FLORA, COSMOS, SALVATIO: PRE-MODERN ACADEMIC INSTITUTIONS AND THE SPREAD OF IDEAS

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Abstract

While good ideas can emerge anywhere, it takes a community to develop and disseminate them. In premodern Europe (1084-1793), there were approximately 200 universities and 150 academies of sciences, home to thousands of scholars from the Middle Ages to the First Industrial Revolution. By inferring co-presence from institutional affiliations, we simulate how ideas would spread from a scholar to another across the European academic network. We find that the implied exposure patterns align with observed urban developments: examples include botanic gardens, astronomical observatories, and Protestantism. Scholars' mobility and multiple affiliations sustain the diffusion, and counterfactual simulations underscore the bridging role played by scientific academies. We also show that the spread of ideas through the affiliation network was locally fragile but globally robust, pointing towards academia as being a connective infrastructure underlying early European development.

JEL classifications: N33, O33, I23

Keywords: Temporal Network, Structural Estimation, Scientific Revolution, European Academia, Epidemiological model

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1 Introduction

In Europe during the Middle Ages and Early Modern period, more than one hundred thousand scholars were engaged in the production, dissemination, and development of various forms of knowledge. These scholars did not operate in isolation: two key institutions, universities and academies, facilitated their interaction. These institutions organized teaching and research within self-governed communities of scholars, as stressed in Rashdall (1895) and McClellan (1985). From medieval universities such as Paris and Bologna, to the Royal Society centuries later, formal institutions brought together scholars to develop and disseminate scientific discovery. These institutions provided scholars not just with employment, but with a physical proximity that facilitated interaction.

Over this period, Europe experienced successive waves of transformation from the medieval urban revolution to the Enlightenment through humanism, the Reformation, and the Scientific Revolution. Universities and academies were closely entwined with these foundational shifts. Whether such institutions were central to Europe's intellectual success, or instead functioned largely as privileged and resource-consuming corporations (Adam Smith 1776), remains an open issue. We address this question by studying one mechanism through which they could matter: the diffusion of ideas through face-to-face interactions within academic institutions.

Specifically, we propose a structural, microdata-driven model to measure how ideas would spread from one scholar to another based on co-presence at the same academic institution. Similar to the approach taken by Becker et al. (2024) in their analysis of the pre-WWII period, we create an affiliation network where connections between scholars are based on their overlapping presence at a university or an academy. To simulate the transmission of ideas, we combine an epidemiological approach with the network structure (Banerjee et al. 2013; Koher et al. 2016; Fogli and Veldkamp 2021). Our framework fits within the class of network diffusion models, such as that formalized in Bramoullé and Genicot (2024). This is the first analysis to reconstruct the European academic affiliation network at such a long-run and granular scale, allowing us to simultaneously capture the continent-wide dynamics of idea diffusion and the local, individual-level conditions under which ideas spread—or fail to do so.

Our network is dynamic and spans 1084 to 1793. Our timeframe starts with the establishment of Irnerius's school of jurisprudence in Bologna (c. 1050 - after 1125) and concludes with the French Revolutionary Convention (1793). The *nodes* of the network are premodern scholars. A connection, or an *edge* in the network, is established between any pair of scholars who share at least one year of concurrent affiliation at the same institution and work within a broadly similar field. We assume that ideas spread through networks like infections, with scholars transmitting their inventions to peers with a certain probability, the *link activation probability*. This parameter governs the overall diffusion of ideas through the network by regulating the likelihood that an interaction between two connected scholars leads to exposure. A value close to zero suggests that face-to-face interactions rarely lead to knowledge transfer (e.g., due to non-academic discussions), while a high value indicates they are an effective channel for diffusion.

Ideally we would estimate this parameter by comparing the model's predictions to empirical moments that reflect the historical spread of ideas. However, a key challenge is that we do not directly observe ideas as they propagate. Unlike studies that trace the trajectory of a single idea—such as the study by Xue (2025) on Wang Yangming's influence in Chinese texts, or Giorcelli, Lacetera, and Marinoni (2022) on the spread of Darwinian theory—or those that focus on specific linguistic or regional contexts, like Chiopris (2024) on 19th-century ideas in the German library consortium, our setting lacks detailed records of idea diffusion. Contemporary work, such as that of Ahmadpoor and Jones (2017), leverages citation and patent data to track knowledge flows over time: no comparable measures exist for Early Modern Europe. Nevertheless, we observe outcomes plausibly linked to idea adoption, which we use to conduct indirect inference.

Our approach is to estimate the link activation probability by simulating the diffusion of ideas through the affiliation network and constructing measures of exposure at the scholar, institution, and city levels. We then correlate these simulated exposures with historical outcomes in what we term auxiliary models, drawing on the framework of indirect inference (see Anthony Smith (2008)). We benchmark our diffusion model on two breakthroughs of the Scientific Revolution that have both clear historical importance and observable city-level proxies.

The first auxiliary model is the rise of botany as an independent discipline (*flora*), driven by Leonhart Fuchs (1501–1566), a professor at the Universities of Tübingen and Ingolstadt. Fuchs' work emphasized direct observation of nature, culminating in the publication of a comprehensive herbal featuring accurate plant illustrations and medicinal descriptions. We label this shift "Botanical Realism". The heightened interest in botany across Europe that followed is evidenced by the spread of botanic gardens. We calculate each city's simulated exposure to Botanical Realism and use a proportional hazard model to estimate the speed at which a botanic garden is being established. We find that higher exposure is associated with a faster establishment of botanic gardens, especially in cities with a smaller scholarly mass susceptible to be exposed.

The second auxiliary model focuses on the mathematical reform of astronomy (*cosmos*), particularly the foundational role of Johannes Regiomontanus (1436–1476) in the advancement of trigonometry and astronomy. We group his innovations, which were later instrumental to the work of Copernicus, Kepler, and Galileo, under the label "Mathematical Astronomy". Regiomontanus held positions in Vienna (Universität Wien 2024), Bratislava (Gabriel 1969), Padua (Facciolati 1757), and Rome (Renazzi 1803), which facilitated the transmission of his ideas. We measure exposure to his innovations and analyze the correlation with the creation of astronomical observatories across Europe. Again using a proportional hazard model, we find that higher exposure is associated with a faster establishment of observatories, with the effect strongest in cities with a smaller eligible scholarly mass.

We then estimate the link activation probability by maximizing the joint likelihood of these two auxiliary models. The estimated value is 0.45. This value generates exposure patterns that align with related historical outcomes and is consistent with an important role of social and institutional connections in the transmission of ideas. In that sense, our results echo both apprenticeship-based models in which the master-apprentice face-to-face communication is key (De la Croix, Doepke, and Mokyr 2018), but also contemporary insights on the persistent importance of face-to-face interactions in innovative environments like the Silicon Valley (Atkin, Chen, and Popov 2022).

With the estimated link activation probability, we use the model in two additional applications by linking exposure to scholasticism (*salvatio*) to the probability of cities adopting Protestantism and the spread of anti-Semitic ideas. Scholasticism was pioneered by Petrus Lombardus (c. 1100 – 1160), a professor in Paris, and it was the dominant approach to philosophy and theology in the Middle Ages. Followers of scholasticism used logical reasoning to explore theological questions, and this method was adopted in many universities. Over time, however, it became increasingly detached from the practical concerns of believers and devolved into abstract debates, a decline often cited in historical literature (Chaunu 2014; Barrett 2023). Exposure to scholasticism may have been associated with an intellectual climate receptive to Reformation ideas, possibly reflecting a backlash against intellectualized theological debate and a stronger emphasis on scripture (Chaunu 2014). To document this association, we simulate the diffusion of scholasticism through the affiliation network. We capture the exposure to scholasticism across universities in 1508 and infer the exposure of nearby cities. Using a linear probability model, we show that a higher exposure to scholasticism correlates with the adoption of Protestantism. In a similar vein, we extend the classical finding that pogroms against Jews were more likely to occur following major shocks, such as the Black Death (Becker and Pascali 2019; Jedwab, Johnson, and Koyama 2019; Voigtländer and Voth 2012), by showing that the anti-Judaic climate embedded in scholastic thought acted as a complementary force in this process.

To assess the features of the network that are most critical for idea diffusion, we turn to exploring counterfactual scenarios. In this analysis, we compare observed outcomes with the hypothetical scenarios that would have emerged under alternative conditions.[1] In the first counterfactual experiment, we reassign the intellectual origin of an idea to different individuals and ask whether it would still propagate across Europe. While some peripheral institutions are not well enough connected to guarantee the survival of an idea, we find that in most cases, ideas still reach the entire network within a couple of centuries. However, the speed and route of diffusion vary, emphasizing the non-ergodic nature of the process and the importance of initial conditions. In the second experiment we compare the role of academies to that of universities. When we remove academies from the network, there is a notable drop in the geographical reach of ideas, especially those that originated in remote or disrupted areas. Academies, with their international memberships, often served as critical diffusion channels, bridging regions and sustaining intellectual exchange during crises such as university closures during the Thirty Years' War. In the third experiment, we simulate the removal of entire countries or regions—such as the British Isles, France, or the Italian and Iberian Peninsulas—to assess their systemic importance. Surprisingly, even when major regions are excluded, most ideas continue to spread widely across Europe. This suggests that most regions were not essential to the flow of knowledge, underscoring the network's remarkable resilience to local shocks.

Taken together, these counterfactuals reveal an affiliation network that is globally robust yet locally fragile. While alternative paths almost always exist, early diffusion often depends on narrow institutional channels, making the survival of ideas partly contingent on chance.

Our paper relates to several strands of the literature. First, we contribute to the growing body of work on the diffusion of knowledge in historical contexts. Existing studies have explored complementary channels such as printed books (Chiopris 2024), correspondence networks (Cervellati et al. 2025; Roller 2023), translations (Abramitzky and Sin 2014), and mentorship influences (Koschnick 2025b). Other contributions combine multiple channels to reconstruct broader diffusion processes (Becker et al. 2020, 2025). By contrast, we emphasize

1. It is important to emphasize that our focus on counterfactual scenarios is primarily methodological. We use counterfactual scenarios to gain a deeper understanding of the academic network's intrinsic properties, rather than to definitively predict what might have occurred in these hypothetical situations. This approach aligns with the spirit of classic works like Fogel's (1964) seminal study on the impact of railroads on American economic development, which emphasized the importance of counterfactual reasoning for historical analysis.

academic institutions as aggregating centers,[2] fostering repeated opportunities for intellectual exchange among their members.[3] This could occur via physical proximity but also through institutionally-organized epistolary exchanges, as practiced in some academies. Focusing on institutional proximity offers two key advantages. On the one hand, observing whether scholars were affiliated with the same institution at the same time allows us to infer potential exposure to ideas, independently of whether those ideas were ultimately adopted or endorsed. On the other, gaps in the network are, at least in part, observable. Gaps occur when universities are underrepresented in our sources, causing some professors to be missing. In contrast, gaps in correspondence networks, such as letters that have not survived, are fundamentally unobservable and thus impossible to systematically evaluate.

Second, our paper engages with the history of science and upper tail human capital, from broad studies on the emergence of science and the scientific method (Needham 1964; Wootton 2015), to analyses of scientists' roles in society (Ben-David 1971; Hanlon 2025). Mokyr (2005; 2016; 2011), Ó Gráda (2016), and Almelhem et al. (2023) explore the roots of the industrial revolutions through the accumulation and application of useful knowledge during the Scientific Revolution and Enlightenment. In addition, historical scholarship highlights the impact of highly skilled individuals (Meisenzahl and Mokyr 2012), specialized engineers (Hanlon 2025; Maloney and Valencia Caicedo 2022), and key inventors (Hallmann, Hanlon, and Rosenberger 2022) in driving Britain's technological edge. Our analysis mostly covers propositional knowledge, complementing these studies by tracing the intellectual roots from which practical knowledge later emerged—for example, when early modern advances in atmospheric science associated with Torricelli and Boyle paved the way for practical applications in the eighteenth century.[4]

Other works show how the institutional context matters: classical composers thrived in more liberal environments (Borowiecki 2013), patent systems shaped the direction of innovation (Moser 2005), and external shocks—such as the U.S. Civil War, spurred targeted technological responses in Britain's textile industry (Hanlon 2015). Our approach also aligns with Akcigit et al. (2018) in its focus on tracking "individuals, their productivity, and their

2. Aggregation centers were crucial for intellectual exchange in the medieval and premodern world. As shown by Brunt and García-Peñalosa (2022), cities played a similar role in fostering knowledge diffusion by concentrating individuals and increasing opportunities for encounters and idea transmission.

3. A striking example of this dynamic is the relationship between the abovementioned Regiomontanus and Polish astronomer Martinus Bylica de Ilkusz, who met at the University of Padua in 1463. Their long-lasting intellectual bond—with Bylica amending the Regiomontanus manuscripts—mirrored that of their mentors, respectively, Georg Peuerbach and Martinus Król (Domonkos 1968), and underscores how institutional settings also fostered scholarly connections across generations.

4. More generally, Koschnick (2025a) provides evidence, through automated text analysis, of knowledge spillovers between propositional and practical knowledge in England, 1600–1800.

interactions over time" (Akcigit et al. 2018, p.2). Our analysis also relates to work on academic superstars, which shows that the removal of central figures can disrupt or reconfigure knowledge networks (Azoulay, Graff Zivin, and Wang 2010; Azoulay, Fons-Rosen, and Zivin 2019). While the focus of those papers is on publication output, the underlying question—how resistant to disruption academic networks are—is also relevant to our framework.

Finally, we also engage tentatively with the literature on the rise of the West, and the Europe-China differences (Greif, Mokyr, and Tabellini 2025). Indeed, having described the strength of European academia in terms of connectivity and resilience, we believe it could have been instrumental to Europe's success during the Early Modern period. This remains speculative, however, as we lack comparable data on academic networks in other parts of the world, and rely only on anecdotal evidence. In 1798, Thomas Malthus (1766–1834), a fellow at the University of Cambridge from 1793, published a treatise on population and development (Malthus 1807). He developed the idea that population growth tends to outpace food production, leading to inevitable constraints to development. In 1818, Malthus became a Fellow of the Royal Society. Malthus' view had an immense influence on political economy in the following decades. Still today his ideas are modeled and debated (André and Platteau 1998; Ashraf and Galor 2011). At about the same time, Hung Liang-Chi (1744–1809), a high official of the Chinese imperial administration, developed similar ideas. The ideas were particularly relevant for understanding Chinese dynamics in the 19th century. Still, Hung Liang-Chi largely disappeared from the record and only rediscovered in the 20th century (Silberman 1960). How can we understand the differences in the fates of these two ideas? The approach we develop in this paper can be applied to explain Malthus' success. Malthus was integrated into the broad European academic network, where his ideas could spread. Hung Liang-Chi belonged to an administration in which ideas were developed by individuals but not subject to broad dissemination and discussion.

The paper is organized as follows. In Section 2 we present the methodology, including the construction of the database and how it is mapped into an affiliation network. We also present the epidemiological model to simulate the diffusion of ideas. In Section 3 we detail the structural estimation of the model parameter, based on *flora* and *cosmos*. In Section 4 we present further empirical assessments, based on *salvatio*. The counterfactual experiments are detailed in Section 5. Section 6 concludes.

2 Data and Methodology

We now present our methodology, starting with the compilation of the database of professors, followed by the definition of the temporal network and the epidemiological model that we use to describe how ideas flow.

2.1 88,792 scholars

Our database of scholars comprises information on 88,792 individuals spanning the period 1000-1800. The data were collected manually from approximately 700 distinct sources. Unlike other studies that rely on ex-post recognition of scholars—such as that derived from Wikipedia/Wikidata (see Laouenan et al. (2022) and Serafinelli and Tabellini (2022))—our selection is based on membership lists or secondary sources related to key higher education institutions. These institutions fall into three categories: universities (referenced in Frijhoff (1996); see also De la Croix et al. (2024)), scientific academies (as cataloged in McClellan (1985), and further discussed in Zanardello (2024)), and various other institutions with links to universities, including Italian Renaissance academies mentioned in The British Library (2021), and other higher education entities that conferred academic degrees.

Medieval universities primarily focused on four disciplines: theology, law, arts and humanities, and medicine. The faculty of arts provided foundational education to grammar school pupils, many of whom became teachers themselves, contributing to rising literacy rates among the general population. Some students progressed to higher faculties, preparing for professions in other fields. The faculty of medicine trained medical practitioners, the faculty of laws produced future administrators with specialized knowledge in canon or civil law, and the faculty of theology trained teachers for episcopal schools, where ordinary parish priests were instructed (Pedersen 1992). Academies, emerging later in the 17th and 18th centuries, were created to foster new areas of research not traditionally covered by universities (McClellan 1985; Applebaum 2003). These ranged from informal groups of amateur naturalists or local historians, to prominent official societies that gathered leading scholars, published journals, and formed networks of corresponding members, known collectively as the Republic of Letters (Mokyr 2016).

To compile the list of scholars from each academy and university, we mostly relied on secondary sources, mainly books on the history of these institutions and their members, which were themselves based on primary records. For universities, our aim was to include scholars involved in teaching, covering a range of positions from royal chairs in France to fellowships in England. Further details on the inclusion criteria for university scholars can be found in De la Croix et al. (2024), while global statistics are available in De la Croix (2021) and different issues of the *Repertorium Eruditorum Totius Europae*. For academies this process was generally straightforward, since comprehensive membership lists are often available. Our data on academies have already been utilized in works such as Blasutto and

De la Croix (2023) for Italian academies, De la Croix and Goñi (2024) for analyzing father-son pairs across academies and universities, and Zanardello (2024) for evaluating the impact of different fields of study within academies. Academies often have several membership categories, including ordinary, corresponding, and honorary members. Corresponding members, though not present at academy meetings, contributed from a distance. Honorary members often included local dignitaries like bishops, wealthy merchants, and governors, who supported and protected the academies. To prevent skewing our results due to the inclusion of these sometimes prominent figures, we excluded anyone holding honorary membership or those who were clearly not scholars or intellectuals (e.g., Napoleon, who was elected to the Académie des Sciences in 1797).

Appendix A reports descriptive statistics. Among the 88,792 scholars, 26,549 lack any personal information (no place of birth, vital dates, or Wikipedia link), while another large group is known only by place of birth. Complete information on all three indicators exists for 17,200 scholars. Overall, 19,579 scholars, about one fifth of the dataset, have a Wikipedia page. Hence, for academia, our dataset is much more comprehensive than Wikipedia-based samples such as Laouenan et al. (2022). Around 80% of scholars are associated with a single field, most commonly the humanities, followed by the sciences (including medicine), theology, and law. For 6,939 scholars the field is unknown, and 3,744 are classified as "honorary," reflecting administrative or ceremonial roles and will be excluded from the analyses. Among multi-field scholars, the most common combinations are theology and humanities (6,707) and humanities and sciences (3,382). Start years of affiliation are known in most cases (90,416), typically corresponding to university appointments or elections to academies. End dates are less systematically recorded, as sources often report when a professorship begins but not when it ends. Academy membership can generally be assumed to last until death, whereas no comparable assumption can be made for university posts. For 12,965 scholars only an approximate activity date can be assigned, and for 1,162 no dating information is available. More details about activity dates in Appendix B.

2.2 Definition of the affiliation network $\mathbb{G}$

We now look at the data on scholars and their affiliation to institutions with reference to network theory, a powerful tool for studying the spread of information over time and space (Jackson 2008; Goyal 2023). We model the affiliation network as a graph, where *nodes* represent scholars and *edges* denote their contemporaneous presence at the same institution. This network is derived from an initial bipartite representation, consisting of two types of nodes: scholars and institutions. In the bipartite version, edges connect scholars to the

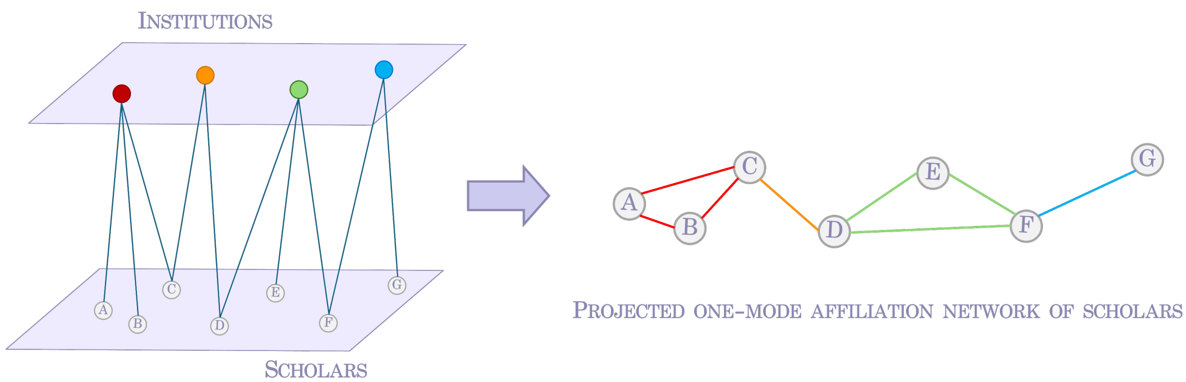


Figure 1: Intuitive representation of network projection: from a bipartite or two-mode graph to the one-mode affiliation network of scholars. Diagram inspired by Geraerts and Vasques Filho (2024).

institutions they were affiliated with. Since our focus is on scholar-to-scholar interactions, we project this bipartite graph onto a single-mode network of scholars, where an edge between two nodes represents their concurrent affiliation with the same institution, as shown in Figure 1. Premodern universities were small, and it is reasonable to assume that professors had regular opportunities for interaction. Appendix A presents some descriptive statistics for the 10 institutions with the highest number of scholars in 1793, differentiating by type (university vs academy). The average university has fewer than 70 professors. Academies hosted a higher number of scholars on average, reaching almost 80 in Halle and 123 in London.

Our analysis spans the foundation of a new school of jurisprudence, which would later become the University of Bologna, in $\underline{t} = 1084$, to the French Convention in $\bar{t} = 1793$, which led to the abrupt closure of all universities and academies on the territory of the new Republic. During this timeframe, the network's nodes (scholars) and edges (connections) existed only within specific periods defined by the duration of each scholar's activity and their affiliations with institutions.

