Winners and Losers from the Protestant Reformation: An Analysis of the Network of European Universities

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Abstract

Using a new database of European academics, we describe how the network of universities was altered following the Protestant Reformation. We focus on fragmentation and on universities' centrality. Dyadic regressions confirm that geography and vernacular languages were important, but did not substitute for religion. We compare simulated networks with and without religious identity. Most universities loose centrality in the religious network compared to the atheist one. As publications per university are correlated with centrality, our simulations lend credence to the view that the loss of connectedness of universities after the Reformation was important in triggering their scientific decline.

Keywords: Upper-Tail Human Capital, Universities, Network, Centrality, Publications, Fragmentation.
JEL Classification Numbers: N33, O15, I25.

1 Introduction

Medieval universities, together with other bottom-up institutions such as monasteries, guilds, and communes, are considered to be central to the development of Europe (Greif 2006). Still, after having played a pivotal role in the Scientific Revolution of the 16th-17th centuries, many of these grand institutions seem to have plunged into an intellectual coma thereafter. This is particularly true for Southern European universities. One possible culprit for this decline is the loss of mobility of persons and ideas following the Protestant Reformation and the ensuing Catholic Counter Reformation. The literature has already stressed several important effects of the Protestant Reformation on the development of Europe (Cantoni, Dittmar, and Yuchtman 2018, Cantoni 2015, Becker and Woessmann 2009, Becker, Pfaff, and Rubin 2016). In addition to the mechanisms stressed in that literature, Ridder-Symoens (1996) argues that the Reformation led to clustering of universities, which shaped the mobility pattern of students in early modern times.[1] Beyond students' mobility, clustering might also affect the mobility pattern of teachers and scholars, which might be even more subject to restrictions than that of students.

In this paper, we analyse teachers' mobility across Europe and provide a global view of the effect of the Reformation on the network of universities and on their individual position within the network. The objects (*nodes*) in the network are universities active before 1793 in Europe. A connection (*edge* or *link*) between two universities is defined as the presence of the same scholar in both universities. To take a famous example, the English philosopher Roger Bacon (1219–1292) lectured in Oxford (c. 1233), then accepted an invitation to teach in Paris (c. 1237). This established (or rather reinforced, as Bacon was not alone in that case) a connection between those two universities, facilitating the flow of ideas, manuscripts, students between the two places. Connections between universities are built from the database of university scholars **RETE** developed by De la Croix (2021). The sources used to build this database are primary (published *cartularia* and *matricula*), secondary (books on history of universities and on biographies of professors in a specific university) and tertiary (biographical dictionaries by topic or regions, and encyclopedias).

Our main motivation for the study of the network of universities lies in the idea that the structure of a network plays a crucial role in the diffusion of information (Jackson, Rogers, and Zenou 2017). The way universities used to be connected with each other through the mobility of scholars might have affected the propagation speed of knowledge, ideas, and the intensity of academic production. Our paper aims at

[1] "There were henceforth three kinds of university: the Protestant universities, many of them proselytizing, active in training clergymen (Wittenberg, Heidelberg, Geneva and Strasburg for example); secondly, the Catholic universities of the Counter-Reformation, also proselytizing, and dedicated to educating competent clergy (in this the Jesuits played a leading part). The studia of Paris, Louvain, Ingolstadt, Vienna, Graz, Würzburg, Cologne, Pon-à-Mousson, Dole and others, as well as the Iberian universities, are of this kind. The third group comprises several universities that consciously adopted a tolerant attitude, and did not willingly refused students who were not of their religion: for instance, Padua and Siena, Orléans and Montpellier, all of them Catholic universities, or Leiden and the other Dutch universities, model Calvinist universities though they were."

exploring to what extent the documented decline in scientific production of universities during the 17th and 18th centuries can be explained by the reorganization of the network induced by the Reformation.

The decline in Catholic Universities echoes the debate on the little divergence occurring within Europe in the early modern period, and on its institutional and cultural determinants (Allen 2003; De Pleijt and Van Zanden 2016; Henriques and Palma 2019; Rota and Weisdorf 2020). Although universities themselves contributed little to the advancement of applied sciences in the early modern period, the quality of universities can still impact development through enhancing the quality of human capital in general, and of its upper tail in particular.

To study the effect of the Reformation on the network of European universities, we build seven successive networks over the period from 1000 (creation of the first associations of professors or students dedicated to education) until 1793 (French Revolution). Each network covers a period of about 100 years. The Reformation started around 1523 (creation of an higher-education college in Strasbourg, followed by the creation of the first full fledged Protestant university in Marburg, Germany). We thus obtain four networks before the Protestant Reformation and three networks after the emergence of Protestantism. We analyze the main characteristics of the network through time and find that Reformation does correlate with a lower density and to more division in the network. In fact, we observe a sharp clear-cut divide between Protestant and Catholic universities in the network after the Reformation, with only 5.75% of all links connecting them in 1598-1684. This is all the more striking as connections between universities that would convert into Protestantism and universities that would remain Catholic reaches 27.81% of all links on the brink of the Reformation. This proportion of interfaith links falls to 3.65% in 1685-1793, suggesting a long lasting impact of the Reformation on the mobility of scholars. Of course, we need to distinguish the effect of religion from geographical or vernacular effects. Using dyadic regressions, we show that religion is a strong determinant of network structure. Moreover, fragmentation increases not only between Protestant and Catholic universities, but also within those broad groups.

Looking at data through the lens of graph theory also endows us with powerful tools to study how well universities are connected in the network. In particular, we find that publications of the top five scholars in each university is strongly correlated with classical measures of centrality in the network over the period under study. In order to isolate the impact of the Reformation on each university centrality, we predict the network structure from dyadic regressions with and without religions. This allows us to compute universities' predicted centrality, along with the "natural" centrality of universities in an atheist world. We compare these two simulated centrality measures and find that the Reformation harmed most universities. The effect varies by period, by religious affiliation, and by the centrality measure which is chosen. Finally, we find that the Reformation impacted directly positively the publications of top five scholars in Protestant Universities. This positive effect was stronger than the negative effect following the deterioration of their position in the network. These trends seem particularly relevant to explain the scientific demise of the universities in the South of Europe (including France) in the modern period.

This paper speaks to the literature on the effect of Protestantism on the development of Europe. It offers a new angle based on unique data about the mobility of university professors. Compared to Cantoni, Dittmar, and Yuchtman (2018), Cantoni (2015), Becker and Woessmann (2009), and Becker, Pfaff, and Rubin (2016), we analyze an additional consequence of the Reformation and the Counter-Reformation based on the relationships between people and universities.

Our paper belongs to a tradition in economic history to use the conceptual framework offered by network theory to describe how relations between nodes shape some economic or social outcome.[2] The seminal paper using networks in economic history is probably Padgett and Ansell (1993). They construct a network of marriages in early Renaissance Florence and analyze its characteristics (centrality, etc.) to understand how the Medici gained political control. Another important paper is by Puga and Trefler (2014), who construct a similar network for Venice in the Middle Ages to study monopolization of the galley trade. Compared to these approaches, we introduce a methodological novelty. We use a dyadic regression to predict links, and, inspired by the quantitative macroeconomics literature, we run counterfactual simulations to show how the network would look if religion did not play a role. A counter-factual network is useful to illustrate the importance of religious affiliation compared to the importance of geographical proximity.[3]

To our knowledge, few other papers study phenomena related to the Protestant Reformation through a network angle. Kim and Pfaff (2012) document the key role of university students in diffusing Evangelical ideas or Catholic orthodox ideology in their places of origin. They explore city-to-university ties in the Holy Roman Empire between 1523 and 1545 and show that cities exposed to Evangelical activism through student enrollments in Wittenberg and Basel universities were more likely to institute reform. By contrast, reform was less likely in hometowns of students enrolled in the universities of Cologne and Louvain, the two leading bastions of Roman orthodoxy. Becker et al. (2020) build Luther's network of interpersonal relations using data on his correspondence, his visits, and the students he could have met

[2] Beyond using network maps to describe relations, there is a rising number of papers using exogenous changes in network structure to build causal identification strategies, see for instance Telek (2018), Becker et al. (2018), Benzell and Cooke (2020).

[3] Other papers in the economic and social networks literature use counterfactuals. Mayer and Puller (2008) explore how alternative university policies could reduce social segmentation among students, while Canen, Jackson, and Trebbi (2020) investigate how political polarization in the U.S. Congress affects legislative activity. Both papers build their counterfactual analysis on a model of network formation. We cannot use this approach as in our framework, nodes (universities) do not decide to create or sever connections. Dyadic regressions have been widely used to study the determinants of network formation, see for instance (De Weerdt 2004, Fafchamps and Gubert 2007, De Weerdt, Genicot, and Mesnard 2019). In the transport network literature, Swisher IV (2017) uses counterfactual networks to quantify the effect of the railroad on U.S. growth from its introduction in 1830 to 1861. He estimates the output loss in a counterfactual world without the technology to build railroads, but retaining the ability to construct canals. His counterfactual canal network is built through a decentralized network formation game played by profit-maximizing transport firms. In our paper, links between universities are created by mobile scholars. Although studying mobility decisions of scholars is beyond the scope of this paper, it can arguably be said that the Reformation increased the cost of moving from a Protestant to a Catholic university, or vice versa. In our atheist world, we would assume that such cost would not depend on religious considerations.

in Wittenberg. Using counterfactual simulation exercise (not too dissimilar from the one used in this paper) they show that the personal network of Luther but also the network of trade routes mattered for the adoption of the Reformation by German cities.

Our analysis is moreover related to the literature on mobility of researchers and scientific production, since the network position of a university reflects by construction the mobility of scholars. De la Croix et al. (2023) analyze the mobility of the same scholars used here (an earlier version of the **RETE** database) but without the religious dimension. They conclude that market forces in Medieval and Early Modern Europe influenced the rise of universities, shaped scholar distribution, and fostered the Scientific Revolution. Ejermo, Fassio, and Källström (2020) show with contemporary Swedish data that mobility between universities increases significantly the scientific publications of researchers. The arrival of new scholars in a university department can also have positive spillover effects thanks to the diffusion of ideas (Moser, Voena, and Waldinger 2014). In this sense, Ductor et al. (2014) study how knowledge about the coauthor network of an individual researcher helps to develop a more accurate prediction of his or her future productivity. Goyal, van der Leij, and Moraga-González (2006) and Ductor, Goyal, and Prummer (2018) respectively study the broad structure of the coauthorship network among economists and gender differences within this network.

