Macro-economic determinants of brain drain in the EU:
An empirical gravity model approach

Michele Cincera, Christophe Colassin, Ela Ince
ULB, Solvay Brussels School of Economics and Management, iCite

1. Introduction

Despite the controversy in perceiving the mobility outflows of high-skilled labour as a source of knowledge inflows in case of its return, continuous net mobility outflows have been considered as brain drain for a country. Brain drain has been widely highlighted as a phenomenon that impedes economic growth and governments have been concentrating their efforts on putting in place mechanisms to facilitate brain gains. The focus on the mobility of highly skilled labour over other groups is also due to the fact that this group of labour is the most mobile labour force in an economy. Attracting talented labour flows have been long perceived as an important source of knowledge creation and flows, as well as an important source of competitive advantage in modern economies.

Brain drain has damaging consequences for the confronting economies. For under-developed and developing economies brain drain towards developed economies constitute big losses in terms of skills, ideas, innovation, and critical services (OECD, 2008). In the case of developed regions, and in particular, looking at the European Union (EU) Member states that experience brain drain (Lutz et al., 2019), it is shown that the continuous brain drain may lead to a decreasing and aging population and a population with lower levels of education.

Career-related factors are important in the decision and the location choice of researchers' mobility together with labour market-related factors and funding, personal and family-related factors, the scientific domain, and the sector of activity. Technological proximity is also among the main factors that determine scientists' destination choice.[1] The stylized facts about the location choice of researchers show that mobility is largely taking place among developed economies (Florida, 2003; Docquier and Rapoport, 2012; and Kerr et al. 2016). Among the developed economies, the US and the UK have been for long the most attractive countries and recent research shows the rising attractiveness of China.[2]

The EU stands as a special case of interest among the developed regions due to its heterogeneity across Member states in terms of mobility flows of researchers. At the international level, the EU has been in deficit in terms of the mobility of scientists vis-à-vis other attractive developed countries such as the United States, Canada, Australia, and New Zealand, and losing mostly its top researchers.[3] The situation is, recently, even more, exacerbated with the Brexit.[4]

[1] Drivas et al. (2020) shows that the technological proximity is the main factor that determine the scientists' destination choice in mobility using patent data.
[2] Using scientific publications data, Verginer and Riccaboni (2021) analyse the changes in affiliations of scientists and show the striking rise of Beijing, China as the destination choice of scientists for mobility since early 2000s.
[3] Docquier and Rapoport (2012) provide a case study on the brain drain of the EU based on the figures presented in the beginning of 2000s for the EU15.
[4] 4

In terms of policy making, the EU policies that seek to increase the mobility of researchers in the EU face the challenges of a heterogeneous and unlevelled setting across countries.
The European Research Area (ERA) has been in place since the beginning of the 2000s with the objective to increase cooperation and coordination between the European states through pan-European initiatives. The pan-European initiatives are ranging from funding opportunities for research & innovation to removing barriers to researchers' mobility and improving the working conditions of researchers by establishing the set of principles and requirements in appointing and recruiting researchers.

The objective of the current note is to investigate the determinants of mobility of researchers within Europe from the perspectives of the countries of origin and destination. We use a gravity model framework to detect quantitatively the pull and push factors of researchers' mobility within Europe including 28 EU Member states in 2019 and 3 additional Associated countries, Norway, Iceland, and Switzerland.[5] The analysis brings together information from different data sources. The information about the mobility outflows is sourced from Centre for Science and Technology Studies (CWTS) and shows the flows with respect to the country of origin (first publication) and the country/ies of destination of the researchers. This dimension is calculated based on the scientometric data and refers to the period 2009-2019. In order to analyse the macroeconomic determinants of mobility outflows of researchers, the paper sources country-level information from the rankings of EUROSTAT, European Innovation Scoreboard (EIS), World Bank, Centre d'Études Prospectives et d'Informations Internationales (CEPII), She Figures Database of the European Commission, Quacquarelli Symonds World University Ranking, EURAXESS - Researchers in Motion initiative of the European Union, Elsevier's Scopus scientific publications database, OECD Database on Governance of Public Research Policy (RESGOV), V-Dem Dataset. The paper also uses survey data sourced from the latest Mobility and Career Paths of Researchers in Europe EU Survey Edition 4 (MORE4).[6]

The gravity model framework has been applied to several types of models in economics, in particular for dealing with trade and foreign direct investment,[7] in the analysis of migration[8] and knowledge flows.[9] It has also been used more recently in the study of inventor and researcher mobility.[10] The results of these studies looking at the knowledge flows and international mobility of scientists have highlighted two factors. As for country-specific characteristics, technological and economic proximity plays an important role in increasing knowledge flows and the mobility of researchers. As policy-related results, it is highlighted that immigration barriers and travel restrictions hamper both the knowledge flows and mobility of researchers. In this regard, our paper is distinguished from the existent studies analysing the mobility of researchers using the gravity model framework. We seek to investigate the determinants of brain drain within the EU Member and Associated States, i.e. within a setting

[5] The Schengen Area includes 26 European countries that have officially abandoned the border controls at the mutual borders. The Schengen Area encompasses most EU countries, except for Bulgaria, Croatia, Cyprus, Ireland, Romania and the UK in the time of analysis. The non-EU member countries are Norway, Iceland and Switzerland.
[6] It is the latest edition of the MORE database projects funded by the European Commission where the focus lies on the mobility, career paths, working conditions and remuneration of researchers in Europe. For the link of the project : https://www.ideaconsult.be/en/projects/more4-fourth-study-on-mobility-and-career-paths-of-researchers-in-europe
[7] See, for instance, Baldwin and Taglioni (2006), De Groot et al. (2004), Jansen and Piermartini (2009), Kleinert and Toubal (2010), Linders and De Groot (2006), Rose (2000), Zwinkels and Beugelsdijk (2010), Neumayer (2011), Cincera and Vu Thi (2006).
[8] See, for instance, Lewer and Van den Berg (2008), Clark et al. (2007), Karemera et al. (2000), Mayda (2005).
[9] See, for instance, Bergman and Usai (2009) and Orazbayev (2017).
[10] See, for instance, Appelt et al. (2015), Drivas et al. (2020).

where the country-level heterogeneities persist but the immigration and international travel barriers are eliminated across countries.

Following the main determinants of researcher mobility in the literature, we model the main determinants of brain drain by using geographic, cultural, and economic proximity, and by augmenting the baseline model with additional determinants of interest. Brain drain is measured as the outflows of researchers having left the country. The factors that influence the brain drain are grouped into several categories: human resources, entrepreneurial possibilities, funding and career-related factors, knowledge-intensive economy, R&D investments, openness, working conditions, virtual mobility, institutional factor, and socioeconomic factors and gender. The models are estimated by using OLS and Random Forest estimation methods. The Random Forest estimation method is a supervised machine learning algorithm that uses the combination of tree predictors and brings improvements in classification accuracy of determinants in an estimation (Breiman, 2001). The method has been shown to adapt and predict better than linear regression in the case of nonlinearities found in the data.[11] In our analysis, the method allows for determining the most important drivers of brain drain that otherwise will have remained hidden from traditional regression techniques due to multicollinearity when estimating the full model.

The paper is organized as follows. In section 2, we describe the related literature and in section 3, we present our data, descriptive statistics, and empirical model. In section 4, we present our econometric results. Section 5 concludes.

2. Review of the literature

The mobility of researchers has become an attractive topic in literature since there has been growing evidence on its impact on science, knowledge spillovers, and productivity. The literature expands from factors that influence the mobility of top researchers to early-stage mobility in academia looking at various factors related to the country of origin and destination.

In terms of destination, global cities benefit from higher rates of innovation in terms of patent and scientific publications, and Verginer and Riccaboni (2021) look at the relationship between the location choices of scientists and the innovative performance of global cities using scientific publications data. Sourcing data from scientific publications that cover the years from 1990 to 2009, the authors track the career paths of two million researchers worldwide. The results of the data analysis highlight the role of global cities. The authors find that the scientists that reside in global cities are more productive, measuring productivity through citation-weighted publications. As the results of the network analysis, the global cities are found to be at the centre of the network of intellectual mobility, both within and across national borders.

As country-level evidence from the United States, Azoulay et al. (2017) analyse the mobility of the “elite” academics in life sciences. The database is composed of 12,935 scientists in the United States that is around 5% of the relevant labour force. The life scientists are identified as elite if they satisfy at least one of the criteria of the authors listed as (i) highly funded scientists; (ii) highly cited scientists; (iii) top patent holders; or (iv) members of the National Academy of Sciences, (5) NIH MERIT awardees; (6) Howard Hughes Medical Investigators; or (7) early career prize winners. The paper considers the factors related to the conditions in the destination as well as the familial situation of the scientists. The results of the paper suggest that productive scientists are more mobile than others and the funding opportunities play a role in their mobility decision. The ranking difference between the institutions is found to have a non-significant

[11] See, for instance, Liu et al. (2017) and Schonlau and Yuyan Zou (2020).

impact. When it comes to the family factors and the factors related to the destination location, the authors find that the quality of the hosting environment plays a role in the choice of mobility as well as the family factors. The scientists' mobility decreases for those who have adolescent children and the effect is more pronounced among female scientists than among their male counterparts.

As another piece of evidence from the United States, Yan et al. (2020) examine the mobility decision of professors. The purpose of the paper is to distinguish the patterns in mobility decisions according to factors related to institutions, location of the destination, funding structure, and gender. The paper considers 5938 tenure-track and tenured professors of the United States that changed affiliations. The database is constructed through the matching of the 2018 version of ORCID and Carnegie Classification of Institutions of Higher Education (CCIHE) where the universities are ranked according to their level of research intensity. The results of the paper suggest that institution and location-related factors play a role in the choice of location as well as gender-specific factors. The professors tend to move more towards the highest-ranked universities in terms of research intensity, and more towards cities than rural areas. In terms of gender-specific factors determining the decision of mobility, female professors are identified to move to closer regions than their male counterparts and to be less likely to get promoted or retain their rank when they move to a higher-ranked university.

Gutherie et al. (2017) examine the mobility of scientists in the UK. The authors point out that researchers tend to concentrate in a few destination countries, and mobility tends to be directed mostly towards Western countries. In addition, they observe different patterns of mobility depending on gender, scientific discipline, nationality, and career stage. The findings suggest that female researchers are less likely to move than male researchers. In terms of the scientific discipline, researchers in the domain of arts and humanities are less likely to move abroad. In addition, the paper reports that non-nationals, as well as postdoctoral researchers, are found to be more mobile than their counterparts. According to the paper, the career-related factors are the main drivers of mobility, and the reasons not to move or return are a mix of family/personal life and career-related factors.

As evidence from the EU member states, Aceituno-Aceituno et al. (2014) examine the determinants of the mobility of researchers in health sciences using survey data on 284 Spanish researchers that moved abroad. The survey investigates the reasons for going abroad and for the choice of the country of destination, the measures that would allow a possible return from abroad, and the reasons to stay abroad. The most important factors that play a role in the departure of the health scientists are related to the research career prospects followed by remuneration. The main reasons behind the choice of the destination country are again related to the research career prospects followed by language fluency. The measures that would facilitate the return of the researchers are highlighted as funding and career-related prospects; and among the reasons hindering a return to Spain, the lack of economic prospects is highlighted the most followed by the lack of career prospects.

Concerning France, Bonnard et al. (2017) analyse the determinants of mobility decisions of Ph.D. graduates. The paper uses survey data concerning the 400 Ph.D. degree holders that obtained their Ph.D. in France and chose to work abroad for more than three months between the years 2003 and 2008 independently from the scientific discipline. The survey was conducted in 2012: 57% of the surveyed Ph.D. holders worked outside of France for at least three years and 41% of them were still abroad when the survey was conducted. The main factor for choosing a career abroad is the lack of appropriate labour demand in France. This also impacts the decision to stay longer than expected. The results of the survey highlight the family-related factors as the main reasons to move back to France.

There has also been European Union (EU)-wide evidence on the mobility of researchers in literature. Van der Vende (2015) investigates with a specific focus on Europe the reasons behind the scientists' tendency to migrate and the motivations for countries to attract them. Among the reasons for scientists to migrate, the paper emphasizes the economic differences in terms of R&D investments and the skill imbalances between countries. The paper underlines the shortages the EU may face in terms of researchers in its labour force and the cross-country imbalances in attracting researchers. In addition to the labour market and economic imbalances, the author argues that the current EU policies seeking to enhance researchers' mobility in Europe are short-term solutions and they seem to generate polarization where some countries in Europe are the winners and the others are the losers of these policies. In line with the traditional mobility patterns worldwide, the paper confirms that scientists' immigration tends to go from the south to the north, and from the east to the west in Europe. The skill concentration in Europe is being exacerbated by the top researchers of Europe due to their choice of location upon obtaining research funds. Multilingualism is also argued as one of the factors that enhance the attractiveness of countries for scientists in Europe.

In another study, Teichler (2015) compared the findings of surveys conducted in advanced countries, especially European countries, to understand academic mobility. The paper seeks to analyse the knowledge base on the academic mobility of actors in different stages from students to academicians. The paper distinguishes between two internationalization phenomena for Europe: mobility within Europe, so-called "Europeanisation", and international mobility as "globalization". The author sees "Europeanisation" as the regional version of "globalization". The conclusions of the paper highlight that insufficient attention is given to researchers' mobility in policy debates given the importance of this type of mobility on knowledge productivity. In addition, regarding researchers´ mobility, the author differentiates across types of mobility: early immigration; mobility during early career for the sake of learning or initiating early academic work; long-term mobility, and visits and sabbaticals.

Using the survey data throughout the EU 27 member states, collected within the MORE project funded by the European Commission, Boring et al. (2015) analyses the mobility of the researchers in academia and other research institutes. The majority of researchers responding to the survey have engaged in international mobility. Estimating the impact of key factors on international mobility patterns using binary logistic regressions, the paper investigates the effects of personal and family-related factors such as age, gender, marital status, and children, as well as career-related factors such as education and training levels and the researchers status. The findings of the paper are firstly pointing out a declining gender gap, finding a still negative yet less important impact of being female on international mobility with respect to the previous literature. The results do not indicate any significant impact of having children and marital status. Increasing age, however, is found to have a significant and negative impact. Second, the paper finds that the higher the education level of the researcher is, the more likely he or she will engage in international mobility. Natural sciences are found to be the scientific domain where the researchers engage in international mobility the most, albeit there is an increasing internationalization in social sciences and humanities in the last three years. Being internationally mobile during post-secondary education through student exchanges or industrial placements is also found to have a positive impact on mobility. Finally, the paper finds higher levels of international mobility for non-university researchers than university researchers.

The survey data collected within the MORE 4 project funded by the European Commission, which is the continuation of the MORE project, also included a global survey analysing the patterns of mobility of the researchers working outside of the EU.[12] The majority of the survey

[12] The most recent of these surveys can be found in MORE4:

respondents are American, followed by Asian and European researchers. The survey conducted in 2019 categorized the researchers as the EU researchers who worked abroad, and non-EU researchers who (i) worked in the EU; (ii) worked abroad but not in the EU; and (iii) never worked abroad. The MORE4 study (2020) highlights career-related factors followed by funding opportunities and access to the equipment as the most important factors that motivate mobility. The drivers of mobility are found to be the same for non-EU researchers as the EU researchers. As another result of the report, the EU is deemed to have a better quality of life concerning other destinations whereas non-EU countries are perceived as providing better remuneration and career prospects than the EU countries. From the perspective of the non-EU researchers, the barriers to mobility are highlighted as the language and visa permits. The non-EU researchers find the EU providing more guidance during their stay in the EU than the rest of the world and they experience positive effects of the mobility toward the EU in their career.

