Research Policy 50 (2021) 104298

Contents lists available at ScienceDirect

Research Policy

journal homepage: www.elsevier.com/locate/respol

Long waves in the geography of innovation: The rise and decline of regional clusters of creativity over time

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ARTICLE INFO

Keywords:
Knowledge spillover
Geography of innovation
Social networks
Social encounters
Mobility
Creativity

ABSTRACT

We explain the rise and decline of regional clusters of creativity over time. We argue that this dynamic is the result of the interplay of individually rational decision-making processes with collective externalities of unplanned social encounters; migration to particular places at particular times interacts with a preference to engage with similar others. This interplay leads to the rise and subsequent decline of opportunities for encounters between people who operate in different domains, a basic requirement for radical innovative change. The consequent decline of formerly innovative regions creates opportunities for new innovative regions to emerge. We test this theory using three independently curated datasets. The first includes the geocoded places and years of the births and deaths of 124,860 notable individuals who lived in Europe between 1000 and 1900 CE, used to measure opportunities for domain-diverse encounters in regions and regions' time-varying attractiveness in global mobility networks. The second and third datasets consist of the geocoded locations and founding years of 3,165 Catholic monasteries and of 16,596 publishing houses. We use these organizational innovations as robust, independent indicators for a region's capacity to foster incremental and radical change. Our paper aims to open a broader social network perspective on the rise and decline of regional clusters of creativity over time.

Introduction

Creative activity concentrates in particular places and at particular times. Consider, as examples, Athens in the fourth century CE, Rome from ancient times to the renaissance, Florence under the Medici, Venice in the twelfth century, Paris in the 1920s, Silicon Valley, and the rise of present-day Jerusalem. The geography of innovation has long highlighted the importance of proximity to such creative centers for innovation and creative change (for overviews, see Audretsch and Feldman, 2004; Ciccone, 2002; Feldman and Kogler, 2010; Henderson, 2007; Sorenson, 2018; Stuart and Sorenson, 2003). Although it is commonly accepted that creativity and innovativeness tend to cluster both spatially and temporally, the social mechanisms by which creative clusters emerge, maintain, and potentially lose their positions over time remain unclear.

Broadly, the literature has argued that innovation concentrates in geographic regions for two main reasons: First, individuals and firms benefit from agglomeration externalities, for example, because spatial proximity allows them to share specialized suppliers and to adopt innovations more rapidly, or because they can draw upon a shared labor pool and benefit from favorable institutional settings (e.g., Feldman and Kogler, 2010; Klepper, 2010; Ponds et al., 2010). Second, individuals and firms benefit from social externalities, a concept that captures the general insight that people can also benefit indirectly from being in proximity to others. In the literature, such social externalities are commonly referred to as "localized knowledge spillovers" (Audretsch, 2003; Bottazzi and Peri, 2003; Branstetter, 2001; Jaffe et al., 1993; Maurseth and Verspagen, 2002; Romer, 1990; Sonn and Storper, 2008; Tappeiner et al., 2008). They have been explained by the "stickiness" of local knowledge (Cohen and Levinthal, 1990; Cook and Brown, 1999; Nelson and Winter, 2009; Polanyi, 1967; von Hippel, 1994) and by the "stickiness" of social relations (Sorenson, 2005, 2018; Stuart and Sorenson, 2003).

Although both accounts help explain what attracts individuals and firms to certain places at particular times, the mechanisms by which being in the right place at the right time fosters individual creativity and innovativeness remain underexplored (Audretsch and Feldman, 2004; Feldman and Kogler, 2010; Henderson, 2007). On the one hand, a similarity-attraction perspective (van Knippenberg and Schippers, 2007; Williams and O' Reilly, 1998) emphasizes that specialization fosters

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https://doi.org/10.1016/j.respol.2021.104298
Received 28 May 2020; Received in revised form 19 May 2021; Accepted 31 May 2021
Available online 11 June 2021