The paper is organized as follows. We first define our network of European universities and present the main mechanisms we have in mind (Section 2). We describe the data we built on professors and universities (Section 3), then and we describe the main features of the network before and after the Reformation (Section 4). Section 5 is dedicated to disentangling the impact of geography and vernacular languages from the influence of religion. Section 6 looks at effects on academic production. Finally, Section 7 concludes.

2 Theory

A network of universities. Let $N = \{1, 2, \dots, n\}$ be the set of universities in the network g. For two universities $i, j \in N$, we define $g_{ij} \in \{0, 1\}$ as the *link* or *edge* between them, with $g_{ij} = 1$ signifying that at least one individual scholar has taught in both universities and $g_{ij} = 0$ otherwise. We consider that the links are *undirected*: if a scholar has moved from university i to university j, this generates a link *between* i and j, and not a link *from* i to j only. Formally, $g_{ij} = g_{ji}$ for all universities i and j. The *strength of the link* s_{ij} is given by the number of scholars who have taught in both universities i and j. If all scholars of a given university stayed in this same university during their entire career, then this university is an *isolate* in the network. This means that it has no connection with other universities in the network. The network of universities, g, is thus the collection of universities (nodes) and the links between them. We define such a network of universities for each period of time that we study.

Diffusion and Learning through the network of universities. The idea behind our definition of the network is the following. When a given professor had appointments in two (or more) places over his life, it established a relationship enhancing the flow of ideas, manuscripts, and students between the two places, which might last well beyond the death of the professor. The network of universities can then reflect priviledged ways of diffusion and learning (Jackson 2008 chap. 7 & 8). Several mechanisms are at play.

First, during the pre-industrial era, knowledge was partly codified in books, but more importantly, was embodied in people. When a scholar moves, she brings knowledge from one place to another. This is why competition to attract talents was fierce among universities, leading to permanent flows between them (Denley 2013). There are many examples of knowledge diffusion through physical moves. Let us mention the rediscovery of Roman law, which was superior to customary law at regulating complex transactions, spread from Italy to France in the Middle Ages either through the hiring by French universities of Italian professors, or by having some French professors be appointed to Italian universities (Arabeyre, Halpérin, and Krynen 2007). Second, codified knowledge in books can also travel physically with scholars. Even though books became more affordable after the invention of the movable type printing press, they were not as accessible as today. Biographical dictionaries contain many examples of professors donating their book collection to the university by testament. Probably the best example of the role of books carried by scholars in the diffusion of knowledge is when the Greek scholars fled the fall of the Byzantine Empire, bringing forgotten books by Greek philosophers to the many Italian universities in which they were hired (Harris 1995). Third, links are established by the presence of doctoral students. When a scholar moves to another university but maintains a connection with current or former students in her original university, a link is established. Students and professors cannot be systematically tracked with the available data, but some examples can be documented using the *Mathematics Genealogy Project*,[4] linking students to masters in the (broad) field of mathematics. Fourth, when a newly created university hires professors from an existing one, a long lasting relationship is established. For example, the University of Dublin, founded in 1592, was originally populated by scholars coming from Cambridge (Venn 1922). This established a long lasting, well documented, link between the two universities. This is also true for Louvain (founded 1425) which started with several professors hired from Cologne, itself founded in 1388 (Lamberts and Roegiers 1990).

In some cases, links are established when a professor has to flee war or persecution. This happened in particular after the Reformation, when scholars reallocated according to their faith (or in some cases changed faith to keep their current location). Still, an intellectual link was created by this move. For example, the Calvinist reformation developed in Geneva in the 16th century owes much to lawyers active in Bourges during the preceding centuries. This rejoins the literature on how practical knowledge flowed

[4] https://genealogy.math.ndsu.nodak.edu

from France to Prussia with the expulsion of the Huguenots (Hornung 2014).

Confessionalization. As soon as we classify universities as either Catholic or Protestant, we use the notion of Confessionalization. According to Lotz-Heumann (2016), Confessionalization refers to the process of "confession-building". This process occurred through "social-disciplining," as there was a stricter enforcement by the churches of their particular rules for all aspects of life in both Protestant and Catholic areas. This had the consequence of creating distinctive confessional identities. Every aspect of life was affected by the move initiated by Luther and Calvin. This paved the way to early modern state formation, increasing the segmentation of Europe (Schilling 1995). The extent and strength of Confessionalization is hard to measure, particularly at the European level, and this is one contribution of our approach.

The science-religion nexus. When we raise the question of the relationship between scientific output and religious affiliation, we implicitly touch the delicate question of the attitude of religions with respect to science. Bénabou, Ticchi, and Vindigni (2015) propose a game-theoretic framework to think about this issue. There are two players in the game: a government which can prevent scientific innovations to avoid the erosion of religious beliefs, and a church which can adjust its doctrine to make it more complementary with scientific progress. The model leads to describe the joint dynamics of religious beliefs and productivity. Two of the possible stationary equilibria highlighted by the authors are of interest for us, and resembles the Catholic/Protestant divide. One is a regime with knowledge stagnation, extreme religiosity with no modernization effort. Another one (called "American") combines scientific progress and stable religiosity with religious institutions engaged in doctrinal adaptation. The theory remains however limited on the role of parameters delimiting the different regimes. Why did the Catholics engage in repressing new knowledge in the sixteenth century (for example through censoring publications, see Becker, Pino, and Vidal-Robert (2020)), while they were more open to science before the Reformation? Our analysis in terms of network of universities may highlight the different position of Catholic and Protestant universities within the network in terms of centrality vs. being marginalized within the network.

3 Professors and Universities

In this section we describe the data on scholars used to construct the network of universities and we report qualitative and quantitative evidence on the decline of Southern universities in the 17 and 18th centuries.

The data on professors we use are obtained from the sources listed in detail in Appendix B. More details can be obtained in the collection *Repertorium Eruditorum totius Europae* with a summary in De la Croix (2021). We detail here the main sources for some important samples, to highlight to the reader the strengths and weaknesses of the individual data on which the network of universities will be built. With

3285 professors, the University of Bologna (founded 1088) provides the largest sample, thanks to its seven centuries of existence and to the excellent coverage found in the secondary literature. Almost all the data were encoded from the book of Mazzetti (1847) which provides short biographies for these professors, including whether they had appointments in other universities. The university of Heidelberg (founded 1386) is the Germanic university with the highest number of recorded scholars, 1210 professors, thanks to the list of professors published in Drüll (1991) and Drüll (2002). For the University of Louvain (founded 1425), an important university in the Renaissance and the university of one the authors of this paper, collecting data was more complicated, as there was no Mazetti or Drull to write a catalogue of professors for this once famous university. Data were collected from a variety of sources: Lamberts and Roegiers (1990), Ram (1861) (for the list of rectors), Nève (1856) (for the history of the Collegium trilingue), Schwinges and Hesse (2019) (for deans before 1550), and Brants (1906) (for the law faculty). Each person was searched for in biographical dictionaries such as Eloy (1755) (doctors), Sommervogel (1890) (Jesuits), and the national biography to find more information about careers. The combinations of these various sources unearth 1138 professors, hence a good coverage of this university. A similar strategy of combining several secondary sources was applied for the University of Paris. English universities, Oxford and Cambridge, are covered by the books on their alumni (Venn (1922) for Cambridge, and Foster (1891) and Emden (1959) for Oxford). Finally, we took the liberty to add some important higher education institutions to the list of "official universities" provided by Frijhoff (1996), such as Gresham College in London, and the Herborn Academy in the Holy Roman Empire (this is detailed in Appendix B).

Even if the coverage of the smaller universities is sometimes unequal, the coverage of the persons who matter for our study remains high: *mobile* scholars are indeed more likely to be identified as they would appear in multiple sources. *Productive* scholars are also more likely to be in the database, as they would be mentioned in books about each university, even if those books are very incomplete (such as books celebrating the xth anniversary of the university).

While searching for professors, we found many qualitative elements about the decline of universities in the 17th century. The view of the literature is that Catholic universities became unattractive during the 17th-18th centuries, partly because of religious views (the Counter Reformation, the Inquisition). Here are some compelling examples. (1) About the medical school at the University of Valencia during the 17th century: "the neoscholastic ideology of the Counter-Reformation converted the Faculty, for the most part of the century, into a nucleus of intransigent Galenism, opposed to the innovations of the Scientific Revolution." (López Piñero 2006) (2) The same view applies to Lleida where the advances of the sixteenth century were later reversed: "The rigid vigilance exercised by the Supreme Council of the Inquisition paralyzed the University and caused the decadence of the university body. In such cases, thought is threatened and all innovation seems dangerous. The teacher dictates the text, students copy it, and that is all. Medieval routines subsist and Aristotle, Galen, and Avicenna reemerge enslaved under the tyranny of obsequious teaching, … This state of affairs lasted for two centuries. It could be said that throughout this long period, Spanish universities, which had been so prestigious until then, disconnected from the European cultural rhythm." (Esteve i Perendreu 2007) (3) On Salamanca, the most prestigious Spanish university, we read "In the early decades of the eighteenth century, Salamanca was simply treading water. Such a condition cannot be wholly ascribed to the often cited isolation of the Spanish university or to the impact of the Inquisition. These two factors had an undoubted effect in the seventeenth century, but by 1750 (…) faculty politics posed a serious handicap (…)" (Addy 1966) (4) Going now to Italy, a general viewpoint is that "Yet in the 17th century, Italy lost its earlier pre-eminence in literary and scientific culture, falling behind by at least 20-30 years compared to other European countries. The 17th century universities in Italy ceased to attract illustrious teachers for lack of adequate salaries, while political and religious divisions considerably reduced the flow of foreign students." (Pepe 2006) (5) For the case of Pavia, we read that "In the last decades of '500 and until the mid '700, the decline of the University of Pavia is sharp; almost abandoned, at that point it conducted a miserable existence without any hint of the past splendour, when – crowded with students and masters of distinguished authority – it had consistently contributed to the progress and diffusion of culture." (De Caro 1961) (6) About the University of Cahors (France): "We enter the 18th century without any more highlight for her. There is no more star standing in the pulpit. (…) There is no longer this immense crowd coming from afar to follow her classes. There are not even any more grievances, abuses, and speculative turbulence to be charged to her; there is no more than an earthy routine, a discolored, anonymous, needy, and penniless company. The Age of Enlightenment is precisely for the University of Cahors as for most of her sisters the dark time of mediocrity." (Ferté 1975) (7) There is also the idea that they expended all of their energy in futile fights between religious factions: "Louvain was for a long time considered the center of Jansenism, as a champion of Catholic-heretical dogma. However, as the true faith continued to be disputed among the different orders and clerical teachers, the University was able (…) successfully to defend its status and privileges, even at a time when its attractiveness as a center of learning already belonged to the past." (Hammerstein 1996)