Regarding the econometric analysis, the gravity model has been proposed to analyse immigration and its drivers. Lewer and Van den Berg (2008) suggest that the gravity model of international trade can be useful to analyse immigration since immigration is also influenced by the discrepancies between the country of origin and the country of destination. The cost of the move in the case of immigration can also be interpreted along similar lines as the cost of transportation in trade. In the case of modelling immigration, the authors underline the difference between labour incomes of the host country and the country of origin; the sizes of the population in the countries; and the physical distance as the determinant of the moving costs as the main variables of interest. In addition, following the immigration literature, the authors take into account the earlier immigrant flows, the familiarity between the language and the culture among the determinants of immigration flows in their baseline model. Lewer and Van den Berg (2008) show that the baseline gravity model of immigration can be augmented by the additional variables of interest that may have an impact on immigration to test the marginal influence of additional variables. Similar to the analysis on immigration, Montobbio and Sterzi (2013) analyse the determinants of international collaborations of patent inventors using a gravity model framework. Sourcing the data from the United States Patent and Trademark Office, the paper looks at the collaboration of inventors in eleven emerging and seven developed countries between the years 1990 and 2004. Together with the main factors of language, costs of transportation and communication, and geographical distance; the results of the paper indicate that technological proximity is an important factor in collaboration. In addition, stronger intellectual property rights are found to harm collaboration except for the collaboration of inventors belonging to the same multinational firm.

Bergman and Usai (2009) look at the impact of physical proximity on determining knowledge flows across regions in Europe using a gravity model applied to spatial data. The main purpose of the paper is to look at the role of proximity, especially for the role of gradual removal of barriers between the Eastern and the Western part of Central Europe. The analysis covers the years from 1990 to 2000. In terms of geographic coverage, the study includes 15 EU countries, and Norway, Switzerland, the Slovak Republic, Poland, Hungary, Czech Republic, and Turkey. Interregional knowledge flows are measured through the European Patent Office (EPO) patent citations considering both the cross-border regional knowledge flows and the interregional flows that take place among 278 NUTS2 level regions in Europe. The descriptive results of the

---

i. Global survey : https://op.europa.eu/en/publication-detail/-/publication/e9a18042-bdce-11eb-8aca-01aa75ed71a1/language-en/format-PDF/source-215702968

ii. EU survey : https://op.europa.eu/en/publication-detail/-/publication/487036ad-bdd1-11eb-8aca-01aa75ed71a1/language-en/format-PDF/source-215702968 paper suggest that the cross-border regional knowledge flows between the Eastern and Western regions of Central Europe are getting shorter over time in terms of geographic distance and that the regions closer to former Eastern and Western borders before the end of the Cold War gained importance in terms of knowledge flows. The spatial analysis across 278 regions demonstrates that GDP per capita and R&D investments of regional origin and destinations have an impact on knowledge flows. In addition, geographical proximity has an impact on regional knowledge flows.

Thomson (2012) looks at the impact of national scientific capacity on R&D offshoring using a gravity model framework. The data is sourced from Rassenfosse et al. (2011) that use the PATSTAT database to measure R&D offshoring through patent data. The offshoring information is extracted through patent data considering the priority patent applications whose inventor is coming from another country than the applicant. The paper uses the R&D offshoring information of 26 OECD countries between the years 1985-2006. To assess the national scientific capacity, the paper uses the following 3 measures: (i) the extent and quality of postgraduate research education, (ii) output in basic science, and (iii) the caliber of research universities. The results of the paper suggest that the scientific capacity of inventor’s countries has a positive impact on attracting R&D offshoring. As an interesting result, the author underlines that the home country has, on average, higher aggregate scientific capacity than the host country.

Using the gravity model framework, Orazbayev (2017) investigates the relationship between immigration policies and international knowledge flows. The author proxies the bilateral flow of knowledge by aggregate citation counts per year between two countries. The data is sourced from Thomson Reuters’ Web of Science. The data on administrative barriers to mobility are sourced from International Immigration Institute's and International Civil Aviation Association's datasets. The analysis covers the years between 1990 and 2014. The results of the paper indicate the negative impact of immigration barriers on international knowledge flows. In the short run, the international knowledge flows are affected more negatively due to the immigration barriers introduced by the knowledge exporter country than those introduced by the knowledge importer country.

Appelt et al. (2015) use the gravity model framework to analyse the international mobility of researchers. The paper identifies mobility through the affiliations of scientists mentioned in research publications. The data on peer-reviewed publications are sourced from Scopus Custom Data of Elsevier and covers the years between 1996 and 2011. The paper investigates the factors that have an impact on the mobility and collaboration of researchers with a focus on policy-related factors. The findings of the paper reveal that bilateral and unilateral travel restrictions hamper mobility. The paper also finds evidence that changes in economic and research environments within a country play a role in mobility and the countries that are catching up with their counterparts experience an increase in inward mobility flows from the other country.

As another empirical evidence within a gravity model framework, Kostas et al. (2020) analyse the mobility of inventors with comparison to non-inventor migrants. The immigration data is sourced from the Organization of Economic Cooperation and Development (OECD), International Migration Database for the period spanning from 2000 to 2012. The paper considers the patent inventors and examines the geographic, technological, and cultural factors along with other factors related to the institutional and policy framework that may be behind the mobility of these highly skilled workers. The mobility of inventors is measured by the number of countries an inventor changes every time the inventor files a patent, and the data is sourced from the World Intellectual Property Organisation (WIPO) database. The factors taken into consideration consider country-level information from various databases to measure the geographical closeness, the density of population, technological closeness, linguistic similarity, regulatory quality, employment rights, public spending on tertiary education, and bilateral trade flows. The findings of the paper first suggest that proximity matters, with a significant drop for distances farther than 700km, albeit less than for the non-inventor workers. Second, the paper finds that technological proximity is another factor that has an impact on inventors' mobility.

Table 1. Summary of revied studies on patterns and factors that affect the mobility of researchers

Authors	**Main findings**
Verginer and Riccaboni (2021)	Scientists that reside in global cities are more productive.
	The global cities are at the center of the network of intellectual mobility.
Azoulay et al. (2017)	Productive scientists are more mobile than the others.
	Having adolescent children and being female decreases the mobility.
	Funding opportunities, the quality of life and the family-related factors affect location choice.
Yan et al. (2020)	Professors tend to move more towards highest ranked universities and cities.
	Female professors tend to move to closer regions and get promoted less when they move.
Gutherie et al. (2017)	Female researchers and researchers in the domain of arts and humanities tend to move abroad less.
	Non-nationals and postdoctoral researchers are found to be more mobile.
	Career-related factors are the main drivers of mobility.
	Reasons not to move or return are a mix of family/personal life and career-related factors.
Aceituno-Aceituno et al. (2015)	Career prospects are the most important factor of departure followed by remuneration.
	Career prospects are the most important factor on the location choice followed by the language.
	Funding and career-related prospects are facilitating the return of the researchers.
Bonnard et al. (2017)	Career prospects are the main factor for choosing a career abroad in France.
	Family-related factors are the main reasons to move back to France.
Van der Vende (2015)	Imbalances in R&D investments and skills between countries are the main factor for migration.
	Scientists immigrate from the South to the North and from the east to the West in Europe.
	Current EU policies for mobility in Europe are short-term solutions and generate polarization.
	The polarization in Europe is being exacerbated by the location choice of the top researchers.
Teichler (2015)	There exists insufficient attention to academicians' mobility in policy debate.
	There is a need to differentiate mobility in terms of career stage, purpose and length.
Boring et al. (2015)	A declining gender gap in mobility is observed, although the impact of gender still persists.
	The mobility of researchers is increasing in the domain of social sciences and humanities.
	Researches in natural sciences are the most mobile.
	Non-university researchers are more mobile than university researchers.
	Increasing age has a negative impact on mobility decisions.
	Education level and previous mobility experience have positive impacts on mobility decisions.
Appelt et al. (2015)	Bilateral and unilateral travel restrictions deteriorating impact on the mobility of scientists
	Changes in economic and research environments within a country play a role in mobility
	Catching up countries experience an increase in inward mobility flows from their counterparts
Kostas et al. (2020)	The technological similarity is the most important factor for inventors' mobility
	Physical and cultural proximity matters for the mobility of inventors
	Institutional factors and job opportunities have a positive impact on mobility.
	Trade linkages between the countries have a positive impact on mobility.

Source: Authors' own elaboration.

Table 2: Summary of reviewed studies: The country and period of analysis, main data sources, and methodology by topics

Authors	Country	Year	Main data sources	Method
Mobility of researchers				
Verginer and Riccaboni (2021)	International	1990 - 2009	Medline scientific publications	FE panel quantile and Heckman 2-stage regressions
Azoulay et al. (2017)	United States	until 2006	PubMed; USPTO patent data; National Institutes of Health	Discrete-time hazard rate model framework
Yan et al. (2020)	United States	unrevealed	ORCID 2018 and CCIHE	Descriptive analysis / Mapping of mobility
Gutherie et al. (2017)	United Kingdom	2017	survey of researchers based in the UK (March 2017)	Descriptive analysis
Aceituno-Aceituno et al. (2015)	Spain	2014	Survey data on 284 researchers in health sciences	Descriptive analysis
Bonnard et al. (2017)	France	2003 - 2008	Survey data on the 400 Ph.D. degree holders	Descriptive analysis
Van der Vende (2015)	OECD countries, with a focus on the EU 27	miscellaneous	OECD database on immigrants in the OECD; CEDEFOP EU Skills Panorama; EUROSTAT	Descriptive analysis
Teichler (2015)	Advanced countries, with a focus on the EU 27	miscellaneous	Statistics: UNESCO, the OECD, and EUROSTAT; Surveys: The GlobSci Survey and The CAP Survey	Descriptive analysis
Boring et al. (2015)	EU 27 member states	2008 - 2010	MORE survey database project of the EU Commission	Descriptive analysis
Appelt et al. (2015)	International	1996 - 2011	Scopus Custom Data of Elsevier	Gravity model framework
Kostas et al. (2020)	International	2000 - 2012	OECD Migration Database; WIPO patent data	Gravity model framework
Immigration				
Lewer and Van den Berg (2008)	16 OECD countries	1991 - 2000	OECD Migration Database; IMF Direction of Trade Statistics Yearbook	Gravity model framework
Inventors' collaboration				
Montobbio and Sterzi (2013)	11 emerging and 7 developed countries	1990 - 2004	USPTO patent data	Gravity model framework
R&D offshoring				
Thomson (2012)	26 OECD countries	1985 - 2006	EPO patent data	Gravity model framework
Knowledge flows				
Bergman and Usai (2009)	EU 17, and the Slovak Republic, Poland, Hungary, Czech Republic, and Turkey	1990 - 2000	EPO patent data	Gravity model framework
Orazbayev (2017)	International	1990 - 2014	Web of Science publications data	Gravity model framework

Source: Authors' own elaboration.

3. Data and empirical framework

3.1. Data

For this note, we understand the concept of brain drain as the outflows of researchers having left a country. This differs from the general definition of brain drain used in other tasks of Work Package 8 where brain drain is understood as the ratio between outflows and inflows of researchers. The definition of brain drain used in this note is based on the fact that it adapts better to the econometric model that is applied (gravity model) and that is explained in more detail below. This gravity model relies on the bilateral flows of researchers between pairs of countries.

Regarding the variable of bilateral flows of researchers between pairs of countries (or dyads), 3 indicators can be considered depending on the method and the country defined as the country of origin[13]:

- By country of citizenship (based on the MORE4 survey);
- By country of highest degree (based on the MORE4 survey);
- By country of affiliation (based on the scientometric approach);

The first two indicators are based on the data gathered in the MORE4 survey and are based on the analysis of the country of citizenship and the country of current employment of researchers. The third indicator was built by the Centre for Science and Technology Studies (CWTS) at Leiden University and was constructed using a large bibliographic dataset (Web of Science) of disambiguated authors and their affiliations found on scholarly papers. Researchers' mobility between two countries is measured by identifying affiliation changes of scientists between these countries (Robinson-Garcia et al., 2018). These flow data are structured in a way that there is always a country of origin and a country of destination. The flows themselves can be measured in levels (absolute numbers or logarithms of absolute numbers), in shares, or relative terms (ratio between the number of outgoing researchers and the total number of researchers in the origin country). Using shares allows to control for the size of the origin country and shows the relevance of each country pair out of all the pairs (moves) for each country of origin. For instance, if 100 researchers leave Austria and 20 of them go to Germany, the pair Austria-Germany will be equal to 20% or 0.20.[14] Using outflows in absolute or relative terms allows gauging the intensity of brain drain between a country of origin and a country of destination.

The geographical scope of these indicators is also important. The indicators 'By country of citizenship' and 'By country of highest degree' only cover intra-Europe flows (27 Member States, UK, Iceland, Norway, and Switzerland). Finally, the indicator 'By country of affiliation' only covers European countries of origin (27 Member States, UK, Iceland, Norway, and Switzerland) but the countries of destination are worldwide. In practice, the third indicator will be used in the econometric analysis given its greater geographic coverage.[15]

In order to analyse the macroeconomic determinants of mobility outflows of researchers, the study sources country-level information from the rankings of EUROSTAT, European

[13] These are the same flows that we have included in the talent circulation mapping (task 8.1).

[14] In an equivalent way, these scientific mobility indicators can be used in level but in this case it is necessary to control for the size of the country of origin in the regression model.

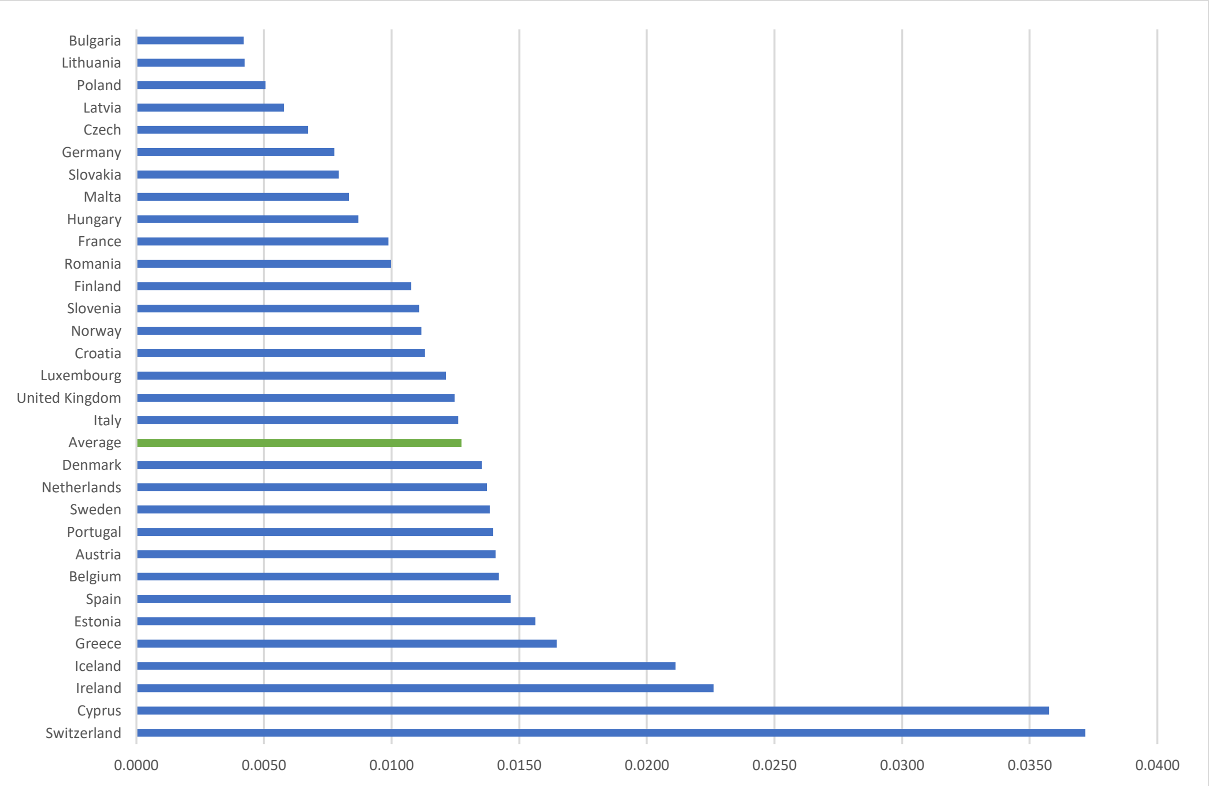
[15] The first indicator is available for 113 dyads, the second for 130 dyads and the third one for 280 dyads. In the case of the survey-based flows, the dataset only includes those pairs origin-destination with more than 15 researchers/observations. This entails that some countries are not included in the dataset for one of the two survey-based flows (e.g. Switzerland in the case of the flows measured by country of citizenship).
Finally, for the three types of flows, the dataset only includes those pairs origin-destination that constitute a share higher than 3% per country to exclude unusual or anecdotical country pairs.

