
60
80
100
120


NAVI
Mill.
10,00
9,00
8,00
7,00
6,00
5,00
4,00
3,00
2,00
1,00
-
0
20
40
60
80
100
120


RBEX
Mill.
14,00
12,00
10,00
8,00
6,00
4,00
2,00
-
0
20
40
60
80
100
120


SCNC
Mill.
4,50
4,00
3,50
3,00
2,50
2,00
1,50
1,00
0,50
-
0
20
40
60
80
100
120

Agents' Network metrics by Area vs Random Networks.

AGENTS' Network	ALL AREAS	Random	EOBS	Random	GSTP	Random	HMFL	Random	LNCH	Random	NAVI	Random	RBEX	Random	SCNC	Random
nodes	1,258	1,258	447	447	543	543	54	54	65	65	353	353	52	52	28	28
edges	2,102	2,107	634	617	797	742	51	53	69	64	437	433	89	87	25	26
% nodes	100%		36%		43%		4%		5%		28%		4%		2%	
Wiring Probability		0.0027		0.001		0.05		0.037		0.04		0.007		0.063		0.07
Network overview																
Average Degree	1.671	1.675	1.418	1.380	1.468	1.366	0.944	0.981	1.062	0.985	1.238	1.227	1.712	1.673	0.893	0.929
Average Weighted Degree (M€)	1.233		0.863		1.221		0.875		1.109		0.798		1.499		0.849	
Diameter	12	14	9	15	9	15	4	10	6	19	11	14	5	6	3	8
Radius	0		0		0		0		0		0		0		0	
Average Path length:	4.429	5.958	4.46	5.93	4.18	6.09	2.30	4.23	3.31	7.37	4.97	5.98	2.79	3.11	1.90	3.91
Density:	0.003	0.003	0.006	0.006	0.005	0.005	0.036	0.037	0.033	0.031	0.007	0.007	0.066	0.066	0.066	0.069
Modularity:	0.668	0.578	0.683	0.642	0.679	0.638	0.703	0.678	0.690	0.700	0.799	0.672	0.468	0.443	0.593	0.586
Number of Communities:	63	69	25	47	50	59	12	12	7	14	24	50	6	8	6	8
Number of triangles:	659	6	111	5	169	3	2	1	4	2	48	2	29	7	0	1
Number of paths (Length 2):	38,889	7,138	7,443	1,684	11,063	2,049	236	86	375	114	2,890	554	981	305	91	41
Value of Clustering Coefficient:	0.051	0.003	0.045	0.009	0.046	0.044	0.025	0.035	0.032	0.053	0.050	0.006	0.089	0.069	0.000	0.000
Number of Weakly Connected Components:	44	49	9	32	33	42	10	8	3	7	11	38	1	4	5	

AGENTS' Network	ALL AREAS	Random	EOBS	Random	GSTP	Random	HMFL	Random	LNCH	Random	NAVI	Random	RBEX	Random	SCNC	Random
Node Overview																
Average Clustering Coefficient:	0.175	0.002	0.177	0.009	0.166	0.003	0.277	0.064	0.238	0.057	0.177	0.003	0.497	0.056	0.000	0.094
Eigenvector centrality	0.025	0.206	0.016	0.079	0.015	0.102	0.004	0.008	0.004	0.012	0.032	0.057	0.001	0.006	0.003	0.005
triangles / nodes	0.346	0.005	0.221	0.011	0.227	0.006	0.037	0.019	0.062	0.031	0.113	0.006	0.365	0.135	0.000	0.036
nw triangles / nodes	0.524	0.005	0.248	0.011	0.311	0.006	0.037	0.019	0.062	0.031	0.136	0.006	0.558	0.135	0.000	0.036
n paths (length 2) / nodes	30.913	5.674	16.651	3.767	20.374	3.773	4.370	1.593	5.769	1.754	8.187	1.569	18.865	5.865	3.250	1.464
connected comp/nodes	0.035	0.039	0.020	0.072	0.061	0.077	0.185	0.148	0.046	0.108	0.031	0.108	0.019	0.077	0.179	0.000

Agents' Project participation metrics - *Horizon 2020* (2014-2020)

Type Code:

Agent type classification.

Description of Activity Type	Code
• Private for-profit entities, excluding Higher or Secondary Education Establishments	(PRC)
• Research Organisations	(REC)
• Higher or Secondary Education Establishments	(HES)
• Public bodies excluding Research Organisations and Secondary or Higher Education Establishments	(PUB)
• Other	(OTH)

 # Nodes:

We count up the number of agents (nodes) per type which participate in *H2020-Space* projects from 2014 to 2019. The percentage we show is the distribution percentage of each type of agent. As we can see, Private for-profit entities, excluding Higher or Secondary Education Establishments (PRC) hold 55% of total agents with at least one participation in one project. Then, Higher or Secondary Education Establishments (HES) with 18% and Research Organisations (REC) with 15% follow.