This qualitative evidence is confirmed by a more quantitative approach. We first classify universities according to their religious affiliation as reported in Frijhoff (1996). Four broad groups are defined as follows. The set **C** includes all universities which have never ceased to endorse the Catholic faith over the period considered. The set **P** includes the universities which either converted to Protestantism at some point, or which were created as such from the beginning.[5] Within **C** it becomes useful to distinguish universities which were run by the Jesuits after the Counter-Reformation, belonging to $\mathbf{C}^{\mathbf{J}}$, from the universities which remained "secular", belonging to $\mathbf{C}^{\mathbf{S}}$, where secular here means not belonging to a monastic

[5]There are two Orthodox universities in our database, Saint-Petersburg, Moscow, that we do not include in the analysis. Three universities moving back and forth between Protestantism and Catholicism, or taught both theologies in parallel: Heidelberg, Erfurt, and Orange. They are not included in the analysis either.

order. The Jesuits' congregation, the Society of Jesus, operated a large number of schools and universities throughout Europe (Grendler 2018), with the aim of educating virtuous leaders who would act for the common good (and fight the Reformation). The oldest and most prestigious Catholic universities fought the influence of this new congregation and kept the Jesuits out (Louvain, Paris, Bologna, Padua, Krakow). Within $\mathbf{P}$, we will distinguish the four brands of Protestantism: $\mathbf{P^P}$ for Presbyterian (only in Scotland), $\mathbf{P^L}$ for Lutheran (Germanic, Nordic), $\mathbf{P^C}$ for Calvinist (Dutch, French, Swiss, German), and $\mathbf{P^A}$ for Anglican (English, Irish), with $\mathbf{P^P} \cup \mathbf{P^L} \cup \mathbf{P^C} \cup \mathbf{P^A} = \mathbf{P}$.

The period under study goes from 1000 until 1793. We divide time into seven periods. Following a tradition in history, we use major events to define seven periods rather than centuries: 1) from the creation of the first associations of professors and students dedicated to education in 1000 until 1199; 2) from the creation of the university of Paris in 1200 until 1347; 3) from the Black Death in 1348 until 1449; 4) from the creation of the printing press in 1450 until 1522; 5) from the creation of the first Protestant university in 1523 until 1597; 6) from the Edict of Nantes in 1598 until 1684; 7) from the Revocation of the Edict of Nantes in 1685 until 1793, in the middle of the French Revolution.

Focusing on the two main types of universities, $\mathbf{C}$ and $\mathbf{P}$, we compute the total number of scholars of universities and their publications over time. Results are shown in Table 1. Detailed data are reported in Appendix (Table C.2). These numbers are computed by summing all the publications recorded in VIAF (Virtual International Authority File) by members of universities. VIAF provides a comprehensive contemporary measure of scientific output. One could argue that a measure of output should be based on the works published while the author was still alive. What was published after the death of the person might reflect how the author gained popularity *post-mortem*, which might not be relevant for determining his/her productivity. This, however, is not possible to implement, because many first editions of books are not available anymore. For example, there is no doubt that Pierre Abélard (1079-1142) was a philosopher of great renown during his life. All his written output available in the libraries today, from philosophical works to love letters, was published after 1600.

Another issue with measuring academic output from contemporaneous library catalogues arises from the possible loss of some publications over time. This does not seem to be of major importance, though. Chaney (2020) compares the books contained in the Universal Short Title Catalogue database of St. Andrews (2019) (`https://ustc.ac.uk/`) with those referenced in VIAF. The USTC aims to cover all books published in Europe between the invention of printing and 1650. Chaney successfully located 81% of these authors in the VIAF data. Such a high level of coverage is consistent with the claim that VIAF provides a reasonable approximation to the population of known European authors.

The total publications of Catholic and Protestant universities founded before 1523 is reported in the first two rows in section A of Table 1. It is obtained by summing the publications of their members. When a person taught at several universities over her life, we divide her publications by the number of affiliations

Table 1: Publications and Scholars over time

	1000 -1199	1200 -1347	1348 -1449	1450 -1522	1523 -1597	1598 -1684	1685 -1793
A. Total number of publications per period							
Old universities (founded bef. 1523)							
C	1503	5202	4162	8697	13844	9451	13362
P	38	431	159	1763	8020	12273	19629
New universities (founded aft. 1523)							
C					2690	4568	6409
P					4279	14783	30621
Ratios **C**/**P**							
old	39.55	12.07	26.18	4.93	1.73	0.77	0.68
new					0.63	0.31	0.21
B. Total number of scholars per period							
Old universities (founded bef. 1523)							
C	253	1912	4402	5527	5541	5044	7063
P	12	99	317	1155	1527	1591	2174
New universities (founded aft. 1523)							
C				770	2601	3783	
P				554	1584	2982	
Ratios **C**/**P**							
old	21.1	19.3	13.9	4.8	3.6	3.2	3.2
new					1.4	1.6	1.3

P bef. 1523 covers universities which converted later to Protestantism.
"Publications" sum titles of members as reported in `www.viaf.org`

Table 2: Publications per Publishing Scholar and of top Scholars over time

	1000 -1199	1200 -1347	1348 -1449	1450 -1522	1523 -1597	1598 -1684	1685 -1793
C. Publications per publishing scholar per period							
Old universities (founded bef. 1523)							
C	14.45	13.87	10.54	12.48	11.39	9.26	9.63
P	9.50	8.98	5.89	12.24	14.12	16.43	17.46
New universities (founded aft. 1523)							
C					12.12	9.32	10.25
P					14.26	15.30	15.57
Ratios **C/P**							
old	1.52	1.54	1.79	1.02	0.81	0.56	0.55
new					0.85	0.61	0.66
D. Publications of top 5 scholars per period							
Old universities (founded bef. 1523)							
C	1090	2252	2296	4189	5754	4018	5348
P	38	218	137	1181	2851	3233	3722
New universities (founded aft. 1523)							
C					1491	2346	3231
P					2213	5461	7895
Ratios **C/P**							
old	28.68	10.33	16.76	3.55	2.02	1.24	1.44
new					0.67	0.43	0.41

P bef. 1523 covers universities which converted later to Protestantism.
"Publications" sum titles of members as reported in `www.viaf.org`

and allocate this amount to each university. The numbers show the rise of publications following the invention of the printing press. The printing press was adopted quickly throughout Europe, with no difference between countries (Timperley 1839). Later, there is growth in the last three periods among old Protestant universities. There is a stagnation among Catholic universities, from 331k publications in 1523-1597 to 200k 1685-1793, despite a large number of scholars of the order of 4000 per period (section B of Table 1). The rise of Protestant scholars is even more striking when we consider new universities. The total output of Protestant scholars is five times that one of Catholic scholars, despite some absolute growth in the Catholic world driven mostly by the elite institutions created by the kings of France (Collège Royal and Jardin des Plantes).

To account for heterogenous coverage of obscure scholars, we restrict the sample to publishing scholars in section C of Table 1. We observe that the productivity of publishing scholars in old Catholic universities systematically decreases over time relative to productivity in old Protestant universities. Within new institutions, publishing scholars are on average twice more productive in Protestant universities than in Catholic universities, from 1523 until 1793. Finally, to address heterogeneity in the coverage of publications by publishing scholars, we consider only publications by top 5 scholars, for which we have very good coverage. Section D of Table 1 confirms the decline of old Catholic universities relative to old Protestant universities over time. Moreover top 5 scholars in new Protestant universities publish almost three times more than their counterparts in the Catholic world from 1598 to 1793.

Finally we report some statistics on the broad academic fields taught by the scholars in Table 3. This measure is not very precise (for example we do not know what all the Oxbridge fellows actually taught) but it is informative. The changes over time are driven by the new universities which do not reproduce what the old ones were doing, more than by drastic changes in existing curricula. Several facts emerge from the Table 3. Sciences were rising with time, from 4% to 12%, with no difference between Catholics and Protestants. Medicine was steady at 10-13%. Theology was on a decreasing trend before the Reformation, but got a boost with the Reformation, both in Catholic and Protestant places, but even more so for Protestants. This contrasts with the results of Cantoni, Dittmar, and Yuchtman (2018) according to whom the Reformation paved the way to secularization. Here we observe the opposite, but we consider professors and not students, and we cover the whole Protestant world, while they cover the Holy Roman Empire only (hence not having England, Scandinavia, Switzerland, The Netherlands). The share of theology reverted to a lower level only in the last period, when the heat of the Reformation had cooled down. Law was on a steady decline, and its share was structurally more important in Catholic universities (heir of the written law tradition).

Table 3: Share of academic fields by period and religion in %

period	theology		law		humanities		medicine		sciences	
bef. 1450	16		37		30		14		4	
1450-1522	12		29		43		11		5	
	C	**P**	**C**	**P**	**C**	**P**	**C**	**P**	**C**	**P**
1523-1597	16	24	34	16	31	45	13	10	6	6
1598-1684	19	28	28	15	30	37	12	11	10	9
1685-1793	21	20	23	16	32	38	11	13	12	12