Innovation Scoreboard (EIS), Worldbank, Centre d'Etudes Prospectives et d'Informations Internationales (CEPII), She Figures Database of the European Commission, Quacquarelli Symonds World University Ranking, EURAXESS - Researchers in Motion initiative of the European Union, Elsevier's Scopus scientific publications database, OECD Database on Governance of Public Research Policy (RESGOV), V-Dem Dataset. The study also uses survey data sourced from the latest Mobility and Career Paths of Researchers in Europe Survey Edition 4 (MORE4).[16]

3.2. Descriptive statistics

Figure 1 represents the importance of brain drain in percentages in European countries. Countries with the highest shares of brain drain are Switzerland (intensity of 3.72%); Cyprus (3.58%); Ireland (2.26%); Iceland (2.11%) and Greece (1.65%). At the other end, we find Bulgaria and Lithuania (both with an average intensity of 0.42%), Poland (0.051%), Latvia (0.058%), and the Czech Republic (0.067%).

Figure 1. Importance of researchers' mobility outflows



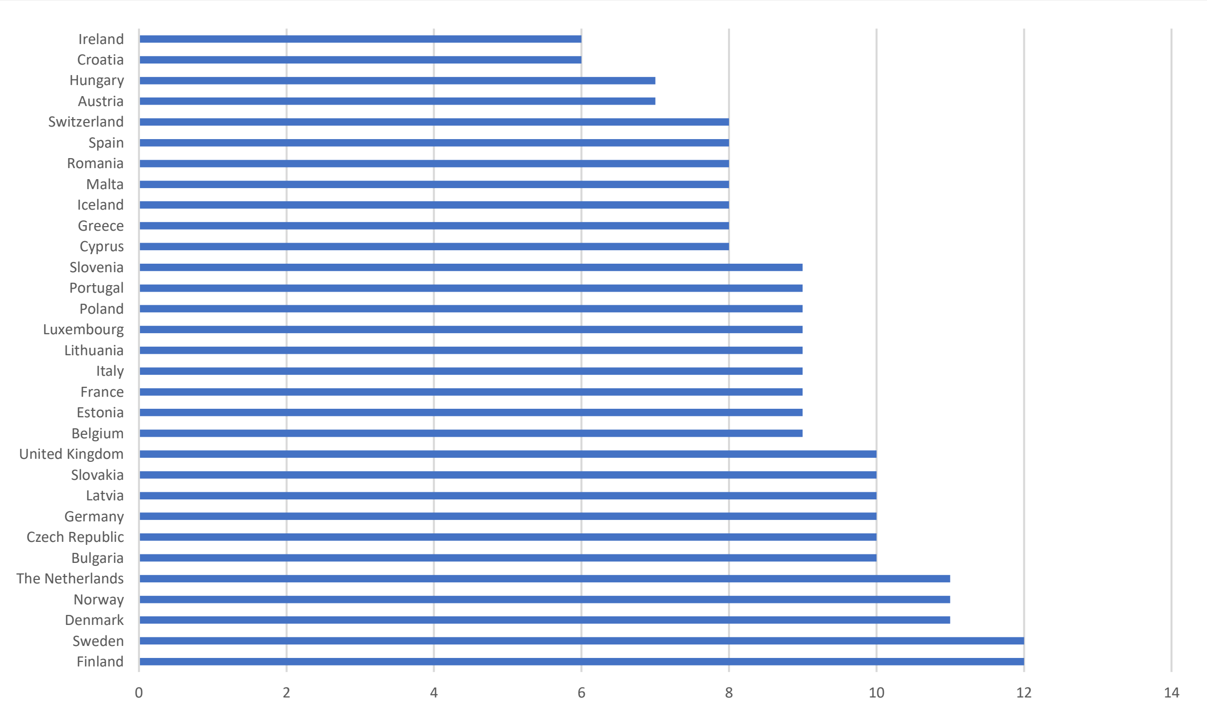
Source: Authors' own elaboration.
Note: outflows of researchers (scientometric indicator) divided by the total number of researchers in the origin country.

Figure 2 represents the number of countries the European researchers choose as the destination for mobility.[17] Finland and Sweden are the most diverse in terms of destination with 12 different location choices, followed by Denmark, Norway, and the Netherlands. The countries that are the most homogenous in terms of choice of location are Ireland and Croatia followed by Hungary and Austria. The figure shows that the diversity in the location choice of researchers

[16] The table 8 in Appendix lists the indicators, their definition and the data sources.
[17] It is worth to note that the data captures all the destination countries European researchers choose including outside of Europe.

is not only influenced by the size of countries, and other factors impact the phenomenon. The largest countries of Europe do not stand out as the most diverse countries in terms of the number of foreign countries researchers choose in terms of the destination location.

Figure 2. Number of foreign countries researchers choose as a destination location.



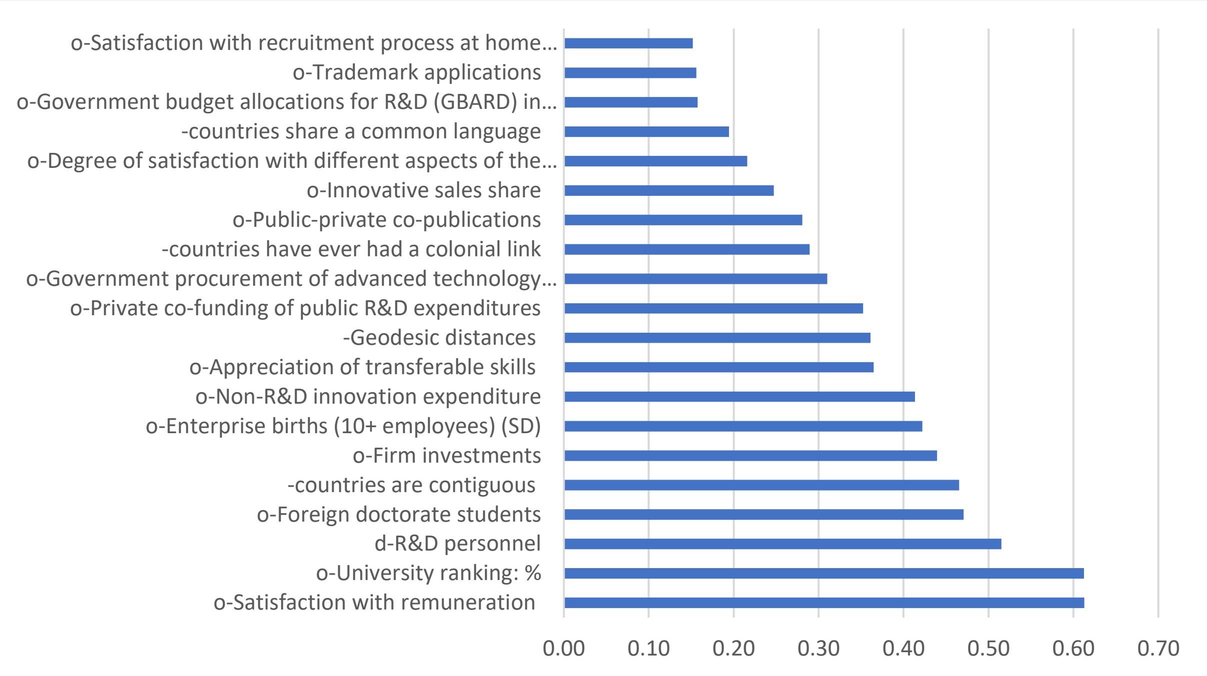
Source: Authors' own elaboration.
Note: Scientometric indicator.

Following the main insights gathered from the review of the literature, 12 types of indicators[18] capturing in total 118 different indicators (cf. Appendix 1) are distinguished to explain mobility outflows in Europe both from the perspective of the country of origin and of the country of destination. The values of the determinants of mobility are calculated for the countries of destination and of origin. The Table in Appendix 2 reports the descriptive statistics.

Figure 3 and Figure 4 represent the factors that have, orderly, the highest positive and negative correlation with the mobility outflows in Europe. Figure 3 indicates that countries with a high ranking of their universities and where a higher share of researchers consider themselves well paid or paid a reasonable salary tend to be less affected by brain drain. Conversely, destination countries with a high number of researchers (size effect) are more likely to welcome foreign researchers.

[18] Geographic and cultural proximity; Policy reforms; Macroeconomic and structural factors; Attractiveness of the ST&I ecosystem; Funding sources; Gender; Human resources; Innovation; Intellectual property; Linkages; and Mobility and Training.

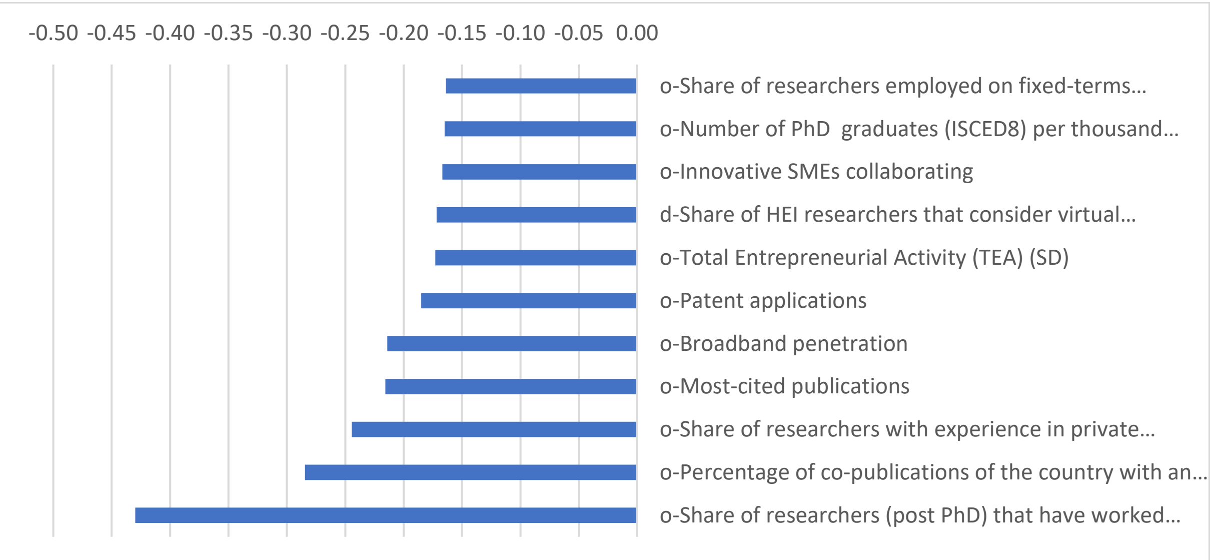
Figure 3. Highest positive correlations between bilateral flows and factors of brain mobility



Source: Authors' own elaboration.
Notes: Scientometric indicator. o – (resp. d -) stands for origin (resp. destination) country.

It follows from Figure 4 that countries characterized with a high share of post PhD researchers that have worked abroad as a researcher more than 3 months in the last 10 years; countries with a high percentage of co-publications of the country with an author from another country, as well as countries with a high share of researchers with experience in the private sector encounter lower outflows of their researchers.

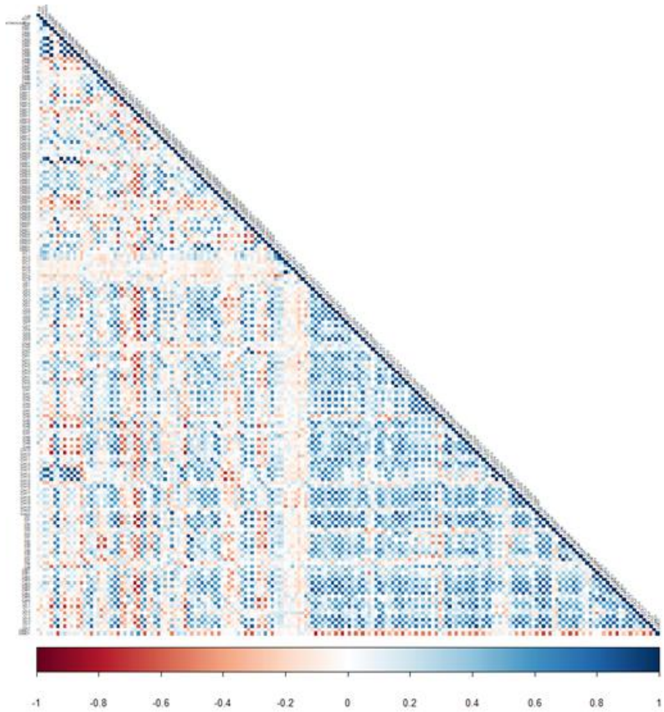
Figure 4. Highest negative correlations between bilateral flows and potential determinants of brain mobility



Source: Authors' own elaboration.
Notes: Scientometric indicator. o – (resp. d -) stands for origin (resp. destination) country.

The correlogram shown in Figure 5 highlights the most correlated variables in the correlation matrix (correlation coefficients are coloured according to the value, i.e. red for negative correlations and blue for positive correlations). It follows that correlations (positive and negative) are very high for a large number of variables which can be the source of (multi-collinearity) between explanatory variables in the regression models.

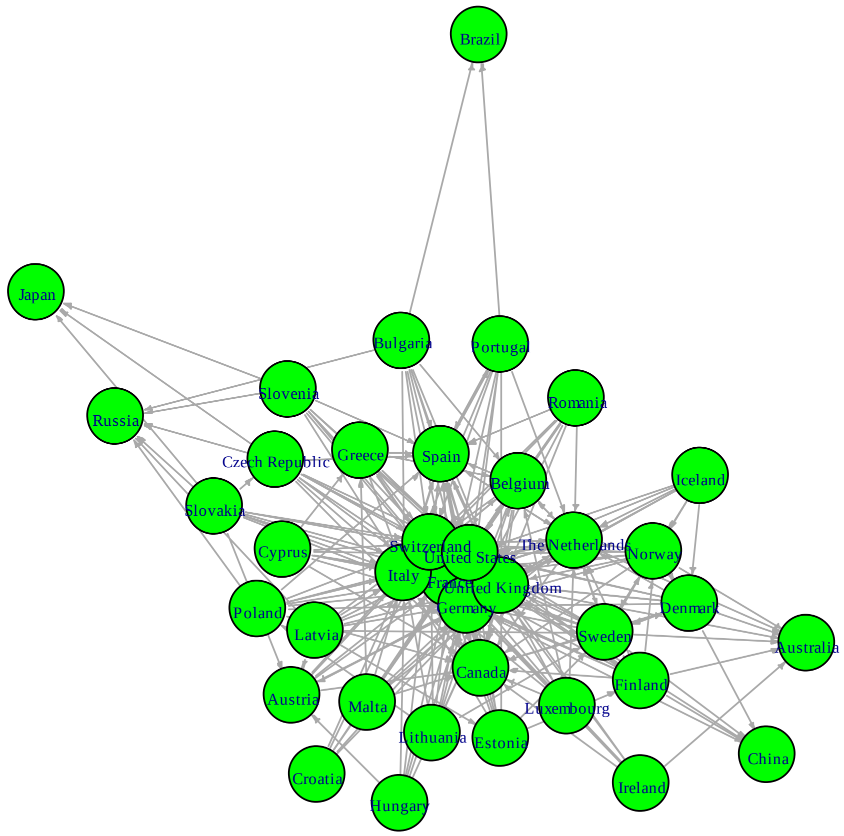
Figure 5. Correlogram[19]



Source: Authors' own elaboration.
Note: Scientometric indicator.