More formally, given two scholars i_s and i_v, the link between i_s and i_v lasts as long as i_s and i_v share an overlapping period of affiliation at the same institution. This implies that the collection of edges is dynamic over time: edges serve as channels for the spread of ideas, appearing and disappearing only while scholars are active at the same institution. In contrast, nodes (scholars) exist in the network as long as they are active, i.e. affiliated with one or more institutions as in our main database. Figure 2 shows the evolution of the number of active scholars over time, showing overall exponential growth, in particular after 1650, with the emergence of academies. Appendix B gives more details on how activity

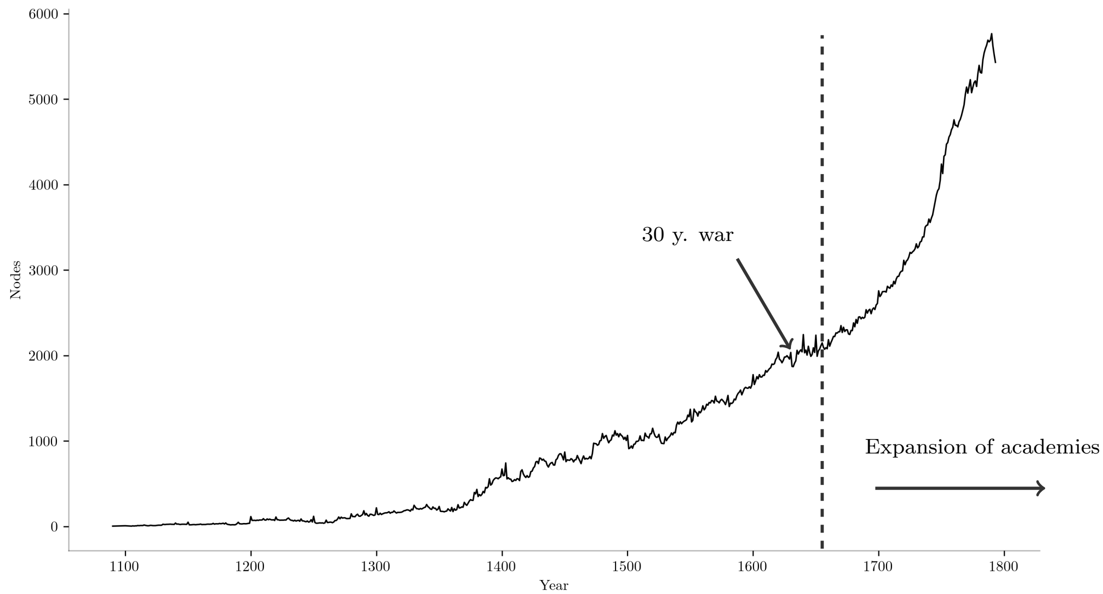
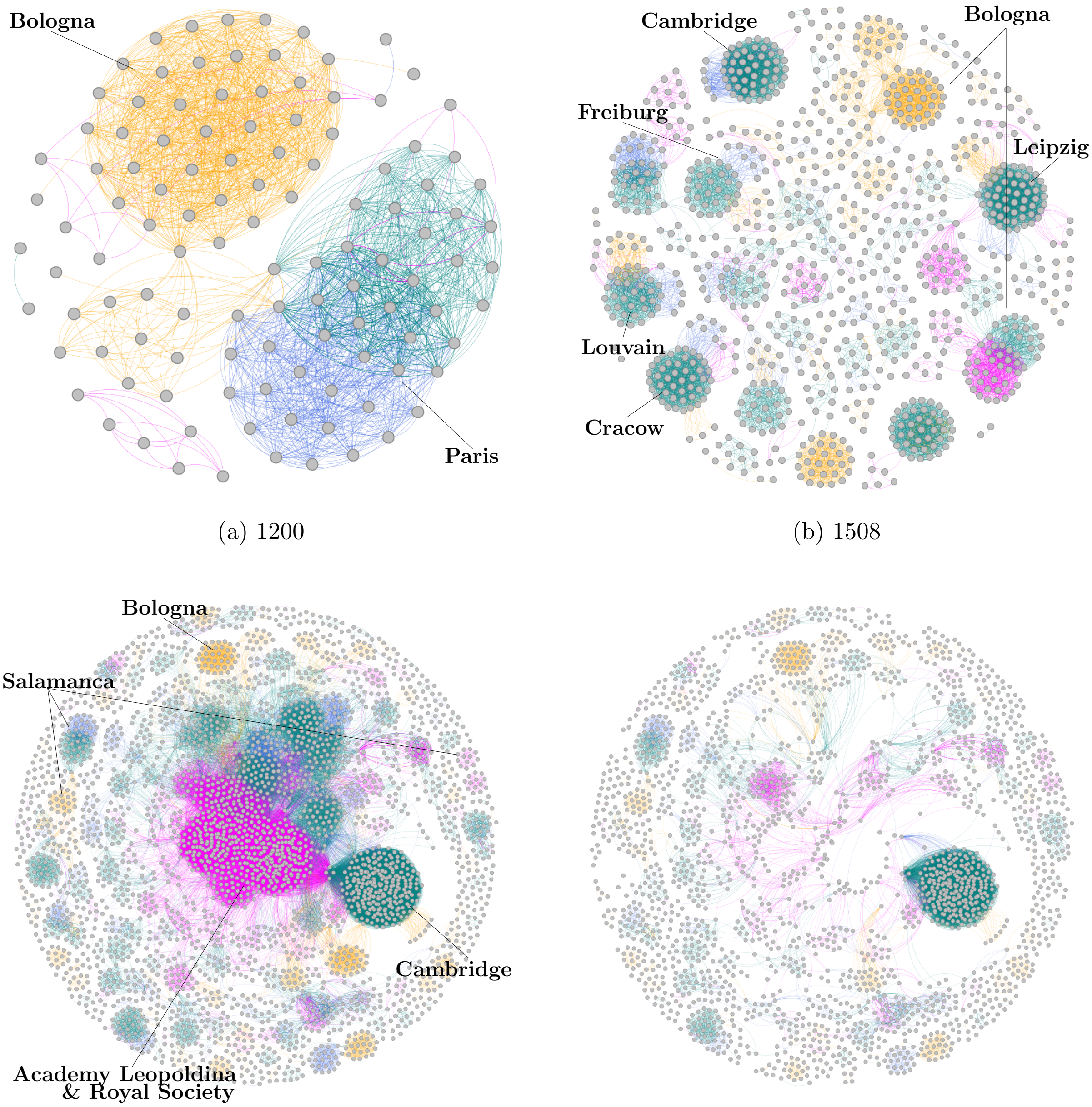


Figure 2: Number of active scholars in the network, 1084-1793.

periods are computed.

The affiliation network reveals several important characteristics, visualized in Figure 3. Before the rise of academies, the network at any given time typically consisted of a series of mostly disconnected clusters, each representing a single university. These clusters in turn comprised *cliques* (fully connected clusters) of scholars operating in the same field at the same university. Occasionally, cliques overlapped, highlighting scholars active in multiple fields. As scholar move, occasional links form among different university clusters, creating pathways between otherwise separate regions of the network. With the emergence of academies, however, connections between scholars multiplied significantly. Academies often appointed foreign members, serving as bridges between previously isolated universities clusters: Figure 3d depicts the 1730 network in a scenario where academies are removed. From the 1650s to the end of the timeframe, the cluster- and clique-based appearance of the early network transformed into a densely interconnected web, and this is likely due to the academies.

This effect is also visible in the share of nodes connected to the main network, known as the giant component—the largest connected subgraph in which any two nodes are mutually reachable—as shown in Figure 4. In the early period, around 1200, the affiliation network was nearly fully connected, reflecting a small number of institutions and high scholar mobility. From the 14th century onward, network connectedness followed a general downward trend, punctuated by occasional spikes. These spikes typically occurred when a mobile scholar



(a) 1200

(b) 1508

(c) 1730

(d) 1730 (No academies)

Figure 3: Snapshots of the affiliation network in 1200, 1508, and 1730 (with and without academies). Edge colors broadly denote the disciplines: theology (blue), law (orange), humanities (teal), and sciences (magenta). Isolated nodes not represented.

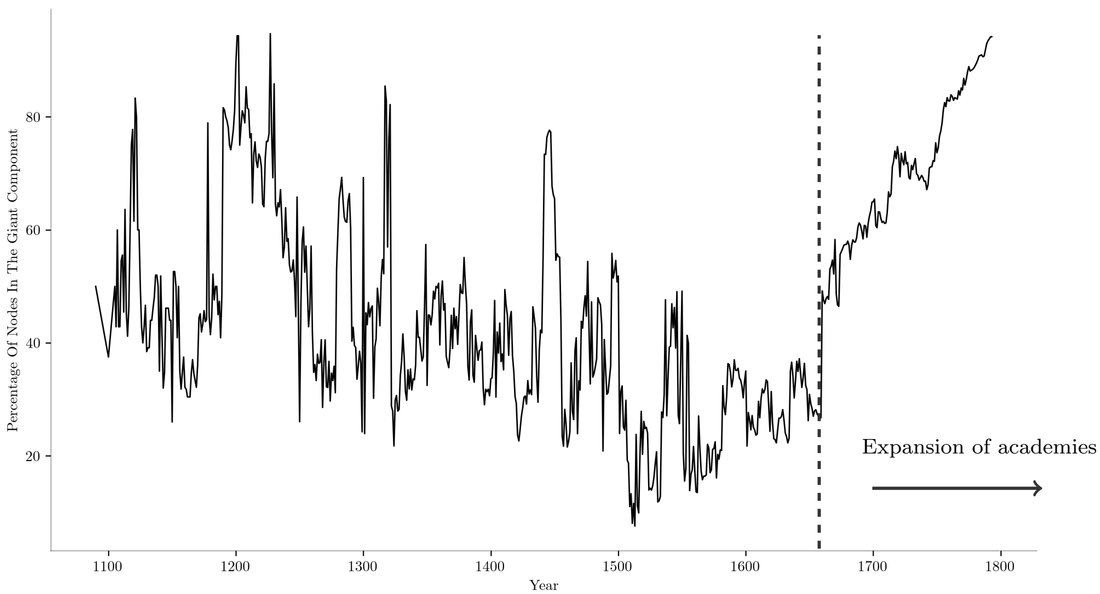


Figure 4: Percentage of active scholars in the giant or connected component over time, 1084-1793.

bridged otherwise disconnected parts of the network. The size of the giant component reached a low point during the Reformation, which curtailed mobility across religious lines, as discussed in De la Croix and Morault (2025). Although the Thirty Years' War (1618–1648) did not drive a further decline, it prolonged the fragmentation, with the giant component remaining relatively small. Connectivity recovered with the rise of academies, as the share of nodes in the giant component increased from 40% in 1650 to 90% by 1793.

In Table 1, we report network statistics at the beginning of each century, between 1200 and 1700, following Goyal, Van Der Leij, and Moraga-González (2006), to assess whether our network exhibits properties of an emerging small world. The graph consistently displays a high clustering coefficient (above 0.88 in all periods), well above the levels expected in a random graph with similar size and density, where clustering would typically approximate to the average degree divided by the number of nodes–and hence close to zero in sparse networks of this scale. At the same time, average path lengths (or distances) within the giant component remain low–between 2.16 and 5.51–and stable over time, even as the number of scholars increases significantly. While the network is highly fragmented in earlier centuries, with the giant component capturing as little as 33.63% of scholars in 1400, its expansion to over 60% by 1700 reflects a growing integration of academic communities across institutions. In other words, in the earlier centuries, the affiliation network resembles an archipelago of small "islands" (i.e. universities) which are internally well connected (as shown by the very high clustering coefficients) but connected to each other only via the occasional mobility

Table 1: Network statistics for the affiliation network, 1200-1700

Year	1200	1300	1400	1500	1600	1700
Number of active scholars	116	218	672	1065	1776	2757
Avg. degree	30.03	17.08	42.14	26.54	42.24	55.68
Size of giant component	104	151	226	552	622	1792
% of giant component	89.66	69.27	33.63	51.83	35.02	65
Size of second-largest component	6	29	139	75	244	51
Avg. clustering coefficient	0.88	0.92	0.93	0.91	0.89	0.90
Avg. distance (giant)	2.16	3.36	1.95	4.14	5.51	4.31

Note: The degree of a node is the number of distinct scholars with which the node is connected. The Avg. degree is the mean of the degrees of all connected scholars in the network. The clustering coefficient of a node is the fraction of all possible links among a node's neighbors that are actually present. The Avg. clustering coefficient is the mean of the clustering coefficients of all connected scholars in the network. The distance between two scholars is the length of the shortest path between them. The Avg. distance is the mean distance among all connected pairs of scholars in the giant component.

of scholars. Over time, particularly by 1700, these isolated islands began to form bridges– thanks to multiple simultaneous affiliations, which was due to the emergence of academies. The result is an increasingly interconnected network, where the size of the giant component grows to nearly two-thirds of all scholars, while clustering remains high and path lengths stay short. The size of the second-largest component further underlines this aspect: it increases up to 1600 but drastically decreases in 1700, thanks also to the arrival of scientific academies. This shift marks the emergence of a small-world structure out of what was once a fragmented archipelago.

This affiliation network is the structure on which we will simulate the spread of ideas. Each idea is assumed to originate in a specific year and from a particular inventor, who can transmit it to their neighbors at each time step, but under certain conditions. Each idea belongs to a broad field that reflects the main disciplines of premodern times, and can spread only among scholars active within that field. Our assumption is that if a scholar is working in science[5] they are presumed to engage productively with peers in medicine or applied science.[6] One may argue that in the past there were all-round scholars who were equally fluent, for example, in both science and philosophy. Still, we decide to assign specific fields to each idea, while acknowledging that this may cause us to underestimate the speed of diffusion of ideas.

5. Science includes mathematics, logic, physics, chemistry, biology, astronomy, earth sciences, geography, and botany.

6. Applied science includes engineering, architecture, and agronomy.

2.3 Ideas, inventors and exposed scholars

Ideas originate from inventors, i.e., scholars who developed a new idea at a specific point in time. Inventors can propagate their ideas to their peers, who, once exposed, can further propagate them to others. Upon being exposed to the idea, scholars can pass it along to their own neighbors without needing to maintain an enduring direct link with the original inventor. In our context, an inventor is a scholar recognized for a groundbreaking idea, as reported in one of the major historical encyclopedias. We use English (2005) for ideas spread before 1500 C.E., and Applebaum (2003) for ideas diffused between the invention of the printing press (circa 1450s) and the French Revolution. From these sources, we identify some significant ideas that changed the course of history, prioritizing those for which historical outcomes are available. For each idea we pinpoint the inventor, as detailed in Section 3.2, Section 3.3, and Section 4.1.

We simulate the spread of three main ideas—*flora*, *cosmos*, and *salvatio*—two from the Scientific Revolution and one from the Middle Ages, and compare simulated exposure to observed outcomes. For the Scientific Revolution, we draw on Applebaum (2003), focusing on the earliest ideas for which European-level outcome data is available. In botany, Applebaum (2003) identifies Botanical Realism, foundational to Fuchs's 1542 herbarium; we link exposure to this idea with the creation of botanic gardens. In astronomy, the idea is attributed to Regiomontanus, whose Mathematical Astronomy (developed from 1450, published in 1496) formalized Ptolemaic models for future research. Its corresponding outcome is the founding of astronomical observatories.

For the Middle Ages, we find key academic ideas using the index in English (2005). These include alchemy, anatomy (including practical surgery), astrology, computus, civil law, economic thought, cartography, humanism, music, optics, political theory, punctuation, and the Scholastic method. To balance the two scientific ideas above, we select one from a different domain: theology. Scholasticism, rooted in the work of Lombardus, emphasized rigorous logic and dialectical reasoning to reconcile faith with reason. It fostered a systematic approach to inquiry that shaped both scientific and philosophical thought. At some point, it coincided with a theological backlash, especially from movements like Protestantism that emphasized scriptural authority over rational deduction. The associated outcome in our empirical analysis is the probability of a city becoming Protestant.

A key challenge, common to all three ideas, is determining when the scholar first developed the concept. To define this moment, we try to establish two dates for each idea: (i) the publication date, which refers to when the scholar first published a work on the topic, and

(ii) the inception date, which is the year when the scholar first conceived the idea and likely began discussing it with colleagues. We identify the inception date manually, by reviewing biographical information and related historical context.

In our model ideas spread via interactions among scholars, and these interactions can only occur when scholars are alive. Therefore, using the inception date rather than the publication date allows us to better capture the dynamics of idea dissemination through the scholarly network, as it reflects the period when discussions and exchanges of the idea were possible. Our preferred date is therefore the inception date, though we rely on the publication date when the inception date is unavailable.

Overall, ideas are more likely to spread if certain conditions are met: (a) scholars have long lifespans, giving them more time to spread their ideas; (b) there is a high density of scholars at a given institution, creating more opportunities for intellectual exchange, and (c) scholars move between institutions, which facilitates the dissemination of ideas across different scholarly communities. However, the spread of each idea may vary significantly depending on specific factors, including the centrality of the inventor within their peer network, their affiliations with large institutions, and the timing of the idea's inception.

To briefly clarify some terminology: we use inventor as shorthand for the main proponent or originator of an idea—not necessarily an inventor in the traditional sense, but often someone who developed, articulated, or popularized a concept. Similarly, idea is used broadly to encompass various intellectual contributions, including theses, paradigms, and methodological approaches, which differ in scope, complexity, and impact.

2.4 Epidemiological model

In our framework, the random nature of the spread of ideas within institutions is essential. The process mirrors infectious disease contagion: contact between colleagues creates the probability of transmission, but not its certainty. We hence adopt an epidemiological approach to model the spread of ideas from a scholar to another (Fogli and Veldkamp 2021; Banerjee et al. 2013). There is a fixed number of nodes, N, each representing a scholar. Time is discrete, with $t \in \{\underline{t}, \dots, \bar{t}\}$, $\underline{t}$ and $\bar{t}$ being the start and end dates of our analysis. At each date, a node can be susceptible or infectious.[7] A contact between two nodes appears as an undirected link in the network at a given time. Interactions are represented by an adjacency matrix $A_t = [a_{sv}]_t$ of dimension $N \times N$, with each element a_{sv} taking value 1 if scholar s and v are connected at time t, and zero otherwise. Connections will depend on whether s and v

7. Here, our model closely relates to Banerjee et al. (2013), since infection does not equate adoption of the idea.

are working in the same field at the same time in the same institution (more on this later). We represent a temporal network $\mathbb{G}$ by a set of adjacency matrices A_t.

The state of the world is described at each date by a vector $I_t = [i_s]_t$ of length N. We only have binary entries in I_t, with $i_s = 1$ if scholar s is infected, and $i_s = 0$ otherwise. Initially, there is no idea and nobody is infected. At some date t_0 an initial "inventor" has an idea. We thus have $[i_s]_t = 0$ for all $t < t_0$, and $[i_{s^\star}]_{t_0} = 1$, where $s^\star$ is the inventor.

Following the binary nature of the state vector, we use Boolean arithmetic, i.e. element-wise addition and scalar multiplication are replaced by the logical "or" and "and", respectively (Koher et al. 2016). Dynamics are then represented by:

$$I_{t+1} = A_t I_t + I_t \tag{1}$$

To understand this formula, consider the s scholar. If they are alive at period t, their infection status at $t+1$ is given by $\sum_v a_{sv} i_v$. With Boolean arithmetics, this term is equal to 1 if there is at least one v such that $a_{sv} = 1$ (s has met v) and $i_v = 1$ (v is infected). If, instead, s is either unborn or dead at time t, $a_{sv} = 0$ $\forall v$, and their infection status does not change.[8]

We also assume that once exposed to an idea, a scholar cannot forget it. Hence the "recovered" state of the epidemiological model is not relevant here.

So far we have assumed that ideas are transmitted upon contact with probability 1. If instead, there is a link activation probability $\alpha \in [0, 1]$,[9] we define a stochastic operator $\Omega^d(A)$ (following Koher et al. (2016)) which acts element-wise on the adjacency matrix: for $a_{sv} = 0$, we have $\Omega^d(a_{sv}) = 0$; for $a_{sv} = 1$, we have $\Omega^d(a_{sv}) = 1$ with probability α and $\Omega^d(a_{sv}) = 0$ with probability $1 - \alpha$. Each potential transmission is evaluated independently on each edge: a susceptible scholar becomes infected through contact with an infected neighbor with probability α, based on an independent draw.

Dynamics of the state vector I are now represented by:

$$I^d_{t+1} = \Omega^d(A_t) I^d_t + I^d_t \tag{2}$$

8. While the model could in principle track how many times s has been exposed to infected neighbors, as suggested by Bramoullé and Genicot (2024), we adopt a simplified binary-state process: infection occurs upon the first effective contact. Subsequent contacts with infected peers do not accumulate and have no further effect on the "intensity" of infection.

9. Rather than assuming automatic transmission, we model a probabilistic approach to idea diffusion, reflecting plausible uncertainty and selectivity observed in historical intellectual exchanges–a logic similar to the stochastic imitation dynamics in Brunt and García-Peñalosa (2022).

where d is an index of simulations (draws). Since each 1 in A_t independently survives with probability α, the expected value of the stochastic contact matrices is:

$$\mathbb{E}[\Omega^d(A_t)] = \alpha A_t.$$

Such a specification increases the computational effort and allows for interactions between topological effects (those coming from the structure of the network) and probabilistic effects.

We now define levels of exposure. These levels are expected levels, given the stochastic nature of the simulations. The expected scholar s exposure $[\bar{i}_s]_t \in [0,1]$ to a given idea is obtained by averaging individual exposure over D simulations:

$$[\bar{i}_s]_t = \frac{1}{D}\sum_{d=1}^{D}[i_s^d]_t \tag{3}$$

Next let us define the set of members of institution k at time t in field φ as $V(k,t,\varphi)$. Institution k Eligible Mass in field φ is:

$$M_t^{k,\varphi} \;=\; \#V(k,t,\varphi). \tag{4}$$

It is the number of scholars at each point in time susceptible of receiving an idea in field φ at institution k.

Institution k Prevalence is then obtained as an average individual exposure over the set of individuals s belonging to $V(k,t,\varphi)$, at time t:

$$P_t^{k,\varphi} = \left(\sum_{s\in V(k,t,\varphi)}[\bar{i}_s]_t\right)/M_t^{k,\varphi} \tag{5}$$

Eligible Mass and Prevalence will be used in the proportional hazard models of Sections 3.2 and 3.3 to assess how these measures at a certain date are correlated with the emergence of botanic gardens or observatories.