4 The Network of Universities

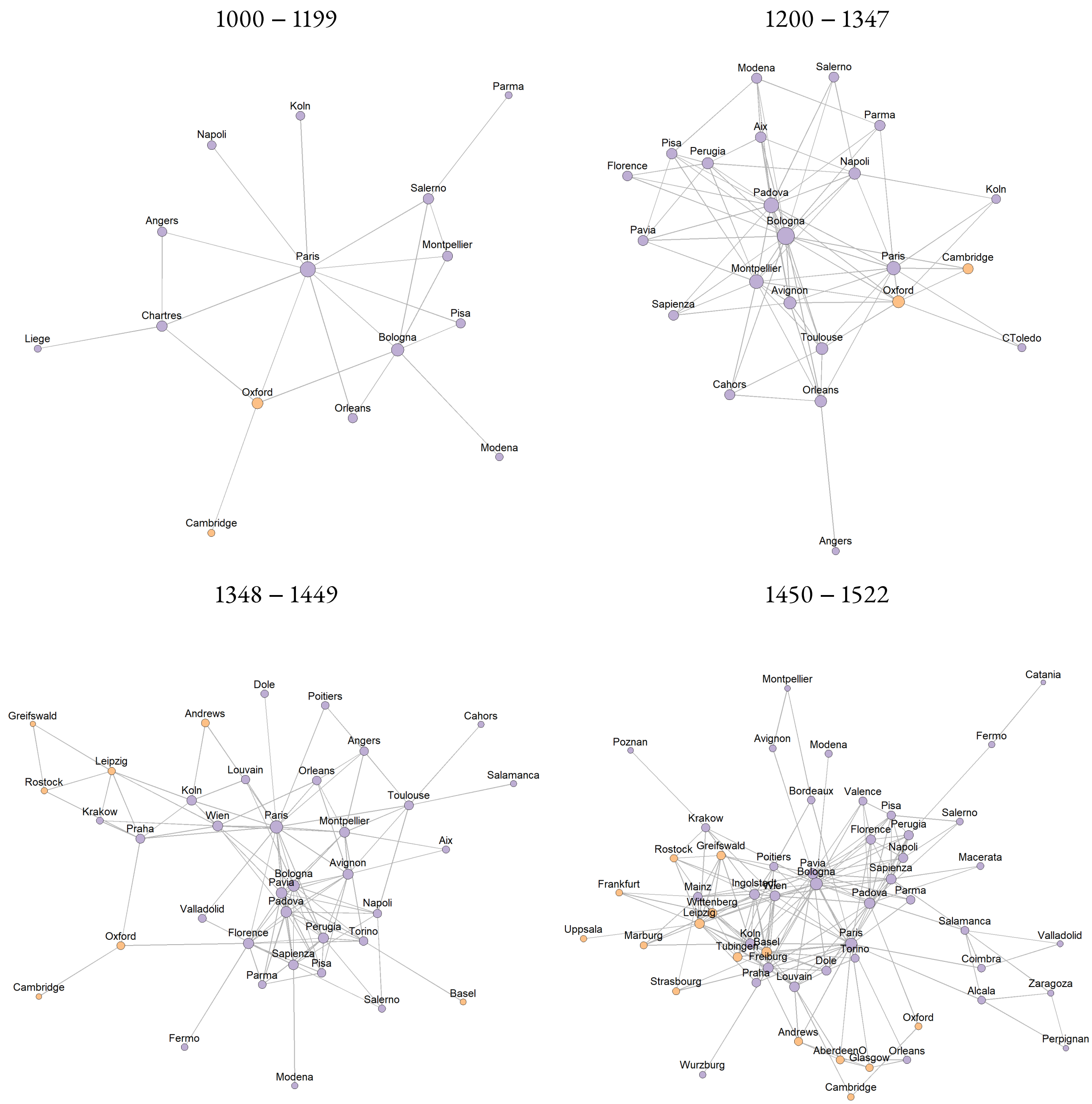
We build the network of European universities for each period, and thus obtain four networks before the Reformation, that started around 1523, and three networks after. In Figures 1 and 2, we map out these networks of universities before and after the Reformation.

A connection between two universities illustrates the transfer of one or several scholars between them, without taking into account the direction of transfer. More specifically, each network captures all the displacements of scholars that occurred by period. The 1523-1597 network in Figure 2 is particular, as it witnesses a reallocation of scholars to fit the new religious conditions: French and Belgian Protestants moving North, but also British Catholics moving to France (Rheims and Douai, see Bideaux and Fragonard 2003).[6] We consider that this reallocation of scholars ends in 1598, when the edict of Nantes is promulgated, granting rights to French Protestants, including the right to have their own universities. We code universities according to their religious affiliation. Before the Reformation, all universities were Catholic, but in the network we nonetheless distinguish between purple universities that remain Catholic after the Reformation and orange universities that convert to Protestantism. After the Reformation, each different brand of Protestantism gets in own color: Anglican are pink, Calvinist yellow, Lutheran orange and Presbyterian maroon. The Jesuit universities that actively took part in the Counter-Reformation are blue, while "secular" Catholic universities are purple. Let us point out that the positioning of universities in these figures is determined by the standard Fruchterman-Reingold force-directed algorithm (Fruchterman and Reingold 1991) that groups universities more closely together when they are linked to each other. So the positioning of universities is not based on geography, religion, or other university attributes. Overall, we already observe a clear-cut divide between Protestant and Catholic universities in the two last networks after the Reformation, based on the mobility of scholars only.

Our figures also show the centrality of each university by changing the size of its circle. We are measuring here closeness centrality, which will be described in more details later. Our network maps can be used to give a crash course on the history of the academic landscape in Europe. It goes as follows. In the first period (1000-1999), the burgeoning Paris and Bologna are, as expected, the two most central universities. The medical centers of Montpellier and Salerno are also quite central, as is the cathedral school of Chartres. Oxford is the little sister of Paris. In the second period (1200-1348), the Bologna-Paris-Oxford-Montpellier group is rejoined by Padova, Avignon (which may have benefitted from the presence of the Pope court), Toulouse, and Siena. Salerno is declining, and Chartres has disappeared from the map. After the black death (1349-1450), it is the Italian moment. The studium in Florence, the university of the Pope in Rome (Sapienza), and Parma rejoin the group of highly central universities. The newly founded universities of Vienna and Louvain start to appear on the map. During the last period before the Reformation (1451-1522), there are additional newcomers, some of whom will ultimately become protestants, such as the universities of Leipzig, Greifswald and Wittenberg. Paris is still there, Louvain centrality has

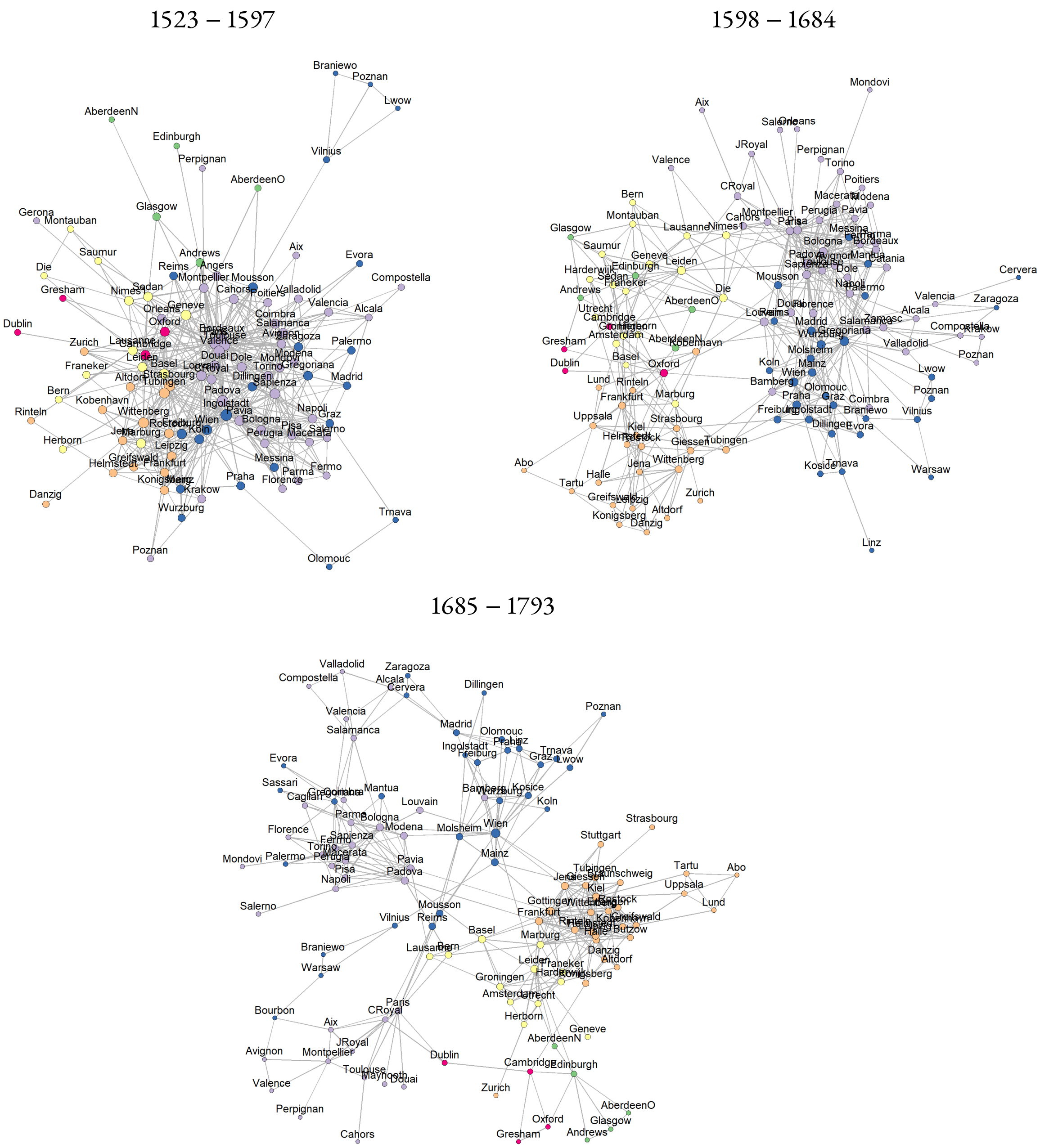
[6] From 1529 to 1536, the English Parliament breaks with Rome and establishes the Church of England. In 1555, the Peace of Augsburg allows rulers within the Holy Roman Empire to choose either Lutheranism or Roman Catholicism as the official confession of their state. In 1560, the Scottish Parliament establishes the Kirk. In the Appendix, Table A.1 summarizes major Reformation events and Figure A.1 shows the religious situation in Europe around 1560.

Figure 1: Networks before the Reformation



Note: Universities that would remain Catholic after the Reformation are purple, while universities that would convert to Protestantism are orange.

Figure 2: Networks after the Reformation



Note: "Secular" Catholic universities are purple, while Jesuit universities are blue-filled. Lutheran, Presbyterian, Calvinist and Anglican universities are respectively orange, brown, yellow and pink.

grown, Oxford centrality has shrunk. The period of the Reformation (1523-1597) is one in which many universities display a high degree of centrality. The network is made of a core of universities having multiple links between each other, with a periphery of less connected places. We remark the emergence of a new type of universities in blue, those either founded by the Jesuits, or in which the Jesuits played a key role. In the period during which Protestantism was tolerated in France (1598-1685), the network is obviously split into two blocks, the Protestants and the Catholics. the Catholic universities are still the most central. But they are of two types. The secular Catholic, not run by any specific monastic order, and the Jesuit universities. We observe that the mothership of all Jesuit universities, the Gregoriana, is indeed the most central one in their network. It is surprising not to see the Dutch universities emerging at this stage. For the German universities, many were engulfed in the Thirty Year War. In the last period (1686-1793), there is a complete reversal of situation, at least seen from the point of view of centrality. The Lutheran universities, led by the newly founded Universities of Gottingen and Halle, are now the most central ones, followed by the Calvinist universities in Holland. The other nodes in the network have lost the centrality they had previously, including the Jesuit universities.