[19] The full corelation matrix with variable names is available here: https://www.dropbox.com/s/dpk310dsnljn7jv/correlation%20matrix %20brain%20drain%20dataset.xlsx?dl=0

Figure 6: Network analysis (flows in levels)



Source: Authors' own elaboration.
Note: Scientometric indicator.

3.3. Empirical framework: gravity model

This article relies on an empirical gravity model of international flows to describe and analyze new aggregate and bilateral data on the international mobility of researchers. The gravity model predicts bilateral flows based on the attributes of origin and destination economies for the phenomenon under investigation and measures of the distance between the two economies that can bear upon the costs and incentives for flows to arise.

In the empirical literature, the gravity model is generally estimated by linear regression in which the log of the flow of researchers, RO_{ij}, from a country (i) to country (j) is a function of the characteristics of the country of origin and destination, OX_i and DX_j, respectively, as well as several measures of the link between country of origin (i) and country of destination (j), including proximity measures sharing the common border or speaking the same language, etc. and others bilateral connections Z_{ij}, and taking into account an error term ε_{ij}.

$$\mathrm{Log}\left(RO_{ij}\right) = \alpha_0 + \alpha_1 \log(OX_i) + \alpha_2 \log\left(DX_j\right) + \alpha_3 \log\left(Z_{ij}\right) + \varepsilon_{ij}$$

This empirical framework will be used to study the bilateral flows of researchers across the EU Member states and countries outside the EU using the variables described in Appendix 1.

Due to the quite large number of indicators, or predictors of brain drain, and the small size of the dataset (i.e. 280 pairs of countries for mobility outflows in Europe and 208 pairs of countries for the bilateral flows of researchers within Europe), a potential problem of (multi) collinearity across predictors variables is likely and needs to be appropriately addressed,[20] and from the correlation matrix (cf. Figure 1), this problem is clearly present in the brain drain dataset at hand.

Before coming back to this limitation of the analysis due to the specific nature of the dataset, two other problems are also affecting the quantitative analysis, namely, first, the fact that for some predictors fewer observations are available. This is because some indicators are not measured in some countries, and second, since some indicators are very similar, e.g. 'Number of Ph.D. graduates (ISCED8) per thousand population' (indicator H3) and 'New doctorate graduates researchers in FTE per thousands of employees (indicator H5).

To address the first problem, and to allow econometric regression estimations based on a dataset with a maximal number of predictors and observations, some indicators with fewer observations have been removed from the analysis.[21] Concerning the second issue, all variables have been thoroughly examined and it was decided to exclude from the analysis the ones that were considered as redundant or very similar and thus gathering the same information, e.g. 'Share of High and Medium high-tech manufacturing (SD)' (indicator M25) and 'Medium and high-tech Industry (including construction) (% manufacturing value-added)' (indicator M34).[22] Overall 77 variables were removed.

Regarding the (multi-)collinearity issue one caveat of traditional regressions is that they assume a linear fit when the underlying function is possibly not. It also assumes that the regression from the input variables is rather clear-cut, implying that variables have limited multi-collinearity among them. In a regression with highly collinear predictors, the estimation routine typically omits these collinear variables. It does so because of a dependency among the independent variables in the proposed model. The drawback of omitting these variables is that they cannot be interpreted whereas they can play a statistically significant influence (positive or negative) on the dependent variable (brain drain). To mitigate this issue, machine learning (ML) algorithms can be implemented.

Machine learning is part of Artificial Intelligence and concerns how programming can adapt and derive insights from new data without human intervention. It works by partitioning data in multiple cohesive clusters that help identify possible, often nonlinear associations, that are then used to predict one important decision that is dependent on a set of variables.

Typically, applied science field has been using regression techniques that use a limited number of data, but assumes probability distributions for generalization, and derive prediction based on some specific rules (like the minimization of the sum of residuals to a fitted model at the

[20] Multicollinearity occurs when independent variables or predictors in a regression model are correlated. This correlation is a problem because independent variables should be independent. If the degree of correlation between variables is high enough, it can cause problems when in the fit of the model and in the interpretation of results.

[21] The indicators removed are: GC5; G2; G3; G4; G5; G6; G7; A12; A13; A14; A15; A20; A21; A22; A23; MO2; MO3; MO4; T1; T2; T3; T4; T5; T6; and R (see Appendix 1 for the definition of these acronyms).

[22] The indicators removed due to similarity are: M3; M4; M5; M7; M9; M10; M11; M12; M13; M14; M15; M16; M20; M21; M23; M27; M28; M31; M32; M34; GC3; GC4; GC6; GC7; F1; F2; F3; F4; F8; F9; H2; H4; H5; A2; A8; A9; I1; I2; I3; I4; I5; I6; I7; IP1; IP2; IP3; IP4; IP5; L2; L3; L4 and V1 (see Appendix 1 for the definition of these acronyms).

square). With the emergence of much larger data, new techniques have emerged to exploit the variety of data, including techniques such as Neural Networks, or Random Forests.

Random forest is a supervised learning algorithm that works as an ensemble learning method based on building a range of regression trees that are then averaged out to compose the final forest (Breiman, 2001). From each tree, the smallest root means square error prediction error variable determines the top of the tree and recursively to create a full tree. Prediction used the average of the response variable in each leaf of the tree. Random forests' advantages are that they are robust to outliers, are effective with non-linear data, and have a lower risk of overfitting.[23]

In a nutshell, the Random Forest technique is important as an alternative to the traditional regression model, given likely non-linearity, and high-order interaction effects. The advantage of this ML technique is that it is not affected by the multicollinearity issue and that it allows uncovering the most important drivers of brain drain that otherwise will have remain hidden from traditional regression techniques.

4. Empirical findings

The empirical analysis proceeds by stages and by blocks of variables grouped by theme. The basic model takes into account a set of standard variables used in empirical gravity models such as geographic, cultural, and economic proximity, to which are then added other explanatory variables.[24]

4.1. Results of Models 1-9

In Table 3a and Table 3b, we present the first three models of the analysis regarding the country of origin (Table 3a) and the country of destination (Table 3b).[25] The coefficients of the baseline model (Model 1) are presented in column (1), and column (2) represents the standard errors.[26] The results of the baseline model suggest that common language as the indicator of cultural proximity increases mobility. We observe a positive sign for the coefficient of having common borders and a negative sign for the coefficient of geodesic distances that represent the indicators of geographical proximity albeit not significant. As for the gross domestic product (GDP) of the countries that proxy the size of the economies, we find, as expectedly, the positive impact of the size of both the country of origin and the country of destination country on the amount of mobility flows. The results of the model where we add the human resources-related factors to the baseline model (Model 2) are represented in column (3). Researchers per thousand employees and the number of Ph.D. graduates per thousand population appear to be a factor that influences positively the mobility outflows from the country of origin as well as the mobility inflows towards a country. The model including the entrepreneurial possibilities in the baseline model (Model 3) is represented in column 5. We observe the prevalence of the positive and the significant impact of the ease of doing business in both countries of destination and origin whereas the ease of doing business in destination country has a larger impact for

[23] See, for instance, Liu et al. (2017) and Schonlau and Yuyan Zou (2020) for the comparison of the Random Forest estimation with linear regression.

[24] The Table in Appendix 3 summarizes the significant results related to these additional determinants of Models 2-12.

[25] For the ease of interpretation, all of the tables representing econometric results are split by the country of origin and the country of destination.

[26] In all result tables, the standard errors of the estimation follow the coefficients in the next column.

attracting researchers inflows. Total entrepreneurial activity in the country of origin is found to be a decreasing factor for mobility outflows.

Table 3a. Regression results of models 1 to 3 – Origin countries

		Model 1		Model 2		Model 3	
		(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES		Y=lro3	se	Y=lro3	se	Y=lro3	se
gc1	Countries are contiguous	0.0953	(0.140)	0.249*	(0.139)	-0.0232	(0.131)
gc2	Countries share a common language	0.368**	(0.160)	0.204	(0.188)	0.540***	(0.178)
lgc8	Geodesic distances	-0.115	(0.0863)	0.0376	(0.0808)	-0.156*	(0.0809)
lm1	Gross Domestic Product	1.002***	(0.0358)	0.915***	(0.0290)	0.975***	(0.0410)
lh1	Researchers (FTE) per thousand employees			0.320***	(0.119)		
lh3	Number of PhD graduates per thousand population			0.491***	(0.106)		
la7	Ease of starting a business					1.507*	(0.881)
li8	Total Entrepreneurial Activity					-0.232*	(0.139)
Constant		-9.741***	(1.026)	-10.89***	(1.330)	-38.11***	(5.899)
Observations		208		208		188	
R-squared		0.849		0.908		0.872	

Source: Authors' own elaboration.
Notes: The first letter of variables, l, stands for logarithm. Model 3 has less observations due to missing data for Slovakia, Iceland and Malta. Robust standard errors in parentheses. Statistical significance level : *** p<0.01, ** p<0.05, * p<0.1

Table 3b. Regression results of models 1 to 3 – Destination countries

		Model 1		Model 2		Model 3	
		(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES		Y=lro3	se	Y=lro3	se	Y=lro3	se
gc1	Countries are contiguous	0.0953	(0.140)	0.249*	(0.139)	-0.0232	(0.131)
gc2	Countries share a common language	0.368**	(0.160)	0.204	(0.188)	0.540***	(0.178)
lgc8	Geodesic distances	-0.115	(0.0863)	0.0376	(0.0808)	-0.156*	(0.0809)
lm1	Gross Domestic Product	0.295***	(0.0547)	0.343***	(0.0524)	0.313***	(0.0567)
lh1	Researchers (FTE) per thousand employees			0.450***	(0.172)		
lh3	Number of PhD graduates per thousand population			0.346***	(0.105)		
la7	Ease of starting a business					5.270***	(1.277)
li8	Total Entrepreneurial Activity					-0.133	(0.161)
Constant		-9.741***	(1.026)	-10.89***	(1.330)	-38.11***	(5.899)
Observations		208		208		188	
R-squared		0.849		0.908		0.872	

Source: Authors' own elaboration.
Notes: The first letter of variables, l, stands for logarithm. Model 3 has fewer observations due to missing data for Slovakia, Iceland, and Malta. Robust standard errors in parentheses. Statistical significance level : *** p<0.01, ** p<0.05, * p<0.1

In Table 4a and Table 4b, we represent the results of the next three models where we augment the baseline model with the indicators related to the institutional procedures of recruitment and career progression (Model 4), knowledge-intensive economy (Model 5), and R&D investment (Model 6). For the three models, we observe that the coefficients of GDP of the countries of origin and destination remain significant and positive. The positive coefficients of the common border indicator become also significant in each model. Common language indicator remains significant only for Model 6.

Table 4a. Regression results of models 4 to 6 – Origin countries

VARIABLES		Model 4		Model 5		Model 6	
		(1)	(2)	(3)	(4)	(5)	(6)
		Y=lro3	se	Y=lro3	se	Y=lro3	se
gc1	Countries are contiguous	0.297**	(0.136)	0.292*	(0.148)	0.242*	(0.125)
gc2	Countries share a common language	0.0382	(0.154)	0.0717	(0.161)	0.236*	(0.139)
lgc8	Geodesic distances	0.0391	(0.0873)	-0.0235	(0.0744)	0.0619	(0.0736)
lm1	Gross Domestic Product	0.990***	(0.0295)	0.930***	(0.0359)	0.913***	(0.0299)
la1	Satisfaction with recruitment process at home research institution	-2.048*	(1.156)				
la4	Transparency and meritocracy in professional advancement in HEIs	1.087	(0.678)				
la6	Attractive research systems	0.698***	(0.0654)				
lm17	Knowledge-intensive services exports			0.233***	(0.0679)		
lm18	Medium and high-tech product exports			-0.324***	(0.116)		
lm19	Non-R&D innovation expenditure			0.00984	(0.0667)		
lm22	Product or process innovators			0.486***	(0.0671)		
lm24	Share of researchers in private sector in total number of researchers			-0.277	(0.186)		
lm25	Share High and Medium high-tech manufacturing			0.801***	(0.216)		
lm26	Share Knowledge-intensive services (%)			-0.408	(0.358)		
lf5	R&D expenditure business sector					0.196*	(0.111)
lf6	R&D expenditure public sector					0.353***	(0.0895)
lf7	Top R&D spending enterprises per 10 mln population					-0.0429	(0.0339)
Constant		-22.16***	(4.487)	-11.00***	(2.474)	-14.69***	(1.155)
Observations		208		183		152	
R-squared		0.914		0.933		0.928	

Source: Authors' own elaboration.

Notes: The first letter of variables, l, stands for logarithm. Model 5 has less observations due to missing data for Iceland, Norway and Romania. Model 6 has less observations due to missing data for Bulgaria, Croatia, Cyprus, Estonia, Latvia, Romania and Slovakia. Robust standard errors in parentheses. Statistical significance level : *** p<0.01, ** p<0.05, * p<0.1

Table 4b. Regression results of models 4 to 6 – Destination countries

VARIABLES		Model 4 (1) Y=lro3	Model 4 (2) se	Model 5 (3) Y=lro3	Model 5 (4) se	Model 6 (5) Y=lro3	Model 6 (6) se
gc1	Countries are contiguous	0.297**	(0.136)	0.292*	(0.148)	0.242*	(0.125)
gc2	Countries share a common language	0.0382	(0.154)	0.0717	(0.161)	0.236*	(0.139)
lgc8	Geodesic distances	0.0391	(0.0873)	-0.0235	(0.0744)	0.0619	(0.0736)
lm1	Gross Domestic Product	0.326***	(0.0630)	0.257***	(0.0779)	0.566***	(0.0631)
la1	Satisfaction with recruitment process at home research institution	2.435*	(1.267)				
la4	Transparency and meritocracy in professional advancement in HEIs	0.234	(0.840)				
la6	Attractive research systems	0.0743	(0.205)				
lm17	Knowledge-intensive services exports			0.721***	(0.216)		
lm18	Medium and high-tech product export			-0.157	(0.584)		
lm19	Non-R&D innovation expenditure			0.0755	(0.104)		
lm22	Product or process innovators			-0.269	(0.246)		
lm24	Share of researchers in private sector in total number of researchers			-0.574*	(0.336)		
lm25	Share High and Medium high-tech manufacturing			0.360	(0.631)		
lm26	Share Knowledge-intensive services (%)			-0.162	(0.493)		
lf5	R&D expenditure business sector					-1.434***	(0.389)
lf6	R&D expenditure public sector					0.753***	(0.277)
lf7	Top R&D spending enterprises per 10 mln population					0.711***	(0.118)
Constant		-22.16***	(4.487)	-11.00***	(2.474)	-14.69***	(1.155)
Observations		208		183		152	
R-squared		0.914		0.933		0.928	

Source: Authors' own elaboration.

Notes: The first letter of variables, l, stands for logarithm. Model 5 has less observations due to missing data for Iceland, Norway and Romania. Model 6 has less observations due to missing data for Bulgaria, Croatia, Cyprus, Estonia, Latvia, Romania and Slovakia. Robust standard errors in parentheses. Statistical significance level : *** p<0.01, ** p<0.05, * p<0.1

Model 4 includes satisfaction with the recruitment process in research institutions, transparency, and meritocracy in professional advancement and attractive research systems. In column (1), we find that attractive research systems increase the mobility of its researchers. Satisfaction with the recruitment process increases mobility inflows to a destination country and decreases the mobility of researchers in a country of origin.