Furthermore, by multiplying Eligible Mass by Prevalence we obtain institution k exposure as

$$S_t^{k,\varphi} = M_t^{k,\varphi} \times P_t^{k,\varphi} \tag{6}$$

So far, the above measures only concern cities which are the headquarter of an institution. To define a measure of exposure for all cities in Europe, we assume that headquarters' exposure affects nearby cities. We accordingly define expected city c exposure $S_t^{c,\varphi} \geq 0$ by averaging over nearby institutions, weighting by inverse distance:

$$S_t^{c,\varphi} = \sum_k w_{ck} S_t^{k,\varphi} \quad (7)$$

The weights w_{ck} are derived from the inverse distance between all the institutions in our database and the cities in our samples (precise details about these cities data are provided in each experiment). Considering the inverse distance means that the further a city is from an exposed institution, the lower the influence that reaches the urban center. An institution fully influences cities within 10 kilometers: essentially the city hosting that institution. Beyond 10 kilometers, the influence power decreases linearly, up to 1000 kilometers. After this threshold, we assume that the institution's influence loses all its power, reaching a weight of zero, and thus it cannot influence any city beyond 1000 kilometers.[10]

3 Structural estimation

3.1 Methodology

How fast ideas spread in the affiliation network depends crucially on the link activation probability α. Estimating this probability is difficult because we do not observe the spread of ideas directly; we only observe some outcomes of the ideas, after some time. These outcomes are related to exposure to ideas through statistical models, described below. We will use two of these outcomes to estimate α. This setup resembles indirect inference (Anthony Smith 2008), where one chooses α to maximize the likelihood of the observed data, given the structural model's output. In practical terms, we take the following steps.

1. We fix α at gridded values over $[0, 1]$ at intervals of 0.05.
2. For each value of α, we simulate the spread of two key ideas through the affiliation network and the epidemiological model.
3. We compute Eligible Mass and Prevalence of cities with a university or academy, given by Equations (4) and (5), for these two ideas.
4. We estimate two auxiliary statistical models correlating the simulated exposure with observed outcomes (detailed below).

10. The results are robust to alternative functional forms, such as exponential decay or varying distance thresholds.

5. We record the log-likelihoods as the sum of the individual likelihoods at each point:

$$\ell_{\text{total}}(\alpha) = \ell_1(\alpha) + \ell_2(\alpha)$$

   This approach treats the two outcomes as conditionally independent given α.

6. We maximize the combined log-likelihood

$$\hat{\alpha} = \arg\max_{\alpha} \ell_{\text{total}}(\alpha).$$

We now describe the two auxiliary models referred to above in item 4.

3.2 Auxiliary model 1: Botanical Realism

During the Scientific Revolution, there were major advancements in botany, which grew from being primarily a descriptive field into a more systematic and experimental science—a shift we call Botanical Realism. A key figure in this transition was Leonhart Fuchs, a German physician and botanist. He is best known for his book *De historia stirpium commentarii insignes* (Notable commentaries on the history of plants). Printed in Basel in 1542, this work laid the foundation for modern botany. Fuchs not only provided visual representations of 511 plant species, he also included his own critical observations on their uses and characteristics, highlighting differences from ancient texts (Applebaum 2003). More contextual information is available in Appendix C.1. Fuchs was based in Tübingen for the majority of his life, where he taught medicine and botany at the local university between 1535 and 1566 (Conrad 1960). Prior to that he was a professor at the University of Ingolstadt from 1522 to 1533 (Schwinges and Hesse 2019). Despite his fame, he was not a mobile scholar and he declined prestigious teaching offers from Denmark and Italy (Applebaum 2003).

In this first empirical assessment, we examine the potential correlation between Prevalence $P_t^{k,\varphi}$ of Botanical Realism and the establishment of botanic gardens. Using our epidemiological approach with link activation probability α, the diffusion of the idea begins with Leonhart Fuchs and spreads to his colleagues at the University of Tübingen from 1542 onwards. Exposed scholars can in turn contaminate their own peers with probability α, and so the idea propagates through the network until 1793 (the end of our timeframe). For each value of α on the grid, we average over $D = 5,000$ simulations, and we compute for each headquarter k the Prevalence $P_t^{k,\varphi}$ of Botanical Realism as defined in Equation (5).

We use the sample of cities that hosted at least one institution, either a university or an academy before 1800, as recorded in our database, resulting in a total of 241 cities, 230 of which have non-null Eligible Mass $M_t^{k,\varphi}$ of scholars susceptible to Botanical Realism. We also gather information on the existence and founding dates of European botanic gardens from Montreal Botanic Garden (1886). Figure 18 in Appendix D.2 illustrates this sample of cities along with their Prevalence $P_t^{k,\varphi}$ of Botanical Realism in 1600, 1700, and 1800.

In what follows, we analyze whether exposure to Botanical Realism accelerates the founding of botanic gardens across cities, using the timing of first establishment as our outcome. Garden creation is a one-time irreversible event: the relevant question is not whether a city eventually gets a garden but when. A Cox proportional hazards model is therefore natural, as it restricts attention at each point in time to cities still at risk, and accommodates time-varying covariates such as our measures of Prevalence $P_t^{k,\varphi}$ and Eligible Mass $M_t^{k,\varphi}$.[11]

Following the Cox model, the instantaneous hazard $h_k(t)$ that a city k founds its first botanic garden at time t, conditional on covariates, is

$$h_k(t) = h_0(t) \exp(\beta_p P_t^{k,\varphi} + \beta_m M_t^{k,\varphi} + \beta_{pm} P_t^{k,\varphi} M_t^{k,\varphi} + \beta_{pop} Pop^k + \beta_d Dist^k) \tag{8}$$

where $h_0(t)$ is the baseline hazard. We include time-invariant regressors such as population in 1500, Pop^k, and the distance from Tübingen, $Dist^k$. In a simple gravity model of diffusion, distance from Tübingen captures the spread of the idea through pathways other than our affiliation network. Our regressors of interest are time-varying and include the Eligible Mass of scholars, $M_t^{k,\varphi}$, that counts the number of botanists, physicians, and scientists susceptible to be exposed to Botanical Realism at time t in city k,[12] the Prevalence of Botanical Realism, $P_t^{k,\varphi}$ (see Equation (5)), and their interaction term. The interaction allows for heterogeneous effects by institutional size: a negative sign implies that the smaller the Eligible Mass, the stronger the association between Prevalence and the 'hazard' of founding a botanic garden; a positive sign implies the opposite.

We consider the period 1500–1793. The first botanic garden in our data is observed in 1520 (Pavia). Fuchs' invention dates to 1542, and our affiliation data runs through 1793. Cities that do not build a botanic garden during this period are treated as right-censored.[13] We estimate the baseline hazard using the Nelson–Aalen estimator. The Cox model's partial likelihood assumes no two events occur simultaneously. In our data, nine years record the founding of two botanic gardens, introducing ties that we handle using the Efron method,

11. Precisely because timing is the object of interest, a logit, which collapses the outcome to a binary, or a panel regression, which cannot cleanly handle exit from the risk set, are ill-suited.

12. These scholars work in fields such as medicine, botany, mathematics, physics, chemistry, astronomy, and applied sciences such as agronomy and engineering.

13. Because botanic gardens are established in only 68 out of 230 cities before 1793, we do not stratify the baseline hazard by city. Instead, we cluster standard errors at the city level.

confirming robustness with the exact method.

Table 2: Cox Proportional Hazards Model – Botanical Realism and botanic gardens

	Dependent variable: Hazard of botanic garden founding					
α	0	0.1	0.3	0.5	0.7	1
Prevalence $P_t^{k,\varphi}$		27.91	7.45***	2.96***	1.93***	1.67***
		(156.66)	(2.16)	(1.00)	(0.63)	(0.52)
(ihs) Eligible Mass $M_t^{k,\varphi}$	0.54***	0.57***	0.88***	0.90***	0.89***	0.89***
	(0.07)	(0.19)	(0.10)	(0.10)	(0.10)	(0.10)
Prevalence $P_t^{k,\varphi}$		-26.69	-4.02***	-1.38***	-0.89***	-0.75***
× (ihs) Eligible Mass $M_t^{k,\varphi}$		(177.85)	(0.77)	(0.28)	(0.18)	(0.15)
(ihs) Distance to	-0.15***	-0.19***	-0.12	-0.11	-0.11*	-0.11*
Tübingen	(0.06)	(0.07)	(0.10)	(0.07)	(0.07)	(0.06)
Log Likelihood $\ell_1(\alpha)$	-343.18	-342.51	-335.76	-335.28	-335.32	-335.28
(ihs) Pop in 1500	✓	✓	✓	✓	✓	✓
Observations	67620	67620	67620	67620	67620	67620

Note: *p<0.1; **p< 0.05; ***p<0.01. Robust standard errors are reported in parentheses. Similar models run for every α between 0 and 1 at an interval of 0.05. Here, we only report results for 0, 0.1, 0.3, 0.5, 0.7, and 1.
Distance to Tübingen is computed using the Haversine formula. All models include (ihs) population in 1500. All the variables with (ihs) are transformed in inverse hyperbolic sine.

Table 2 shows the results for the Cox proportional hazard models at different levels of α. We run similar specifications for every α between 0 and 1 at an interval of 0.05 to obtain the log likelihoods which enter the joint maximization described in Section 3.

3.3 Auxiliary model 2: Mathematical Astronomy

In the 15th and 16th centuries, growing interest in experimental science led astronomers to challenge Ptolemaic models and refine them through observation and mathematics. This shift, characterized by advances in trigonometry, geometry, and the use of decimals, laid the groundwork for the later Copernican revolution. A central figure in this transformation was Regiomontanus, a pseudonym of Johannes Müller. He studied the original works of Ptolemy through his mastery of Greek and mathematics, and around 1454 began collaborating with his mentor Georg Peurbach (1423–1461) at the University of Vienna on new methods for solving plane and spherical trigonometry problems, including the use of sine and tangent functions. Regiomontanus also created extensive trigonometric tables with values calculated to decimal units, which remained influential for centuries, and published *Theoricæ novæ planetarum*, his collaboration with Peurbach, in 1472, after Peurbach's death. He can thus be considered a pioneer of Mathematical Astronomy (Applebaum 2003). More details are available in Appendix C.2.

In this second empirical assessment, we examine whether cities more exposed to what we label Mathematical Astronomy—the transition towards higher mathematical precision in astronomical practice—were faster to establish astronomical observatories. Advances in trigonometry and decimal calculation created demand for more precise instruments and dedicated observation sites, providing a direct link between the diffusion of Mathematical Astronomy and the founding of observatories. Regiomontanus himself opened an instrument shop that specialized in building and printing works related to Mathematical Astronomy (Applebaum 2003). We collect the names and foundation dates of observatories from Howse (1986).

For each value of α on the grid, the diffusion of Mathematical Astronomy begins with Regiomontanus, who shared it with his colleagues in Vienna, Bratislava, Padua, and Rome. Exposed scholars can in turn contaminate their own peers with probability α, and so the idea propagates through the network until 1793. Averaging over D simulations, we compute for each institution k the yearly Prevalence $P_t^{k,\varphi}$ of Mathematical Astronomy as defined in Equation (5), restricting to scholars working in fields such as mathematics, logic, physics, chemistry, biology, astronomy, geography, and botany. Figure 19 in Appendix D.3 depicts the resulting exposure patterns in 1600, 1700, and 1793.

We estimate the hazard of establishing an observatory for each city using a Cox model identical to that used for Botanical Realism, replacing distance from Tübingen with distance from Vienna. We focus on the same period, 1500–1793, dating the spread of Regiomontanus' ideas from 1454. The first observatory in our data was established in Kassel in 1560. Cities that do not establish an observatory by 1793 are treated as right-censored.[14]

Table 3 shows the results for the Cox proportional hazard models at different levels of α. We run similar specifications for every α between 0 and 1 at an interval of 0.05 to obtain the log likelihoods which enter the joint maximization described in Section 3.

14. As with Botanical Realism, tied events are handled using the Efron method, with the exact method as a robustness check.

Table 3: Cox Proportional Hazards Model – Mathematical Astronomy and observatories

	Dep. var.: Hazard of astronomical observatory creation					
α	0	0.1	0.3	0.5	0.7	1
Prevalence $P_t^{k,\varphi}$		6.39***	2.49***	1.83***	1.66***	1.62***
		(1.94)	(0.73)	(0.53)	(0.48)	(0.45)
(ihs) Eligible Mass $M_t^{k,\varphi}$	0.46***	1.11***	1.11***	1.12***	1.11***	1.06***
	(0.07)	(0.18)	(0.19)	(0.19)	(0.20)	(0.20)
Prevalence $P_t^{k,\varphi}$ × (ihs) Eligible Mass $M_t^{k,\varphi}$		-3.69***	-1.44***	-1.08***	-0.97***	-0.89***
		(0.77)	(0.32)	(0.24)	(0.22)	(0.21)
(ihs) Distance to Vienna	-0.16***	-0.08*	-0.09**	-0.10**	-0.10**	-0.10**
	(0.05)	(0.05)	(0.04)	(0.04)	(0.04)	(0.04)
Log Likelihood $\ell_2(\alpha)$	-324.83	-316.08	-317.22	-317.31	-317.49	-318.04
(ihs) Pop in 1500	✓	✓	✓	✓	✓	✓
Observations	67620	67620	67620	67620	67620	67620

Note: *p<0.1; **p< 0.05; ***p<0.01. Robust standard errors are reported in parentheses. Similar models run for every α between 0 and 1 at an interval of 0.05. Here, we only report results for 0, 0.1, 0.3, 0.5, 0.7, and 1.
Distance to Vienna is computed using the Haversine formula. All models include (ihs) population in 1500. All the variables with (ihs) are transformed in inverse hyperbolic sine.

3.4 Results

The joint likelihood $\ell_1(\alpha) + \ell_2(\alpha)$ achieves a maximum of -652.568 at $\hat{\alpha} = 0.45$, which we interpret as the estimated link activation probability. Appendix E reports the full likelihood table, the maximization plot, and the Cox model results at $\hat{\alpha} = 0.45$. In the remainder of the paper, we therefore hold α fixed at this estimated value. An important open question is whether α varies systematically across fields, periods, religions, institutional types, or other dimensions. Unfortunately, the available data do not permit a reliable estimation of such variation.

Before interpreting the results, we verify the proportional hazards assumption—which requires that the effect of each covariate on the hazard remains constant over time—using scaled Schoenfeld residuals (Schoenfeld 1982). For Botanical Realism, the coefficients on Prevalence $P_t^{k,\varphi}$, Eligible Mass $M_t^{k,\varphi}$, and their interaction show no evidence of drift over time when tested individually. The global test (including population and distance to Tübingen) yields a p-value of 0.075, indicating borderline evidence against proportionality at the 10%

level. Inspection of the Schoenfeld residual plots in Appendix F reveals no systematic trend, suggesting the borderline p-value reflects noise rather than a genuine violation. For Mathematical Astronomy, both individual and joint tests are comfortably non-significant (global p-value = 0.189), and residual plots confirm no drift. We proceed on this basis for both models.

We interpret results through hazard ratios, computed by exponentiating the estimated coefficients. For Botanical Realism, the association between Prevalence $P_t^{k,\varphi}$ and the hazard of founding a botanic garden is not constant but varies with Eligible Mass $M_t^{k,\varphi}$—and vice versa. Specifically, with coefficients $\beta_p = 3.61$, $\beta_m = 0.90$, and interaction term $\beta_{pm} = -1.70$, the hazard ratio for a change $\Delta P_t^{k,\varphi}$ in Prevalence at a given level of Eligible Mass is:

$$HR(\Delta P_t^{k,\varphi} | M_t^{k,\varphi}) = \exp((\beta_p + \beta_{pm} \times M_t^{k,\varphi}) \Delta P_t^{k,\varphi}) \tag{9}$$

A 10 percentage point increase in Prevalence is associated with a 23% higher hazard of founding a botanic garden at average Eligible Mass ($\mu = 0.93$),[15] and a 43% higher hazard when Eligible Mass is zero. At high Eligible Mass the association attenuates, with the HR approaching 1 once Eligible Mass exceeds approximately 2.1—about one standard deviation above the mean. Turning to Eligible Mass, at median Prevalence (zero), doubling Eligible Mass raises the hazard by 86% ($HR = 1.86$); at mean Prevalence (0.084), the same doubling raises it by 69% ($HR = 1.69$). The negative interaction captures a substitutability between size and exposure: where the susceptible pool is small, a given increase in Prevalence is more decisive; where it is large, the marginal contribution of Prevalence diminishes. These patterns are robust across all values of $\alpha \geq 0.3$.

The pattern of Mathematical Astronomy results mirrors that of Botanical Realism. With $\beta_p = 1.93$ ($\mu = 0.12$, $SD = 0.28$), $\beta_m = 1.12$ ($\mu = 0.62$, $SD = 1.06$), and $\beta_{pm} = -1.13$, a 10 percentage point increase in Prevalence is associated with a 13% higher hazard of establishing an observatory at average Eligible Mass, and a 21% higher hazard when Eligible Mass is zero. As with Botanical Realism, the interaction is negative: size amplifies diffusion when exposure is low but adds little once Prevalence is already high.

4 Further empirical assessments

In the analysis of Botanical Realism and Mathematical Astronomy, we examined both the correlation between the Prevalence (Equation (5)) of these ideas and the Eligible Mass (Equation (4)) of scholars, and the time required to establish a botanic garden or an observatory

15. See summary statistics of the covariates in Table 11 in the Appendix.

at the headquarters of institution k.

We now extend our empirical analysis beyond the early modern period and the context of the Scientific Revolution. As in the previous sections, the scope of the analysis is shaped by the availability of outcome data. We examine three distinct cases: a backlash against an idea in the context of the relationship between scholasticism and Protestantism; an extension of the plague–pogrom nexus that incorporates exposure to anti-Judaic ideas; and the diffusion of a demonstrably false belief, namely that the Swedes are descendants of the inhabitants of Atlantis.

These experiments focus on outcomes at the level of European cities. For cities without academic scholars, Prevalence and Eligible Mass are not meaningful concepts. Nevertheless, such cities may still be exposed to intellectual influences originating from nearby institutions. For this reason, the following analyses relate city-level exposure (Equation (7)) to city-level outcomes.

4.1 Scholasticism and Protestantism

Scholastic theology is an approach to theological questions that uses logical analysis and systematic reasoning, influenced by ancient Greek philosophers (see an example in Appendix G). It is more a paradigm than a single idea. Petrus Lombardus is often recognized as an early proponent and influential figure in the scholastic tradition. According to Genet (2019) and Herbermann (1913) he taught at what would become the University of Paris from 1145 to his death in 1160. Mazzetti (1847) claims that he was at the University of Bologna in about 1150.

Petrus Lombardus' primary work is the *Sentences*. Completed in the mid-12th century, the *Sentences* cover key theological topics such as the nature of God, creation, the Trinity, grace, and sacraments. The *Sentences* became a foundational text for theological education in medieval universities and was the starting point for many scholastic theologians who followed, including Thomas Aquinas, who wrote extensive commentaries on it.

Martin Luther (1483–1546), the 16^{th}-century German monk and theologian who sparked the Protestant Reformation, was initially trained in the scholastic tradition and engaged with its methods. But as his personal spiritual crisis deepened, he became increasingly critical of many aspects of the Catholic Church's theology—including scholasticism's emphasis on human reason. Luther laid out his objections in a striking document, the *Disputatio contra scholasticam theologiam* (1517), a series of 97 theses. In it, he made provocative claims such as: "No syllogistic form is valid when applied to divine terms," and "…the whole Aristotle is to theology as darkness is to light" (theses 47 and 50, respectively).

A major grievance that fueled the rise of Protestantism was the desire to reform theological teachings and Church practices that, in the Reformers' view, were not grounded in Scripture. Scholastic theology—especially in its later form known as nominalism—was a central target. The historian Chaunu (2014) argues that this style of theology, which emphasized logic and abstraction, distanced ordinary believers from their faith and ultimately left them receptive to the message of the Reformation. From this we draw our hypothesis that the adoption of Protestantism was a backlash to (exposure to) scholasticism. This view is rarely made explicit in the scholarly literature, but it underlies much of the Reformation's intellectual context.[16]

We highlight three key ways in which Luther offered a clear and spiritually compelling response to the crisis of salvation induced by scholastic theology—each emphasizing *direct access to God* by *faith* rather than through a rational merit-based system (Chaunu 2014).

(A) The Catholic Church taught that salvation comes through both faith and works, a position formalized in scholastic doctrines of grace and merit. Luther rejected this, arguing that Scripture teaches that salvation comes by faith alone (*sola fide*), not through human effort or achievement.

(B) Catholic theology placed Scripture and Church tradition—along with papal authority—on equal footing. This framework relied on a scholastic synthesis of Aristotelian philosophy and ecclesiastical tradition. Luther broke with this, insisting that Scripture alone (*sola scriptura*) is the final authority in matters of faith. He viewed the scholastic approach as placing human reason above divine revelation.

(C) The Catholic Church mediated grace through a complex sacramental system, including the sale of indulgences and a strict divide between clergy and laity. Luther opposed this mediation of grace and denied the special status of clergy rooted in scholastic definitions of ordination and apostolic succession. Instead, he emphasized the "priesthood of all believers" (*sola gratia*).

To test for a positive correlation between the exposure to scholasticism and the rise of Protestantism, we propose the following experiment. We feed the idea of scholasticism to Petrus Lombardus. The idea would spread to his colleagues in Paris, and then beyond, thanks to the mobility of scholars. We simulate the spread of this idea in Europe, using the epidemiological approach described in Section 2.4, all the yearly network snapshots built

16. The theologian Barrett (2023) argues that it was the degeneration of scholasticism in the later Middle Ages that was a significant catalyst for the Reformation. This view is not universally accepted. For example, Cross (2024) sees substantial continuity between Luther and late scholasticism.

from our data, and our $\hat{\alpha} = 0.45$.

Averaging the outcomes of many simulations, we compute the $S_t^{k,\varphi}$ exposure of each institution to scholasticism in 1508, the year Luther started teaching at the University of Wittenberg. We measure exposure by counting the number of theologians exposed to scholasticism in 1508, by institution. We then obtain the exposure to scholasticism of each institution in the network, using Equation (6). Figure 5 depicts this level of exposure. We can further compute the exposure to this paradigm for European cities even if they do not host any institution, as in Equation (7). We do this by computing the distance between each city in our sample and each institution in our network, and summing up institutions' exposure at the city level weighted by the inverse of distance, w_{ck}.