innovativeness by concentrating talent in particular sectors and regions (Marshall, 2009 [1920]). On the other hand, an information-decision-making perspective (van Knippenberg and Schippers, 2007; Williams and O' Reilly, 1998) argues that exposure to dissimilar others is an important stimulant of creativity and innovative renewal (Jacobs, 2016 [1969]). The empirical literature shows that both perspectives exhibit merit, depending on the activities in question (Beaudry and Schiffauerova, 2009; Feldman and Kogler, 2010; Van der Panne, 2004; van Knippenberg and Schippers, 2007; Williams and O' Reilly, 1998). In line with this assessment, studies find overall performance of regional clusters to be greatest when the local firm base is diverse but concentrated in related industries and technologies (Aarstad et al., 2016; Boschma and Iammarino, 2009; Castaldi et al., 2015; Frenken et al., 2007). While this literature connects local diversity to both firm- and cluster-level performance and value creation (as measured, e.g., by inventive activity, employment numbers, or profitability), it lacks a conceptual micro-foundation for the emergence and decline of local clusters of creative activity as precondition for radical–as opposed to incremental–innovativeness (Hervás-Oliver et al., 2018; Hesse and Fornahl, 2020; Lazzeretti et al., 2019). How and why do some regions become hotspots for creative renewal and innovation while others remain obscure? And why do regions lose this status in the long run?

In this paper, we develop a dynamic network account of the rise and decline of local clusters of creativity over time. We combine a creativity perspective on how domain-diverse encounters and specialization affect local innovativeness with a dynamic network perspective that considers the motivation of creative individuals to migrate between regions over time. Creativity theory posits that exposure to people who operate in different domains fosters radical advancements that fundamentally alter the way problems are solved, whereas exposure to people who operate within the same domain fosters incremental solutions to well-defined problems within that domain. Social network theory adds that relationships cluster locally in social space. We bring both perspectives together by modeling the likelihood of chance encounters between people of different domains as a function of opportunity structures (Blau, 1994; Sorenson, 2018): the number of creative people in a region, and how likely they are to encounter others who work in the same domain as themselves. This account highlights that creative clusters form as a result of rational decision-making processes, namely of individuals migrating to places where other creatives have been successful before them, and of social externalities, namely of how changes in local network size and composition affect opportunities for unplanned encounters with other creative individuals over time.

Our theory explains why some domain-diverse regions become hubs of radical innovations and why the innovativeness of these hubs nevertheless ultimately declines over time. It predicts that the opportunities for domain-diverse encounters in local environments, and thus the local potential to foster radical or incremental innovation, are driven by dynamic network mechanisms. Specifically, the potential for domain-diverse encounters is greatest in peripheral regions that are too remote to sustain large domain-specialized networks, forcing individuals to engage with others who operate in domains other than their own. However, as regions gain reputations as creative hotspots, they attract ever more creative individuals who go where others have been successful before them. Such individually rational "domain-preferential" location decisions set in motion social externalities that adversely affect the likelihood of domain-diverse encounters: local specialization and domain-preferential attachments. As regions become known for particular activities, they disproportionately attract individuals from those specific domains, resulting in local specialization. Once specialized domains grow beyond a certain size, a preference to associate with similar others (a social phenomenon that is referred to as "homophily" in the social networks literature) dampens the likelihood of encounters between domains. This suggests first a rise and then a decline of opportunities for domain-diverse contacts within regions, which we explain by the interplay between individually rational decision-making and unplanned social externalities.

Empirically, we study the worldwide mobility of 124,860 notable individuals who lived in Europe between 1000 and 1900 CE and how these creative people formed and dissolved local clusters of creativity and innovative potential over a 900-year period in Europe. We measure the diversity of local clusters of creative people and quantify the opportunities for domain-diverse encounters in a region conditional upon the attractiveness of this region in the global mobility network at the time. To measure indirect processes of knowledge spillovers originating from these clusters of creative people, we use two independent output measurements that only indirectly link to the activity domains of the individuals considered: the founding of 3,165 Catholic monasteries and of 16,596 publishing houses. We treat these output measures as indicators of a region's capacity to foster incremental and radical innovations and change.

The systematic analysis of the innovativeness of 331 regions over a 900-year period offers insights that hold across settings and over time. In line with earlier research, our findings emphasize the importance of social networks for regional development (Bathelt and Glückler, 2018; Boschma and Frenken, 2011; Ter Wal and Boschma, 2009). We add to this literature by highlighting how social networks regulate serendipitous encounters and how these in turn affect a region's prospects for creativity and innovation. The diversity of local social networks is identified as important driver for radical, transformative change Ter Wal and Boschma (2011). From a broader sociological perspective, the presented account insists that regional clusters of creativity are embedded in local settings that condition the type and quality of knowledge spillover that occur.