The comparison of the network in 1598–1684 with any other of its predecessor is striking. After the Reformation, the network was literally cut into two distinct part.

We now examine the main macro characteristics of the networks. Let us first define them. The *density of the network* is the ratio of observed links in a network to the maximum number of possible links. For an undirected network with N nodes, the maximum number of links is $N(N-1)/2$ so the density for an undirected network is: $2L/[N(N-1)]$, where L is the number of observed links in the network. The *degree of a university* i, $\mathcal{D}_i$, is the number of distinct universities with which the university i is connected. Formally $\mathcal{D}_i = \#|j : g_{ij} = 1|$. The *average degree* of a the network g, denoted $\mathcal{D}(g)$, is the mean of the degrees of all connected universities in the network. The *distance* $l(ij)$ between two universities i and j is the length of the shortest path between them. The *diameter* is the largest distance between any two universities in the network. The *average distance* of all pairs of universities in the network g is denoted $l(g)$. The *average number of communities* is computed thanks to several community detection algorithms from the *igraph* package in R (Csardi et al. 2006). These community detection algorithms are designed to identify internally cohesive subgroups that are also to a certain extent separated from other groups or nodes. Note that we compute these statistics for each network without taking isolates into account. Statistics defined above are displayed in Table 4.

First, we observe a large increase in the number universities across time, going from 17 to 127. In contrast, the number of connected pairs of universities keeps increasing before the Reformation, until it reaches a peak during the 1523-1597 period. As we already discussed, this period is specific as it witnesses a constrained reallocation of scholars due to the emergence of Protestantism. Interestingly, the number of connected pairs decreases during the two last periods after the Reformation. However, when we con-

Table 4: Descriptive Statistics of the Networks

	1000 -1199	1200 -1347	1348 -1449	1450 -1522	1523 -1597	1598 -1684	1685 -1793
Universities	17	27	43	61	103	126	127
Connected universities	15	23	37	54	100	119	121
Connected pairs	22	79	108	187	543	452	384
Scholars in connected pairs	41	317	556	610	1347	1386	1861
Density	0.21	0.31	0.16	0.13	0.11	0.06	0.05
Average degree	2.93	6.87	5.84	6.93	10.86	7.60	6.35
Diameter	4.00	3.00	5.00	5.00	6.00	6.00	7.00
Average distance	2.11	1.81	2.41	2.45	2.47	3.02	3.46
Average number of communities	2.33	2.67	2.67	5.67	7.67	9	9

sider the total number of scholars connecting each pair of universities, it keeps increasing over the period. As a result, the average number of scholars connecting two universities increases from 3.26 just before the Reformation to 4.85 in the 1685-1793 period. So a professor in a given university was more likely to move to another university that already had a connection with his current university after the Reformation than just before, even though the number of universities more than doubled between these two periods. Then, the networks of universities are sparser after the Reformation: the density of the network more than halved. This is due to both the increase in the number of universities in the networks and the decrease of links after the peak mentioned in the 1523-1597 period. The average degree of universities in the networks is quite stable for the three periods just before the Reformation and the two last periods after: on average, universities are connected to about 6 other universities over the period. This number strikingly increases to slightly more than 10 during 1523-1597 period: again, this is due to the forced reallocation of scholars during this troubled period which increased mobility significantly. The average distance of the networks increases after the Reformation. For the four first periods, it requires on average 2.12 steps to connect any pair of universities in the networks and at most 5 steps. In contrast the average distance of the networks increases to 3.02 and 3.46, and the diameter reaches 6 and 7 in the two last periods. Finally, the average number of communities detected in the networks increases drastically after the Reformation. In the three first periods, we detect on average 2.5 communities in the networks. In contrast, we detect on average 8.5 communities after the Reformation. This is an indication that the network of European universities is much more fragmented after the Reformation.

We now explore to what extent the individual position of universities in the networks correlates with the publications of their top 5 scholars. As explained in Section 3, we focus on top 5 scholars for which we have a very good coverage. We consider five classic network measures of centrality. We already defined the first one, the *degree* of a university i, $\mathcal{D}_i$, which measures the number of university i's neighbors. The four other centrality measures are as follows. The *strength* $\mathcal{S}_i$ captures the average strength of existing links of university i with its neighbors. The *closeness centrality* $\mathcal{C}_i$ describes how quickly university i is reachable from all other universities in the network. The *betweenness centrality* $\mathcal{B}_i$ measures the importance of university i in connecting other universities in the network. The *eigenvector centrality* $\mathcal{E}_i$ captures how "well-connected" university i's neighbors are. We provide detailed definitions of these four measures in Appendix E. We regress academic output of top 5 scholars in each university on the different network measures described above, in a panel over our seven periods. Results are displayed in Table 5.

Table 5: Position in the network and Scientific Production

	Dependent variable: p_{it}				
degree	4.156***				
	(0.820)				
strength		0.007			
		(0.007)			
closeness			1.123**		
			(0.552)		
betweenness				3.054**	
				(1.403)	
eigenvector					0.571**
					(0.258)
Observations	469	469	469	469	469
Adjusted R^2	0.650	0.624	0.627	0.628	0.628

*p<0.1; **p<0.05; ***p<0.01 Includes university and period fixed effects, controls for varying coverage & activity periods.

Every column of Table 5 presents a regression of the inverse hyperbolic sine of publications of top 5 scholars of each university, which we denote p_{it}, on our five measures of network position. It includes university and period fixed effects along with controls for coverage and activity period. The coverage of a university is the number of observed professors who taught there divided by its activity period length. The activity period length of a university is the number of years during which this university is active. We find that, except for strength, all these centrality measures correlate significantly with academic output of top 5 scholars. This indicates that the more central a university in the network along these different dimensions, the higher its academic output. Assuming that the flow of ideas follows the paths created by mobile scholars, we may understand that the more central a university, the more new and diversified ideas it can access, which would enhance its academic production. Of course, our regressions only allow us to establish correlation between position in the network and academic production, not to infer causality. Moreover it is also very plausible that causality goes the other way: more prestigious and productive universities likely attract more scholars, which improves their central position in the network. But still, the diffusion of ideas mechanism described above is also possibly at play.

We now examine more closely how religious affiliation interacts with network structure. Connections between Catholic and Protestant universities over time are shown in Table 6.

Table 6: Connections between Catholic and Protestant Universities

	1450 -1522	1523 -1597	1598 -1684	1685 -1793
Proportion of **C**-**P** edges	27.81	24.68	5.75	3.65
IH index for **C** univ	0.52	0.60	0.88	0.96
IH index for **P** univ	0.30	0.32	0.70	0.71
Modularity religion	0.10	0.19	0.40	0.46

We first note that in 1450-1522, just before the Reformation, almost 28% of connections are between **C** universities and would-be **P** universities, while this share shrinks to 5.75% and 3.65% during the last two periods after the Reformation. During the first three periods under study, this proportion is low because there are few would-be **P** universities relative to **C** universities. Additionally, Catholic and Protestant universities tend to have more connections with universities of the same religion over and above the relative size of their religious group. We use the *inbreeding homophily index* developed by Coleman (1958). It measures the tendency for universities to form connections with others who share the same attribute (religion) (see Appendix D for a definition) in order to compare the degree of homophily among Catholic and Protestant universities across time. The inbreeding homophily index is positive and increases significantly in the two last periods after the Reformation for **C** and **P** universities. While the IH index for **C** universities equals 0.52 from 1450 to 1522, it peaks to 0.88 and 0.96 in 1598-1684 and 1685-1793 respectively. We find a similar pattern for **P** universities: their IH index increases from 0.30 before the Reformation to 0.70 and 0.71 in the two last periods after the Reformation.

Finally, we use the modularity score to evaluate to what extent the partition of universities along their religious affiliation explains the structure of the network. We consider a community structure Π based on religions. We distinguish two communities in Π : Catholic and Protestant. The partition of universities along religious affiliations exhibits positive modularity scores, indicating that there are more links in communities than we would expect in a randomly generated graph. But while the modularity score just before Reformation is 0.10, it reaches 0.40 and 0.46 in the two last periods under study, indicating that religion is a good predictor of the network structure after the Reformation. To make sure that the partition along religious affiliations is a significant community structure, we replicate 1000 randomized networks that have the same degree distribution as the original data and evaluate their modularity scores for the two last periods after Reformation. We find that no randomized networks have a modularity score higher than 0.40 and 0.46 respectively in 1598-1684 and 1685-1793. In fact, the maximal modularity scores of these 1000 networks for these two periods are respectively 0.06 and 0.08. Thus it can be said that division along religious affiliations significantly impacts the structure of the network of universities after the Reformation.

However, we should not omit the fact that religious affiliation is highly correlated with geography and vernacular languages, as most Protestant universities are located in Northern Europe and use a Germanic language for everyday life, and most Catholic universities are to be found in Southern European countries and use a Romance language. To ensure that our previous analysis does not simply capture the impact of closer geographic or linguistic distance rather than membership of the same religious group, we disentangle these two effects in the next Section.

5 Geography and vernacular languages vs. Religion

In this Section we show that geography and culture (vernacular languages) are also important, which is not surprising, but does not substitute for the role of religion. To do so, we investigate the determinants of the relationship between each possible pair of nodes. In our setting, we investigate the presence or the absence of a link g_{ij}. Our aim is to estimate to what extent belonging to the same religious group determines the presence of a connection between two universities, controlling for geography, culture and curricula. Since there may exist heterogeneous effects across subreligions, we decompose the effect of sharing the same religious affiliation by distinguishing the effect of both being Lutheran from the effect of both being Calvinist, and so on. Our main independent variables of interest are thus the geographic and linguistic distances between any pair of universities, differences in curricula, and dummy functions indicating whether the two universities of the dyad are both Lutheran, Calvinist, etc.

To study the determinants of a connection between two universities, two types of approaches are possible. The first consists in estimating the whole network at once, using for example the exponential random graph model (ERGM). In this approach, each dyadic link is potentially affected by all the other links. For example, a major empirical regularity of networks is that they have elevated rates of triadic closure: if Alice knows Bob, and Bob knows Christina, than the probability Christina knows Alice tends to be higher than the probability she knows another randomly drawn person. The ERGM approach allows the model to incorporate network features like the number of triangles in the modeling process (Robins et al. 2007). The second consists in estimating dyadic regressions. In this case the probability that a link between two nodes exists depend only on the characteristics of these two nodes. Two models can be used to estimate such bivariate links: linear probability model and generalized linear model (typically, a logit).[7]

[7] Alternatively the strength or intensity of the link s_{ij} can be analyzed with a negative binomial model; and the inverse of the length of the shortest path $1/l(ij)$ can be analyzed with simple OLS.