The sample of cities used to compute exposure is taken from Rubin (2014), which provides a database of over 800 European cities and classifies them as Catholic or Protestant based on the dominant religion in three different years: 1530, 1560, and 1600.[17] Figure 5 illustrates the sample of cities and the spread of Protestantism as in 1600. Cities that remained Catholic are shown in grey, while those that became Protestant are marked in red. The blue bubbles represent institutions' exposure to scholasticism as in 1508. The figure already suggests a possible positive correlation between exposure to scholasticism, and the likelihood that a city would become Protestant.

We employ a linear probability model to estimate the correlation between exposure to scholasticism and the likelihood that a city became Protestant in 1530, 1560, and 1600. For this experiment, we cannot use a Cox proportional hazard model because in some European regions, such as England and Scotland, the shift towards Protestantism was a top-down decision, meaning hundreds of cities share the same event year. With ties of this magnitude, the partial likelihood approximation underlying the Cox model breaks down, and a linear probability model is more appropriate.

Table 4 shows the results. The key variable of interest is exposure to scholasticism S_{1508}^c, whose estimated coefficient is consistently positive and statistically significant in 1560 and 1600. Columns (1)-(3) show the variable of interest alone. Columns (4)-(6) show that the results are robust at the addition of controls and fixed effects. We control for the presence of all universities active in 1500 as indicated in our database to show that exposure to scholasticism S_{1508}^c is not merely proxying for the presence of a university. We also include the city populations in 1500 taken from Buringh (2021), transformed in inverse hyperbolic sine

17. We updated Rubin's data to better account for the fact that in France and the Low Countries (modern-day Belgium), several cities adopted Protestantism temporarily before being reconquered by Catholic forces. See Appendix H.

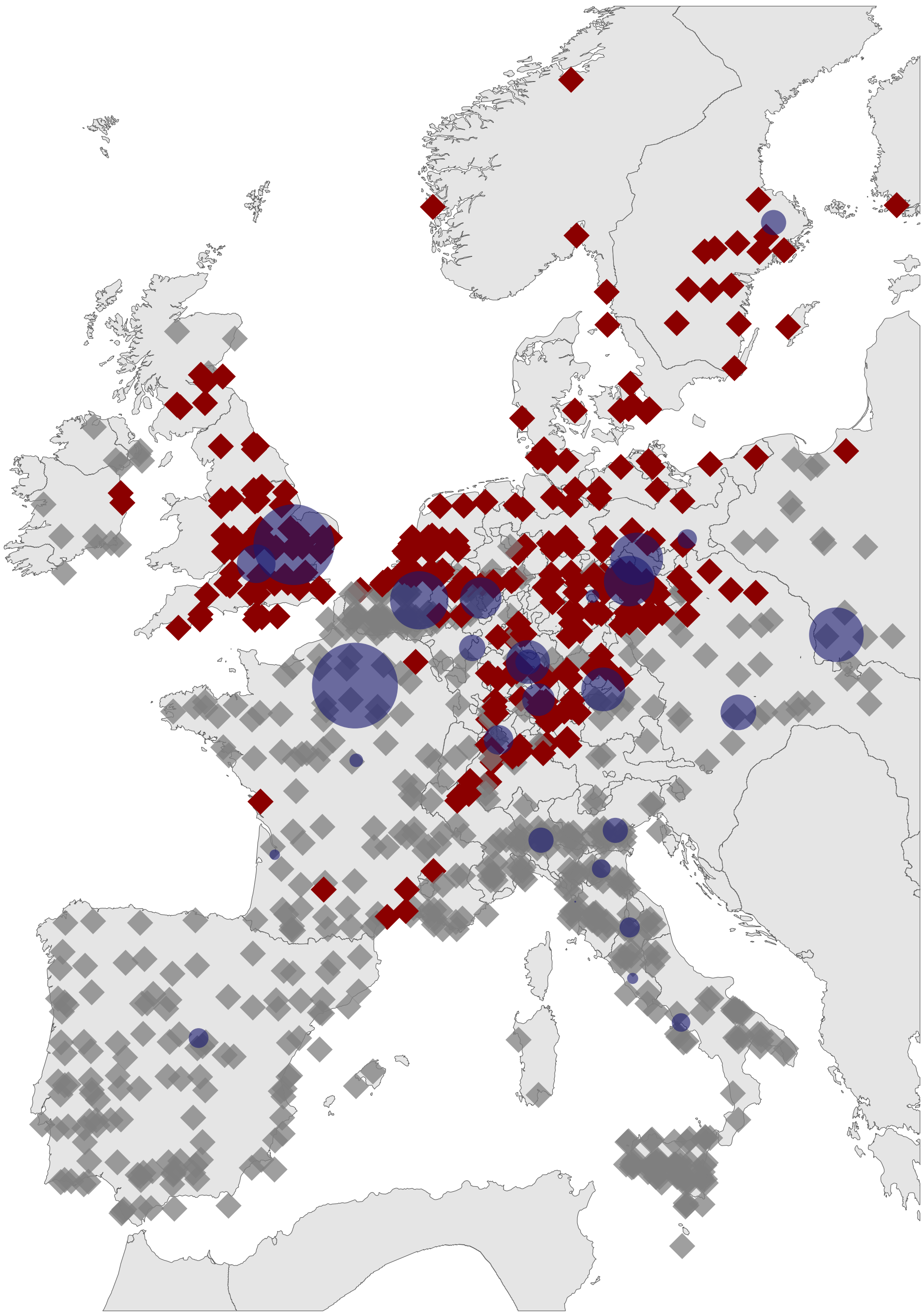


Figure 5: Blue bubbles represent the exposure to scholasticism in 1508. $\alpha = 0.45$ and $D = 5,000$. Protestant cities are the red diamonds, and Catholic cities are the grey diamonds. Data on cities' religion are taken from Rubin (2014) and updated as in Appendix H, they reflect the religious status in 1600.

(ihs) to account for cities with no recorded population estimates.[18] The remaining control variables are taken from Rubin (2014) and include factors related to the economic status of cities: the presence of a printing press by 1500, whether the city was a free city by 1517, the market potential of the city in 1500, its membership in the Hanseatic League by 1517, whether it hosted a bishop or archbishop by 1517, and whether the city had direct access to water. We also include fixed effects capturing time-invariant characteristics common to each imperial circle and historical country as in 1500.

Using the estimated coefficients in Table 4, Columns (1)–(3), we quantify the association between scholastic exposure and the estimated probability of adopting Protestantism. Taking Trier—the most exposed city in the sample—as a reference point, we evaluate how estimated Protestant adoption probabilities differ for other cities when exposure is set to Trier's observed level. For Barcelona, in the lowest quartile of the exposure distribution, the estimated probability is 9.4 percentage points higher in 1530, 39 percentage points higher in 1560, and 47 percentage points higher in 1600. The corresponding differences are 7.1, 28.5, and 35.6 percentage points for Copenhagen; 5.3, 21, and 26.3 percentage points for Padova; and only 0.1, 0.2, and 0.3 percentage points for Leuven, whose observed exposure is already close to Trier's.

4.2 Anti-Judaism and the Persecution of Jews

Our model can propagate not only good ideas, but also bad or even false ones. One such idea is anti-Judaism. The availability of data on Jewish persecutions from Anderson, Johnson, and Koyama (2017) and Jedwab, Johnson, and Koyama (2019) allows us to apply the same approach as in Section 4.1. The roots of anti-Judaism run deep and are widely discussed in the literature. Scholasticism, once again, played a role in rationalizing prejudice against Jews. Thomas Aquinas (1225–1274), one of the most influential scholars at the University of Paris and the intellectual heir of Lombardus, endorsed many prevailing medieval Christian views about Jews. He supported the idea that Jews should live in subjugation as a reminder of their supposed rejection of Christ. In the *Summa Theologiae*, he also discusses Jews in ways that reinforce their marginalization.

The next generation of scholastic theologians, such as John Duns Scotus (c. 1266–1308) and William of Ockham (c. 1287–1347), contributed to the broader scholastic discourse that pathologized Judaism as a theological error (see Abulafia (2011), which provides a

18. The inverse hyperbolic sine is similar to the logarithmic transformation but can accommodate zero (Bellemare and Wichman 2020), which makes it particularly useful when dealing with the large number of cities from Rubin (2014) with no available population estimates in Buringh (2021).

Table 4: Linear Probability Model - Exposure to scholasticism in 1508 and cities' probability to become protestant in 1530, 1560, and 1600

	Protestant in			Protestant in		
	1530	1560	1600	1530	1560	1600
	(1)	(2)	(3)	(4)	(5)	(6)
Exposure scholasticism S^c_{1508}	0.001	0.004***	0.005***	0.001**	0.004***	0.004***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Presence of university in 1500				0.003	-0.008	-0.007
				(0.021)	(0.031)	(0.032)
Printing press by 1500				-0.043*	-0.050**	-0.057**
				(0.022)	(0.023)	(0.022)
(ihs) City population in 1500				0.012**	0.004	0.004
				(0.005)	(0.007)	(0.007)
Free Imperial City by 1517				0.115	0.166*	0.261**
				(0.082)	(0.097)	(0.104)
Market potential in 1500				-0.006**	-0.014**	-0.013**
				(0.003)	(0.006)	(0.005)
Hanseatic by 1517				0.023	0.078	0.080
				(0.039)	(0.052)	(0.049)
Lay magnate				-0.015	0.145**	0.164**
				(0.037)	(0.068)	(0.073)
(Arch)Bishop by 1517				-0.032*	-0.050**	-0.055**
				(0.019)	(0.024)	(0.024)
Access to water				0.008	-0.00003	-0.004
				(0.016)	(0.019)	(0.019)
Imperial Circle FE	✗	✗	✗	✓	✓	✓
1500 Country FE	✗	✗	✗	✓	✓	✓
Observations	867	867	867	867	867	867
Adjusted R^2	0.016	0.103	0.185	0.503	0.719	0.736
Log Likelihood	-201.49	-486.38	-486.18	111.67	34.10	20.66

Notes: Robust SE clustered by territory in parentheses. A constant term is included in all regressions. Dependent variable 'Protestant' takes value 1 if the city is protestant in 1530, 1560, 1600, respectively. Data on cities' religion taken from Rubin (2014) and updated as in Appendix H. "Presence of university in 1500" is a dummy variable taking value 1 if the city had a university in 1500 as in our database. "Exposure to scholasticism S^c_{1508}" is computed as in Equation (7). The remaining control variables are selected from Rubin (2014).

substantial discussion of how scholastic theology and legal reasoning shaped Christian–Jewish relations between 1000 and 1300). While these theological ideas do not explicitly advocate persecution, they may have interacted with the mechanisms identified by Anderson, Johnson, and Koyama (2017) and Jedwab, Johnson, and Koyama (2019). In Anderson, Johnson, and Koyama (2017), cold temperatures are shown to increase the probability of persecution of Jewish communities. Jedwab, Johnson, and Koyama (2019) extend this insight, showing that negative shocks more broadly, particularly plagues, raise the likelihood of minority persecution.

To study if there is an association between yearly exposure to scholasticism S_t^c and the probability of violent acts against Jews, we use data from Anderson, Johnson, and Koyama (2017) and Jedwab, Johnson, and Koyama (2019).[19] Building on this literature, we hypothesize that the association between negative shocks and the likelihood of Jewish persecutions is stronger in cities with greater exposure to scholasticism S_t^c. One possible interpretation of this pattern is that, in cities where local priests were more exposed to scholastic teachings and disseminated anti-Judaic arguments, the local intellectual and religious climate was more receptive to scapegoating Jews in times of crisis. To test this hypothesis, we augment the empirical framework of Anderson, Johnson, and Koyama (2017) by including an interaction term between our measure of scholastic exposure and the incidence of plague outbreaks.

Table 5 presents the results of this panel regression. The dependent variable, Persecutions, takes the value 1 when either an expulsion or another violent act against Jews occurred in a given year, following the definition in Jedwab, Johnson, and Koyama (2019). As in both Anderson, Johnson, and Koyama (2017) and Jedwab, Johnson, and Koyama (2019), we restrict the analysis to cities with a documented Jewish presence.

Column (1) replicates specification (2) of Table 3 in Anderson, Johnson, and Koyama (2017, p. 940). The estimated coefficient on lagged temperature is nearly identical: we find that a one-degree decrease in temperature increases the probability of Jewish persecutions in the following year by 0.467 percentage points, compared to 0.464 percentage points in Anderson, Johnson, and Koyama (2017). Despite this similarity, our sample differs slightly for two main reasons: (i) our dependent variable is drawn from a more recent version of the dataset used by Anderson, Johnson, and Koyama (2017), and (ii) we eliminate duplicate city entries prior to estimation.

Column (2) introduces an interaction between yearly exposure to scholasticism S_t^c at the city level and a dummy variable indicating the presence of a plague, following Anderson,

19. We thank the authors for sharing the most recent (and still unpublished) version of the pogroms and persecutions data.

Table 5: Linear Probability Model - Yearly Exposure to scholasticism and cities' probability of persecution of Jews

	Persecutions	
	Replication	S_{ct} x Plague
	(1)	(2)
Temperature$_{c,t-1}$	-0.467***	-0.472***
	(0.125)	(0.124)
Plague	5.100*	-1.880
	(2.149)	(1.172)
Exposure to scholasticism S_{ct}		0.162*
		(0.064)
Exp. to scholasticism S_{ct} x Plague		5.158***
		(1.520)
Controls	✓	✓
City Fixed Effects	✓	✓
Observations	273,879	273,879
R^2	0.013	0.018

Note: *p<0.1; **p< 0.05; ***p<0.01. Standard errors clustered at the climate grid level in parentheses. City fixed effects are always included.
Column (1) replicates Anderson, Johnson, and Koyama (2017) specification (2) Table 3, p.940.
Coefficients are multiplied by 100 to represent percentage points.
Controls include a slope variable for the 10 years surrounding the Black Death and a measure of population density as in Anderson, Johnson, and Koyama (2017).

Johnson, and Koyama (2017). Interestingly, the plague dummy is not statistically significant on its own anymore, while exposure to scholasticism S_t^c is only slightly significant at 10% level. However, their interaction is both statistically and substantively significant. This suggests that the coexistence of a theoretical framework portraying Jews as a threat and a plague outbreak is associated with a significantly higher likelihood of violence against Jews. The coefficient on the interaction term is also sizable: during a plague, a one-unit increase in exposure to scholasticism is associated with a 5.2 percentage point higher likelihood of Jewish persecutions.

4.3 Finding Atlantis: A True Story of Genius and Madness

We now turn to Olaus Rudbeck's (1630–1702) claim that Sweden was the cradle of civilization and the site of the lost city of Atlantis. It is an interesting case to simulate using our model for two reasons. First, it illustrates that ideas–whether accurate or not–can still spread through affiliation networks, which further underscores the crucial role of institutions in shaping intellectual diffusion. Second, it highlights that individuals do not necessarily need to agree with an idea in order to help propagate it.

Rudbeck, who was professor of medicine at the University of Uppsala from 1658 to 1692 (Von Bahr 1945), claimed that Sweden was in fact the mythical island of Atlantis, and thus the cradle of all ancient civilization. He supported this sweeping theory by drawing connections between the Norse mythology, the Bible, and classical sources. Rudbeck explained his thesis in the book *Atlantica* (also known as Atland eller Manheim), first published in four volumes between 1679 and 1702 (King 2005). It was written in Latin (vol. 1) and Swedish (vols. 2–4). *Atlantica* was not fully translated into major European languages during the 18th century. The length, complexity, and eccentricity of Rudbeck's arguments likely discouraged publishers. His ideas were seen by many contemporaries as extravagant, although some Nordic nationalist thinkers admired them. Despite its eccentricity, *Atlantica* was referenced and critiqued by various 18th-century thinkers, including two academic scholars, Denis Diderot and Ludvig Holberg. They may have been exposed to Rudbeck's ideas indirectly through the affiliation network, given that they are unlikely to have read his books in Swedish themselves.

Denis Diderot (1713–1784) was a member of the Prussian Academy of Sciences from 1751 (Amburger 1950). Diderot's radical thinking, conflict with French authorities, and nonconformist personality kept him outside the fold of French academies. In the article *Étymologie* of his Encyclopédie (published over the period 1751–1765), Diderot used Rudbeck's work as a cautionary example of how speculative etymology can lead to erroneous conclusions, critiquing the methodology employed in *Atlantica*. Our simulation reveals that Diderot had a 100% chance of being exposed to Rudbeck's ideas as early as 1751–the year of his election–because he hypothetically encountered numerous members who were already exposed to the idea.

Ludvig Holberg (1684–1754) was a prominent Danish-Norwegian writer and philosopher, and professor at the University of Copenhagen from 1717 to 1754 (Slottved 1978). He satirized Rudbeck's theories, mocking the idea of Sweden as Atlantis and highlighting the speculative nature of Rudbeck's claims. According to our simulation, the chance Holberg was exposed to Rudbeck's idea is 0 until 1753, when it goes to 48.74%. It gains an additional 46.52% in the following year, before he died. This highlights two features of our approach: first, our exposure is a lower bound, and in this case Holberg might have been acquainted with Rudbeck's work through other means. In other words, even in cases where we know from historical evidence that a scholar engaged with an idea, our model still captures eventual exposure through the network alone. Second, Holberg was never affiliated with an academy, but only with a university, which in our model means it must have taken more time for ideas to reach him. As we will later show, this institutional feature plays a key role in shaping how easily ideas circulate through the network.

5 Counterfactual experiments

In this section, we identify the features of the academic network that are more conducive to spreading ideas. We perform two kinds of experiment. We assign ownership of an idea to fictitious inventors, in order to track whether the idea would spread differently in alternative realities. In the second experiment we remove some parts of the network to assess their importance in spreading ideas.

5.1 Placebo inventors of Botanical Realism

To better understand how the structure of a network influences the speed at which ideas spread, we run counterfactual experiments using Fuchs' Botanical Realism as a case study. In these experiments, we imagine that it was not Fuchs who introduced the new paradigm of Botanical Realism, but another contemporary scientist from a different region of Europe. We simulate the diffusion of this paradigm, still originating in 1542, but emerging in various alternative locations: in Salamanca with Juan Aguilera (1507-1560), in Oxford with John Warner (c. 1500-1565), in Louvain with Jeremius Dryvere (1504-1554), in Wittenberg with Andreas Goldschmidt (1513-1559), in Cracow with Mikołaj Mleczko Wieliczki (1490-1559), in Rostock with Jacob Bording (1511-1560), in Montpellier with Antoine Saporta (1507-1573), in Padua with Girolamo Donzellini (1513-1587), from the Royal College of France with Oronce Fine (1494-1555), in Pisa with Realdo Colombo (1510-1559), and in Leipzig with Georg Joachim Porris (1514-1574). Appendix J presents a short biography of each of these scholars. These counterfactual simulations allow us to explore how regional networks and academic hubs would have shaped the spread and influence of Botanical Realism across Europe.

Many of these scholars came from strong intellectual backgrounds and were part of the broader Renaissance shift toward empiricism and direct observation. Several, particularly those with medical training (e.g., Saporta, Colombo, Bording), had practical reasons to study plants carefully and could have contributed to a scientific approach to botany.[20]

Figure 6 illustrates the percentage of individuals in medicine and sciences who were exposed to the idea across the twelve simulated scenarios. This simulation offers valuable insights into the diffusion process. Notably, in one case, the idea fails to spread: Wieliczki in Cracow (professor from 1513 to 1552) lacked other mobile peers for meaningful intellectual exchange, and the idea does not take hold. In ten other cases, we observe that by the end of the period, nearly all relevant scholars had encountered the idea. It is important to note that these results are averaged over 5,000 simulations, meaning a consistently high rate of diffusion across all simulations. This reflects how effectively the European intellectual network functioned to disseminate ideas. Regardless of their point of origin, ideas eventually spread throughout Europe in the long run. For instance, Warner's idea remained localized in Oxford for some time, but reached Cambridge and Gresham College by 1650, before spreading further. Similarly, Saporta's concept, originating in Montpellier, reached Basel, Lincei, and Toulouse by 1600, and continued to propagate across Europe afterward. After two centuries, both Bording's and Saporta's ideas had spread at a similar rate to various locations. This demonstrates that, despite differences in individual pathways and speed of diffusion, the overall outcome was the same: the widespread diffusion of ideas across Europe.

This confirms that the diffusion process generated by our model is non-ergodic: the success of an idea remains dependent on its initial conditions – specifically, the network position of its inventor. Appendix J.1 provides a more detailed discussion about this point. This implies that the distribution of successful ideas does not converge to a single stationary form, i.e. even as time progresses, the expected success of an idea remains contingent on the initial conditions. It also implies that outcomes across different realizations of the process do not average out over time (in an ergodic process, averaging over time should yield the same result as averaging over different realizations of the process: see Peters (2019) for a history of the idea of ergodicity).

The case of Fuchs (4) is particularly interesting, as the diffusion of his herbal plateaus at 40%, unlike the other simulations where ideas either reach full exposure or fade out entirely. This reflects the fact that, in roughly 90% of the simulations, Fuchs' idea dies out quickly, keeping exposure at zero. In the other 10%, Fuchs' idea spreads successfully, reaching high levels of adoption after a century. This outcome suggests that the spread of Fuchs' herbal

20. That said, Botanical Realism required not just empirical skills but also an interest in plants themselves, which some of these figures might not have had. Fuchs' success came from a combination of his medical background, interest in plants, access to talented illustrators, and the specific intellectual environment in Germany at the time.