A theory of localized knowledge spillover in long waves of the geography of innovation

The role of domain diversity in local environments for creative change: a static perspective

Creativity theory assumes that creativity is a basic prerequisite for innovations because it leads to the generation of novel and appropriate ideas, processes, and solutions (Amabile, 1996; Burt, 2004; Kanter, 1988; Mumford, 2000; Perry-Smith and Mannucci, 2017; Perry-Smith and Shalley, 2003; Rost, 2011; Simonton, 1984; Sytch and Tatarynowicz, 2014). Creativity originates in individuals but is strongly affected by external factors, notably by exposure to information, diverse perspectives, varying interests, and alternative approaches to solving problems. Opportunities to meet and observe other creative people are thus very important for the emergence and promotion of creativity in individuals who develop innovations.

However, there has been a lively debate about which type of social network exposure better fosters creative ideas within individuals. One view, often called the information-decision-making perspective, argues that exposure to creative people from diverse functional, educational, task, and industry backgrounds, also termed domain diversity, fosters creativity in individuals (van Knippenberg and Schippers, 2007; Williams and O' Reilly, 1998). From this perspective, diversity is positive because it increases the extent of cognitive resources, the breadth of perspectives, and problem-solving capacity in general (Hambrick and Mason, 1984; Janis, 1982; Lant et al., 1992). In line with this argument, studies have shown that diversity is associated with greater information use (Dahlin et al., 2005). This is accompanied by a positive assessment of task conflicts (Bantel and Jackson, 1989; Pelled et al., 1999). Task conflict occurs when people in a local environment have different opinions about how to solve a problem (Hambrick and Mason, 1984; Janis, 1982; Lant et al., 1992). It generates greater variance in decision-making alternatives Cox (1993), stimulates creative thinking and thought processes that improve the decisions of individuals (Coser, 1956; De Wit and Greer, 2008; Deutsch, 1969; Schweiger et al., 1986), and prevents complacency and groupthink or "homophily bias"

(Eisenhardt and Bourgeois, 1988).

Another view, often called the similarity-attraction perspective, argues that exposure to creative people from similar functional, educational, and industry backgrounds fosters creativity through task specialization (van Knippenberg and Schippers, 2007; Williams and O' Reilly, 1998). From this perspective, task homogeneity fosters creativity because the more people interact with similar people, the more likely they are to absorb and pass on information. Similarity also results in greater familiarity and emotional intimacy, which helps to avoid interpersonal conflicts and reduce uncertainty and fear (Ancona and Caldwell, 1998; Ibarra and Andrews, 1993a; Tsui et al., 2002). From this perspective, the threat of interpersonal conflicts can cause anxiety (Jehn et al., 1997), thereby negatively impacting cognitive performance and creating barriers to communication and cooperation (Kearney et al., 2009).

The same views on domain diversity versus domain homogeneity have been advanced in the geography of innovation. The Jacobsian view argues that exposure to dissimilar others is an important stimulant of creativity and innovative renewal (Jacobs, 2016 [1969]). The Marshallian view emphasizes that specialization fosters innovativeness by concentrating talent in particular sectors and regions (Marshall, 2009 [1920]). The empirical literature shows that both perspectives exhibit some merit, depending on the tasks to be solved (Beaudry and Schiffauerova, 2009; Feldman and Kogler, 2010; Van der Panne, 2004; van Knippenberg and Schippers, 2007; Williams and O' Reilly, 1998).

The innovation literature shows that domain diversity improves solutions to complex, nonroutine problems because people's disagreements about task issues lead to the inclusion of a greater number of perspectives, whereas domain homogeneity improves solutions to routine problems because people absorb and pass on information more readily (Bantel and Jackson, 1989; Pelled et al., 1999). The solution of complex, nonroutine problems often results in radical advancements that fundamentally alter the way problems are addressed (Schumpeter, 2003 [1943]), whereas the solution of routine problems leads to more incremental adjustments, recombinations, and extensions of existing principles within a field. The literature suggests that domain diversity in environments often leads to radical innovations, whereas domain homogeneity in environments often leads to incremental innovations Breschi and Lenzi (2016). This conclusion is supported by creativity theory: Exposure to people who operate in the same domain is likely to increase those people's specialist ability to generate feasible, appropriate, and unique solutions to well-defined problems within that domain (Amabile, 1996; Perry-Smith and Shalley, 2003). By contrast, individuals' exposure to others who are active outside their domain is likely to enhance their creativity-relevant skills. As Kanter explains, contact with "those who see the world differently is a logical prerequisite to seeing it differently ourselves" (1988, 175). Overall, this leads us to predict that if a region offers many opportunities for local interactions with other domains, it should foster the region′s potential to generate radical innovative change. Conversely, if a region offers many opportunities for local interactions within domains, it should foster the region′s potential to generate incremental innovative change.