Model 5 includes indicators of exports from knowledge-intensive services and high-tech and medium-high-tech manufacturing, non-R&D innovation expenditures, product and process innovators, and share of researchers that work in the private sector. For the country of origin, we find a negative impact of high-tech and medium-high-tech manufacturing exports whereas the share of high and medium-high-tech manufacturing in total manufacturing increases the mobility of researchers. We also find the positive impact of an exporting knowledge-intense services industry and the levels of product and process innovators on mobility. For the destination country, we find that the exports from knowledge-intensive services have a positive and significant impact, whereas the share of researchers that work in the private sector has a negative impact on mobility in column (3). This may reflect the lack of appropriate career opportunities for the researchers and also the size effect of the public sector.[27] The higher share of researchers in the private sector, the lower the share of researchers in the public sector. Besides, the indicator of mobility flows sourced from the affiliations of researchers in scientific publications is, by its construction, biased towards researchers in academia.

Concerning R&D investments, the results of Model 6 are represented in column (5). For the country of origin, we find the positive and significant impacts of private and public R&D investments on researchers' mobility. We find a positive and significant impact of public R&D investments and a negative and significant impact of R&D investments in the private sector in the destination country. Enterprise characteristics are important for explaining differences in R&D spending and innovation activities. Large enterprises, defined as enterprises with 250 or more employees, account for almost 80 percent of EU business R&D expenditures.[28] As another indicator of private-sector R&D investments, the importance of top business R&D spenders in the economy has a positive and significant impact on attracting mobility inflows.[29]

In Tables 5a and 5b, we represent the results of the next three models where we add to the baseline model the indicators related to the openness of the economy (Model 7), and working conditions (Model 8 and Model 9)

The results of Model 7 are represented in column (1). We observe that the coefficients of GDP of the origin and destination countries remain significant and positive. The coefficient of the common border indicator is positive and significant. Concerning international collaboration, we find the positive impacts of international co-publications on mobility outflows from the country of origin as well as attracting mobility inflows to the destination country. On the other hand, we find the negative impact of the share of researchers that have worked in non-academic sectors on mobility outflows from the country of origin as well as attracting mobility inflows to the destination country.

[27] The dependent variable is constructed from the web of science database and is more likely to measure the flow of researchers from Higher Education Institutions and public Research and Technology Organisations.
[28] The source link: http://iri.jrc.ec.europa.eu/scoreboard.html.
[29] The top business R&D spenders delocalise on order to gain access to knowledge base and contribute to brain gain and brain exchange in the economy (Cincera, 2004).

Table 5a. Regression results of models 7 to 9 – Origin countries

VARIABLES		Model 7		Model 8		Model 9	
		(1)	(2)	(3)	(4)	(5)	(6)
		Y=lro3	se	Y=lro3	se	Y=lro3	se
gc1	countries are contiguous	0.269**	(0.114)	0.164	(0.150)	0.0923	(0.151)
gc2	countries share a common language	0.0618	(0.117)	0.325**	(0.165)	0.229	(0.180)
lgc8	Geodesic distances	-0.0935	(0.0681)	-0.048	(0.0929)	-0.121	(0.0847)
lm1	Gross Domestic Product	1.037***	(0.0292)	1.017***	(0.0361)	0.952***	(0.0341)
la10	International co-publications	0.455***	(0.0790)				
la8	Foreign doctorate students	-0.0187	(0.0758)				
ll1	Percentage of co-publications of country with an author from another country	0.239	(0.263)				
lm30	Share of researchers (post PhD) that have worked abroad as researcher or more than 3 months in the last 10 years	0.112	(0.189)				
lnew	Share of researchers having worked in non-academic sectors (M29+M30+M33)	-0.908***	(0.172)				
la3	Degree of satisfaction with different aspects of the current academic position.: Composite indicator including career related aspects.			0.184	(0.473)		
la11	Share of researchers employed on fixed-terms contracts in their current academic position (%)			0.143	(0.0914)		
la16	Share of researchers that consider themselves well paid or paid a reasonable salary (%)					-0.396***	(0.111)
la17	Share of researchers that consider the remuneration package in their current academic position better than that of people with comparable skills and experience outside academia (%)					-0.346	(0.340)
la18	Share of researchers satisfied with their pension plan in the current academic position(%)					0.655	(0.422)
la19	Share of researchers satisfied with their social security rights and benefits in the current academic position (%)					0.435	(0.805)
Constant		-9.46	(6.538)	-10.09***	(1.307)	-2.375	(7.297)
Observations		199		208		208	
R-squared		0.94		0.865		0.875	

Source: Authors' own elaboration.
Notes: The first letter of variables, l, stands for logarithm. Model 7 has less observations due to missing data for Greece. Robust standard errors in parentheses
Statistical significance level : *** p<0.01, ** p<0.05, * p<0.1

Table 5b. Regression results of models 7 to 9 – Destination countries

VARIABLES		Model 7 (1) Y=lro3	(2) se	Model 8 (3) Y=lro3	(4) se	Model 9 (5) Y=lro3	(6) se
gc1	countries are contiguous	0.269**	(0.114)	0.164	(0.150)	0.0923	(0.151)
gc2	countries share a common language	0.0618	(0.117)	0.325**	(0.165)	0.229	(0.180)
lgc8	Geodesic distances	-0.0935	(0.0681)	-0.048	(0.0929)	-0.121	(0.0847)
lm1	Gross Domestic Product	0.453***	(0.0925)	0.325***	(0.0582)	0.287***	(0.0515)
la10	International co-publications	0.528**	(0.251)				
la8	Foreign doctorate students	-0.222	(0.192)				
ll1	Percentage of co-publications of country with an author from another country	0.588	(1.698)				
lm30	Share of researchers (post PhD) that have worked abroad as researcher or more than 3 months in the last 10 years	-0.316	(0.252)				
lnew	Share of researchers having worked in non-academic sectors (M29+M30+M33)	-1.202**	(0.533)				
la3	Degree of satisfaction with different aspects of the current academic position.: Composite indicator including career related aspects.			1.672***	(0.377)		
la11	Share of researchers employed on fixed-terms contracts in their current academic position (%)			-0.245**	(0.106)		
la16	Share of researchers that consider themselves well paid or paid a reasonable salary (%)					-0.0913	(0.0866)
la17	Share of researchers that consider the remuneration package in their current academic positon better than that of people with comparable skills and experience outside academia (%)					0.491	(0.628)
la18	Share of researchers satisfied with their pension plan in the current academic position(%)					1.21	(1.415)
la19	Share of researchers satisfied with their social security rights and benefits in the current academic position (%)					-3.599*	(2.168)
Constant		-9.46	(6.538)	-10.09***	(1.307)	-2.375	(7.297)
Observations		199		208		208	
R-squared		0.94		0.865		0.875	

Source: Authors' own elaboration.

Notes: The first letter of variables, l, stands for logarithm. Model 7 has less observations due to missing data for Greece. Robust standard errors in parentheses. Statistical significance level : *** p<0.01, ** p<0.05, * p<0.1.

In the next models of Model 8 and Model 9 of Table 5a and Table 5b, we look at the impact of working conditions in academia on the mobility of researchers. In model 8, we find the positive impact of satisfaction with the career-related aspects of the academic positions on attracting researcher inflows whereas a negative impact of fixed-term contracts on mobility inflows in the destination country is represented in Column (3) of Table 5b. In Model 9, we find that the satisfaction with the remuneration of the contract in the country of origin decreases the mobility of researchers whereas satisfaction with the social security rights decreases the mobility inflows in the country of destination.

In Table 6a and 6b, we represent the results of the next three models where we add to the baseline model the indicators related to virtual mobility (Model 10), academic freedom (Model 11), and socioeconomic factors and gender equality (Model 12).

The results of Model 10 represented in column (1) show that the more researchers consider virtual mobility as an alternative to physical mobility, the fewer mobility outflows in the country of origin, and the less attractive is the country of destination.

Model 11 includes institutional factors in academia such as freedom of academic exchange, institutional autonomy, and campus integrity. Although we confront relative homogeneity between the countries given the country sample from Europe, we face certain variability when it comes to few countries, especially for Hungary, scoring the least in all of the three indicators. The results of the regression represented in Column (3) of Table 6a and 6b indicate that the freedom of academic exchange and dissemination increases the attractiveness of the country of destination for the mobility inflows of researchers. Institutional autonomy indicator which is related to the autonomy in internal government and finance is found to have a negative impact on mobility inflows in a destination country.[30]

Socioeconomic and gender-related factors are included in the baseline model in column (5). We find a negative relationship between GDP per capita and mobility outflows. The finding of a negative impact of GDP growth may be due to the higher GDP growth in smaller and relatively less developed countries of Europe. Finally, the results indicate a positive and significant relationship between new women doctoral graduates per thousand population aged between 25-34 and mobility outflows in the country of origin.

[30] The indicator follows the definition in Lima declaration and “means the independence of institutions of higher education from the State and all other forces of society, to make decisions regarding its internal government, finance, administration, and to establish its policies of education, research, extension work and other related activities”. Empirically, we observe the highest variation with respect to other institutional indicators and the lowest, even negative, correlation with other institutional indicators for the countries in the sample.

Table 6a. Regression results of models 10 to 12 – Origin countries

VARIABLES		Model 10 (1) Y=lro3	(2) se	Model 11 (3) Y=lro3	(4) se	Model 12 (5) Y=lro3	(6) se
gc1	countries are contiguous	-0.029	(0.144)	0.163	(0.144)	0.218	(0.142)
gc2	countries share a common language	0.515**	(0.200)	0.318*	(0.179)	0.131	(0.195)
lgc8	Geodesic distances	-0.143*	(0.0836)	-0.153*	(0.0839)	-0.0483	(0.0895)
lm1	Gross Domestic Product	1.061***	(0.0364)	0.988***	(0.0374)	0.789***	(0.0376)
lm8	Broadband penetration	0.0478	(0.114)				
lmo1	Share of HEI researchers that consider virtual mobility as substitute or short- or long- term mobility (%)	-0.745*	(0.416)				
v2	Freedom of academic exchange and dissemination			0.15	(0.111)		
v3	Institutional autonomy			-0.0259	(0.0787)		
v4	Campus integrity			-0.0844	(0.108)		
lm2	GDP per capita (Thousands of €) (SD)					-0.0361	(0.194)
lm6	Average annual GDP growth (SD)					-0.484***	(0.0955)
lg1	New women doctoral graduates (ISCED 8) per thousand population aged 25- 34					0.487***	(0.123)
Constant		4.157	(3.496)	-9.735***	(1.329)	-6.454**	(2.800)
Observations		168		208		208	
R-squared		0.881		0.86		0.884	

Source: Authors' own elaboration.
Notes: The first letter of variables, l, stands for logarithm. Model 10 has less observations due to missing data for Iceland and Switzerland. Robust standard errors in parentheses
Statistical significance level : *** p<0.01, ** p<0.05, * p<0.1

Table 6b. Regression results of models 10 to 12 – Destination countries

VARIABLES		Model 10		Model 11		Model 12	
		(1)	(2)	(3)	(4)		(6)
		Y=lro1	se	Y=lro1	se	Y=lro1	se
gc1	countries are contiguous	-0.029	(0.144)	0.163	(0.144)	0.218	(0.142)
gc2	countries share a common language	0.515**	(0.200)	0.318*	(0.179)	0.131	(0.195)
lgc8	Geodesic distances	-0.143*	(0.0836)	-0.153*	(0.0839)	-0.0483	(0.0895)
lm1	Gross Domestic Product	0.392***	(0.0688)	0.304***	(0.0605)	0.287***	(0.0680)
lm8	Broadband penetration	0.121	(0.127)				
lmo1	Share of HEI researchers that consider virtual mobility as substitute or short- or long- term mobility (%)	-3.218***	(0.613)				
v2	Freedom of academic exchange and dissemination			0.276**	(0.124)		
v3	Institutional autonomy			-0.394***	(0.130)		
v4	Campus integrity			0.081	(0.166)		
lm2	GDP per capita (Thousands of €) (SD)					-0.00937	(0.481)
lm6	Average annual GDP growth (SD)					-0.0162	(0.108)
lg1	New women doctoral graduates (ISCED 8) per thousand population aged 25- 34					0.376	(0.279)
Constant		4.157	(3.496)	-9.735***	(1.329)	-6.454**	(2.800)
Observations		168		208		208	
R-squared		0.881		0.86		0.884	

Source: Authors' own elaboration.

Notes: The first letter of variables, l, stands for logarithm. Model 10 has less observations due to missing data for Iceland and Switzerland. Robust standard errors in parentheses

Statistical significance level : *** p<0.01, ** p<0.05, * p<0.1

4.2. Results of Full model

The table in Appendix 4 presents the results of the linear regression model by ordinary least squares (OLS) as well as those of the random forest model.

Table 7a. Results of OLS and Random Forest ML algorithm – Origin countries

Indicator		Regression Model		Random Forest Model	
		Estimates coeff.	se	importance	rank
gc1	Countries are contiguous	0.189***	(0.0549)	1474692	4
gc2	Countries share a common language	0.386***	(0.128)		
lgc8	Geodesic distances	-0.200***	(0.0537)	1623967	3
lom1	Gross Domestic Product	1.097***	(0.0872)	7477369	1
o.loh1	Researchers (FTE) per thousand employees	-		435377	12
o.loa7	Ease of starting a business (SD)	-		399156	16
lom17	Knowledge-intensive services exports	-0.481***	(0.158)		
lom18	Medium and high-tech product exports	-0.857**	(0.398)		
lom19	Non-R&D innovation expenditure	0.252***	(0.0693)		
o.lom24	Share (%) of researchers in the private sector in the total number of researchers	-		349850	19
o.lom25	Share High and Medium high-tech manufacturing (SD)	-		346290	20
lof5	R&D expenditure business sector	0.819***	(0.154)		
lof6	R&D expenditure public sector	-0.596***	(0.110)		
lof7	Top R&D spending enterprises per 10 mln population (SD)	-0.171**	(0.0659)	488213	8
o.loa10	International co-publications	-		480571	9
loa8	Foreign doctorate students	0.333***	(0.0644)	392574	17
o.lol1	Percentage of co-publications of the country with an author from another country (%)	-		474141	10
loa11	Researchers employed on fixed-terms contracts in their current academic position (%)	-0.195*	(0.0998)		
loa16	Researchers that consider themselves well paid or paid a reasonable salary (%)	0.468**	(0.203)		
o.loa17	Researchers that consider the remuneration package in their current academic position better than outside academia (%)	-		420192	14
o.loa18	Researchers satisfied with their pension plan in the current academic position (%)	-		536234	7
o.lomo1	HEI researchers that consider virtual mobility as a substitute or short- or long-term mobility (%)	-		1795868	2
ov3	Institutional autonomy	-0.327***	(0.113)		
ov4	Campus integrity	0.660***	(0.157)	379391	18
o.lom2	GDP per capita (Thousands of €) (SD)	-		607208	6
Constant		-13.78***	(3.368)		
Observations		98			
R-squared		0.983			

Source: Authors' own elaboration.
Notes: « o. » omitted variables (due to collinearity) in the regression model.
Robust standard errors in parentheses. Statistical significance level : *** p<0.01, ** p<0.05, * p<0.1

Table 7b. Results of regression model (Ordinary Least Squares) and Random Forest ML algorithm – Destination countries

Indicator	Description	Regression Model		Random Forest Model	
		Estimates coeff.	se	importance	rank
gc1	Countries are contiguous	0.189***	(0.0549)	1474692.0000	4
gc2	Countries share a common language	0.386***	(0.128)		
lgc8	Geodesic distances	-0.200***	(0.0537)	1623967.0000	3
ldm1	Gross Domestic Product	0.537***	(0.0527)	1261996	5
o.ldm18	Medium and high-tech product exports	-		407533	15
ldm19	Non-R&D innovation expenditure	0.343***	(0.122)	471049	11
ldf7	Top R&D spending enterprises per 10 mln population (SD)	0.295***	(0.0804)		
o.ldnew	Share of researchers having worked in non-academic sectors (M29+M30+M33)	-		433790	13
lda11	Researchers employed on fixed-terms contracts in their current academic position (%)	-0.560***	(0.166)		
dv4	Campus integrity	0.402***	(0.0923)		
ldm22	Product or process innovators	-0.505**	(0.223)		
Constant		-13.78***	(3.368)		
Observations		98			
R-squared		0.983			

Notes:« o. » omitted variables (due to collinearity) in the regression model
Robust standard errors in parentheses. Statistical significance level : *** p<0.01, ** p<0.05, * p<0.1

As can be seen, the OLS model has many variables omitted because of the collinearity between these variables and other explanatory variables. Since the routine of the program omits the correlated variables arbitrarily, it is not guaranteed that these omitted variables influence the dependent variable, i.e. the bilateral flows of researchers between pairs of countries.