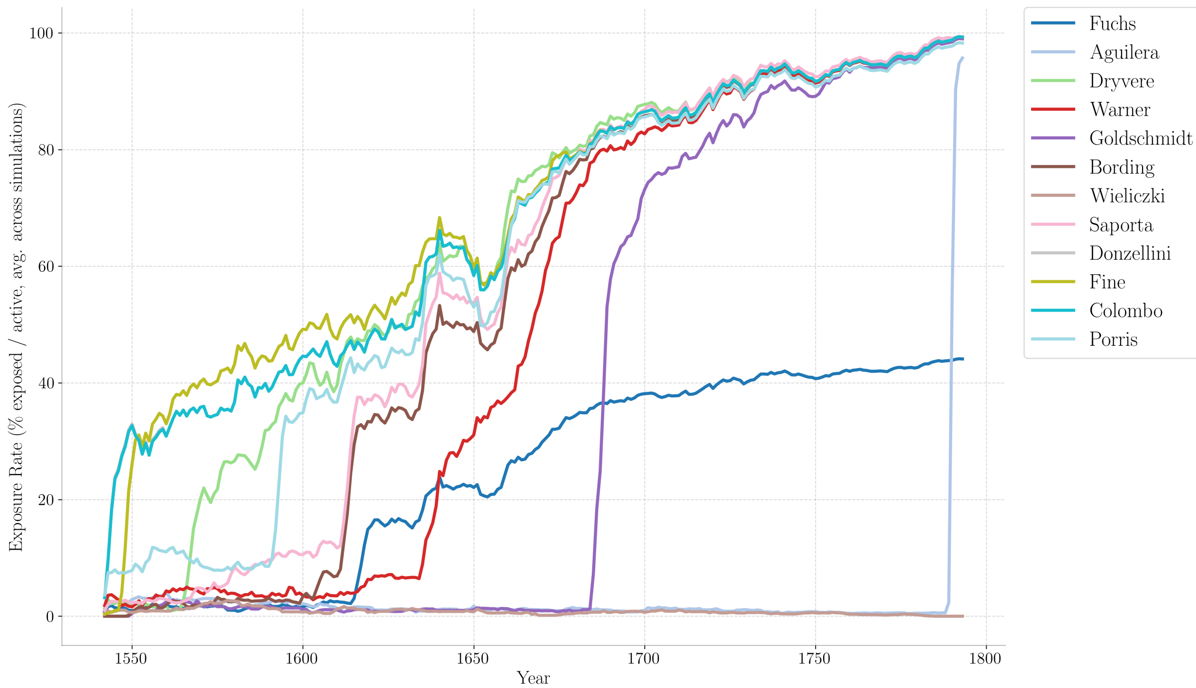


Figure 6: Exposure rates of active scholars in the network from 1084 to 1793, considering different hypothesized proponents of Botanical Realism.

hinges on a fragile initial phase, where its survival occurs with a probability of about one tenth.

To understand the European academic network, we can examine the transmission of ideas through the case of Fuchs' Botanical Realism. Figure 7 highlights the key individuals and institutions involved. This idea originated at the University of Tübingen, where it thrived for over a century due to the steady presence of scholars in science and medicine. However, the Thirty Years' War effectively closed the university and disrupted this continuity, especially between 1628 and 1634, during its occupation by Imperial (Catholic) forces of the Holy Roman Empire.

Despite this disruption, the idea spread to other institutions via Tübingen scholars who secured positions elsewhere. Jakob Degen taught briefly in Strasbourg (Berger-Levrault 1890), while Michael Mästlin held a temporary post in Heidelberg (Drüll 2002). However, these transfers did not result in sustained knowledge transmission: Strasbourg was too small to establish permanent positions in the sciences, and Heidelberg faced the same wartime challenges as Tübingen. Nevertheless, in Strasbourg, the physician Kasper Maliński may have encountered Fuchs' ideas. His subsequent move to the University of Zamość (Kedzoria 2021) could have carried the concept further.

At Zamość, the mathematician Adrien Van Roomen (also known as Romanus) might have engaged with the idea. Near the end of his life, Romanus became a member of the Accademia dei Lincei, where he potentially reintroduced the concept. Through the Lincei, an informal academy with prominent members such as Galileo and Kepler, the idea could have spread internationally. Thus Adrien Van Roomen, Jakob Degen, Michael Mästlin, and Kasper Maliński are necessary for the survival of the idea. Van Roomen is only the last of a series of key players according to Zenou's (2016) definition, which was developed in the context of criminal networks: "the key player who is the agent that should be targeted by the planner so that, once removed, she will generate the highest level of reduction in total activity" (p. 1403).

This hypothetical trajectory highlights three features of European academia in the sixteenth and seventeenth centuries. First, the dense network of connections ensured that ideas could survive even amid significant disruptions, such as the Thirty Years' War. Marginal institutions, like the University of Zamość, played a crucial role in this resilience. Second, early informal academies, such as the Lincei, were vital for preserving and disseminating ideas across borders. Third, the European academic network was strongly path-dependent and non-ergodic as described in (David 1985): it was shaped by more or less random historical events "rather than systematic forces" (p.332).

5.2 Removing components of the network

As explained above, we simulate the spread of ideas in a network stripped of certain components. This gives us better insight into the role of each component. Under this approach, we rewrite Equation (1) as

$$I^B_{t+1} = B_t I^B_t + I^B_t \tag{10}$$

where the new affiliation matrix $B \leq A$ in the Hadamard order (that is, every entry of B_t is less than or equal to the corresponding entry of A_t). Then it is obvious that $I^B_t \leq I_t \ \forall t$, assuming the same initial condition $I_0 = I^B_0$. Indeed, in the new dynamics, there will be fewer exposed persons at every time step, since reducing the number of connections reduces the opportunities for ideas to spread. This follows from the fact that matrix multiplication with a reduced adjacency matrix B_t leads to a weakly lower infection count at every step.

In the stochastic version, as $\mathbb{E}[\Omega^d(B_t)] = \alpha B_t$, we have $\mathbb{E}[\Omega^d(B_t)] < \mathbb{E}[\Omega^d(A_t)]$ in the Hadamard order, and $\mathbb{E}[I^B_t] \leq \mathbb{E}[I_t]$, $\forall t$. This means that, with an infinite number of simulations D, the world with B (fewer contacts) will still have fewer exposures than the world with A, even in the presence of stochastic transmission. But this statement is no

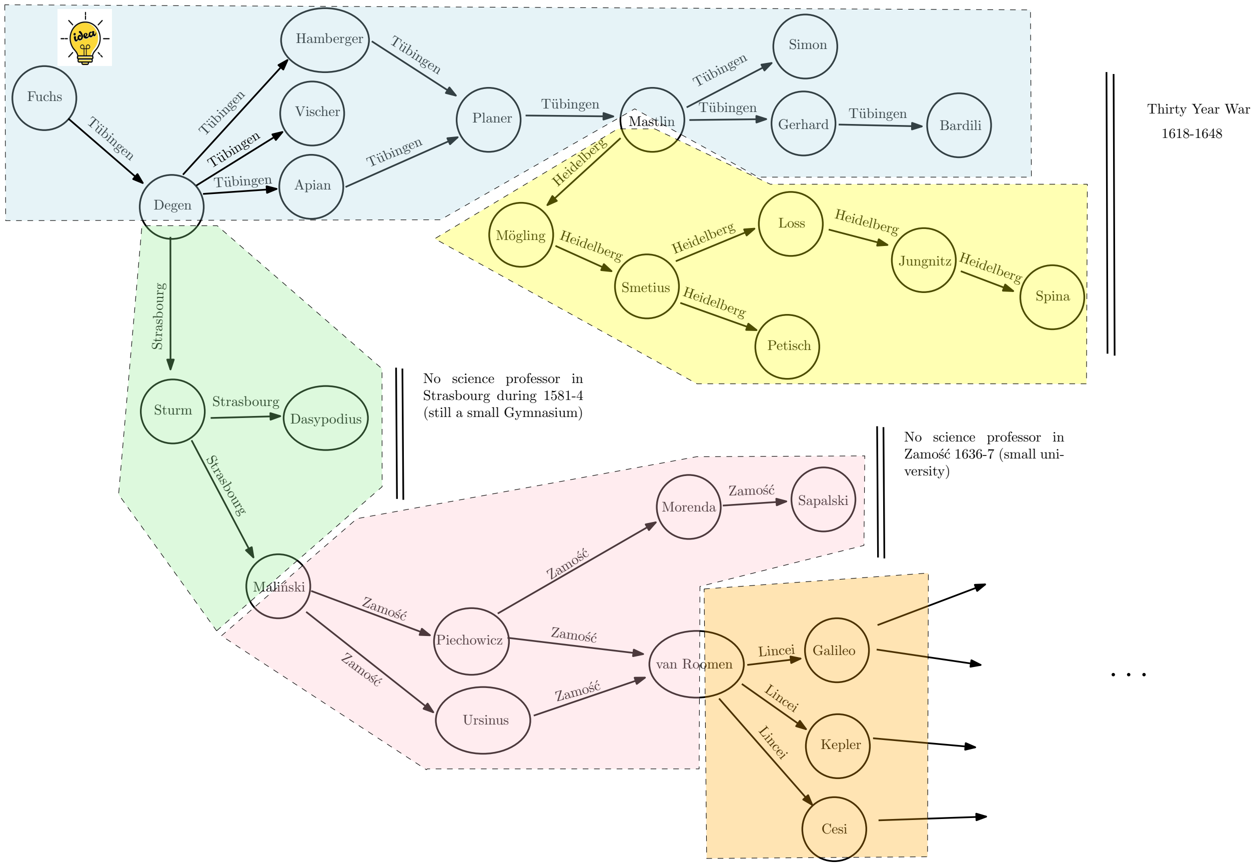


Figure 7: Botanical Realism path

longer strictly true in every realization. If we simulate the process many times, the law of large numbers implies that the average outcome of these simulations should converge to the expectation. The required number of simulations D may however be very large, because of strong non linear effects coming from the topology of the network.

First, we let Botanical Realism and Mathematical Astronomy spread over the affiliation network as if academies never emerged, to assess whether academies were key for the diffusion of the ideas of the Scientific Revolution (McClellan 1985; Pedersen 1992). To measure diffusion we use Equation (7), which computes the exposure of any European city to an idea. We use the set of cities in Buringh (2021), excluding those in the Ottoman Empire and in Russia. This leaves us with 1,916 cities. We report quartiles of the distribution of exposure across this set of cities relative to the benchmark.

In reporting the results, we distinguish between two roles of academies. First, they contribute directly to the exposure of nearby cities to ideas – for example, when Greenwich benefits from the presence of the Royal Society in London. Second, they facilitate the diffusion of ideas within the affiliation network by bridging university communities – for instance, when Greenwich benefits from scholars at Oxford and Cambridge, whose intellectual development and connectivity have been enhanced by the Royal Society. In Table 6, the line "No direct contribution" gives the exposure distribution when the direct contribution is shut down. Practically, we keep the vector of the individual exposures I_t^d from the benchmark but we remove academies' exposure $S_t^{k,\varphi}$ from the computation of city exposure $S_t^{c,\varphi}$. The line "No academies at all" is based on an alternative affiliation matrix where all the edges stemming from academies are removed, and the various measures of exposures are computed with this matrix. The first line for each year "With academies" represents the baseline exposure distribution, which can be used for comparison.

The following insights can be drawn from Table 6: there are very few academies in 1600. The Ricovrati in Padua was just created (in 1599), and it was mostly literary at that time. The same is true of the Accademia della Crusca (founded in Florence in 1583 to preserve the purity of the Italian language). The Lincei, already mentioned above in the context of its relationship with Romanus and Botanical Realism, was founded in 1603 (Gabrieli 1989). As a result, academies did not have a big influence on the exposure to Botanical Realism, and both lines remain the same as in the benchmark. However, academies already played a role in spreading Mathematical Astronomy, as the exposure distributions drops with respect to the benchmark: the median drops by almost 23% in both scenarios. Even at this early stage, when academies are few and primarily informal, they contribute to the dissemination of ideas.

By 1650, academies begin to influence Botanical Realism, both as part of the network (due to figures like Romanus) and directly. By this time, both Botanical Realism and Mathematical Astronomy have reached nearly all cities. After 1700 academies are increasingly significant. For Botanical Realism, academies are essential, as indicated by the third row in each scenario dropping to zero. In contrast, while Mathematical Astronomy does not depend strictly on academies for its survival, they play a crucial role in amplifying exposure. By 1793, the absence of academies would lead to a dramatic reduction in exposure to Mathematical Astronomy: in the scenario without academies at all, the median would drop by more than 95%.

We can use this same tool to analyze the role of specific regions or nations. The literature has examined the contributions of each nation to the rise of science and knowledge in Europe. Each country possessed unique characteristics that, when combined, created a fertile environment for intellectual and scientific transformations. For example, Italy laid the foundations with the Renaissance and early scientific methods (Applebaum 2003); the British Isles drove empiricism and practical applications (Mokyr 2011a); France spearheaded

Table 6: Counterfactual experiment with and without academies.

Botanical Realism	Q1	Median	Q3
With academies in 1600	0	1.31	2.73
No direct contribution in 1600	0	1.31	2.73
No academies at all in 1600	0	1.31	2.73
With academies in 1650	8.86	25.02	41.80
No direct contribution in 1650	7.13	20.65	34.48
No academies at all in 1650	0	0.13	0.43
With academies in 1700	31.07	93.63	153.18
No direct contribution in 1700	20.91	47.95	74.33
No academies at all in 1700	0	0	0
With academies in 1750	58.77	190.58	292.93
No direct contribution in 1750	23.86	57.09	98.47
No academies at all in 1750	0	0	0
With academies in 1793	94.67	376.86	616.56
No direct contribution in 1793	21.15	62.04	109
No academies at all in 1793	0	0	0
Mathematical Astronomy	Q1	Median	Q3
With academies in 1600	0	6.20	17.10
No direct contribution in 1600	0	4.79	13.59
No academies at all in 1600	0	4.78	13.58
With academies in 1650	9.16	27.02	45.72
No direct contribution in 1650	6.60	20.80	35.66
No academies at all in 1650	0	7.19	24.97
With academies in 1700	26.24	82.13	131.15
No direct contribution in 1700	16.52	37.51	62.11
No academies at all in 1700	0.11	6.90	21.91
With academies in 1750	67.64	220.03	334.68
No direct contribution in 1750	25.27	60.47	105.78
No academies at all in 1750	5.61	21.40	37.53
With academies in 1793	121.76	455.02	744.32
No direct contribution in 1793	19.50	65.41	105.18
No academies at all in 1793	7.90	22.51	39.05

Quartiles of cities' exposure distributions to ideas when [0] academies are fully considered (benchmark) [1] academies have no direct contribution on cities but are present in the network [2] academies have no effect at all.

Enlightenment thinking and institutional science (Ferris, Stella, and Yon 2010); the Iberic Peninsula advanced economic theory and natural law, and the Holy Roman Empire advanced theoretical frameworks in mathematics and astronomy.

Table 7: Counterfactual Experiment with and without European regions.

Botanical Realism	Q1	Median	Q3
No Italian Peninsula	0	0	0
No British Isles	83.77	285.19	543.02
No France	70.98	280.54	478.80
No Iberic Peninsula	92.87	374.70	614.42
No Holy Roman Empire	0	0	0
Benchmark	94.67	376.86	616.56
Mathematical Astronomy	Q1	Median	Q3
No Italian Peninsula	0	0	0
No British Isles	95	334.40	630
No France	83.46	346.68	581.16
No Iberic Peninsula	118.94	453.81	742.57
No Holy Roman Empire	118.13	433.65	694.37
Benchmark	121.76	455.02	744.32

Quartiles of cities' exposure distributions to ideas in five counterfactual networks without a specific European region, and the benchmark in 1793.

We apply our model to study separately the importance of each nation in spreading and keeping alive each idea. To measure how nations are key for an idea, we construct five counterfactual networks, removing institutions belonging to specific geographical areas: one without the Italian peninsula, one without the British Isles, one without France,[21] one without the Iberian peninsula, and one without the Holy Roman Empire (as defined in Stelter, De la Croix, and Myrskylä (2021). We then simulate the spread of Botanical Realism and Mathematical Astronomy in these five networks, and in the benchmark model.

Results are presented in Table 7. Each number is a summary statistic of the exposure $S^{c,\varphi}_{1793}$ of the cities' distributions, together with the relative exposure distribution in the benchmark. Without the Italian Peninsula, neither Botanical Realism nor Mathematical Astronomy would have survived. For example, for the latter, the universities of Rome and Bologna were critical hubs, allowing scholars previously exposed to the Mathematical

21. We exclude from France cities which became French towards the end of the period: Strasbourg (1681), Molsheim (1648), Nancy (1766), Pont-a-Mousson (1766), Nice (1860), Perpignan (1659), Arras (1659), Douai (1667).

Astronomy in Vienna or Bratislava to continue disseminating it among their colleagues. It appears that the Holy Roman Empire is necessary for Botanical Realism, but not for Mathematical Astronomy. No other regions in this simulation were necessary for either idea to spread. For example, both Botanical Realism and Mathematical Astronomy spread throughout Europe even without the British Isles, although the median drops by 24.3% and by 26.5%, respectively. Even if the British Isles had a key role in the propagation and implementation of useful knowledge (Hallmann, Hanlon, and Rosenberger (2022) show that British inventors worked on technologies that were more central within the innovation network), it is not the case as far as our example of propositional knowledge is concerned (Mokyr 2011b).

The same reasoning holds for the other regions: the spread of ideas across Europe is not significantly hindered by the absence of France, and the contribution of the Iberian Peninsula appears particularly limited or even negligible.

Overall, this analysis underscores the resilience of the European network of academies and universities. Even when some parts are removed, the network remains sufficiently dense to sustain the circulation of ideas.

Finally, we focus on the role of Jesuits, and present the simulation results when Jesuits are removed from the network. The Society of Jesus, founded in 1540 by Ignatius of Loyola, was a highly influential religious order in the Catholic Church. Its members underwent rigorous training, including years of spiritual exercise and intellectual formation. To counter Protestantism, Jesuits rapidly established an extensive network of schools, colleges, and universities across Europe (Grendler 2019) and beyond. In the RETE database, we count 52 Jesuit institutions among the 213 universities and colleges of some renown, and more than 6800 scholars (Jesuit priests)–approximately 8% of all recorded scholars between 1000 and 1800, a figure that rises to 11% when the sample is limited to the period after the Jesuit order was founded. Known for their high academic standards, Jesuits taught humanities, sciences, philosophy, and theology. Their growing influence led to political tensions and subsequently expulsions from several countries: Portugal (1759), France (1764), Spain (1767), and Naples (1767). In 1773, under pressure from European rulers, Pope Clement XIV suppressed the order, though it survived in Russia and Prussia (and later in the USA, where Georgetown University was founded in Washington DC).

Table 8 presents the results for the year 1750 (a few years before the dissolution of the order). When we remove all Jesuit nodes from the network and simulate the spread of Mathematical Astronomy, we observe some differences, especially in peripheral regions largely neglected by non-Jesuit institutions (such as Sicily, Andalusia, and Romania). Given the

Table 8: Counterfactual experiment with and without Jesuits

Botanical Realism	Q1	Median	Q3
Benchmark	58.77	190.58	292.93
No direct contribution	53.76	174.62	265.14
No Jesuits at all	52.75	172.09	261.64
Mathematical Astronomy	Q1	Median	Q3
Benchmark	67.64	220.03	334.68
No direct contribution	57.68	188.67	283.43
No Jesuits at all	56.98	186.90	281.26

Quartiles of cities' exposure distributions to ideas in the counterfactual network without Jesuits and the benchmark in 1750.

widely recognized contributions of Jesuits to science—particularly astronomy—as evidenced by the many lunar craters named after Jesuit astronomers and all the observatories they built (Udías 2003), it is unsurprising that the median drop is around 15% when analysing Mathematical Astronomy in both scenarios. On the other hand, removing the Jesuits does not really impact the spread of Botanical Realism, where the median drop is around 9% in both cases. One possible explanation for their limited role in the broader diffusion of Botanical Realism is that they operated within a relatively isolated network, separate from the rest of academia.

Figure 8: Jesuit inbreeding homophily over time

To test this hypothesis, we examine whether Jesuit nodes are densely connected internally while remaining weakly connected to the rest of the network. We define two groups of nodes: Jesuits and non-Jesuits. To quantify Jesuit insularity, we compute the Coleman (1958) inbreeding homophily index, which ranges from -1 (no internal Jesuit connections) to 0 (connections similar to a random network) to 1 (complete inbreeding). Following Currarini, Jackson, and Pin (2009), we define IH as follows:

$$IH_{Jesuits,t} = \frac{H_{Jesuits,t} - \omega_{Jesuits,t}}{1 - \omega_{Jesuits,t}}$$

where $H_{Jesuits,t}$ is the fraction of edges entailing only Jesuits at time t, and $\omega_{Jesuits,t}$ is the relative fraction of Jesuits in the scholar population any given point in time t.

Figure 8 plots $IH_{Jesuits,t}$ from 1556 to 1767, the period over which Jesuits were most active. For most of the timeframe, the index remains between 0.6 and 0.8, indicating a high degree of inbreeding. Jesuit universities were typically closed to non-Jesuit professors, and Jesuit scholars rarely taught outside them. However, the index is slightly lower at the beginning, when the Jesuits were establishing their university network, and at the end, preceding their gradual dissolution.[22]

6 Conclusions

We have studied how academic networks in the premodern era provided support to the spread of ideas. Using dynamic network models and counterfactual experiments, we showed that features like the emergence of academies and the connections they created across regions helped ideas to spread more widely. By examining the diffusion of groundbreaking ideas and paradigm shifts such as Botanical Realism, Mathematical Astronomy, and scholasticism, we have highlighted the role of higher-education institutions in European development.

The counterfactual experiments reveal the nuanced importance of academies: not only did they act as hubs of direct idea dissemination, but they also enhanced the connectivity of the broader network, bridging university communities. Without academies, the spread of ideas born in university settings would have been significantly slower. Our approach also provided insights into regional contributions to scientific progress, highlighting the resilience of the European network of academies and universities, which was dense enough to sustain the circulation of ideas even if certain parts were removed.

While our results are robust to several modelling choices, the analysis treats the observed affiliation network as given. This is a limitation of our approach. In practice, the network

22. Appendix K provides additional statistics on the Jesuits' position and connectivity in the network, including their number, density, conductance, and decompositions by field.

arises from individuals' location choices, which are shaped by agglomeration forces and positive sorting. These forces are thus integral to the broader process we study. Mobilizing network formation theory would be a challenging next step.

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A Descriptive Statistics

A.1 Completeness of the data

Figure 9 provides an overview of missingness in the scholars dataset across three indicators: the presence of a Wikipedia page, the availability of birth and death years (and thus longevity), and the availability of a place of birth. The largest segment consists of scholars for whom none of these pieces of information is observed—no place of birth, no vital dates, and no Wikipedia link. In the plot, this group is labelled "no.info" and comprises 26,549 individuals. A second large segment (25,381), labelled "Origin.known", includes scholars for whom only the place of birth is known. The third-largest group, with 17,200 scholars, has complete information on all three indicators. Two additional groups are also sizeable. One includes scholars with complete information except for a missing Wikipedia page (13,528). Finally, the set-size bars indicate that scholars with a Wikipedia page — roughly corresponding to the samples used in studies such as Laouenan et al. (2022) — number about 20,000, i.e. approximately one quarter of the full dataset.