The simplest model in this menu is the linear probability model, which we implemented in the working paper version of this work. It is an approach that is widely used in economics, in particular in international trade models. If one needs to simulate the model, it has one major inconvenient. Nothing guarantees that the fitted probabilities will be between 0 and 1. In our case, for all our regressions, around 30% of the fitted probabilities were below 0 (and a small proportion above 1). Such a high share of negative values is not acceptable, and indicates that a logit or a probit would be more appropriate.

At the other end of the complexity spectrum, we tried to estimate the full network with the ERGM. Here, the number of independent variables is too high, and convergence is not achieved. This reflect the results of Chandrasekhar (2016) on the difficulty to estimate networks with ERGM when the size of the network is large. Another inconvenient of the ERGM approach is that it is not possible to integrate into the analysis node fixed effects.

We thus finally opted for estimating the dyadic regressions with a logit model. As with the ERGM, estimations based on the standard maximum likelihood estimator suffered from convergence issue related to the number of regressors. The bias-reduced estimator proposed by Kosmidis and Firth (2020) led instead to satisfactory results. The bias-reduction method is an improvement over traditional maximum likelihood because its estimator is second-order unbiased and has smaller variance than the maximum likelihood estimator and its corresponding standard errors are always finite while the maximum likelihood estimates can be infinite. This model enables the integration of node fixed effects, a crucial factor for controlling unobservable attribute variables. The primary criticism that could be directed at such a network formation model is its potential failure to generate as many triads as observed in real networks. To address this concern, we compare the proportions of triads in our observed networks with those in networks generated using our estimates. We find that our fitted networks produce a similar proportion of triads as observed in our real networks. This result reinforces our confidence in the decision to use this network formation model.

Our estimated model is

$$\begin{aligned} \text{logit}(g_{ij}) = &\beta_0 + \beta_1 d_{ij} + \beta_2\, \mathbf{I}(i,j \in \mathbf{P}^L) + \ldots + \beta_7\, \mathbf{I}(i,j \in \mathbf{C}^J) \\ &+ \beta_9 \ell_{ij} + \beta_{10} q_{ij} + \beta_{11} v_{ij} + \beta_{12} \underline{v}_{ij} + \gamma\, \mathbf{K}_{ij} + \alpha_i + \alpha_j \end{aligned} \tag{1}$$

The dependent variable g_{ij} is the dyadic network measure equal to 1 if there is a link between universities i and j, and 0 otherwise.

Geographical distance is defined as $d_{ij} = \ln(\text{cost}^{\text{min}} + \text{cost}_{ij})$, where cost_{ij} is the minimum cost it takes to travel from i to j computed using Özak's (2010, 2018) human mobility index. Parameter cost^{min} is the minimum cost incurred when travelling within the same city (say from Jardins des Plantes to Sorbonne). We assume it is equivalent to the cost of walking within the old city of Rome between the Vatican City and the Colosseum (3.5 km).

Linguistic distance ℓ_{ij} is controlled for by including a dummy variable which takes the value 1 when both i and j belong to the same broad linguistic family, and 0 otherwise. We consider three broad language subgroups of the Indo-European language family (Fortson IV 2011), Italic (or Romance), Germanic, Slavic, and the Uralic family. Even if Latin was the common language for research and teaching, vernacular languages may play a role in everyday life.

We also control for curricula differences across institutions. To measure such a distance, we first compute the share of each broad field f in each institution i, s_{if}. The broad fields are based on what scholars are teaching and include: theology, law (all sorts), humanities, medicine, sciences, applied sciences, and social sciences. The last two fields are very rare, and only appear in the last period. To measure the similarity between two institutions i and j we apply the Renkonen similarity index (Renkonen 1938) to our context. It is a measure of similarity between two biological communities (universities here), based on relative (proportional) abundances of individuals of different species (fields here). This measure of sample similarity is considered robust to sample size and species number. Its formula is:

$$q_{ij} = \sum_{f} \min(s_{if}, s_{jf})$$

It ranges from 1 (identical proportional abundances of fields to 0 (no field shared).

Dummy functions $\mathbf{I}(i, j \in \mathbf{P}^L)$, etc, indicate whether or not universities i and j are both Lutheran, Calvinist, etc. We include such a dummy function for each subreligion, i.e. $\mathbf{P^L}$, $\mathbf{P^C}$, $\mathbf{P^P}$, $\mathbf{P^A}$, $\mathbf{C^S}$, and $\mathbf{C^J}$. For each specification, we include cross effects to control for the differentiated impact of belonging to different subreligious groups. We introduce dummy functions, captured by the vector $\mathbf{K}_{ij}$, for each configuration except the one which will be the reference category.[8]

We also add two other explanatory variables: the number of overlapping years during which both universities i and j are active, which is denoted v_{ij}, and the minimum coverage denoted $\underline{\nu}_{ij} = \min(\nu_i, \nu_j)$ where the coverage ν_i of university i is the number of observed professors who taught there divided by its activity period length. This is to control for the fact that two universities that are simultaneously active during a long time period are more likely to have a connection than two universities that only share a couple of active years. We add minimum coverage controls because we are more likely to observe a connection between two universities for which we have lots of information in our sample, as this is the case for Germany and Italy, than between universities for which we have poorer coverage.

To address the issue of spatial correlation, we use a two-way fixed effect model, which includes a fixed effect for universities i and j, α_i and α_j (see De Weerdt (2004) and De Weerdt, Genicot, and Mesnard (2019)).

[8] For instance, $\mathbf{I}(i \in \mathbf{P}^L \text{ and } j \in \mathbf{P}^A \text{ or } i \in \mathbf{P}^A \text{ and } j \in \mathbf{P}^L) \in \mathbf{K}_{ij}$ is equal to 1 if there is one Lutheran university and one Anglican university in the dyad, and 0 otherwise.

Autocorrelation is the possible correlation between the error term associated with the dyad formed by university i and university j, ϵ_{ij}, and all the error terms associated with other dyads in which i or j appear, $\epsilon_{.i}$, $\epsilon_{i.}$, $\epsilon_{.j}$ and $\epsilon_{j.}$. Concretely, we include one dummy for each university that indicates whether the specific university is part of the dyad or not. This means that there are two dummy variables equal to one for each observation. By including these university fixed effects we control for observable attribute variables, for instance the fact that big universities may have more connections than universities with small capacity. These university fixed effects also enable us to control for unobserved attribute variables: for instance, universities that encourage mobility are more likely to have more links than universities that do not. Including these dummies thus purges the effects of all attribute variables and therefore eliminates autocorrelation.

To run our dyadic regressions, we make a dataset of all possible unique combinations of two universities. We include in this dataset all universities where at least one scholar taught during the period under study and which are connected in the networks.[9] For instance, in 1685-1793 we count 121 such universities, so the number of possible dyads is 7260.[10] We delete dyads for which the two universities were not active during a same period of time. This is to avoid two potential biases in our estimates. The first one is simply the fact that two universities that were not simultaneously active are less likely to share a connection. For instance, if university i was active until 1690, it is very unlikely that it shares a connection with university j that opened ten years later. Second, even for universities whose active periods are separated by less than 100 years, deleting such dyads mitigates the issue of the mobility of scholars triggered by the closing of their university. Assume that university i closes, forcing its scholars to find another teaching position at another university that is currently active. If university j opens only a few years after the closing of university i, we cannot know whether scholars would have chosen university j or not if it were active when their previous university i closed. Deleting such dyads removes these possible biases. Thus our final sample for 1685-1793 reduces to 7229 dyads. We show in Table 7 results when the dependent variable is the presence or the absence of a link.

Our main result is that religion significantly explains the structure of the network of European universities after the Reformation, even when geography, langage and curricula are controlled for. First, the impacts of geographic distance, language and curricula are unsurprisingly significant and consistent across periods. Increasing traveling costs between two universities reduces their odds of being connected (first line of Table 7). The more similar two universities in terms of curricula, the more likely they share a connection (second line of Table 7). Belonging to the same broad linguistic family increases the odds of being connected (third line of Table 7). We are surprised to see no spectacular increase in the coefficient of linguistic distance over time. Binzel, Link, and Ramachandran (2020) claim that by the end

[9] In other words, we remove from the dataset the universities that are isolated in the networks defined above. We do so because the dependent variable is always 0 for isolated universites.

[10] In a network with N nodes, the number of possible dyads is $N(N-1)/2$.

Table 7: Dyadic Regressions

	Dependent variable: presence or absence of a link						
	1000 -1199	1200 -1347	1348 -1449	1450 -1522	1523 -1597	1598 -1684	1685 -1793
d_{ij}	-1.361^{**}	-1.719^{***}	-2.421^{***}	-2.476^{***}	-1.801^{***}	-1.569^{***}	-1.831^{***}
	(0.633)	(0.365)	(0.315)	(0.227)	(0.108)	(0.099)	(0.115)
q_{ij}	5.545^{*}	4.933^{***}	3.519^{***}	1.111	2.602^{***}	2.357^{***}	3.583^{***}
	(3.193)	(1.851)	(1.350)	(1.049)	(0.496)	(0.513)	(0.693)
ℓ_{ij}	1.959	0.282	1.336^{***}	1.017^{***}	0.999^{***}	0.759^{***}	1.192^{***}
	(1.278)	(1.069)	(0.482)	(0.275)	(0.162)	(0.165)	(0.245)
$\mathbf{I}(i, j \in \mathbf{P}^L)$					−0.436	0.344	1.570
					(0.834)	(1.064)	(1.282)
$\mathbf{I}(i, j \in \mathbf{P}^C)$					6.030^{***}	2.472	5.200^{***}
					(1.185)	(2.339)	(1.768)
$\mathbf{I}(i, j \in \mathbf{P}^P)$					3.227^{**}	2.926^{*}	3.061
					(1.461)	(1.622)	(2.265)
$\mathbf{I}(i, j \in \mathbf{P}^A)$					7.734^{***}	9.140^{***}	5.865^{***}
					(1.996)	(2.280)	(2.137)
$\mathbf{I}(i, j \in \mathbf{C}^S)$					1.677^{**}	5.610^{***}	6.123^{***}
					(0.794)	(1.097)	(1.344)
$\mathbf{I}(i, j \in \mathbf{C}^J)$					2.554^{**}	2.822^{*}	5.940^{***}
					(1.224)	(1.556)	(1.771)
Observations	104	250	666	1,431	4,950	7,017	7,229
Log Likelihood	−15.478	−67.374	−119.030	−266.348	−912.420	−900.882	−626.100
Akaike Inf. Crit.	70.955	190.748	322.059	650.695	2,064.839	2,079.764	1,534.201

Notes: *p<0.1; **p<0.05; ***p<0.01
Includes university fixed effects, controls for varying coverage & activity periods, interaction terms between all subreligion. Reference category: $\mathbf{C}^S$-$\mathbf{P}^L$ dyads.

of the 16th century, vernacular works became the majority, which led to more knowledge production in the early modern period. The use of spoken tongues in teaching may of course prevent a professor of medicine from Rome to teach in Jena, breaking down the homogeneity in the European university landscape. One should however not overestimate the importance of vernacularization. The work by Binzel, Link, and Ramachandran (2020) is based on all types of works published, and may not be an accurate description of scholarly work. To clarify this point, we looked at the languages used in the publications of the university professors of our database, and found that Latin resisted longer in academia. It started to decline for professors starting their career in 1700, implying that vernacularization is a late eighteenth century phenomenon in academia.