Table 7a and 7b use the complete model of the Table in Appendix 3 but in this table, only the statistically significant variables (OLS model) at the statistical threshold of 10% and/or which are among the 20 variables which contribute more to the random forest model. We also keep the variables from this list of the most important variables that are omitted in the OLS regression. The advantage of the random forest model is that it does not suffer from this collinearity problem. This model also makes it possible to measure the relative importance of each explanatory variable to the whole of the estimated model (cf. column importance). We retrieve the rank of the 20 most important variables. Overall, the results confirm the ones obtained in Models 1 to 12. Some variables with a significant impact in the partial models are however omitted in the full model due to multicollinearity issues and some other variables become significant.

When we look at the results of the random forest model, the top 10 factors that impact the most mobility are, in the first place, the baseline indicators of size, cultural and physical proximity. In addition to the baseline indicators the virtual mobility as an alternative to physical mobility, GDP per capita and satisfaction with the remuneration package, and the existence of the top R&D spending enterprises in the country of origin stand as the most important factors followed by international collaboration indicators. OLS regression also highlights the importance of the baseline indicators in the full model. This shows that physical and cultural proximities matter. In addition, the existence of the top R&D spending enterprises in the country of origin is also found to be decreasing the mobility outflows from the country of origin whereas it stands as a factor that attracts the mobility inflows of researchers in a destination country. The OLS regression, however, omits the GDP per capita, remuneration package, and international collaboration indicators in the full model. Among the openness indicators, the foreign doctorate students become positive and significant in the model.

5. Conclusions

The objective of the current note is to investigate the determinants of brain drain in Europe using a gravity model framework that allows for studying the pull and push factors for researchers in the countries of origin and destination. The analysis covers 28 EU Member States in the time of analysis and, 3 additional Associated countries: Norway, Iceland, and Switzerland. The information about the mobility outflows is sourced from Centre for Science and Technology Studies (CWTS) and shows the flows with respect to the country of origin (first publication) and the country/ies of destination of the researchers. This dimension is calculated based on the scientometric data and refers to the period 2009-2019. In order to analyse the macroeconomic determinants of the mobility of researchers, the paper brings together information from various data sources that attribute country-level values to the potential determinants of mobility outflows.

The factors that influence the mobility outflows are grouped into twelve models: human resources, entrepreneurial possibilities, institutional framework, funding, and career-related factors, knowledge-intensive economy, R&D investments, openness, working conditions, virtual mobility, institutional factors, and socio-economic factors, and gender. The models are estimated by using linear regression and random forest estimation method that allows for determining the most important drivers of mobility outflows of researchers within Europe from the perspectives of the countries of origin and destination.

The findings of the analysis show that cultural and physical proximities matter in the mobility of researchers in Europe. As expectedly, the size of the economy is an increasing factor of mobility inflows and outflows. These indicators of the baseline model are also highlighted as among the most important factors in the results of random forest estimation.

Apart from the baseline indicators, the results indicate that countries' researcher base and entrepreneurial activities increase the mobility outflows and inflows. Satisfaction with the recruitment process is found to be a factor that increases the knowledge inflows in a destination country whereas a decreasing factor for mobility outflows in the country of origin. Attractive research systems are found to increase the mobility of its researchers. Indicators related to the knowledge-intensive economy are found to increase significantly the mobility of researchers. As for the R&D investments, we find the positive impact of public R&D spending on researchers' mobility and the positive impact of the existence of top R&D spending enterprises in the economy on attracting mobility inflows in a destination country.

Concerning the openness indicators, we find that international collaboration increases the mobility of researchers in the country of origin whereas the non-academic placements of researchers decrease the mobility both in the countries of origin and destination. Among the contract-related factors, we find that satisfactory academic positions are increasing the attractiveness of a country for mobility inflows whereas fixed-term contracts have a negative impact. We also find that the more satisfied the researchers with their salary levels the less they choose mobility in the country of origin.

The perception of virtual mobility as an alternative for physical mobility is found to be a decreasing factor for mobility in both countries of origin and destination. Among the institutional factors, the freedom of academic exchange and dissemination is an increasing factor of mobility inflows in a destination country whereas the random forest model results

highlight the campus integrity in the country of origin among the main determinants of mobility of researchers. Finally, the results suggest that countries with more female researchers are more mobile whereas the ones with higher GDP growth rates are less.
Visa policies and immigration barriers have been the main policies highlighted in the literature using the gravity model framework to analyse the determinants of international mobility of researchers.[31] In this regard, the study is distinguished from the existent studies analysing the international mobility of researchers using the gravity model framework. In this study, we seek to investigate the determinants of brain drain within the EU Member and three Associated countries, i.e. within a regional setting where the country-level heterogeneities persist but the immigration and international travel barriers are largely eliminated across countries. Concerning policy, the findings of our study highlight the positive impact of satisfying conditions in academia in terms of salary levels, openness, and freedom; and, therefore, the importance of mechanisms and conditions that reinforce these factors to increase the attractiveness of a country for researchers.
There are limitations to mention in the analysis. The country coverage of the note is limited and concerns European states. Although the strong majority of researchers' mobility has been shown to take place among developed economies and, hence, biased towards developed economies worldwide, the study has the clear purpose of assessing the determinants of mobility within Europe. Another limitation of the coverage is that the origin of researchers is only considered for EU Member States. The data used for the analysis allow to capture the brain drain from the EU to outside of the EU but do not allow to capture the brain gain of the EU countries from outside of the EU. The EU countries have been shown to compensate the brain drain towards other developed countries by brain gains from developing countries and this is not captured by the data. In addition, the scientometric indicator used in the analysis to assess the mobility of researchers carries the usual limitations of this type of indicator used in research and it remains institutional defining the origin of the researchers. Finally, the survey data used in the analysis is aggregated at the country-level that is not allowing for investigating the micro-level drivers of brain drain. A comprehensive survey data would enable to the investigation of personal factors for the researchers that are not able to detect through scientific publications and patent applications databases. An important improvement for future research would be the use of survey data at the micro-level and the assessment of micro-level determinants of brain drain creating the country dyads at the researcher-level.

References

Ackers, L., L. Oliver (2007). From Flexicurity Flexsecquality. The Impact of the Fixed-Term Contract Provisions on Employment in Science Research. International Studies of Management & Organization, 37(1), 53-79.

Azoulay, P., Ganguli, I., & Zivin, J. G. (2017). The mobility of elite life scientists: Professional and personal determinants. Research Policy, 46(3), 573-590.

Bergman, E., & Usai, S. (2009). Knowledge diffusion in European regions. IAREG Deliverable, 4.

Bonnard, C., Calmand, J., & Giret, J. F. (2017). International mobility of French Ph. Ds. European journal of higher education, 7(1), 43-55.

[31] See, for instance, Appelt et al. (2015), Drivas et al. (2020)

Børing, P., Flanagan, K., Gagliardi, D., Kaloudis, A., & Karakasidou, A. (2015). International mobility: Findings from a survey of researchers in the EU. Science and Public Policy, 42(6), 811-826.

Christie, E. (2002). Potential Trade in Southeast Europe: A Gravity Model Approach. Working Paper, the Vienna Institute for International Economic Studies-WIIW downloaded on 14 March 2002.

Cincera, M. H. Vu Thi (2006). Gravity model for trade among Caribbean countries: Is the sample selection biased?

Drivas, K., Economidou, C., Karamanis, D., & Sanders, M. (2020). Mobility of highly skilled individuals and local innovation activity. Technological Forecasting and Social Change, 158, 120144.

Guthrie, S., Lichten, C., Harte, E., Parks, S., & Wooding, S. (2017). International mobility of researchers. RAND EUROPE.

PPMI, IDEA Consult and WIFO. (2020). MORE4 study. Support data collection and analysis concerning mobility patterns and career paths of researchers. Survey on researchers outside Europe

Lewer, J. J., & Van den Berg, H. (2008). A gravity model of immigration. Economics letters, 99(1), 164-167.

Montobbio, F., & Sterzi, V. (2013). The globalization of technology in emerging markets: a gravity model on the determinants of international patent collaborations. World development, 44, 281-299.

Morley, L., Alexiadou, N., Garaz, S., González-Monteagudo, J., & Taba, M. (2018). Internationalisation and migrant academics: the hidden narratives of mobility. Higher Education, 76(3), 537-554.

OECD (2008), "The Brain Drain and Negative Social Effects: When is the Home Country Hurt?", in Policy Coherence for Development 2007: Migration and Developing Countries, OECD Publishing, Paris, https://doi.org/10.1787/9789264026100-6-en.

Orazbayev, S. (2017). International knowledge flows and the administrative barriers to mobility. Research Policy, 46(9), 1655-1665.

Siekierski, P., Lima, M. C., & Borini, F. M. (2018). International mobility of academics: Brain drain and brain gain. European Management Review, 15(3), 329-339.

Teichler, U. (2015). Academic mobility and migration: What we know and what we do not know. European Review, 23(S1), S6-S37.

Thomson, R. (2013). National scientific capacity and R&D offshoring. Research Policy, 42(2), 517-528.

Van Der Wende, M. (2015). International academic mobility: Towards a concentration of the minds in Europe. European review, 23(S1), S70-S88.

Verginer, L., & Riccaboni, M. (2021). Talent goes to global cities: The world network of scientists' mobility. Research policy, 50(1), 104127.

Yan, E., Zhu, Y., & He, J. (2020). Analyzing academic mobility of US professors based on ORCID data and the Carnegie Classification. Quantitative Science Studies, 1(4), 1451-1467.

). On the detrimental impact of visa restrictions on bilateral trade and foreign direct investment. Applied Geography, 31(3), 901-907.

Aceituno-Aceituno, P., Romero-Martínez, S. J., Victor-Ponce, P., & García-Nuñez, J. (2015). Determinants factors of Spanish researchers mobility in Health Sciences. Medicina clinica, 144(11), 520-524.

Azoulay, P., Ganguli, I., & Zivin, J. G. (2017). The mobility of elite life scientists: Professional and personal determinants. Research Policy, 46(3), 573-590.

Baldwin, R., & Taglioni, D. (2006). Gravity for dummies and dummies for gravity equations (No. w12516). National bureau of economic research.

Bergman, E., & Usai, S. (2009). Knowledge diffusion in European regions. IAREG Deliverable, 4.

Bonnard, C., Calmand, J., & Giret, J. F. (2017). International mobility of French Ph. Ds. European journal of higher education, 7(1), 43-55.

Børing, P., Flanagan, K., Gagliardi, D., Kaloudis, A., & Karakasidou, A. (2015). International mobility: Findings from a survey of researchers in the EU. Science and Public Policy, 42(6), 811-826.

Breiman, L. (2001). Random forests. Machine learning, 45(1), 5-32.

Christie, E. (2002). Potential Trade in Southeast Europe: A Gravity Model Approach. Working Paper, the Vienna Institute for International Economic Studies-WIIW downloaded on 14 March 2002.

Cincera, M., (2004) Brain Drain, Brain Gain and Brain Exchange: The Role of MNEs in a Small Open Economy, Brussels Economic Review, 47(1): 159-184.

Cincera, M. H. Vu Thi (2006). Gravity model for trade among Caribbean countries: Is the sample selection biased?

Clark, X., Hatton, T. J., & Williamson, J. G. (2007). Explaining US immigration, 1971–1998. The Review of Economics and Statistics, 89(2), 359-373.

De Groot, H. L., Linders, G. J., Rietveld, P., & Subramanian, U. (2004). The institutional determinants of bilateral trade patterns. Kyklos, 57(1), 103-123.

Docquier, F., & Rapoport, H. (2012). Globalization, brain drain, and development. Journal of economic literature, 50(3), 681-730.

Drivas, K., Economidou, C., Karamanis, D., & Sanders, M. (2020). Mobility of highly skilled individuals and local innovation activity. Technological Forecasting and Social Change, 158, 120144.

Guthrie, S., Lichten, C., Harte, E., Parks, S., & Wooding, S. (2017). International mobility of researchers. RAND EUROPE.

IDEA Consult. (2013). Support for continued data collection and analysis concerning mobility patterns and career paths of researchers. Final report MORE, 2.

Jansen, M., & Piermartini, R. (2009). Temporary migration and bilateral trade flows. World Economy, 32(5), 735-753.

Karemera, D., Oguledo, V. I., & Davis, B. (2000). A gravity model analysis of international migration to North America. Applied economics, 32(13), 1745-1755.

Kleinert, J., & Toubal, F. (2010). Foreign sales strategies of multinational enterprises (No. 327). Tübinger Diskussionsbeiträge.

Lewer, J. J., & Van den Berg, H. (2008). A gravity model of immigration. Economics letters, 99(1), 164-167.

Linders, G. J., & De Groot, H. L. (2006). Estimation of the gravity equation in the presence of zero flows.

Lutz W. (Ed.), Amran G., Bélanger A., Conte A., Gailey N., Ghio D., Grapsa E., Jensen K., Loichinger E., Marois G., Muttarak R., Potančoková M., Sabourin P., Stonawski M., Demographic Scenarios for the EU - Migration, Population and Education, EUR 29739 EN, Publications Office, Luxembourg, 2019, ISBN 978-92-76-03216-8, doi:10.2760/590301, JRC116398.

Mayda, A. M. (2005). International migration: a panel data analysis of economic and non-economic determinants, IZA Discussion Papers, No. 1590

Montobbio, F., & Sterzi, V. (2013). The globalization of technology in emerging markets: a gravity model on the determinants of international patent collaborations. World development, 44, 281-299.

Neumayer, E. (2011Aceituno-Aceituno, P., Romero-Martínez, S. J., Victor-Ponce, P., & García-Nuñez, J. (2015). Determinants factors of Spanish researchers mobility in Health Sciences. Medicina clinica, 144(11), 520-524.

Liu, X., D. Wu, G. K. Zewdie, L. Wijerante, C. I. Timms, A. Riley, E. Levetin, and D. J. Lary. 2017. Using machine learning to estimate atmospheric Ambrosia pollen concentrations in Tulsa, OK. Environmental Health Insights 11.

OECD (2008), "The Brain Drain and Negative Social Effects: When is the Home Country Hurt?", in Policy Coherence for Development 2007: Migration and Developing Countries, OECD Publishing, Paris, https://doi.org/10.1787/9789264026100-6-en.

Orazbayev, S. (2017). International knowledge flows and the administrative barriers to mobility. Research Policy, 46(9), 1655-1665.

Rose, 2007Rose, A.K (2000). One Money, One Market: Estimating the Effect of Common Currencies on Trade. Economic Policy, (30), 7-45.