C. Nodes:

These columns show how many of those agents of each type have been acting as Coordinator in, at least, one project. Although PRC lead the coordinating role with 22% of PRC agents acting as coordinator, REC and HES with 18% and 17% are not too far. However, those percentages fall to 10% for Public bodies excluding Research Organisations and Secondary or Higher Education Establishments (PUB) and Other Agents (OTH) get 14%.

 # Coord:

Here we count up how many times a project is been coordinated by a given type of agent. We find PRC with 60%, leading this ranking with more project coordination roles than the corresponding 55% of agent type distribution. We also may highlight how PUB have only coordinated 2% of projects whilst they are 6% of agents. REC, HES and OTH do not show much differences between the type distribution and project coordination role.

 # Part:

These columns show the number and percentage of times an agent has participated in a project, distributed by activity type. Although we have to be aware there are several projects (58 of 347 meaning 16.7%) where the coordinator is the only participant, the effect is not really high as those 58 participations are very low compared with the 2102 participations. We see PRC figures at 47%, lower than the expected 55% of number of PRC agents. However, REC and HES increase their share in 4% and 3% respectively. PUB and OTH keep 6% percentage.

 # Self:

This column shows the number of times the coordinator is the only participant in one project. These figures will help us to calculate the actual number of participations in projects. Projects of this type mean 16.7% of the 347 considered, most of them (82%) belonging to a single PRC.

Total part:

The obtained figures sum the coordination and the participation roles and subtract the number of times the coordinator is the only participant. These figures give us percentages not certainly different to the number of participations in projects analysed above.

Avg Part:

The average of participation in projects per activity type of agents is calculated as the quotient of the total participations and the number of nodes for each type.

We can see hoy REC and HES lead this ranking while PRC gets the lowest rate. The specialisation of companies and the multiple university departments and different research tracks in technological centres may explain those differences.

CORDIS Dataset - EU research projects under *Horizon 2020* (2014-2020)

Editor: Oficina de Publicaciones »

Description

This dataset contains projects and related organisations funded by the European Union under the Horizon 2020 Framework Programme for research and innovation from 2014 to 2020.

The file 'H2020 Projects' contains the public grant information for each project. Including the following information: Record Control Number (RCN), project ID (grant agreement number), project acronym, project status, funding programme, topic, project title, project start date, project end date, project objective, project total fund, EC maximum contribution (commitment), call ID, funding scheme (type of action), coordinator, coordinator country, participants (ordered in a semi-colon separated list), and participant countries (ordered in a semi-colon separated list).

The participating organisations are listed in the file 'H2020 Organisations' that includes the following information: Record Control Number (RCN), project ID, project acronym, organisation role, organisation ID, organisation name, organisation short name, organisation type, participation ended (true/false), EC contribution, and organisation country.

The periodic or final report summaries (or publishable summaries) from the projects have been included since September 2018.

The lists of publications and deliverables from the projects have been included since May 2019.

Reference data (programmes topics, funding schemes (types of action). organisation types and countries) are available at:

https://data.europa.eu/euodp/en/data/dataset/cordisref-data

CORDIS datasets publish monthly. Therefore, inconsistencies may occur between what is presented on the CORDIS live website and the finally published datasets.

Horizon 2020 principal investigators and MSCA researchers were last extracted November 2018.

Eurovoc fields:

Science and technology. Government and public sector

Resource file names:

- *DESCARGARH2020 Organisations* EXCEL XLS
- *DESCARGARH2020 Organisations* CSV
- *DESCARGARH2020 Project publications* CSV
- *DESCARGARH2020 Project publications* EXCEL XLSX
- *DESCARGARH2020 Projects* CSV
- *DESCARGARH2020 Projects* EXCEL XLS
- *DESCARGARH2020 Projects (individual XML files)* ZIP
- *DESCARGARH2020 Report summaries* EXCEL XLS
- *DESCARGARH2020 Report summaries* CSV
- *DESCARGARH2020 Report summaries (individual XML files)* ZIP
- *DESCARGARH2020 project deliverables* CSV
- *DESCARGARH2020 project deliverables* EXCEL XLSX
- *DESCARGARPrincipal Investigators in Horizon 2020 ERC projects* EXCEL XLS
- *DESCARGARResearchers in H2020 MSCA projects* EXCEL XLS

Visualizations

- *VISUALIZARCORDIS H2020 organisations' collaboration network*

Landing Page	https://cordis.europa.eu/
Título alternativo	H2020 research projects
Fecha de publicación	2015-07-29
Fecha de modificación	2018-12-10
Periodicidad de acumulación	mensual
Idioma	inglés
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