Second, for almost all subgroups, sharing the same religious affiliation is associated with a statistically higher probability of being connected in the network after the Reformation (three last columns of Table 7).

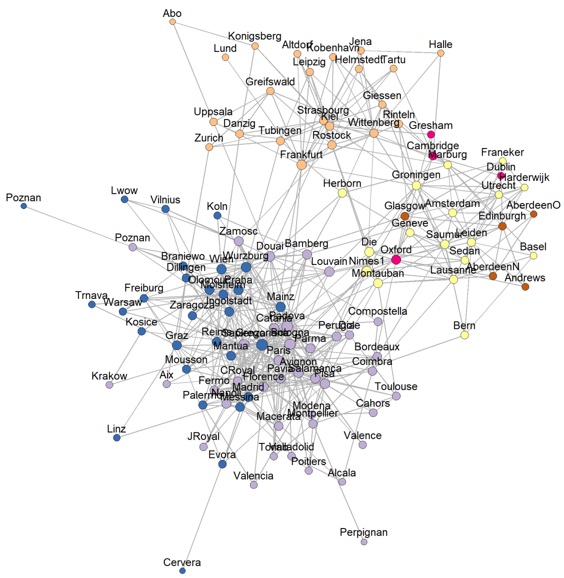
To enhance our comprehension of the significance of religion, we employ a simulation approach based on dyadic regression, both with and without the inclusion of religious variables. Leveraging the outcomes derived from these dyadic regressions, we embark on the creation of predicted networks and counterfactual atheist networks. In the construction of predicted networks, each dyad is ascribed its anticipated probability of connection between the respective universities. Subsequently, we generate 1000 predicted networks using these estimated probabilities. Conversely, in the formation of atheist networks, we assign to each dyad its expected probability of connection, excluding the estimated coefficients linked to subreligion dummy variables. Another set of 1000 atheist networks is then generated based on these probabilities, devoid of religious considerations.

It is noteworthy that the connection probability between universities in the atheist networks is inherently lower than in the predicted networks. To rectify this inherent difference, we recalibrate these probabilities, ensuring that the average number of connected universities in the atheist networks aligns with that in the predicted networks. The 500th draw of both predicted and atheist networks for the two final periods post-Reformation is illustrated in Figure 3, while Table 8 presents the corresponding descriptive statistics.

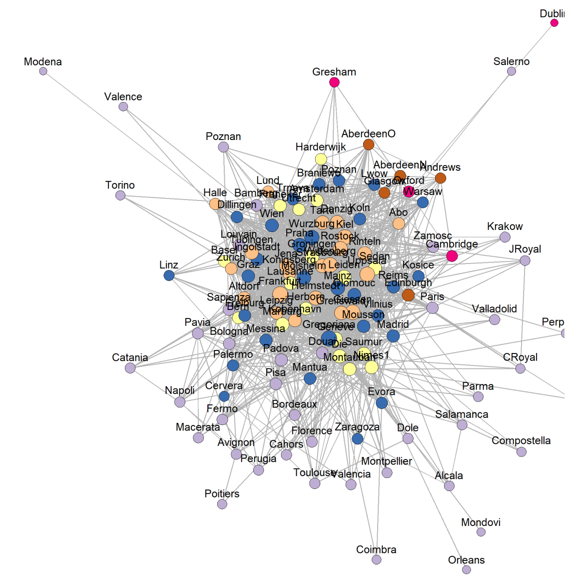
When comparing the main descriptive statistics of the predicted networks with the ones of the observed network, we find that our simulation performs well for most measures. We then compare predicted networks with atheist networks. We find that if religion was not a determinant of network structure, the proportion of connections between Protestant and Catholic universities would have risen from about 6% to 42% on average. If religion had not been a criterion for mobility, we would have observed many more exchanges between scholars in the Protestant and Catholic worlds. The overall structure of the network would have been affected, as illustrated by the drop in modularity scores between the predicted and atheist networks. While the partition of universities across religions explains significantly the structure of predicted networks with modularity scores around 0.42, it is a poor predictor of the atheist networks,

Figure 3: Simulated Networks

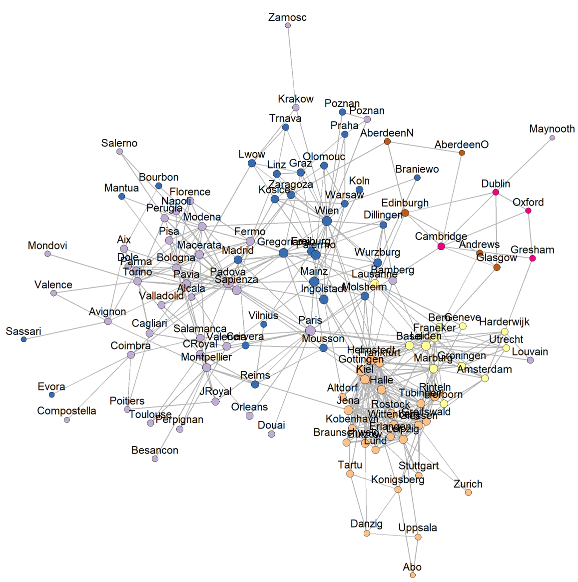
1598 – 1684: Predicted Network



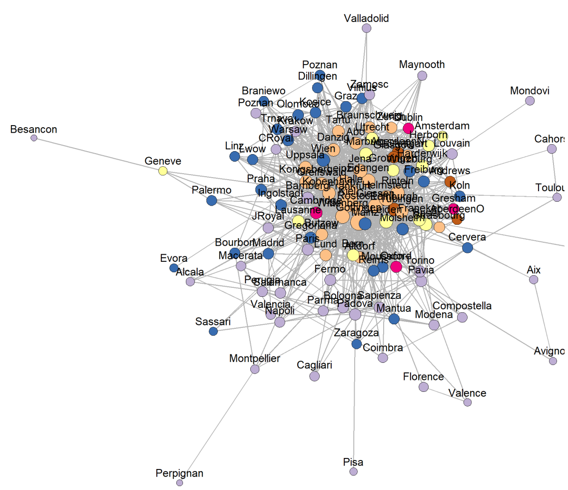
Atheist Network



1685 – 1793: Predicted Network



Atheist Network



Note: "Secular" Catholic universities are purple, while Jesuit universities are blue-filled. Lutheran, Presbyterian, Calvinist and Anglican universities are respectively orange, brown, yellow and pink.

Table 8: Descriptive Statistics of Observed, Simulated, and Counterfactual Networks after Reformation

		Observed	Predicted	s.e.	Atheist	s.e.
1598-1684	Connected U.	119	117	1.35	117	1.20
	Connected pairs	452	491	36.85	1563	26.62
	Density	0.06	0.07	0.01	0.22	0.00
	Average distance	3.02	2.73	0.07	1.88	0.02
	Modularity (**P** – **C**)	0.40	0.39	0.02	0.03	0.01
	Interfaith Edges (%)	5.75	7.05	1.61	46.09	0.83
1685-1793	Connected U.	121	118	1.62	118	1.53
	Connected pairs	384	421	26.63	1165	21.33
	Density	0.05	0.06	0.00	0.16	0.00
	Average Distance	3.46	3.09	0.10	2.04	0.04
	Modularity (**P** – **C**)	0.46	0.45	0.02	0.03	0.01
	Interfaith edges (%)	3.65	5.20	1.44	39.45	0.96

Average number of connected universities in the predicted networks and in the atheist networks matched by construction

as their modularity scores do not exceed 0.01. Additionally, it is likely that if religion had not mattered the network of European universities would have been smaller, as illustrated by the decrease in average distance for atheist networks. But it is not easy to discern to what extent this drop is due to the removal of the religion effect, or to the increase in links in atheist networks.

We thus confirm that, on top of geography and vernacular languages, religion was a strong determinant of network structure. What could be the mechanisms behind this effect? Religious intolerance is an obvious candidate. The economic literature has stressed the importance of intolerance on the Catholic side (Blasutto and De la Croix 2023; Becker, Pino, and Vidal-Robert 2020; Dewitte et al. 2022), but Protestants were not immune from intolerance either (see for example the book by Walsham (2006) on religious persecution in England).

6 Reformation, centrality and academic production

In this Section, we explore whether universities were harmed after the (Counter-)Reformation in terms of their individuals positions in the network. We saw in Section 4 that position of universities in the network was significantly correlated with publications of their top 5 scholars (see Table 5). Moreover, Section 5 showed that the structure of the network of European universities changed radically after the Reformation. Thus we would like to investigate whether publications' performances also changed after the Reformation, through the network structure.

To do so, we compute the average centrality score of each university in the predicted networks, $\hat{\lambda}_{it}$, as well as their average centrality score in the atheist networks, $\tilde{\lambda}_{it}$, for several normalized measures of centrality. The centrality score in the atheist networks can be interpreted as the "natural" centrality score of universities: it tells us what would have been the centrality score of each university if the Reformation had never taken place. The difference between these two scores for university i, $\hat{\lambda}_{it} - \tilde{\lambda}_{it}$, thus measures the increase (or decrease) of its centrality score after Reformation relative to its natural centrality score. If the difference is positive, then it can be said that Reformation had a positive impact on university i in terms of centrality score. We average these differences in centrality scores for each subreligion after the Reformation. Results on degree, closeness and eigenvector centralities are shown in Table 9.