Siekierski, P., Lima, M. C., & Borini, F. M. (2018). International mobility of academics: Brain drain and brain gain. European Management Review, 15(3), 329-339.

Schonlau, M., & Zou, R. Y. (2020). The random forest algorithm for statistical learning. The Stata Journal, 20(1), 3-29.

Teichler, U. (2015). Academic mobility and migration: What we know and what we do not know. European Review, 23(S1), S6-S37.

Thomson, R. (2013). National scientific capacity and R&D offshoring. Research Policy, 42(2), 517-528.

Van Der Wende, M. (2015). International academic mobility: Towards a concentration of the minds in Europe. European review, 23(S1), S70-S88.

Verginer, L., & Riccaboni, M. (2021). Talent goes to global cities: The world network of scientists' mobility. Research policy, 50(1), 104127.

Yan, E., Zhu, Y., & He, J. (2020). Analyzing academic mobility of US professors based on ORCID data and the Carnegie Classification. Quantitative Science Studies, 1(4), 1451-1467.

Zwinkels, R. C., & BBeugelsdijk, S. (2010). Gravity equations: Workhorse or Trojan horse in explaining trade and FDI patterns across time and space?. International Business Review, 19(1), 102-115.

APPENDIX 1. Brain drain indicators and determinants

indicator	dimension	definition	year	source
RO1	brain drain	researchers outflow by country of citizenship	2020	MORE4 survey
RO2	brain drain	Researchers outflow by country of highest degree	2020	MORE4 survey
RO3	brain drain	Researchers outflow by country of affiliation	2020	CWTS
M1	MACRO	Gross Domestic Product	2019	EUROSTAT
M2	MACRO	GDP per capita (Thousands of €) (SD)	2020	EIS
M3	MACRO	Population	2020	EUROSTAT
M4	MACRO	Gross Expenditures on R&D	2019	EUROSTAT
M5	MACRO	R&D personnel	2019	EUROSTAT
M6	MACRO	Average annual GDP growth (SD)	2020	EIS
M7	MACRO	Average annual population growth (SD)	2020	EIS
M8	MACRO	Broadband penetration	2020	EIS
M9	MACRO	Employment fast-growing enterprises of innovative sectors	2020	EIS
M10	MACRO	Employment impacts	2020	EIS
M11	MACRO	Employment MHT manufacturing KIS services	2020	EIS
M12	MACRO	Employment share Manufacturing (SD)	2020	EIS
M13	MACRO	Employment share Services (SD)	2020	EIS
M14	MACRO	Enterprise births (10+ employees) (SD)	2020	EIS
M15	MACRO	Firm investments	2020	EIS
M16	MACRO	Foreign-controlled enterprises – share of value added (SD)	2020	EIS
M17	MACRO	Knowledge-intensive services exports	2020	EIS
M18	MACRO	Medium and high-tech product exports	2020	EIS
M19	MACRO	Non-R&D innovation expenditure	2020	EIS
M20	MACRO	Population density (SD)	2020	EIS
M21	MACRO	Population size (SD)	2020	EIS
M22	MACRO	Product or process innovators	2020	EIS
M23	MACRO	Sales impacts	2020	EIS
M24	MACRO	Share (%) of researchers in the private sector in the total number of researchers	2020	EUROSTAT
M25	MACRO	Share High and Medium high-tech manufacturing (SD)	2020	EIS
M26	MACRO	Share Knowledge-intensive services (%) (SD)	2020	EIS

M27	MACRO	Share of R2-3-4 researchers who have worked as a researcher (excluding PhD) in public or government sector (%)	2020	MORE4
M28	MACRO	Share of R2-3-4 researchers who have worked as a researcher (excluding PhD) in the private not-for-profit sector (%)	2020	MORE4
M29	MACRO	Share of researchers (post PhD) that have worked abroad as a researcher or less than 3 months in the last ten years (%)	2020	MORE4
M30	MACRO	Share of researchers (post PhD) that have worked abroad as researcher or more than 3 months in the last 10 years (%)	2020	MORE4
M31	MACRO	Share of researchers with experience in private sector (%)	2020	MORE4
M32	MACRO	Turnover share large enterprises (SD)	2020	EIS
M33	MACRO	Turnover share SMEs (SD)	2020	EIS
M34	MACRO	Medium and high-tech Industry (including construction) (% manufacturing value added)	2018	Worldbank
GC1	Geographic and cultural proximity	dummy variables indicating whether the two countries are contiguous	2011	CEPII
GC2	Geographic and cultural proximity	dummy variables indicating whether the two countries share a common language	2011	CEPII
GC3	Geographic and cultural proximity	dummy variables indicating whether the two countries share a common language	2011	CEPII
GC4	Geographic and cultural proximity	dummy variables indicating whether the two countries have had a common colonizer after 1945	2011	CEPII
GC5	Geographic and cultural proximity	dummy variables indicating whether the two countries have had ever had a colonial link	2011	CEPII
GC6	Geographic and cultural proximity	dummy variables indicating whether the two countries have had a colonial relationship after 1945	2011	CEPII
GC7	Geographic and cultural proximity	dummy variables indicating whether the two countries are currently in a colonial relationship	2011	CEPII
GC8	Geographic and cultural proximity	Geodesic distances calculated following the great circle formula, which uses latitudes and longitudes of the most important cities/agglomerations (in terms of population)	2011	CEPII
GC9	Geographic and cultural proximity	dummy variables indicating whether the two countries were/are the same country	2011	CEPII
F1	Funding sources	FDI net inflows (SD)	2020	EIS
F2	Funding sources	Finance and support	2020	EIS
F3	Funding sources	Government procurement of advanced technology products (SD)	2020	EIS
F4	Funding sources	Private co-funding of public R&D expenditures	2020	EIS
F5	Funding sources	R&D expenditure business sector	2020	EIS
F6	Funding sources	R&D expenditure public sector	2020	EIS
F7	Funding sources	Top R&D spending enterprises per 10 mln population (SD)	2020	EIS
F8	Funding sources	Venture capital	2020	EIS
F9	Funding sources	Government budget allocations for R&D (GBARD) in % of GDP	2020	EIS
G1	Gender	New women doctoral graduates (ISCED 8) per thousand population aged 25- 34	2020	EUROSTAT
G2	Gender	Share (%) of female researchers in the total number of researchers	2020	EUROSTAT
G3	Gender	Glass Ceiling Index	2020	SHE Figures
G4	Gender	Gender pay gap (%) in the research sector	2020	MORE4

G5	Gender	Proportion of women as Grade A academic staff (%)	2020	SHE Figures
G6	Gender	Proportion of women on boards(%)	2020	SHE Figures
G7	Gender	Share of female researchers with experience in private sector (%)	2020	MORE4
H1	Human resources	Researchers (FTE) per thousand employees	2020	EUROSTAT
H2	Human resources	Number of young PhD graduates (ISCED8) per thousand population aged 25-29	2020	EUROSTAT
H3	Human resources	Number of PhD graduates (ISCED8) per thousand population	2020	EUROSTAT
H4	Human resources	Human resources	2020	EIS
H5	Human resources	New doctorate graduates	2020	EIS
A1	Attractiveness	Satisfaction with recruitment process at home research institution (open. transparent. merit-based) (%)	2020	MORE4
A2	Attractiveness	Appreciation of transferable skills (e.g. project management. data cleaning. networking. etc.) are regarded as positive factors for career progression (%)	2020	MORE4
A3	Attractiveness	Degree of satisfaction with different aspects of the current academic position. Composite indicator with career related aspects.	2020	MORE4
A4	Attractiveness	Transparency and meritocracy in professional advancement in HEIs (composite indicator) (%)	2020	MORE4
A5	Attractiveness	Share of researchers who published in (or sent articles or review to) open access journals (%)	2020	MORE4
A6	Attractiveness	Attractive research systems	2020	EIS
A7	Attractiveness	Ease of starting a business (SD)	2020	EIS
A8	Attractiveness	Foreign doctorate students	2020	EIS
A9	Attractiveness	Innovation-friendly environment	2020	EIS
A10	Attractiveness	International co-publications	2020	EIS
A11	Attractiveness	Share of researchers employed on fixed-terms contracts in their current academic position (%)	2020	MORE4
A12	Attractiveness	Most-cited publications	2020	EIS
A13	Attractiveness	University ranking: rank	2020	QS World University Rankings
A14	Attractiveness	University ranking: cumulated score	2020	QS World University Rankings
A15	Attractiveness	University ranking: %	2020	QS World University Rankings
A16	Attractiveness	Satisfaction with remuneration - share of researchers that consider themselves well paid or paid a reasonable salary (%)	2020	MORE4
A17	Attractiveness	Satisfaction with remuneration - Share of researchers that consider the remuneration package in their current academic position better than that of people with comparable skills and experience outside academia (%)	2020	MORE4
A18	Attractiveness	Satisfaction in current academic position regarding pensions/social security - Share of researchers satisfied with their pension plan in the current academic position (%)	2020	MORE4
A19	Attractiveness	Satisfaction in current academic position regarding pensions/social security - Share of researchers satisfied with their social security rights and benefits in the current academic position (%)	2020	MORE4
A20	Attractiveness	Share of researchers with part-time employment in their current academic position (%)	2020	MORE4
A21	Attractiveness	Transferability of pensions/social security - share of researchers acknowledging the importance of transferring pensions as barrieror post-PhD mobility (%)	2020	MORE4

A22	Attractiveness	Transferability of pensions/social security - share of researchers acknowledging the importance of transferring social security as barrier or post-PhD mobility (%)	2020	MORE4
A23	Attractiveness	Number of HRS4R acknowledged institutions per thousand researchers	2020	EURAXESS
I1	Attractiveness	Innovation index	2020	EIS
I2	Innovation	Buyer sophistication (SD)	2020	EIS
I3	Innovation	Innovative sales share	2020	EIS
I4	Innovation	Innovators	2020	EIS
I5	Innovation	Marketing or organisational innovators	2020	EIS
I6	Innovation	Opportunity-driven entrepreneurship	2020	EIS
I7	Innovation	SMEs innovating in-house	2020	EIS
I8	Innovation	Total Entrepreneurial Activity (TEA) (SD)	2020	EIS
IP1	Intellectual property	Design applications	2020	EIS
IP2	Intellectual property	Intellectual assets	2020	EIS
IP3	Intellectual property	Patent applications	2020	EIS
IP4	Intellectual property	Rule of law (SD)	2020	EIS
IP5	Intellectual property	Trademark applications	2020	EIS
L1	Linkages	Percentage of co-publications of the country with an author from another country (%)	2020	SCOPUS
L2	Linkages	Innovative SMEs collabourating	2020	EIS
L3	Linkages	Linkages	2020	EIS
L4	Linkages	Public-private co-publications	2020	EIS
MO1	Mobility	Share of HEI researchers that consider virtual mobility as substitute or short- or long- term mobility (%)	2020	MORE4
MO2	Mobility	R1-R2 PhD degree mobility (%)	2020	MORE4
MO3	Mobility	Interdisciplinary mobility as a positive actor of career progression (%)	2020	MORE4
MO4	Mobility	Mobile PhD students (ISCED 6/8) from abroad as a share of total PhD students of the country	2020	EUROSTAT
T1	Training	Share of researchers receiving transferable skills training during PhD (%)	2020	MORE4
T5	Training	Lifelong learning	2020	EIS
T2	Training	Share of PhD students who received training in open science approaches (%)	2020	MORE4
T6	Training	Tertiary education	2020	EIS
T3	Training	Basic-school entrepreneurial education and training (SD)	2020	EIS
T4	Training	Enterprises providing ICT training	2020	EIS
R	Reforms	Which reforms to institutional autonomy have been important to enhance the impacts of public research?	2017	OECD Resgov
V1	Academic freedom	Freedom to research and teach	2020	V-Dem

V2	Academic freedom	Freedom of academic exchange and dissemination	2020	V-Dem
V3	Academic freedom	Institutional autonomy	2020	V-Dem
V4	Academic freedom	Campus integrity	2020	V-Dem

Source : Authors' own elaboration.

APPENDIX 2. Descriptive statistics

Variable	Obs.	Mean	Std. Dev.	Min	Max
ro3	280	1357.804	2255.782	5	16970
om1	280	571515.2	795989.3	14863.8	3186484
dm1	208	1611297	996349.3	35342.1	3186484
om2	280	31.59786	12.44058	15	79.4
dm2	208	34.88125	6.325219	20.4	47.3
om3	280	17400000	23100000	364134	83200000
dm3	208	46500000	28500000	1328976	83200000
om4	280	12111.11	20678.44	94.919	101205.1
dm4	208	36490.48	29987.37	569.475	101205.1
om5	280	119360.6	173033.7	1576	734200
dm5	208	341107.6	225652.2	6448	734200
om6	280	2.705	1.381198	0.55	6.85
dm6	208	1.499663	0.5958158	0.55	4.75
om7	280	0.4243571	0.9265098	-0.95	3.55
dm7	208	0.3924038	0.3332072	-0.2	1.17
om8	280	235.5357	114.915	0	410
dm8	208	195.3846	120.3612	0	410
om9	280	107.4057	56.86143	0	204.82
dm9	208	96.14005	40.34439	0	187.02
om10	280	115.3313	37.98057	45.19	200.86
dm10	208	117.5656	28.20205	57.37	167.78
om11	280	123.9618	51.14916	27.03	254.05
dm11	208	143.7374	38.97331	63.51	216.22
om12	280	14.82329	5.637717	4.5	27.78
dm12	208	13.58808	3.759722	8.03	27.78
om13	280	41.69818	4.710033	31.28	54.17
dm13	208	43.62861	2.877899	35.04	49.28
om14	280	1.298464	0.8149245	0.21	4.05
dm14	208	1.220144	1.224155	0.21	4.05
om15	280	117.8841	40.80572	10.57	223.76
dm15	208	139.7478	46.70844	83.58	223.76
om16	280	12.52061	6.11953	0	35.25
dm16	208	9.465625	4.924536	0	21.32
om17	280	79.0945	38.88709	4.43	152.48
dm17	208	96.63466	28.92065	30.01	127.83
om18	280	87.37293	38.70619	0	147.3
dm18	208	103.1232	25.06766	0	142.99
om19	280	119.8576	63.21238	0	250.2
dm19	208	129.809	65.44531	15.65	250.2
om20	280	170.1642	265.3444	3.4	1569.14
dm20	208	208.1504	116.6799	17.07	501.07
om21	280	17.37411	22.97539	0.35	82.78
dm21	208	46.33351	28.43342	1.32	82.78
om22	280	104.9606	47.80339	0	176.39
dm22	208	122.291	28.42133	27.82	176.39
om23	280	79.08889	24.56936	31.57	128.7