Hypothesis 1. *Regions with many opportunities for domain-diverse encounters foster radical innovation.*

Hypothesis 2. *Regions with many opportunities for within-domain encounters foster incremental innovation.*

Domain diversity and the tendency for homophily in social networks: a dynamic perspective

The arguments presented so far are static. They cannot explain why formerly innovative regions become less innovative over time, nor do they explain why initially obscure regions can become hotbeds of creativity and radical change. To address these questions, a dynamic account is needed that considers how the creative potential and innovativeness of regions affects the size and composition of local social networks over time. The following account builds on the premise that creative individuals are drawn to places where other creative individuals have gone before them, suggesting that regional hubs of radical change attract other creative individuals. Local environments are thus embedded in a global mobility structure in which they are connected by creative individuals who move between regions (Bathelt et al., 2004; Godart et al., 2014; Henn and Bathelt, 2017; Lomi and Larsen, 1996; Owen-Smith and Powell, 2004; Uzzi and Spiro, 2005). At the same time, however, these migratory flows of creative individuals affect the size and composition of social networks within regions and thus affect the conditions for localized knowledge spillovers to occur. This mutual causality has been addressed in various literatures, for example on geographic concentration as unplanned social encounter externalities at the local level (e.g., Sorenson, 2005, 2018; Sorenson and Audia, 2000); in the co-evolution of firms, social networks, and regions (Boschma and Ter Wal, 2007; Lazzeretti and Capone, 2017; Ter Wal and Boschma, 2011); and on the relation between creativity and social networks (Perry-Smith, 2006; Perry-Smith and Mannucci, 2017).

As a region attracts creative individuals from other regions, it becomes more central in the global mobility structure, which in turn attracts more individuals. One network centrality measure that captures this dynamic of relative regional importance particularly well is eigenvector centrality Bonacich (1987). Eigenvector centrality assigns relative scores to regions in the global mobility structure based on the premise that immigration from central regions contributes more to a region's centrality than does immigration from peripheral regions. Regions of high eigenvector centrality are at the center of information and knowledge circulating within the global mobility structure. Regions of low eigenvector centrality are on its periphery: they neither attract many creative individuals, nor do they originate them. This sets processes in motion that have the potential for fostering localized knowledge spillovers. As the network grows, the opportunities for local interactions with other domains, and thus the opportunities for domain-diverse encounters, increase dramatically. Moreover, the creativity literature shows that being in a more central region leads to higher perceptions of freedom, more personal discretion, and more calculated risk-taking (Florida, 2005; Ibarra and Andrews, 1993b; Perry-Smith, 2006). As people in central regions have improved access to information from other regions, centrality in the global mobility structure should also lead to more favorable exposure to new ideas.

For a time, the attraction of creative individuals to a region thus suggests the best of both worlds: a growing base for agglomeration externalities as basis for local specialization and contact among creative individuals that provides productive friction. Over time, successful regions develop reputations for particular approaches, attracting specialists and encouraging newcomers to imitate and converge on tried and tested solutions Wenting (2008). Growth can initiate self-perpetuating dynamics as locally viable solutions that prove particularly effective are codified, passed on, and replicated in subsequent ventures (Buenstorf and Klepper, 2009; Klepper, 2009, 2010). In this period of ascendancy, overall innovative performance will increase as the local knowledge base finds application in related domains (Aarstad et al., 2016; Boschma and Iammarino, 2009; Castaldi et al., 2015; Frenken et al., 2007). The resulting dynamics – of network growth through reputation, convergence on tried solutions, and increasing specialization – extend the status quo into increasingly specialized activity domains.