Figure 10 offers a similar overview for affiliations. The number of affiliations exceeds the number of scholars because many individuals held multiple affiliations over their lifetimes. The figure focuses on academic fields. Roughly 80% of scholars are associated with a single field, most commonly the humanities, followed by the sciences (including medicine), theology, and law. 6,939 scholars have an unknown field, and 3,744 are classified as "honorary" because they are not scholars in the strict sense but instead hold honorary or administrative roles (e.g., academy protectors, or students serving as rectors in Italian universities). The plot also highlights frequent combinations of fields among multi-field scholars, notably theology with humanities (6,707) and humanities with sciences (3,382).

Figure 11 shows how complete our information is for identifying scholars' periods of activity. In the vast majority of cases, the start year is known, typically the year of appointment at a university or the year of election to an academy. End dates, however, are recorded less systematically, as many sources report the year a professorship begins but not when it ends. For academies, it is generally reasonable to assume that membership lasts until death, whereas no comparable assumption can be made for university posts. For 12,965 scholars we can only assign an approximate activity date, and for a small minority (around 1,000) no dating information is available at all.

A.2 Universities, academies, scholar over time

Figure 12 and Figure 13 show the number of scholars over time of the top-10 universities and academies ranked by size in 1793, respectively. By the end of the period, Cambridge is the most populated university and the Royal Society the most populated academy. Tables 9 and 10 report detailed descriptive statistics for each institution.

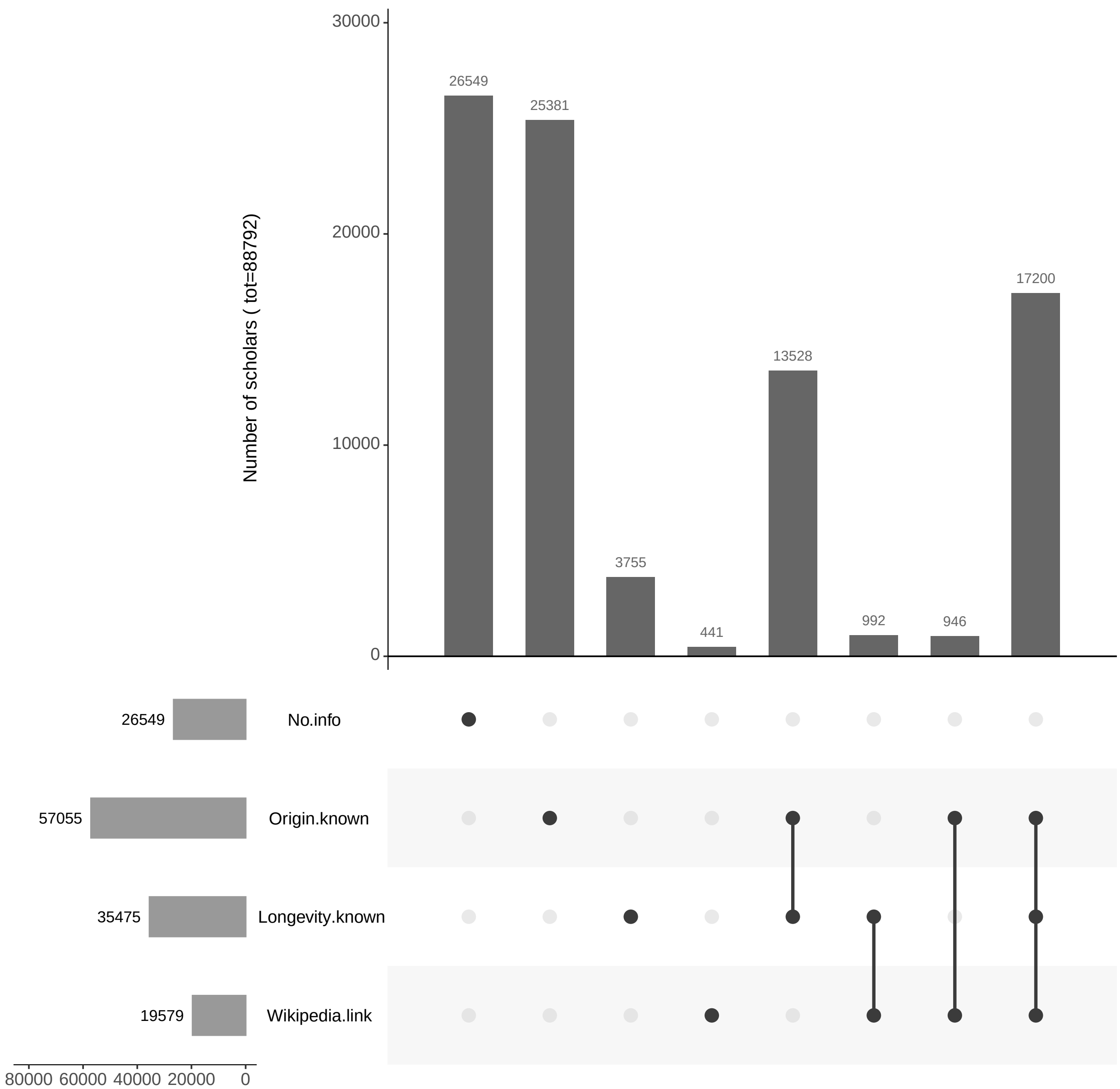


Figure 9: UpSet diagram for persons (matrix-based visualization of intersections across variables).

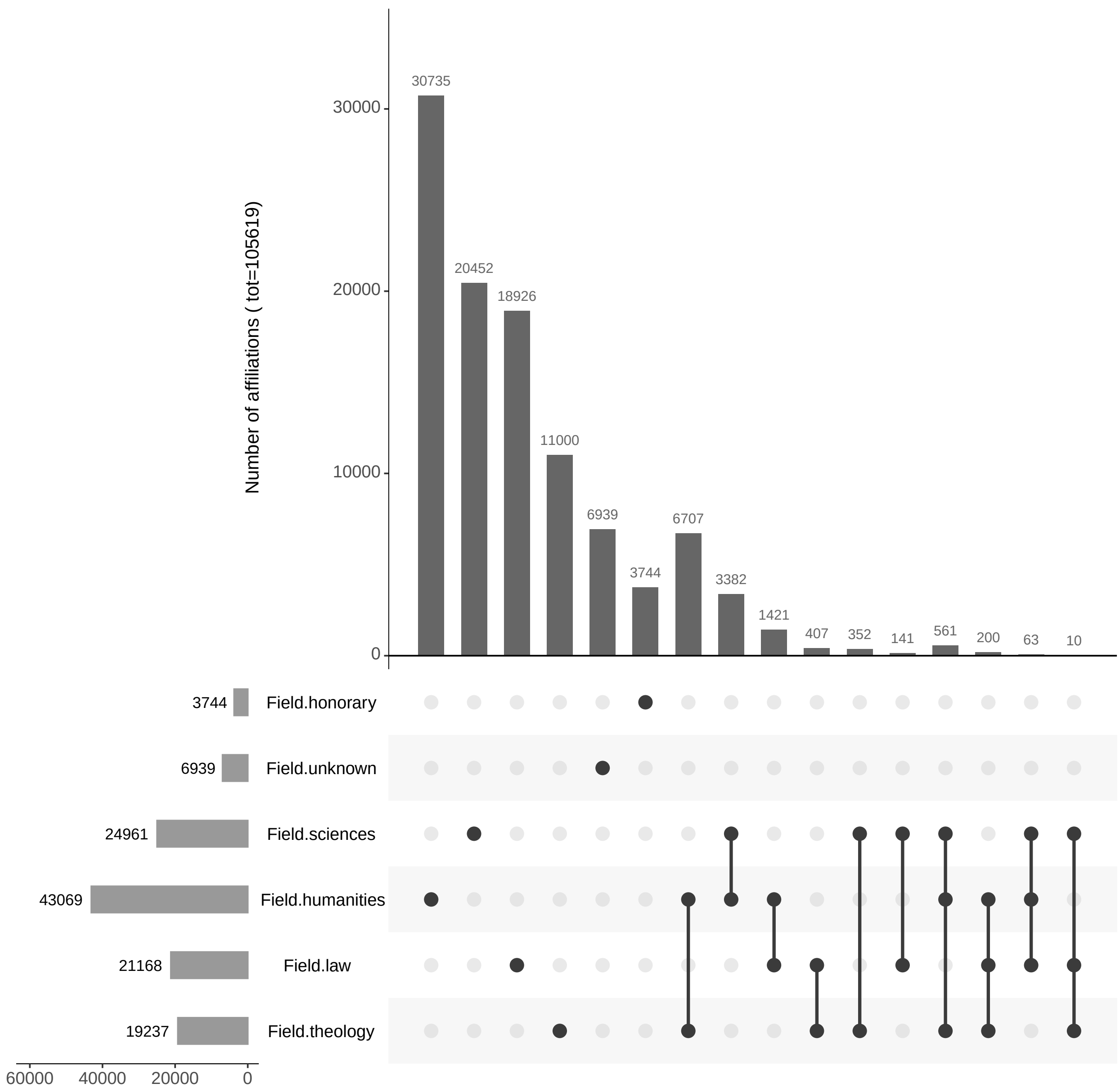


Figure 10: UpSet diagram for affiliations and academic fields (matrix-based visualization of intersections across variables).

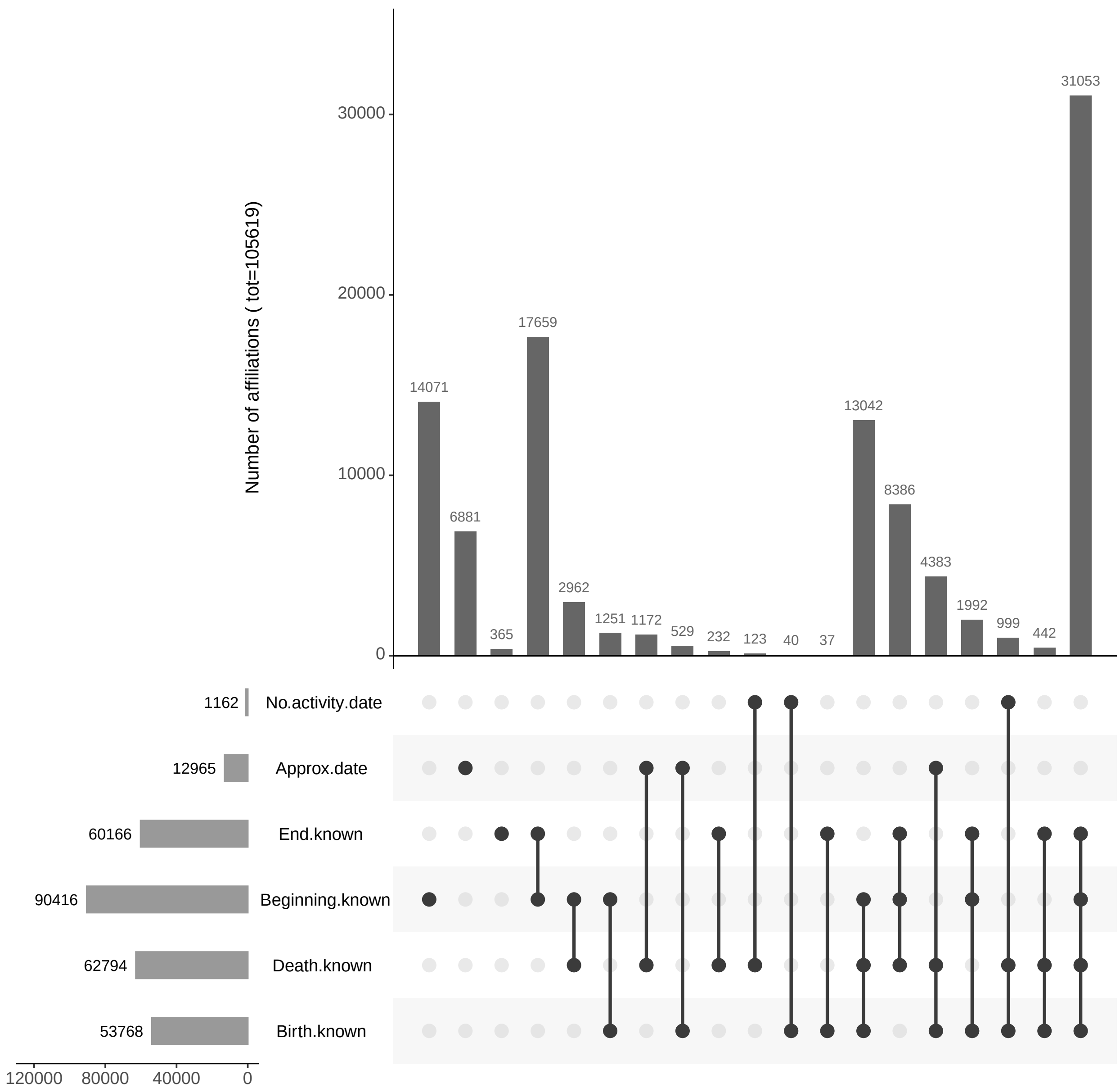


Figure 11: UpSet diagram for affiliations and activity periods (matrix-based visualization of intersections across variables).

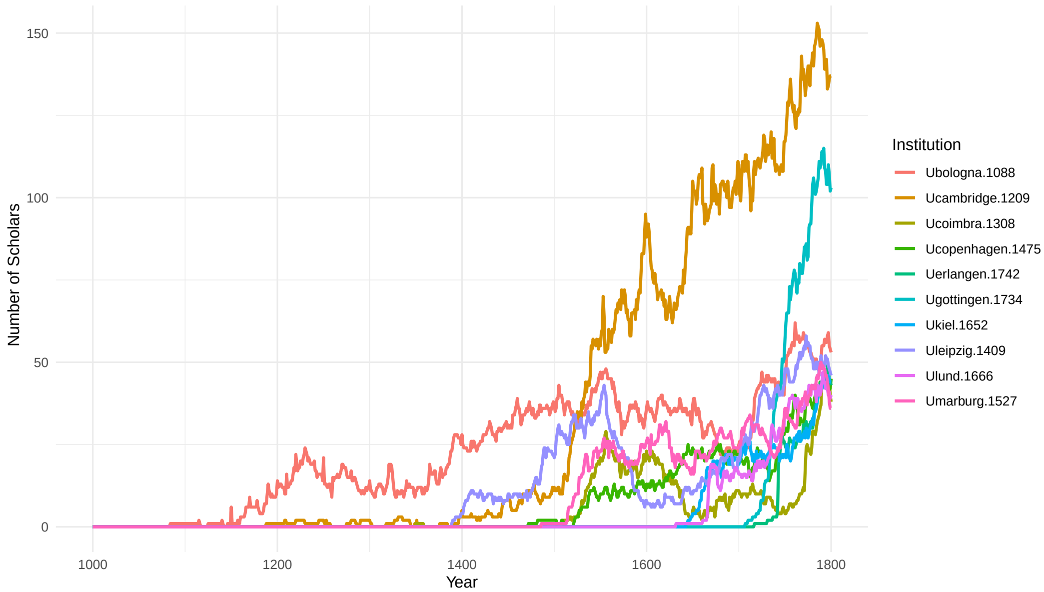


Figure 12: Number of university professors between 1000 and 1800 of the top 10 universities considering the number of scholars in 1793. In the legend, the name of the institution with the foundation date.

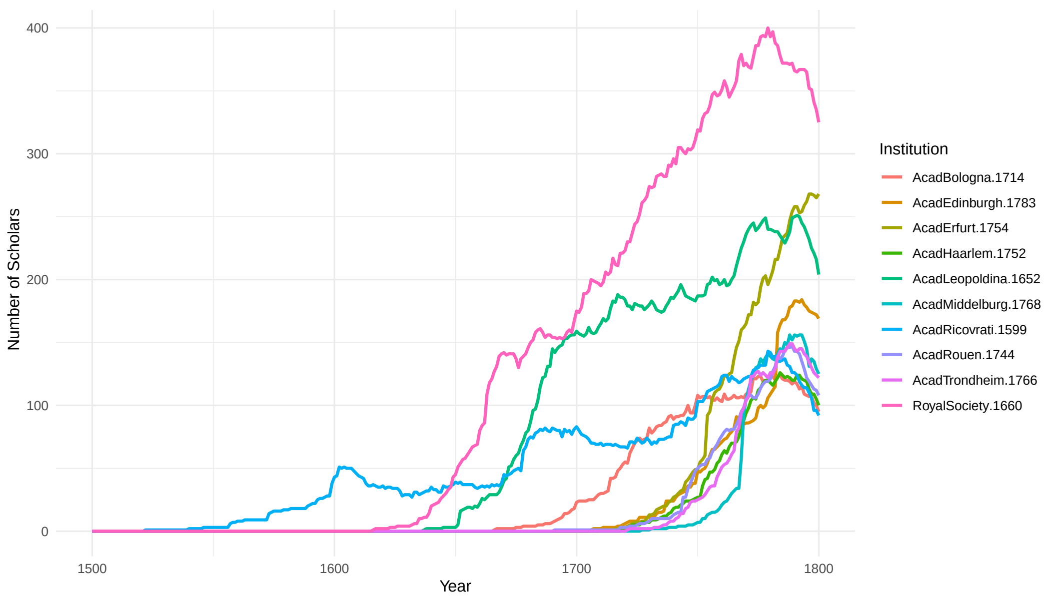


Figure 13: Number of academicians between 1500 and 1800 of the top 10 academies considering the number of scholars in 1793. In the legend, the name of the institution with the foundation date.

Institution	Mean	Median	SD	Min	Q1	Q3	Max
Ubologna.1088	34.14	37	13.02	14	26.5	41	53
Ucambridge.1209	69.57	105	60.38	1	8.5	113.5	137
Ucoimbra.1308	8.29	4	13.70	0	0	8	38
Uerlangen.1742	9.71	0	17.38	0	0	12.5	43
Ugottingen.1734	22.86	0	41.23	0	0	28.5	103
Ukiel.1652	12.71	4	16.66	0	0	20.5	44
Ucopenhagen.1475	17.57	22	17.45	0	1	27	45
Uleipzig.1409	21.29	20	19.17	0	7	33.5	48
Ulund.1666	13.14	1	17.67	0	0	25.5	40
Umarburg.1527	16.43	18	16.35	0	0.5	30	36

Table 9: Descriptive statistics for the top 10 universities, considering the number of scholars in 1793. In the first column, the name of the institution with the foundation date. "SD" stands for Standard Deviation, "Min" for minimum, "Q1" for first quartiles, "Q3" for third quartiles, and "Max" for maximum.

Institution	Mean	Median	SD	Min	Q1	Q3	Max
AcadBologna.1714	32.29	0	48.17	0	0	59	108
AcadEdinburgh.1783	31	0	63.43	0	0	24	169
AcadErfurt.1754	45.29	0	99.89	0	0	24.5	268
AcadHaarlem.1752	18.14	0	37.47	0	0	13.5	100
AcadLeopoldina.1652	79	3	98.48	0	0	173	204
RoyalSociety.1660	123.43	45	149.10	0	0	247	325
AcadRicovrati.1599	45.29	39	46.78	0	0	87.5	103
AcadRouen.1744	22.71	0	41.94	0	0	25.5	108
AcadTrondheim.1766	21	0	45.50	0	0	12.5	122
AcadMiddelburg.1768	18.86	0	46.88	0	0	3.5	125

Table 10: Descriptive statistics for the top 10 academies, considering the number of scholars in 1793. In the first column, the name of the institution with the foundation date. "SD" stands for Standard Deviation, "Min" for minimum, "Q1" for first quartiles, "Q3" for third quartiles, and "Max" for maximum.

B Definition of active periods

The active period of each scholar commences at the start of their academic career and concludes at their retirement or death. Activity begins in the earliest known year of affiliation with a formal educational institution, when available. For university professors, this is the year they began teaching, while for academy members, it is the year they were elected as members of the academy. If the exact affiliation date is unavailable, we infer the first year of affiliation from approximate dates. In more extreme cases, we use the earliest available date among: 30 years after the birth year, the year of death, the institution's closing date, or 1793, which marks the end of our study period. This approach aims to provide a conservative estimate of each scholar's active period.

Scholars cease to be active when they leave the institution, if this date is available. For university professors it is the year their teaching ends. For members of academies it is usually the death year, or in some rare case, the year the member was expelled. When there is no precise information about the end of their activity, we infer it in one of two ways for university professors and academicians. For university professors without a precise end affiliation date, we assume it is equal to the approximate affiliation date when available. Otherwise, if these pieces of information are unknown, we assume that a university professor will teach in that university for eight years.[23] Hence, we take the earliest date between the beginning date (after adding eight years) and the year of death. For academicians without a precise end date of their affiliations, we also assume it from more approximate dates if available. When not possible, for these scholars, we assume a lifelong affiliation,[24] so we take the year of death when there is no more precise information. Otherwise, when we do not know the year of death either, we assume they stay in the academy only one year, imposing the end affiliation date equal to the beginning date.

C Contextual information

C.1 Botanical Realism and botanic gardens

In Europe, natural history traces its roots back to ancient Greek philosophers such as Aristotle, Theophrastus, and Dioscorides. During the Scientific Revolution, botany underwent major advancements, transitioning from a primarily descriptive field into a more systematic and experimental science. By the 16^{th} and 17^{th} centuries, botany started encompassing not only the identification and classification of plants species, but also the growing field of plant physiology, investigating the properties and functions of plants life. This marked a shift in botanical practices, expanding beyond the descriptive and illustrative focus of ancient authors (Applebaum 2003), towards a more empirical approach that we will refer to as "Botanical Realism". Before 1650, botany was considered merely a complement to medical studies, but it became an independent field of study during the Scientific Revolution. Uni-

23. Eight years being the median of the affiliation years in the sample of university professors for whom we know the precise beginning and end affiliation dates. This data is consistent with the literature: Koschnick (2025b) finds that the median length of academic careers at Oxford and Cambridge is 9 years.

24. Academies usually grant a lifelong affiliation.

versities renown for their medical faculties began offering innovative botany lectures, where students were taken directly to gardens to observe plant species first-hand. These universities were also the first to establish their own botanic gardens to support further research and development in botany. Following this trend, private citizens and local lords also recognized the importance of botanical studies and funded the creation of such gardens (Applebaum 2003).