dm23	208	98.22865	17.42306	52.79	119.12
om24	280	45.89454	14.53303	18.58	71.97
dm24	273	53.73802	11.6649	30.31	73.75
om25	280	31.43961	11.25683	12.08	51.48
dm25	208	38.88082	7.325077	14.38	51.48
om26	280	35.57564	6.796032	25.01	59.78
dm26	208	38.07764	4.422334	28.42	46.36
om27	280	13.57506	3.055126	7.375138	20.32479
dm27	234	12.07997	2.942176	7.375138	17.62614
om28	280	7.623487	2.661859	3.352335	14.03157
dm28	234	7.102961	2.600068	3.352335	13.01623
om29	280	32.28269	4.50486	24.09618	41.70817
dm29	234	34.26544	4.216366	27.36955	41.07068
om30	280	27.96845	9.235906	12.62846	62.73543
dm30	234	30.38698	7.798162	20.63453	48.6055
om31	280	9.89905	3.230241	2.971408	17.40105
dm31	234	9.189061	4.163534	2.971408	17.40105
om32	280	33.07111	14.80659	0	54.33
dm32	208	37.14817	17.11483	0	54.33
om33	280	36.92918	14.70302	0	52.77
dm33	208	32.42611	14.23651	0	48.7
om34	280	41.03286	13.26399	11.30913	64.56213
dm34	280	48.03568	9.651231	19.65247	64.56213
gc1	280	0.1571429	0.364587	0	1
gc2	280	0.1285714	0.3353243	0	1
gc3	280	0.0285714	0.1668969	0	1
gc4	280	0.0142857	0.1188785	0	1
gc5	280	0.0607143	0.2392331	0	1
gc6	280	0.0035714	0.0597614	0	1
gc7	280	0.0035714	0.0597614	0	1
gc8	280	2738.853	3242.5	59.61723	17230.5
of1	280	4.656143	9.72867	-11.8	47.56
df1	208	2.792933	2.094838	-2.53	5.94
of2	280	103.143	45.30276	13.45	190.83
df2	208	132.7798	37.74967	46.81	190.83
of3	280	3.444036	0.5503845	2.48	4.65
df3	208	3.744423	0.4871138	2.57	4.56
of4	280	72.406	32.12541	8.2	149.28
df4	208	96.05577	34.13196	44.19	149.28
of5	280	87.55375	54.44422	10.15	187.42
df5	208	122.2015	47.09565	43.34	187.42
of6	280	81.86957	47.0444	2.87	162.31
df6	208	101.8062	37.03612	39.52	162.31
of7	280	29.78296	50.67474	0	271.35
df7	208	30.95274	22.20899	0	79.09
of8	280	134.1593	85.39631	0	272.58
df8	208	184.7979	78.77298	10.99	272.58
of9	280	0.5833929	0.2494041	0.19	1.02

df9	273	0.6982784	0.1653616	0.35	1.02
og1	280	0.5671786	0.249082	0.15	1.23
dg1	234	0.7931624	0.2240407	0.25	1.23
og2	231	32.98641	8.938232	21.22	51.54
dg2	172	27.68738	6.077203	21.22	39.5
og3	253	1.59913	0.2934213	1.04	2.6
dg3	232	1.668276	0.0939123	1.42	1.85
og4	264	15.55117	8.494527	-6.71	30.45
dg4	234	17.1794	4.612594	6.37	25.37
og5	263	26.11471	8.974073	12.99	54.32
dg5	233	22.03914	2.844055	14.65	29.36
og6	270	33.11007	12.64054	11.72	54
dg6	204	28.77265	9.357515	14.58	54
og7	280	7.671352	2.994694	2.489785	15.13806
dg7	234	7.424757	3.251018	2.489785	13.54835
oh1	280	8.795464	3.658985	2.21	16.23
dh1	234	9.84953	2.19403	5.54	16.23
oh2	280	0.9498929	0.6523058	0.07	2.44
dh2	234	1.593205	0.5505272	0.26	2.44
oh3	280	0.2451071	0.1067774	0.08	0.49
dh3	268	0.2989179	0.108417	0.08	0.49
oh4	280	132.5379	55.72719	13.64	252.86
dh4	208	158.2114	56.76272	61.45	252.86
oh5	280	105.0676	58.65243	13.78	229.16
dh5	208	150.1175	54.81461	13.78	229.16
oa1	280	82.804	5.29056	70.70187	91.92654
da1	234	83.40213	5.570351	70.70187	89.74006
oa2	280	86.58822	4.617401	75.52664	93.66664
da2	234	86.25792	5.070169	75.52664	92.22593
oa3	280	0.8256429	0.0699433	0.64	0.93
da3	234	0.804188	0.0874409	0.64	0.91
oa4	280	74.58189	8.248508	50.27627	88.25609
da4	234	73.08342	7.706863	50.27627	86.26835
oa5	280	83.68988	5.141105	68.89592	95.61175
da5	234	80.81226	5.739606	68.89592	90.51855
oa6	280	132.8691	67.43277	29.42	259.12
da6	208	164.9782	56.35113	36.65	259.12
oa7	280	74.22732	15.00223	0	85.01
da7	208	77.92529	3.48259	67.65	85.01
oa8	280	143.6072	97.78146	0	357.96
da8	208	203.9103	102.8435	0	357.96
oa9	280	189.2696	79.49259	71.37	329.62
da9	208	193.3656	66.6335	76.73	329.62
oa10	280	215.8545	124.071	30.63	406.94
da10	208	222.5789	107.0396	52.58	406.94
oa11	280	23.70095	12.17011	3.048681	53.76235
da11	234	24.54185	10.85869	7.688723	41.93064
oa12	280	92.99414	40.94219	20.85	156.92

da12	208	122.3897	26.00784	41.19	156.92
oa13	187	24.57219	15.71859	2	56
da13	280	9.692857	8.401567	1	55
oa14	280	297.4354	516.4726	0	2559.5
da14	280	1277.341	1326.278	25.6	4545.3
oa15	280	1.344869	2.335258	0	11.57291
da15	280	5.775564	5.996836	0.1157517	20.55181
oa16	280	12.84471	5.397376	3.434785	25.03737
da16	234	9.614599	4.840962	3.434785	22.58155
oa17	280	66.12167	18.40273	23.4807	92.30073
da17	234	75.66214	15.35357	23.4807	91.7121
oa18	280	76.88853	14.81995	38.59771	96.592
da18	234	81.23539	11.00906	38.59771	96.592
oa19	280	86.06678	9.640404	54.91828	98.54419
da19	234	89.7513	5.086148	54.91828	96.21102
oa20	280	10.11306	6.78905	2.216695	26.23173
da20	234	9.458566	6.894848	2.216695	23.9697
oa21	235	31.70039	16.5324	6.815016	67.62623
da21	225	32.69127	18.69995	9.88345	67.62623
oa22	235	34.60525	15.6331	8.69634	63.69638
da22	225	34.25467	16.58324	13.80864	63.69638
oa23	238	0.2919748	0.3213065	0.04	1.79
da23	206	0.2062136	0.1909954	0.04	0.75
oi1	280	107.824	33.70235	34.4	179.73
di1	208	127.3425	27.39571	64.07	179.73
oi2	280	3.875107	0.6452878	2.76	5.02
di2	208	4.342212	0.4839261	2.99	5.02
oi3	280	70.35379	39.25284	14.28	152.75
di3	208	94.7137	33.31514	20.71	146.95
oi4	280	93.49693	44.29936	0	164.27
di4	208	112.0266	26.73102	14.31	164.27
oi5	280	82.76975	43.59959	0	162.4
di5	208	108.174	30.28529	0	162.4
oi6	280	136.8543	78.7214	0	275.59
di6	208	156.234	54.0091	56.06	275.59
oi7	280	90.25693	50.17636	0	170
di7	208	106.1406	32.68487	16.18	170
oi8	280	8.182893	3.805019	0	19.38
di8	208	6.976635	2.302723	3.75	19.38
oip1	280	72.01104	42.93619	10.74	158.89
dip1	208	88.07986	35.07463	13.59	153.89
oip2	280	84.97821	34.02452	23.78	148.45
dip2	208	99.81529	27.28584	39.13	148.45
oip3	280	74.68696	36.23802	21.78	144.39
dip3	208	98.42115	26.35098	33.19	144.39
oip4	280	1.192607	0.6445676	-0.04	2.03
dip4	208	1.436971	0.5371709	0.11	2.03
oip5	280	119.0719	56.75306	30.67	250.46

dip5	208	116.9297	36.41469	51.73	222.7
ol1	280	57.03246	10.85557	32.8726	78.2554
dl1	273	56.21406	11.24543	21.74	71.0733
ol2	280	140.4611	81.55359	6.27	265.09
dl2	208	142.8072	73.96283	40.04	265.09
ol3	280	108.9412	49.42131	17.1	187.75
dl3	208	128.2606	38.26538	40.68	187.75
ol4	280	152.6025	114.7111	17.39	367.29
dl4	208	185.0827	100.7676	33.19	367.29
omo1	280	68.98374	8.365511	52.76923	92.18537
dmo1	234	68.82636	5.065917	52.76923	75.75492
omo2	248	19.14643	12.63001	1.540652	51.61994
dmo2	232	18.72539	6.177144	6.012912	32.43009
omo3	280	77.54781	6.484933	60.06277	87.50429
dmo3	234	75.23147	6.914046	60.06277	86.8313
omo4	234	9.149017	10.5447	0.36	54.45
dmo4	173	8.358613	5.060365	0.36	18.84
ot1	248	50.32123	12.95867	31.00813	89.3928
dt1	232	50.22398	10.52776	35.12331	70.32642
ot2	256	22.47056	12.28557	0	72.33396
dt2	208	17.52214	5.910349	0	37.14717
ot3	280	2.05975	0.7046565	0	3.31
dt3	208	2.117212	0.4635818	1.58	3.31
ot4	280	142.7198	67.79795	0	253.85
dt4	208	140.1263	68.61761	0	253.85
ot5	280	136.2099	90.54918	0	306.67
dt5	208	164.7975	81.30307	40	306.67
ot6	280	159.4661	65.64457	11.57	274.38
dt6	208	161.226	69.66428	32.23	238.02
or	221	0.8778281	0.3282277	0	1
dr	189	0.7883598	0.409556	0	1
ov1	280	2.807143	0.3952483	2	3
dv1	280	2.678571	0.4678611	2	3
ov2	280	2.331614	0.5603983	0.071	2.974
dv2	280	2.179807	0.8628378	-1.803	2.974
ov3	280	1.77595	0.6837425	-0.247	2.871
dv3	280	1.608596	0.7418794	-1.155	2.871
ov4	280	2.546982	0.6390394	0.52	3.281
dv4	280	2.1413	0.9034207	-1.93	3.281

Source: Authors’ own elaboration.

APPENDIX 3. Summary of results

DETERMINANTS OF RESEARCHERS' MOBILITY		PULL & PUSH	PUSH - ORIGIN	PULL - DESTINATION
Model2: Human Ressources				
lh1	Researchers (FTE) per thousand employees	positive		
lh3	Number of PhD graduates (ISCED8) per thousand population	positive		
Model3: Entrepreneurial activity				
la7	Ease of starting a business	positive		
li8	Total Entrepreneurial Activity		negative	
Model4: Attractive research systems				
la1	Satisfaction with recruitment process at home research institution (open. transparent. merit-based) (%)		negative	positive
la6	Attractive research systems		positive	
Model5: structure of R&D economy				
lm17	Knowledge-intensive services exports	positive		
lm18	Medium and high-tech product exports		negative	
lm22	Product or process innovators		positive	
lm24	Researchers in the private sector in the total number of researchers (%)			negative
lm25	Share High and Medium high-tech manufacturing		positive	
Model6: R&D expenditures/top R&D firms				
lf5	R&D expenditure business sector		positive	negative
lf6	R&D expenditure public sector	positive		
lf7	Top R&D spending enterprises per 10 mln population			positive
Model7: Openness				
la10	International co-publications	positive		
lnew	Researchers having worked in non-academic sectors (%)	negative		
Model8: Satisfaction with different aspects of the current academic position/fixed term contracts				
la3	Degree of satisfaction with different aspects of the current academic position: Composite indicator			positive
la11	Researchers employed on fixed-terms contracts in their current academic position (%)			negative
Model9: satisfaction with remuneration/pension/social security				
la16	Researchers that consider themselves well paid or paid a reasonable salary (%)		negative	
la19	Researchers satisfied with their social security rights and benefits in the current academic position (%)			negative
Model10: Virtual mobility				
lmo1	HEI researchers that consider virtual mobility as substitute or short- or long- term mobility (%)	negative		
Model11: Institutional factors				
v2	Freedom of academic exchange and dissemination			positive
v3	Institutional autonomy			negative
Model12: Wealth and gender				
lm6	Average annual GDP growth (SD)		negative	
lg1	New women doctoral graduates (ISCED 8) per thousand population aged 25- 34		positive	

Source: Authors' own elaboration.

APPENDIX 4. Full model

		Regression Model	
Indicator	Description	Estimates coeff.	SE
gc1	countries are contiguous	0.189***	(0.0549)
gc2	countries share a common language	0.386***	(0.128)
lgc8	Geodesic distances	-0.200***	(0.0537)
lom1	Gross Domestic Product	1.097***	(0.0872)
ldm1		0.537***	(0.0527)
o.loh1	Researchers (FTE) per thousand employees	-	
o.ldh1		-	
loh3	Number of PhD graduates (ISCED8) per thousand population	0.237	(0.164)
o.ldh3		-	
o.loa7	Ease of starting a business (SD)	-	
o.lda7		-	
o.loi8	Total Entrepreneurial Activity (TEA) (SD)	-	
o.ldi8		-	
o.loa1	Satisfaction with recruitment process at home research institution (open. transparent. merit-based) (%)	-	
o.lda1		-	
o.loa4	Transparency and meritocracy in professional advancement in HEIs	-	
o.lda4		-	
o.loa6	Attractive research systems	-	
o.lda6		-	
lom17	Knowledge-intensive services exports	-0.481***	(0.158)
o.ldm17		-	
lom18	Medium and high-tech product exports	-0.857**	(0.398)
o.ldm18		-	
lom19	Non-R&D innovation expenditure	0.252***	(0.0693)
ldm19		0.343***	(0.122)
lom22	Product or process innovators	0.127	(0.151)
ldm22		-0.505**	(0.223)
o.lom24	Share (%) of researchers in the private sector in the total number of researchers	-	
o.ldm24		-	
o.lom25	Share High and Medium high-tech manufacturing (SD)	-	
o.ldm25		-	
o.lom26	Share Knowledge-intensive services (%) (SD)	-	
o.ldm26		-	
lof5	R&D expenditure business sector	0.819***	(0.154)
o.ldf5		-	
lof6	R&D expenditure public sector	-0.596***	(0.110)
o.ldf6		-	
lof7	Top R&D spending enterprises per 10 mln population (SD)	-0.171**	(0.0659)
ldf7		0.295***	(0.0804)
o.loa10	International co-publications	-	
o.lda10		-	
loa8	Foreign doctorate students	0.333***	(0.0644)
o.lda8		-	
o.lol1	Percentage of co-publications of the country with an author from another country (%)	-	

o.ldl1		-	
o.lom30	Share of researchers (post PhD) that have worked abroad as researcher or more than 3 months in the last 10 years (%)	-	
o.ldm30		-	
o.lonew	Share of researchers having worked in non-academic sectors (M29+M30+M33)	-	
o.ldnew		-	
o.loa3	Degree of satisfaction with different aspects of the current academic position.	-	
o.lda3		-	
loa11	Share of researchers employed on fixed-terms contracts in their current academic position (%)	-0.195*	(0.0998)
lda11		-0.560***	(0.166)
loa16	Satisfaction with remuneration	0.468**	(0.203)
lda16		0.072	(0.216)
o.loa17	Satisfaction with remuneration	-	
o.lda17		-	
o.loa18	Satisfaction in current academic position regarding pensions/social security	-	
o.lda18		-	
o.loa19	Satisfaction in current academic position regarding pensions/social security	-	
o.lda19		-	
lom8	Broadband penetration	0.114	(0.237)
ldm8		0.232	(0.239)
o.lomo1	Share of HEI researchers that consider virtual mobility as substitute or short- or long- term mobility (%)	-	
o.ldmo1		-	
o.ov2	Freedom of academic exchange and dissemination	-	
dv2		-0.401	(0.321)
ov3	Institutional autonomy	-0.327***	(0.113)
dv3		0.134	(0.297)
ov4	Campus integrity	0.660***	(0.157)
dv4		0.402***	(0.0923)
o.lom2	GDP per capita (Thousands of €) (SD)	-	
o.ldm2		-	
lom6	Average annual GDP growth (SD)	-0.102	(0.109)
o.ldm6		-	
log1	New women doctoral graduates (ISCED 8) per thousand population aged 25- 34	-0.185	(0.319)
o.ldg1		-	
Constant		-13.78***	(3.368)
Observations		98	
R-squared		0.983	

Source: Authors' own elaboration.