However, this positive effect of local network growth on creativity cannot last forever, because the increasing convergence on established approaches ushers in a period of incremental change (Anderson and Tushman, 1990; Menzel and Fornahl, 2010). As local networks of creative individuals grow in size and reputation, individuals' efforts to establish themselves in their own activity domain increasingly exerts normative pressures to adhere to received views DiMaggio and Powell (1983); this has the effect of limiting the prospects of radical change (de

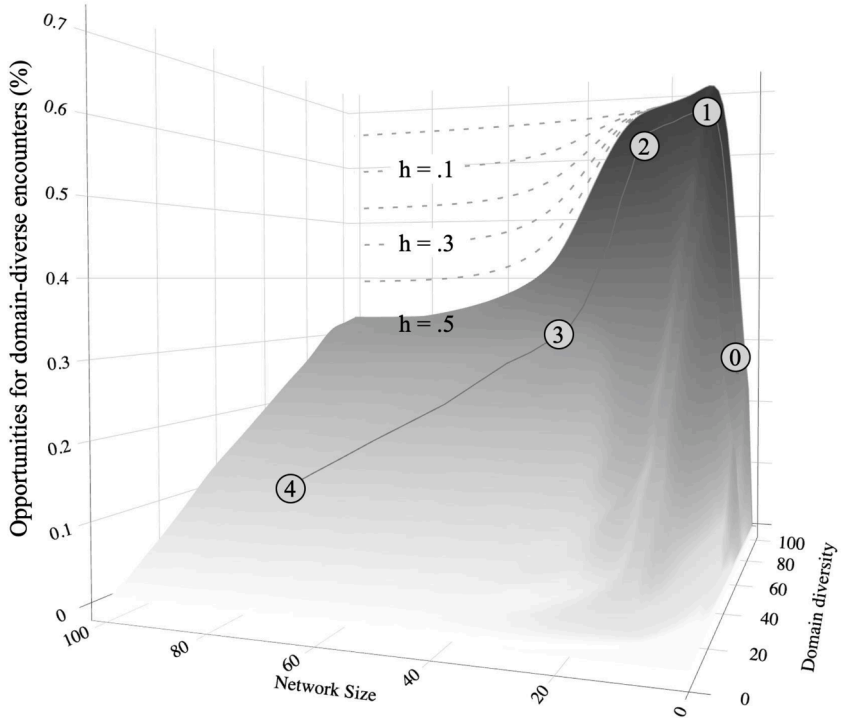

Fig. 1. Opportunities for domain-diverse encounters as a function of domain diversity and network size.

Vaan et al., 2019). The resulting inward orientation of those who operate in established activity domains detracts individuals' finite attention from encounters with those who operate in other domains. Once the social networks of creative individuals grow beyond a certain size, the opportunities for encounters that challenge the prevailing view must decline. We model the underlying process as mutually reinforcing interactions between increasing centrality in social networks, rising numbers of creative individuals in local environments, and declining opportunities for domain-diverse encounters. The resulting framework suggests that regions evolve from Jacobsian regimes of creativity-related spillovers that solve complex, nonroutine problems and develop radical innovations, as described in Hypothesis 1, to Marshallian regimes of specialization-related spillovers that solve well-defined problems and develop incremental solutions within domains, as described in Hypothesis 2. This process can be modelled mathematically by considering the social mechanisms working in local environments, more precisely, by modeling a preference for domain-homophilous contacts.

Social network theory shows that relationships tend to exist locally not just in physical space but also in social space. The likelihood of chance encounters that bring people of different domains into contact with one another is thus a function of local opportunity structures: how many people live within a region and how likely they are to meet other people of the same task domain. These local opportunity structures give rise to *opportunities for domain-diverse encounters*. As shown in the previous section, domain-diverse encounters are important for the type of problems that can be solved in local environments. Complex, nonroutine problems will foster radical innovation, and noncomplex, routine problems will foster incremental innovation.

If local interactions between individuals occurred independently of domain backgrounds, the likelihood of contacts between individuals of different domains could be expressed as a domain-diversity index, $\prod_i^N$ (see Eq. 1). This index measures the likelihood of between-domain encounters as sum of the opportunities for interactions n_i within domains i divided by the opportunities for interactions n irrespective of domain. The index ranges from 0 to 1, with higher values indicating higher domain diversity in local environments.

$$\prod_i^N = 1 - \Sigma_{i=1}^N \frac{(n_i \cdot (n_i - 1)/2)}{n \cdot (n-1)/2} \tag{1}$$

However, due to homophily, those with similar task backgrounds often develop similar interests and belong to the same professions and organizations (Blau and Schwartz, 1984; Marsden, 1988; McPherson and Smith-Lovin, 2001). Shared activities and group memberships act as social focal points that create opportunities for similarly minded people to meet and interact (Feld and Grofman, 2009; Feld, 1981; Sorenson, 2018), resulting in locally clustered social networks (Centola, 2015; Gulati et al., 2012). This process is intensified by the fact that individuals are only able to maintain a limited number of relationships overall (Roberts et al., 2009). We therefore operationalize opportunities for domain-diverse encounters $\prod_{g,h}^n$ by adding a corrective parameter h that applies only to members of large-domain groups $n_i \geq l$. Parameter h captures the extent to which individuals who are active in large-domain groups seek out within-group interactions over random interactions. The homophily parameter h ranges between 0 and 1 and captures the proportion of local interactions that members of large domain groups assign to members of their own group i compared to the random assignment of local interactions to all domain groups.