Table 9: Centrality losses following the Reformation

			1523-1597	1598-1684	1685-1793
degree	Lutheran	$E_{i\in\mathbf{P}^L}[\hat{\mathcal{D}}_{it} - \tilde{\mathcal{D}}_{it}]$	−0.270	−0.338	−0.265
	Calvinist	$E_{i\in\mathbf{P}^C}[\hat{\mathcal{D}}_{it} - \tilde{\mathcal{D}}_{it}]$	−0.003	−0.249	−0.133
	Anglican	$E_{i\in\mathbf{P}^A}[\hat{\mathcal{D}}_{it} - \tilde{\mathcal{D}}_{it}]$	−0.015	−0.042	−0.109
	Presbyterian	$E_{i\in\mathbf{P}^P}[\hat{\mathcal{D}}_{it} - \tilde{\mathcal{D}}_{it}]$	−0.026	−0.120	−0.129
	Cath. Secular	$E_{i\in\mathbf{C}^S}[\hat{\mathcal{D}}_{it} - \tilde{\mathcal{D}}_{it}]$	−0.140	−0.009	−0.014
	Jesuit	$E_{i\in\mathbf{C}^J}[\hat{\mathcal{D}}_{it} - \tilde{\mathcal{D}}_{it}]$	−0.116	−0.185	−0.065
closeness	Lutheran	$E_{i\in\mathbf{P}^L}[\hat{\mathcal{C}}_{it} - \tilde{\mathcal{C}}_{it}]$	−0.173	−0.279	−0.263
	Calvinist	$E_{i\in\mathbf{P}^C}[\hat{\mathcal{C}}_{it} - \tilde{\mathcal{C}}_{it}]$	−0.036	−0.213	−0.185
	Anglican	$E_{i\in\mathbf{P}^A}[\hat{\mathcal{C}}_{it} - \tilde{\mathcal{C}}_{it}]$	−0.052	−0.098	−0.198
	Presbyterian	$E_{i\in\mathbf{P}^P}[\hat{\mathcal{C}}_{it} - \tilde{\mathcal{C}}_{it}]$	−0.070	−0.164	−0.221
	Cath. Secular	$E_{i\in\mathbf{C}^S}[\hat{\mathcal{C}}_{it} - \tilde{\mathcal{C}}_{it}]$	−0.108	−0.081	−0.102
	Jesuit	$E_{i\in\mathbf{C}^J}[\hat{\mathcal{C}}_{it} - \tilde{\mathcal{C}}_{it}]$	−0.114	−0.183	−0.157
eigenvector	Lutheran	$E_{i\in\mathbf{P}^L}[\hat{\mathcal{E}}_{it} - \tilde{\mathcal{E}}_{it}]$	−0.327	−0.684	−0.175
	Calvinist	$E_{i\in\mathbf{P}^C}[\hat{\mathcal{E}}_{it} - \tilde{\mathcal{E}}_{it}]$	−0.071	−0.499	−0.203
	Anglican	$E_{i\in\mathbf{P}^A}[\hat{\mathcal{E}}_{it} - \tilde{\mathcal{E}}_{it}]$	−0.030	−0.119	−0.258
	Presbyterian	$E_{i\in\mathbf{P}^P}[\hat{\mathcal{E}}_{it} - \tilde{\mathcal{E}}_{it}]$	−0.023	−0.269	−0.297
	Cath. Secular	$E_{i\in\mathbf{C}^S}[\hat{\mathcal{E}}_{it} - \tilde{\mathcal{E}}_{it}]$	−0.114	+0.154	−0.088
	Jesuit	$E_{i\in\mathbf{C}^J}[\hat{\mathcal{E}}_{it} - \tilde{\mathcal{E}}_{it}]$	−0.133	−0.184	−0.214

We observe that average differences in degree, closeness and eigenvector centrality scores are almost all negative for all subreligious groups. In other words, the network reorganization due to the constrained mobility of scholars during the Reformation and Counter Reformation is associated with losses for all universities in terms of centrality.

We now want to measure the association between the Reformation and publications through the network structure. We do so by explaining the publications of institutions in a panel of universities over the seven periods. The estimated model is:

$$p_{it} = \beta_0 + \beta_1 I(i \in \mathbf{P}) + \beta_2 \tilde{\lambda}_{it} + \beta_3(\hat{\lambda}_{it} - \tilde{\lambda}_{it}) + \alpha_i + \alpha_t + \epsilon_{it} \tag{2}$$

The dependent variable p_{it} is the inverse hyperbolic sine of publications of top 5 scholars. We add a religious dummy $I(i \in \mathbf{P})$ indicating whether the university is Protestant. The reference category is Catholic universities. In doing so, we aim at separating a direct correlation between Protestantism and publications from an indirect link through the network of universities. We code all universities as Catholic before 1523. We add centrality in the atheist network $\tilde{\lambda}_{it}$ to capture changes in the non-religious features of the network affecting publications, as well as the difference in centrality between predicted and atheist networks $\hat{\lambda}_{it} - \tilde{\lambda}_{it}$ as a measure of the role of religious affiliation through the network. Finally, we add university and period fixed effects α_i, α_t. Results are displayed in Table 10.

Table 10: Religions, centrality and publications

		Dependent variable: p_{it}			
degree	$i \in \mathbf{P}$	1.432***		0.617*	0.837***
		(0.355)		(0.334)	(0.328)
	$\tilde{\mathcal{D}}_{it}$		4.987***	4.705***	7.771***
			(0.522)	(0.542)	(0.871)
	$\hat{\mathcal{D}}_{it} - \tilde{\mathcal{D}}_{it}$				5.825***
					(1.318)
	Adjusted R^2	0.411	0.516	0.520	0.546
closeness	$i \in \mathbf{P}$	1.432***		0.417	0.780**
		(0.355)		(0.310)	(0.303)
	$\tilde{\mathcal{C}}_{it}$		9.017***	8.738***	12.530***
			(0.717)	(0.745)	(0.978))
	$\hat{\mathcal{C}}_{it} - \tilde{\mathcal{C}}_{it}$				9.690***
					(1.714)
	Adjusted R^2	0.411	0.583	0.584	0.620
eigenvector	$i \in \mathbf{P}$	1.432***		0.377	0.424
		(0.355)		(0.333)	(0.335)
	$\tilde{\mathcal{E}}_{it}$		2.975***	2.862***	3.016***
			(0.282)	(0.299)	(0.327))
	$\hat{\mathcal{E}}_{it} - \tilde{\mathcal{E}}_{it}$				0.423
					(0.367)
	Adjusted R^2	0.411	0.538	0.538	0.539

No. observations: 469 *p<0.1; **p<0.05; ***p<0.01
Includes university and period fixed effects. Reference: $i \in \mathbf{C}$.

The first column of Table 10 shows that becoming Protestant correlates undoubtedly with publications of top 5 scholars, which is consistent with Table 1. The second column tells us that becoming more central in terms of degree, closeness and eigenvector centrality "naturally" correlates with publications, which is consistent with Table 5. In the fourth column, the significant coefficient associated to the difference in centrality between predicted and atheist networks is an indication that becoming more central in terms of degree or closeness centrality after the Reformation correlates with publications. The fact that the coefficient associated to the Protestant dummy is still significant in column 4 for degree and closeness centrality suggests that part of publications is directly related to the Protestant culture, which arguably relied more on writings than the Catholic one. But the fact that the two other coefficients of this specification are also positive and significant is an indication that position in the network mattered as well, especially reorganization of positions in the network after the Reformation and Counter Reformation. We saw in the previous paragraph that Reformation and Counter-Reformation induced constrained mobility of scholars during the 17th-18th centuries, which likely harmed all universities in the European network of universities. Thus it can be said that part of the decline of Catholic universities in terms of publications in the modern period shown in Table 1 correlates with the Reformation. We may also conjecture that the rise of Protestant universities in terms of publications at the same period would have been even greater had the mobility of scholars not been constrained.

Finally, we zoom in on the very low proportion of links between Catholic and Protestant universities in 1598-1684 and 1685-1793. In 1598-1684, twenty two professors link the Catholic and Protestant worlds, representing only a very small share of the total number of professors who taught in at least two universities in this period (22/879 = 2.5%). In 1685-1793, this proportion falls to 0.9%, with only eleven scholars connecting Catholic and Protestant universities out of 1266 mobile scholars. A short biography of these bridge builders is provided in Appendix F. There is a majority of renowned scholars, who might be immune from petty religious fights. Who would dare to ask one of the Bernoulli to convert to Catholicism if Padova really wants to hire him ? We also note that these links involving superstars touch a small number of universities. Padova seems an example of openness. The Dutch universities too seem to have been quite open. We do not observe any connection involving a Spanish or a Polish university. Beyond the stars, we also have a few "obscure" scholars establishing links between the two worlds. This seems to occur more often when they teach some very specialized topic (Hebrew, Arabic). Then, there are cases of conversion, for which we do not know what came first: a true conversion requiring a change of university, or a better job offer requiring a conversion.

Table 11 displays the results of a regression of the inverse hyperbolic sine of the number of academic works on a dummy variable indicating if a professor connects a Protestant and a Catholic university and on another dummy indicating if a professor is a mobile scholars.

In both periods, mobile scholars publish already significantly more than scholars who stayed in the same

Table 11: Publications of the Connecting Scholars

	Dependent variable: inverse hyperbolic sine of number of works	
	1598 -1684	1685 -1793
constant	0.799***	0.904***
	(0.015)	(0.012)
mobile	0.523***	0.484***
	(0.049)	(0.042)
connecting **P** and **C**	1.116***	1.472***
	(0.294)	(0.432)
Observations	9,780	14,590
Adjusted R^2	0.013	0.010
Notes:	*p<0.1; **p<0.05; ***p<0.01	
	Estimator is OLS. Reference group: immobile scholars.	

university during their entire career. Publications of mobile scholars are on average 68.9% and 62.3% more numerous than publications of immobile scholars, in 1598-1684 and 1685-1793 respectively. Results are even more striking for scholars connecting a Protestant and a Catholic university. In 1598-1684, our 22 connecting persons have on average 206.6% more publications compared to immobile scholars. In 1685-1793, our 11 connecting scholars publish on average 337.4% more than immobile scholars.

7 Conclusions

For a long time, the European academic world was an interconnected network with scholars moving positions at will. With the Reformation and the Counter-Reformation, the academic world became divided. Few people held positions in both worlds. We show in this paper that this religious divide had severe consequences. Universities were hit hard in terms of centrality, which had consequences in terms of research output. Publications in the Catholic world peaked at their pre-reform level. On the Protestant side, we show that the Reformation impacted positively their publications through a direct effect, but this effect was partly offset by loosing centrality in the network of European universities.

These results were obtained by looking at a new database of tens of thousands of European scholars through the lens of network theory. We also create a new tool by generating simulated and counter factual networks as predicted from a dyadic regression. With this tool it is possible to separate the effect of religion and show that the proportion of connections between Protestant and Catholic universities would have been multiplied by a factor of seven if religion did not intervene.

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