One key figure in this transformation was Leonhart Fuchs, a German physician and botanist. He is best known for his book *De historia stirpium commentarii insignes*, which translates to "Notable commentaries on the history of plants". First printed in Basel in 1542, one year before Nicolaus Copernicus' *De revolutionibus orbium coelestium* and Andreas Vesalius' *De humani corporis fabrica*, this work laid the foundation for modern botany. Fuchs not only provided ideal visual representations of 511 plant species, but he also included his own critical observations on their uses and characteristics, highlighting differences from ancient texts (Applebaum 2003). Figure 14 shows a page of this book, emphasizing the realistic description of a plant.

Figure 14: A page of *De historia stirpium commentarii insignes*

Furthermore, we gathered information on the existence and founding dates of European botanic gardens. Our starting point was the first annual report of the Montreal Botanic Garden (1886), which lists the botanic gardens open worldwide in 1885. From this, we selected only European gardens and determined their founding dates using AI-assisted tools, which were then manually verified through sample checks. We then matched this sample of botanic gardens with our university cities, assuming that a city without a botanic garden was not listed in the first annual report by Montreal Botanic Garden (1886). To fix ideas, Figure 15 shows the *Hortus botanicus* (botanic garden) of the University of Leiden, which was opened in 1590. This is a case of a large garden with a dedicated building, but some other gardens were much smaller.

C.2 Mathematical Astronomy and astronomical observatories

The 15th and 16th centuries witnessed a growing interest in experimental science and increasing dissatisfaction with the explanations offered by ancient astronomical authorities, such as Claudius Ptolemy (c. 100–c.170, Alexandria). Similar to the approach seen in Botanical Realism, this paradigm shift led mathematicians and astronomers to question the accuracy of Ptolemy's models and refine them through observation and mathematical analysis. This era

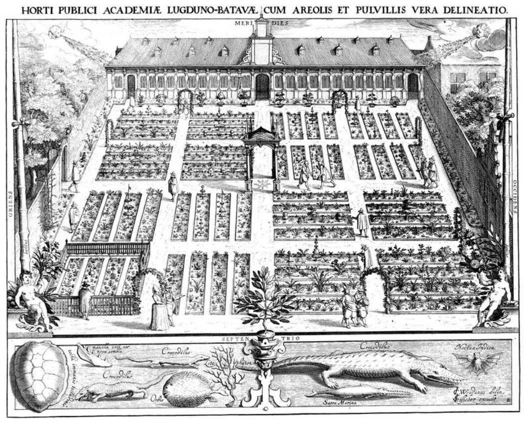


Figure 15: The Hortus botanicus of Leiden

marked the beginning of a mathematical reform in astronomy, characterized by advances in trigonometry, new geometric formulas, and the adoption of decimal calculations. The focus shifted from simply explaining celestial motions to understanding the physical mechanisms behind them.

A key figure in this revolution was Regiomontanus, pseudonym of Johannes Müller. His mastery of Greek and mathematics enabled him to study the original works of Ptolemy and other ancient thinkers. At the University of Vienna, around 1454, he and his mentor, Georg Peurbach (1423–1461), began collaborating on *Theoricæ novæ planetarum*. This seminal work introduced new methods for solving plane and spherical trigonometry problems, including the use of sine and tangent functions. Regiomontanus also created extensive trigonometric tables with values calculated to decimal units, which remained influential for centuries. As such, he can be considered a pioneer of Mathematical Astronomy. While trigonometry had been used in astronomy and other sciences, Regiomontanus's contributions greatly enhanced its application. His work, alongside Peurbach's, laid the groundwork for later revolutionary astronomers such as Copernicus, Kepler, and Galileo (Applebaum 2003).

After Peurbach's death, Regiomontanus moved to Northern Italy, then to Hungary in 1467. Later, he settled in Nuremberg, drawn by its status as a free city and central location. There, he established a workshop and printing press, dedicating himself to the dissemination of scientific knowledge. In 1463, he published *Epitoma in Almagestum Ptolemaei*, which clarified, corrected, and expanded Ptolemaic astronomy. Two pages of *Epitoma* are shown in Figure 16. In 1472, he published *Theoricæ novæ planetarum*, his collaboration with Peurbach. In 1475, Pope Sixtus IV invited him to Rome to work on calendar reform, but Regiomontanus died shortly after, at age 41.

We examine the creation of observatories in the same 185 university cities defined in Section 3.2. We collected the names and foundation dates of observatories from *The Greenwich List of Observatories* compiled by Howse (1986). As with the botanic gardens, we only considered observatories in continental Europe, assuming that a location lacked one if it was not listed in our source. To fix ideas, Figure 17 shows the main building of the University

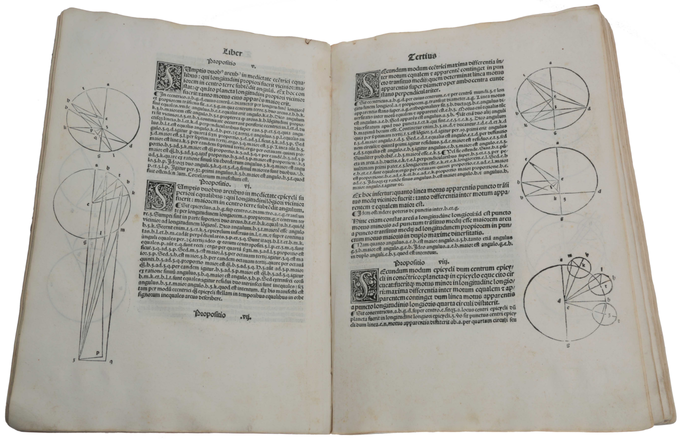


Figure 16: Two pages of *Epitoma in Almagestum Ptolemaei*

of Prague, the Clementinum. There, a tower was built in 1722. Later, in 1751, instruments were installed, and the tower became an astronomical observatory.

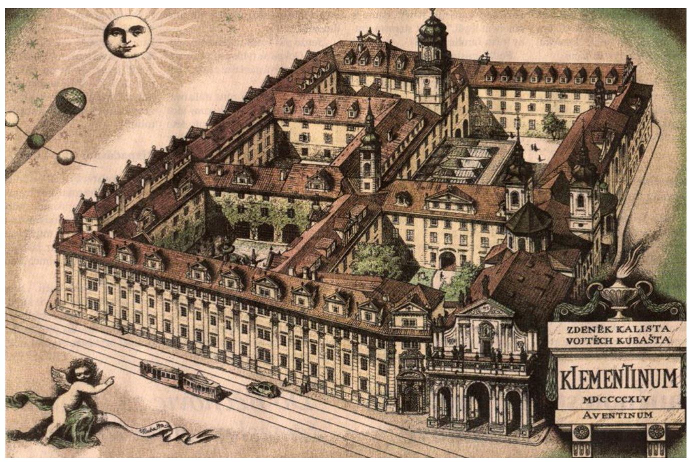


Figure 17: The *Clementinum* in Prague with its observatory

D Empirical Assessments

D.1 Descriptive Statistics

Table 11 presents some descriptive statistics, which supports the results in the main text, Table 2 and Table 3. Here we consider $\hat{\alpha} = 0.45$.

Table 11: Summary statistics.

Variable	Obs	Mean	Median	SD	Min	Max
Prevalence of Botanical Realism	67620	0.084	0	0.172	0	1
(ihs) Eligible Mass of Botanical Realism	67620	0.928	0	1.302	0	6.471
Prevalence × Eligible Mass of Botanical Realism	67620	0.226	0	0.522	0	2.856
Prevalence of Mathematical Astronomy	67620	0.120	0	0.288	0	0.843
(ihs) Eligible Mass of Mathematical Astronomy	67620	0.619	0	1.063	0	6.054
Prevalence × Eligible Mass of Mathematical Astronomy	67620	0.298	0	0.813	0	5.103
(ihs) City population in 1500	67620	2.531	2.492	1.243	0	5.521
(ihs) Distance to Tübingen	67620	7.026	7.101	0.823	0	8.338
(ihs) Distance to Vienna	67620	7.388	7.466	0.748	0	8.434

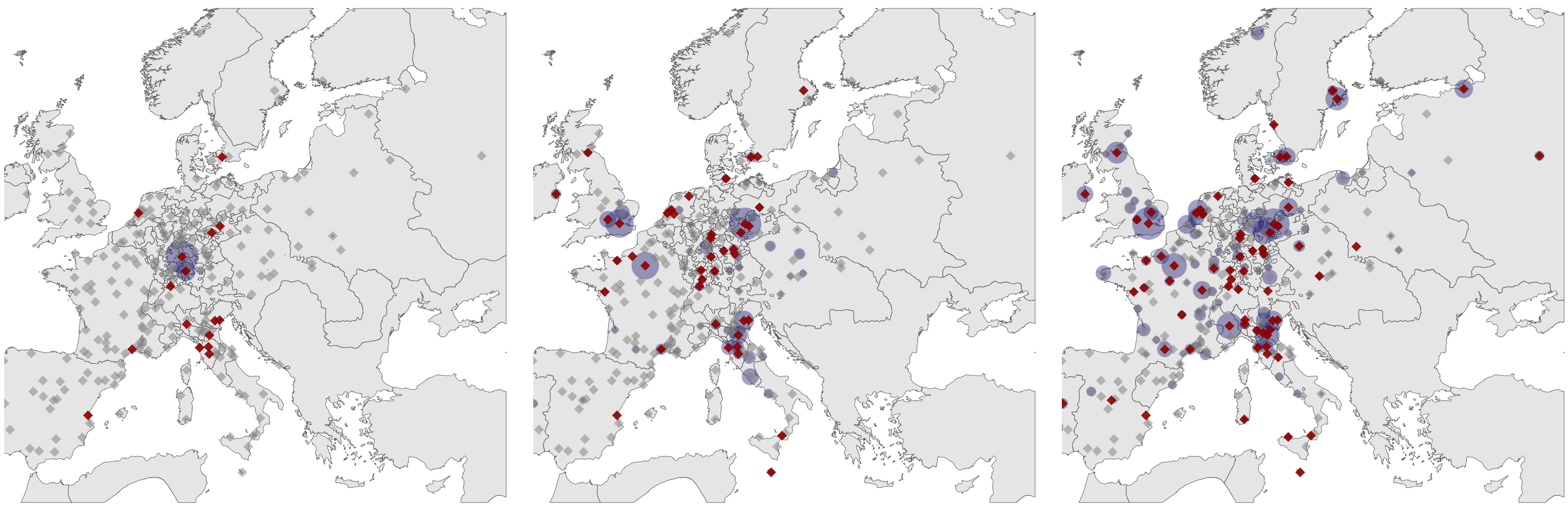
(ihs) refers to the transformation in inverse hyperbolic sine of the relative variable.

D.2 Botanical Realism

Figure 18 shows yearly exposure to Botanical Realism at three points in time. It visualizes how exposure evolves over time and space, from a concentration around Tübingen in 1600 to a spread across Europe by 1700, and a further expansion to smaller and more distant urban centers by 1793. Blue bubbles represent exposure to Botanical Realism, while red diamonds indicate cities that had at least one botanic garden by the respective year.

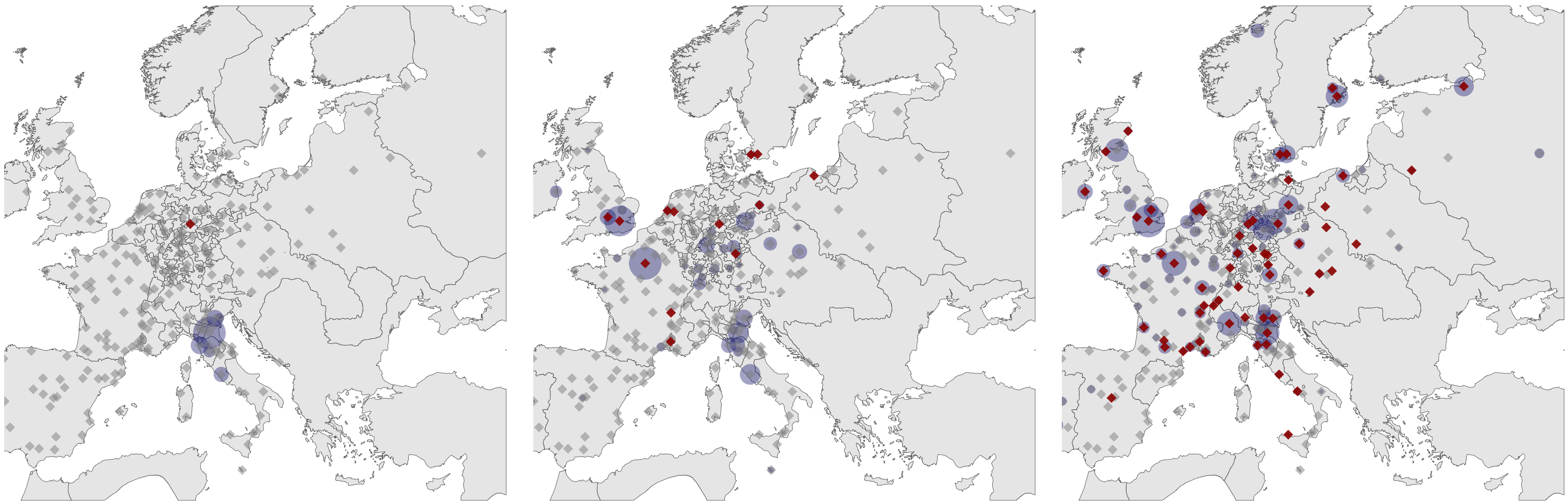
D.3 Mathematical Astronomy

Figure 19 visualizes the sample of universities cities with their yearly exposure to Mathematical Astronomy in 1600, 1700, and 1793. This figure shows how the exposure evolves over time and its interaction with the creation of observatories. As in the first experiment, blue bubbles represent exposure to Mathematical Astronomy, while red diamonds indicate cities that had at least one observatory in the relative year.



(a) Year 1600 (b) Year 1700 (c) Year 1800

Figure 18: Blue bubbles represent the yearly exposure of Botanical Realism in years 1600, 1700, and 1793, respectively. $\alpha = 0.45$ and $D = 5,000$. Cities with a botanic garden are the red diamonds, and without botanic gardens are the grey diamonds.



(a) Year 1600 (b) Year 1700 (c) Year 1800

Figure 19: Blue bubbles represent the yearly exposure of Mathematical Astronomy in years 1600, 1700, and 1793, respectively. $\alpha = 0.45$ and $D = 5,000$. Universities cities with an astronomical observatory are the red diamonds, and without astronomical observatories are the grey diamonds.

E Structural estimation

Table 12 reports the log-likelihoods for each level of α relative to both Botanical Realism (Flora, column 1) and Mathematical Astronomy (Cosmos, column 2). Column 3 shows the joint likelihood $\ell_1(\alpha)+\ell_2(\alpha)$, confirming that the maximum is reached at $\hat{\alpha} = 0.45$. Figure 20 confirms it visually. Finally, Table 13 shows the results of the Cox models with $\hat{\alpha} = 0.45$ for both Flora and Cosmos.

Table 12: Log-likelihood values for different values of α.

α	**Flora** ℓ_1	**Cosmos** ℓ_2	**Sum** $\ell_1(\alpha) + \ell_2(\alpha)$
0	-343.178	-324.834	-668.012
0.01	-342.610	-313.493	-656.103
0.02	-342.625	-313.633	-656.258
0.03	-342.623	-314.785	-657.408
0.04	-342.648	-315.396	-658.044
0.05	-342.671	-315.552	-658.223
0.10	-342.511	-316.084	-658.595
0.15	-339.284	-316.661	-655.945
0.20	-337.442	-316.995	-654.437
0.25	-336.348	-317.147	-653.495
0.30	-335.757	-317.216	-652.973
0.35	-335.453	-317.242	-652.695
0.40	-335.330	-317.262	-652.592
0.45	-335.286	-317.282	**-652.568**
0.50	-335.280	-317.308	-652.588
0.55	-335.289	-317.342	-652.631
0.60	-335.300	-317.385	-652.685
0.65	-335.310	-317.432	-652.742
0.70	-335.315	-317.488	-652.803
0.75	-335.315	-317.562	-652.877
0.80	-335.312	-317.645	-652.957
0.85	-335.307	-317.735	-653.042
0.90	-335.299	-317.832	-653.131
0.95	-335.288	-317.939	-653.227
1.00	-335.276	-318.044	-653.320

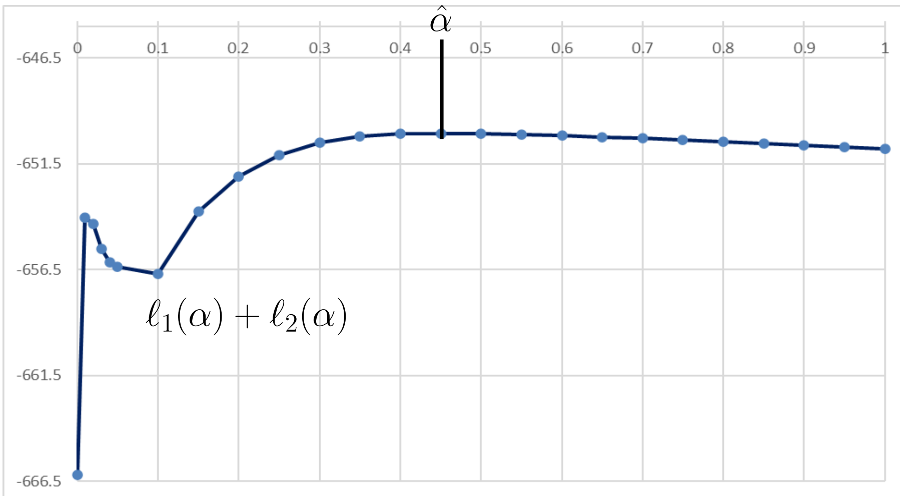


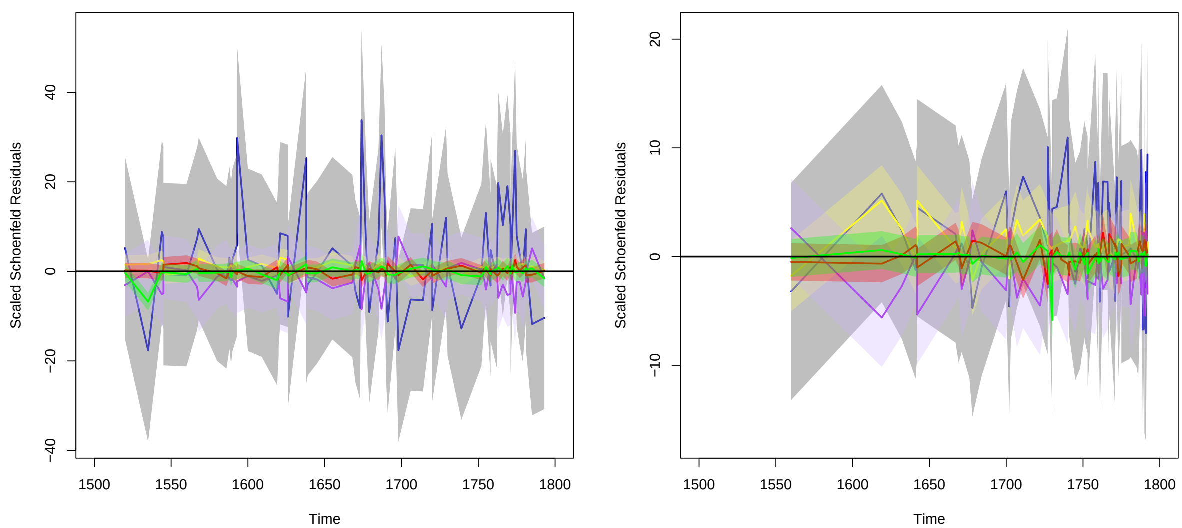
Figure 20: Plot of log-likelihood values for different values of α.

Table 13: Cox Proportional Hazards Models for alpha = 0.45

& the hazard of creating	Botanical Realism botanic gardens	Mathematical Astronomy astronomical observatories
α	0.45	0.45
Prevalence $P_t^{k,\varphi}$	3.61*** (1.23)	1.93*** (0.56)
(ihs) Eligible Mass $M_t^{k,\varphi}$	0.90*** (0.10)	1.12*** (0.19)
Prevalence $P_t^{k,\varphi}$ × (ihs) Eligible Mass $M_t^{k,\varphi}$	-1.70*** (0.35)	-1.13*** (0.25)
(ihs) Distance to Tübingen	-0.11 (0.08)	
(ihs) Distance to Wien		-0.10** (0.04)
Log Likelihood $\ell(\alpha)$	-335.286	-317.282
(ihs) Pop in 1500	✓	✓
Observations	67620	67620

F Tests for the proportionality of Hazard Functions

In this section we test the proportionality of the hazard functions (e.g.,scaled Schoenfeld residuals) of all the covariates of Table 2 and Table 3, respectively, and time, with $alpha = 0.45$. The global correlation is only slightly significant in the case of Botanical Realism, while it is not at all significant for Mathematical Astronomy. We can see that by looking at the confidence intervals almost always overlapping with the zero line. The blue line and grey confidence interval relates to the hazard ratios of Prevalence $P_t^{k,\varphi}$ of Botanical Realism (Fig 21a) and of Mathematical Astronomy (Fig 21b), respectively. The yellow line and confidence interval correspond to the hazard ratios of Eligible Mass $M_t^{k,\varphi}$ of Botanical Realism (Panel a) and of Mathematical Astronomy (Panel b). The purple line and confidence interval relates to the hazard ratios of the interaction term between Prevalence $P_t^{k,\varphi}$ and Eligible Mass $M_t^{k,\varphi}$. The red line and confidence interval correspond to the scaled Schoenfeld residuals of "(ihs) City population in 1500", while the green line and interval of confidence represent the hazard ratios of "(ihs) Distance to Tübingen" (Fig 21a) and "(ihs) Distance to Vienna" (Fig 21b), respectively.



(a) Botanical Realism

(b) Mathematical Astronomy

Figure 21: Joint correlations between the scaled Schoenfeld residuals (e.g. hazard ratios) of all the covariates in column (3) of (a) Table 2 and time, and (b) Table 3 and time.