$$\prod_{i,h}^N = \left(1 - h_{n_i \geq l} \cdot \frac{n_i \cdot n_i}{n^2}\right) \cdot \prod_i^N \tag{2}$$

Fig. 1 graphically illustrates the opportunity index in Eq. 2, which depends on network size and the distribution of individuals across different domains, domain diversity.[1] Based on our empirical data, we assume the existence of three activity domains and that homophily comes into effect if a local domain consists of 15 people or more. The figure shows the effects of varying homophily between $h = 0.0$,

[1] Opportunities for domain diversity change erratically for small networks. For example, a network of size 2 is 100% diverse if both individuals are active in different domains and 0% diverse if both are in the same domain. To reflect the intended, more general, sense of opportunities for domain diversity, we average values across neighboring size–composition combinations.

suggesting that members of large-domain groups randomly assign their interactions to all domain groups, and $h = 0.5$, suggesting that members of large-domain groups assign half of their interactions to members of their own group and the other half randomly across all domain groups. Fig. 1 shows clearly that in domain-diverse local environments the opportunities for domain-diverse encounters first increase with network size but soon decrease if local networks continue to expand. This decrease in opportunities for domain-diverse encounters is more pronounced the greater the tendency is for homophilous interaction in social networks.

The previous considerations suggest that as regions gain centrality in the global mobility structure, they attract more and more creative individuals from other regions. However, as the prominence of regions increases, network mechanisms are set in motion that affect the likelihood of interactions generating radical as opposed to incremental knowledge. Increasing local network size and domain-preferential attachment result in a decline in opportunities for domain-diverse encounters. These network mechanisms supply a micro-foundation to the macro-dynamics of cluster evolution. Once activity domains grow large enough that their members organize and consolidate their activities, individuals increasingly associate with others in their own domains. As Fig. 1 shows, even modest individual-level preferences for associating within one's domain substantially diminish the overall opportunities for domain-diverse encounters in a region. This process explains why Jacobsian regimes of creativity-related spillovers that foster complex, nonroutine solutions and radical innovations, as described in Hypothesis 1, evolve over time into Marshallian regimes of specialization-related spillovers that solve well-defined problems within that domain and develop incremental solutions, as described in Hypothesis 2. As once radically innovative environments evolve into environments that only foster incremental change, this creates opportunities for new regions to emerge as hotbeds of radical innovation. This leads us to predict that

Hypothesis 3. *As regions grow in eigenvector centrality, the opportunities for domain-diverse encounters decrease.*

In sum, this dynamic view allows two ideal-typical stages to be identified in the evolutionary development of regions, as indicated in Fig. 1: emergence and growth (the region transitions from position 0 to 2, see Fig. 1), and consolidation and decline (the region transitions from position 2 to 4, see Fig. 1). In the process of emergence and growth, peripheral regions are generally relatively unknown and, thus, attract few creative individuals from outside. As they fail to attract consistent flows of creative individuals, the specialization of creative individuals in different domains is somewhat arbitrary. If two or more individuals come into contact with one another, they will likely be active in different domains. Peripheral regions will thus be characterized by high levels of opportunities for domain-diverse encounters but will lack access to access to a sufficiently developed and up-to-date domain-specific knowledge base. Most peripheral regions will therefore not be particularly innovative. If they are, however, new solutions are likely to be unaligned with the status quo ante and thus radical in nature and/or impact. Most regions remain peripheral. However, if a region develops a reputation for changing the status quo by fostering creativity and radical new solutions, it begins to attract aspiring creatives, who are drawn to places where other creative individuals have been successful before them Florida (2005). As a region attracts creative individuals from other regions, it gains centrality in the global mobility structure. This sets self-reinforcing processes in motion that have the potential for fostering localized knowledge spillovers. As the network grows, the opportunities for local interactions with other domains, and thus the opportunities for domain-diverse encounters, increase dramatically. In the process of consolidation and decline, regions increase in prominence and attract ever more people from further afield. Increasing local network size and domain-preferential attachment results in a decline in opportunities for domain-diverse encounters, suggesting that once radically innovative environments evolve into environments that only foster incremental change.