G Example of scholastic reasoning

To fix ideas, a good example of reasoning using the tools of scholastic theology is the second proof of the existence of God by Aquinas as reported by Copleston (1993). Remark that it does not rely much on the scriptures, but rather on a kind of mathematical/logical argumentation:

1. In the world, we can see that things are caused.
2. But it is not possible for something to be the cause of itself because this would entail that it exists prior to itself, which is a contradiction.
3. If that by which it is caused is itself caused, then it too must have a cause.
4. But this cannot be an infinitely long chain, so, there must be a cause which is not itself caused by anything further.
5. This everyone understands to be God.

H Augmenting Rubin's data

Rubin (2014) compiled data on whether European cities were Protestant in 1530, 1560, and 1600, focusing primarily on cities within the Holy Roman Empire. His approach assumed that cities located in officially Catholic countries remained Catholic throughout the period. However, this assumption does not hold for regions such as France and the Low Countries (approximately corresponding to the modern-day Benelux area), where several cities adopted Protestantism temporarily before being reconquered by Catholic forces.

To address this limitation, we have updated the religious status of the following cities to reflect periods of Protestant control, based on information from the Catholic Encyclopedia (Herbermann 1913).

- Die. Protestant control: 1562-1628/1629. Became a Protestant stronghold in Dauphiné during the Wars of Religion. Occupied by royal troops during Richelieu's repression of Huguenot fortresses.
- La Rochelle. Protestant period: 1550s-1628. Key Huguenot stronghold. Besieged and subdued by royal forces under Richelieu in 1628.
- Montauban. De facto Protestant Rule: 1561-1629. Montauban became one of the most fortified and independent Huguenot cities in France. Finally capitulated (1629) to royal troops under Richelieu after the fall of La Rochelle and a renewed campaign to suppress Huguenot political autonomy.
- Montpellier. Protestant control: 1562-1622. Served briefly as a de facto capital of Huguenot political assemblies. Lost military and political autonomy after Siege of Montpellier (1622) by royal troops under Louis XIII.
- Nîmes. Protestant control: 1561-1629. After violent iconoclasm in 1561, the city came under Huguenot control. Held by Protestants throughout the Wars of Religion; formally lost autonomy in 1629 after Richelieu's campaigns.

- Ostend. In 1572, Ostend joined the Dutch Revolt and came under the control of the rebel States-General of the Netherlands, aligning with Protestant (Reformed) forces. After the Siege of Ostend (1601-1604), the city was almost entirely destroyed, and Catholicism was restored under Spanish Habsburg rule.
- Uzès. Protestant control: ca. 1562-1629. Important center in the Languedoc region. Remained predominantly Protestant until submission to royal forces in 1629, when Richelieu dismantled Protestant strongholds.

For the sake of completeness, we list here the cities with Protestant control outside Rubin's years 1530,1560, and 1600.

- Antwerp. Protestant period: ca. 1566-1585. During the Reformation, Antwerp became a Calvinist stronghold. After the Fall of Antwerp in 1585, Protestant worship was banned, and many Protestants fled north.
- Caen. Protestant control: 1562-1572. Important Protestant stronghold in Normandy. The St. Bartholomew's Day Massacre (1572) led to widespread killings and ended Protestant rule.
- Ghent. Protestant period: ca. 1577-1584. Calvinist Republic of Ghent established during the Dutch Revolt. Ended with Spanish reconquest.
- Tournai. Protestant control: 1577-1581. Strong Calvinist presence; fell to Spanish forces in 1581.

I Additional Results with Practical Surgery

In addition to the results in Table 4, we present results controlling for a specific, orthogonal idea: *Exposure to Practical Surgery* PS^c_{1508}. This is interesting because it captures a distinct effect, separate from scholasticism. We compute exposure to Practical Surgery similarly to scholasticism, with the only difference being the starting point. Its "inventor", Guy de Chauliac (c. 1300–1368), was the most prominent physician and surgeon of the Middle Ages. His most famous work *Chirurgia Magna*, published in 1363, was the first to detail surgical procedures, previously handled mostly by charlatans. It remained the main reference well into the 17$^{\text{th}}$ century (The Editors of Encyclopaedia Britannica 2024).

The orthogonal relationship between scholasticism and Practical Surgery is evident in Figure 22: Practical Surgery was more prominent in Southern Europe, spreading independently of scholasticism. In the linear probability model shown in Table 14, *Exposure to Practical Surgery* PS^c_{1508} always has a negative sign, but it is significant only in 1560 and 1600 in the specifications without controls and fixed effects, and only in 1560 when controls and fixed effects are included. We interpret this as further evidence of robustness: even when controlling for university presence and exposure to an orthogonal intellectual tradition, the correlation between scholasticism and a city's likelihood of becoming Protestant remains positive and significant. This reinforces our hypothesis of a "disgust" effect triggered by scholasticism.

Table 14: Linear Probability Model - Exposure to scholasticism in 1508 and cities' probability to become protestant in 1530, 1560, and 1600

	Protestant in			Protestant in		
	1530	1560	1600	1530	1560	1600
	(1)	(2)	(3)	(4)	(5)	(6)
Exposure to	0.001**	0.005***	0.007***	0.002**	0.004***	0.004***
scholasticism S^c_{1508}	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Presence of university	-0.026	-0.035	-0.073*	0.002	-0.010	-0.009
in 1500	(0.027)	(0.042)	(0.044)	(0.021)	(0.031)	(0.032)
Exposure to	-0.001	-0.003**	-0.005***	-0.001	-0.002**	-0.002
Practical Surgery	(0.001)	(0.002)	(0.001)	(0.0004)	(0.001)	(0.001)
Printing press by 1500				-0.038*	-0.035	-0.045**
				(0.022)	(0.022)	(0.020)
(ihs) City population				0.012**	0.003	0.003
in 1500				(0.005)	(0.007)	(0.007)
Free Imperial				0.108	0.143	0.244**
City by 1517				(0.082)	(0.098)	(0.105)
Market potential				-0.005**	-0.011**	-0.010**
in 1500				(0.003)	(0.005)	(0.005)
Hanseatic by 1517				0.020	0.068	0.072
				(0.039)	(0.051)	(0.047)
Lay magnate				-0.022	0.124	0.147*
				(0.037)	(0.075)	(0.079)
(Arch)Bishop by 1517				-0.027	-0.035	-0.043*
				(0.019)	(0.026)	(0.025)
Access to water				0.008	0.002	-0.003
				(0.016)	(0.019)	(0.019)
Imperial Circle FE	✗	✗	✗	✓	✓	✓
1500 Country FE	✗	✗	✗	✓	✓	✓
Observations	867	867	867	867	867	867
Adjusted R^2	0.019	0.149	0.274	0.503	0.724	0.739
Log Likelihood	-199.53	-462.37	-434.54	112.69	41.98	25.32

Notes: Robust SE clustered by territory in parentheses. A constant term is included in all regressions. Dependent variable "Protestant" takes value 1 if the city is protestant in 1530, 1560, 1600, respectively. Data on cities' religion are taken from Rubin (2014) and updated as in Appendix H. "Presence of university in 1500" is a dummy variable taking value 1 if the city had a university in 1500 as in our database (De la Croix 2021). "Exposure to scholasticism S^c_{1508}" and "Exposure to Practical Surgery PS^c_{1508}" are computed as in Equation (7).

J Placebo Inventors of Botanical Realism

Here, we list the twelve scholars we use as "placebo" inventors in the counterfactual analysis in Section 5.1. While it is speculative to say whether each of these twelve individuals could have invented Botanical Realism, many of them were indeed prominent scholars in fields that could have contributed to the development of a more empirical approach to botany. However, the emergence of a paradigm like Botanical Realism depended on a combination of factors–intellectual, cultural, and scientific–beyond the work of individual scholars. Below, a closer look at the potential of each of the individuals:

- Juan Aguilera was professor of medicine and sciences at the University of Salamanca from 1538 to 1560 (Vidal y Díaz et al. 1869; Esperabé de Arteaga et al. 1917): as he had a background in natural philosophy or medicine, he could have contributed to a more empirical study of plants, as Salamanca was a leading university with a strong focus on scientific inquiry during the Renaissance.
- John Warner taught medicine at the University of Oxford from 1520 to 1554 (Gunther 1937) and was a member of the Royal College of Physicians (1561): he might have had access to Renaissance humanist ideas, but Oxford was more conservative at the time, and Warner would need a strong inclination toward natural science to spearhead Botanical Realism.
- Jeremius Dryvere taught medicine at the University of Louvain from 1522 to 1554 (Lamberts and Roegiers 1990): Louvain was a center of scientific learning, and someone like Dryvere could have contributed to botanical studies.
- Andreas Goldschmidt taught medicine at the University of Königsberg from 1550 to 1559 (Schwinges and Hesse 2019): As a scholar trained in Wittenberg, where humanism and scientific inquiry were encouraged, Goldschmidt could have been part of the intellectual currents that led to developments like Botanical Realism.
- Mikołaj Mleczko Wieliczki was professor of medicine at the University of Cracow from 1512 to 1552 (Uniwersytet Jagielloński 2019): Cracow had a strong tradition in astronomy and natural sciences, and a scholar like Wieliczki could have contributed to the empirical study of nature.
- Jacob Bording was professor of medicine at the University of Rostock from 1549 to 1556 and at the University of Copenhagen from 1556 to 1560 (Slottved 1978): as a prominent physician, Bording would likely have been interested in botany as it related to medicine, which was a key motivator for many early botanists.
- Antoine Saporta was professor of medicine at the University of Montpellier from 1531 to 1573 (Dulieu 1979): Montpellier was a leading medical school, and Saporta, as a physician, would have had a strong interest in medicinal plants. He could have been well-positioned to develop a more scientific approach to botany.
- Girolamo Donzellini taught medicine at the University of Padua from 1541 to 1543 (Facciolati 1757): The University of Padua was a hub of medical and scientific learning, so Donzellini, with his interest in medicine, might have had the right environment to develop Botanical Realism.
- Oronce Fine taught sciences at the Royal College in Paris from 1530 to 1555 (Collège de

France 2018) : Although primarily a mathematician and cartographer, Fine was part of a broader Renaissance movement that emphasized empirical study, and he could have contributed to a more systematic approach to botany.

- Realdo Colombo taught medicine at the universities of Padua (1538–1544), Pisa (1544–1548) and Roma (1548–1559), see Del Negro (2015): he was a noted anatomist, and his empirical methods in anatomy could have translated well into botany, particularly in the detailed study of plant structures.
- Georg Joachim Porris taught sciences at the universities of Wittenberg (1537–1542), Leipzig (1542–1551) and Vienna (1554–1555), see Schwinges and Hesse (2019) and Aschbach (1865). Also known as Rheticus, Porris was an astronomer and mathematician. While not a botanist, his scientific mindset might have inclined him toward an empirical approach in natural studies if he had turned his attention to plants.

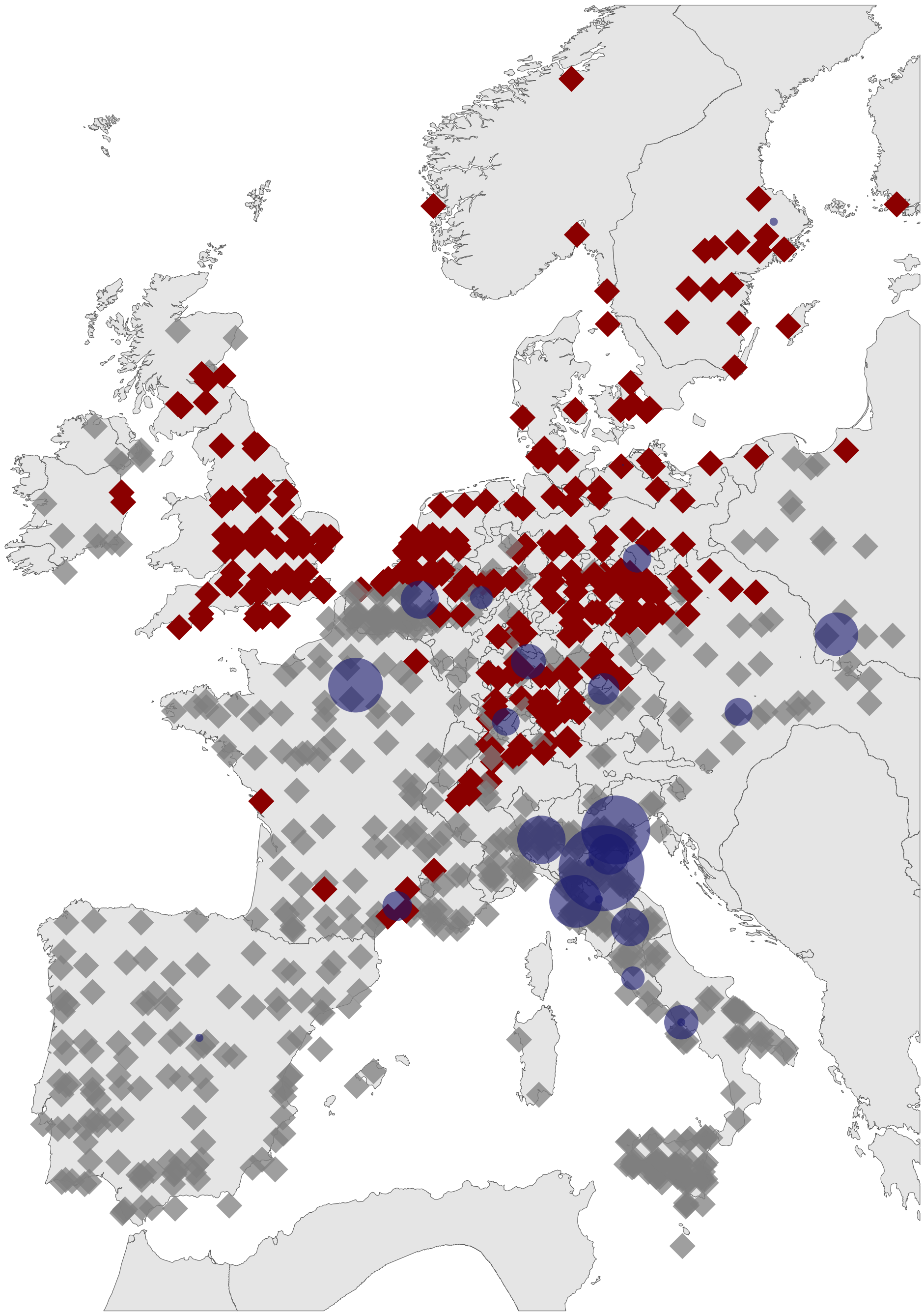


Figure 22: Blue bubbles represent the yearly exposure to Practical Surgery in 1508. $\alpha = 0.45$ and $D = 5,000$. Protestant cities are the red diamonds, and Catholic cities are the grey diamonds. Data on cities' religion are taken from Rubin (2014) and updated as in Appendix H, they reflect the religious status in 1600.

J.1 Centrality of the Placebo inventors

The likelihood of an idea spreading depends on how well-connected its inventor is, typically measured by degree centrality—the number of edges a node has. However, degree centrality (and other centrality measures) does not fully capture the dynamics of idea diffusion, which unfolds over time rather than at a single moment. A high degree centrality does not necessarily equate to greater reach. To illustrate this, we report the degree centrality of each placebo inventor in 1542 (i.e., the number of colleagues in the same field) or in the first available year of activity.

If Fine (2) or Colombo (19) had been the originators, the idea would have already spread to around 50% of the academic population by the second half of 1600. The next fastest spread would have occurred with Dryvere (8) and Porris (22), followed by Saporta (6) and Bording (2 in 1550). For Warner (10), the spread would occur significantly later, only accelerating after the establishment of the first major academies, with a sharp increase around 1640. If Goldschmidt (0 in 1542, but 1 in 1549) had been the inventor, the idea would have struggled to survive initially, only gaining rapid traction around 1680. Interestingly, had Aguilera (8) been the inventor, the idea would have remained confined to Salamanca, persisting without spreading elsewhere until the end of the 18th century, when we observe a sudden spike. This shift coincides with scientists from the Spanish university beginning to affiliate with more international academies. In one case (Wieliczki (3) in Cracow), the idea fails to spread altogether. These simulations demonstrate how academic institutions can play a crucial role in preserving ideas that might otherwise remain obscure due to their development in less influential locations.

K Placebo networks and the role of the Jesuits

In the paper, we explore a counterfactual scenario examining the spread of ideas after removing Jesuit scholars from the network. Here, we present key statistics on the position and connectivity of Jesuits within the affiliation network. The network metric in Figure 23d quantifies how well-connected Jesuit-affiliated nodes are to the rest of the network. In our network structure, conductance reflects the extent to which Jesuits were integrated into mixed institutions rather than remaining isolated. The initially high conductance suggests that early Jesuits were present in diverse academic environments. Over time, the decline in conductance aligns with their increasing concentration within Jesuit institutions. Figure 24b shows the Homophily Index of Jesuits, by field between 1556 and 1767. Notably, the decreasing trend in inbreeding homophily among Jesuit scientists is likely a consequence of the rise of academies, which were largely centered on scientific disciplines and saw a relatively active participation from Jesuits.

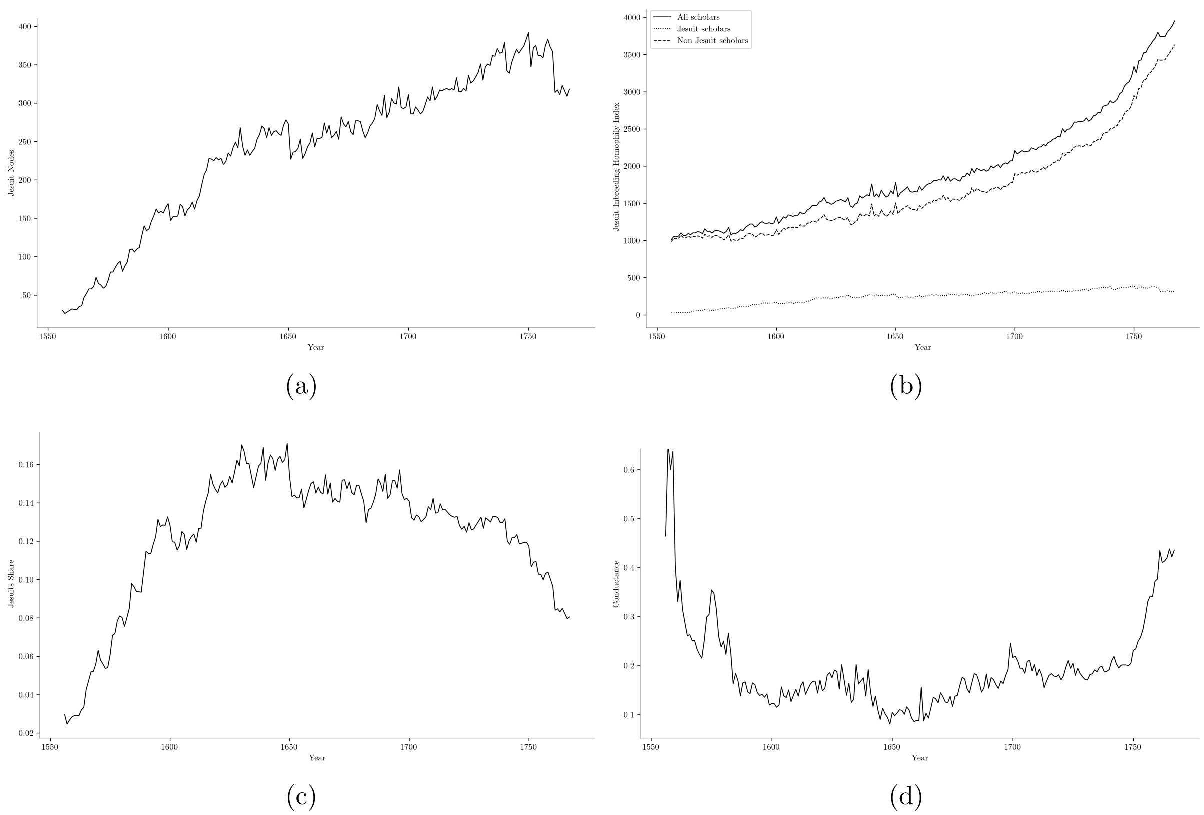
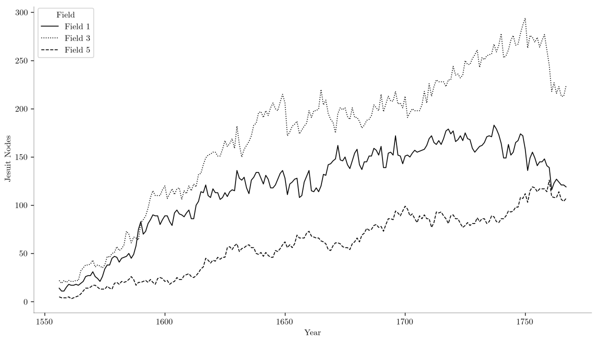
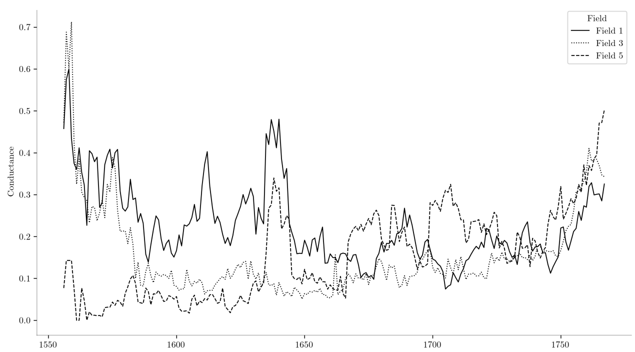


Figure 23: (a) Number of Jesuit scholars active in the network, 1556-1767. (b) Comparison of number of scholars by type: all (solid line), Jesuits (dotted line), and non Jesuit scholars (dashed line),1556-1767. (c) Fraction of Jesuit scholars active in the network, 1556-1767. (d) Conductance of Jesuits in the affiliation network, 1556–1767.



(a)

(b)



(c)

Figure 24: (a) Number of Jesuit scholars active in the network by field, 1556-1767. Field 1 stands for theology, field 3 for humanities, and field 5 for sciences. (b) Homophily Index of Jesuits, by field, 1556-1767. Field 1 stands for theology, field 3 for humanities, and field 5 for sciences. (c) Conductance of Jesuits in the affiliation network by field, 1556–1767. Field 1 stands for theology, field 3 for humanities, and field 5 for sciences.

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