Data and method

A note on the use of historical data

We test the presented hypotheses using historical data. Historical data are suitable for the analysis of very long-term developments, as is proposed by the shift of a region from a Jacobsian regime of creativity-related spillovers that foster radical innovations into a Marshallian regime of specialization-related spillovers that foster more incremental solutions. In general, such a development needs several decades if not even centuries. Consider the examples given in the introduction, of Athens in the fourth century CE, Rome from ancient times to the renaissance, Florence under the Medici, Venice in the twelfth century, Paris in the 1920s, Silicon Valley, or the rise of present-day Jerusalem. Such long-term observation periods preclude the use of many common methods of data collection, such as experiments, surveys, and contemporary archive data like patent, publication data, and annual reports. Historical data have the decisive advantage that developments can be traced quantitatively over centuries and general conclusions drawn for social science theory. However, this advantage comes at the expense of clear causality between phenomena as well as the precision of the measuring instruments used.

In contrast to experiments, historical research is generally not able to isolate one or a few test factors and thus cannot test causal relationships between test and effect factors. However, this disadvantage is of minor relevance for our theory, because we assume that the dependent and independent variables, the innovativeness of a region and the opportunities for domain-diverse encounters respectively, mutually influence each other. In addition, experiments and survey data have the clear advantage that the instruments used to measure effects can be defined very precisely. Historical data do not have this advantage. Rather, it is necessary to use proxies that reflect part of the variance of the constructs of interest. Furthermore, historical variables are often incomplete, which makes quantitative historical research challenging. In this respect, however, historical research differs only slightly from the approaches widely used in innovation research with contemporary archive data. Here, too, researchers use proxies, such as the number of patent citations to measure the degree of innovation or technological path dependency, the number of co-authorships to measure collaborations, or the demographics of top managers as indicators of executives' cognitive frames. These disadvantages are accompanied by considerable advantages that explain the use of archival and historical research methods.

As mentioned, the time horizon of archival data can be much longer than that of experiments and surveys and is thus able to address long-term phenomena. Moreover, historical and archive data often provide large samples if not whole populations rather than analyzing more or less representative subsamples. Finally, the external validity of historical and archival data is considerably higher than that of either surveys or experiments. The evidence can be based on factual events and not on perceptions, socially desirable behavior, or abstract tasks that only vaguely correspond to real-world situations. Weighing up these advantages and disadvantages, the use of historical data seems the most suitable for our research question.

Data and data preparation

We combine and analyze three independently curated longitudinal datasets. The first consists of the geocoded places and years of the births and deaths of 124,860 notable artists, politicians, entrepreneurs, scientists, and academics who lived in Europe between 1000 and 1900 CE and whose life-time achievements received universal recognition (Schich et al., 2014). In the aggregate, these biographical data yield time-varying indicators of local clusters of notable creative individuals within regions and capture the major cultural centers that these creative

individuals were drawn to in their lifetimes (Laouenan et al., 2016; Schich et al., 2014). We use these data to measure local opportunities for domain-diverse encounters and the centrality of regions in the evolving global mobility network. The second dataset includes the geocoded locations and founding years of 3,165 Catholic monasteries established by the twelve largest Roman Catholic orders between 1000 and 1900 CE. The third dataset includes the geocoded locations and founding years of 16,596 publishing houses established between 1500 and 1900. We use these datasets to measure localized knowledge spillovers: how opportunities for domain-diverse encounters in regions indirectly foster radical or incremental innovations.

The biographical data for creative individuals is taken from Schich et al. (2014), who have compiled a dataset of the years and places of the births and deaths of 294,177 notable individuals throughout history. They draw on four sources: *Freebase.com*, the *Allgemeines Künstlerlexikon*, the *Getty Union List of Artist Names*, and the *Winckelmann Corpus*. These sources differ in coverage, precision, and completeness, with recorded places ranging from "Number 10 Downing Street" as the site where the former British Prime Minister Henry Campbell-Bannerman died in 1908, to "India" as the country where Copenhagen-born zoologist Theodor Edvard Cantor passed away in 1860. Adopting a conservative, multistep approach to matching place IDs included in the dataset, city names, and georeferences rounded to three digits, we were able to establish harmonized geo-coordinates for 189,817 of the 210,470 famous individuals born before 1900 CE. After checking for errors, we aggregated these harmonized geo-coordinates to 2,485 regions around the world based on geospatial proximity. All individuals were assigned to regions whose geometric centers are less than 100 km removed from their recorded place of birth or death. Because we focus on developments in Europe, we limited the analyses to individuals who were either born or who died in one of the 331 regions that are located in present-day Europe. This attenuates the regional bias of the data, which has a preponderance of notable individuals from the Western hemisphere (cf. supplementary materials to Schich et al., 2014). The final dataset includes 124,860 individuals whose places of birth and death are assigned to one of 1,604 regions around the world, 331 of which are located in Europe.

The second dataset includes the geocoded locations and founding years of all monasteries founded by the twelve largest Roman Catholic orders. This dataset also contains the founding year of each Roman Catholic order and detailed information on the economic, political, social, and technological conditions of the geographic regions. Data have been sourced from books, encyclopedias, websites, and official statistical records with the help of 40 graduate students and four research assistants, who were responsible for quality control. For this article, we restricted the sample to the 3,165 monasteries that were founded in Europe between 1000 and 1900 CE. We assigned each monastery to the closest of the 331 regions of the person mobility structure. All monasteries are located less than 100 km from the center of the region to which they have been assigned.

The third dataset consists of geocoded locations and founding years of 16,596 publishing houses founded throughout Europe between 1500 and 1900 CE. We constructed this dataset from the B3Kat database. B3Kat is a book metadata repository that is maintained by the joint cataloging platform of the library networks of the German federal states of Bavaria, Berlin, and Brandenburg. It consolidates the holdings of more than 200 specialist libraries. As of 2019, the B3Kat contained bibliographic information on 23 million texts in total, including 1.8 million digitized texts published across Europe between 1450 and 1900. Although structured, the data are only partly standardized and required extensive preprocessing and cleaning. We harmonized imprint places and corporate names using the thesaurus file maintained by the Consortium of European Research Libraries (www.cerl.org) and manually validated the years and places of publication of 1,530,162 texts that had been published by 16,596 publishers in 220 of the 331 identified regions in Europe. We approximate the founding year of each publisher as the first year in which a text published under its name appeared in the dataset.

Justification of the proxies used to capture localized knowledge spillover

Incremental versus radical innovations

Our main dependent variables are counts of the foundings of monasteries and publishers in each region and over time to measure localized knowledge spillover leading to incremental or radical innovation. In general, organizations are considered innovative when they generate and implement ideas, technologies, products, processes, and behaviors that differ incrementally or radically from the prevailing zeitgeist, including in technical aspects and forms of organization (Schumpeter, 2003 [1912]). Incremental organizational innovations improve existing technical and nontechnical solutions, whereas radical organizational innovations develop solutions that fundamentally challenge and alter the status quo. From a dynamic perspective, radical and incremental innovations map onto different positions in the life cycle, or 'S-curve', of their underlying technology Rogers (2005). This S-curve identifies an early stage at which the technology is not yet established but breaks radically with the status quo ante and a late stage in which the technology has matured and reaches its limit. Broadly, innovations on an established S-curve of the underlying technology are characterized as incremental, whereas innovations that initiate a new S-curve are radical. Our analysis uses the founding of monasteries in Europe between 1000 and 1900 CE as a proxy for incremental organizational innovation and the founding of publishing houses in Europe between 1500 and 1900 as a proxy for radical organizational innovations. In the following, we justify this choice in more detail.

Monastery foundings as a general proxy for incremental organizational innovations

In monasteries, the divison of labor, bureaucratic rules, and vocational training emerged as a consequence of processes of rationalization (Rost, 2015; Weber, 1958, 1973). Around 323 CE, the Egyptian Saint Pachomius changed the prevalent view of work by stating that monks have a duty to work because labor is the basis of their subsistence Kieser (1987). The Rule of Pachomius was a radical innovation in its time: it introduced the division of labor and the formulation of bureaucratic rules and job descriptions. It underlay the founding of the first major institutions of precapitalist enterprise around 500 CE: Catholic Orders of local communities, organized around monasteries Schmidtchen and Mayer (1997).

From the early sixth century to the tenth century, the early medieval monastery was arguably the most innovative organizational form of its time (Rost, 2015; Rost and Graetzer, 2014; Rost et al., 2010). In essence, it was a "perfect laboratory for the production of an industrious, reliable person" (Kieser, 1987: 108; Treiber and Steinert, 1980) as "the rigid timetable, the impossibility of deviating from the Rule without facing punishment–brings to mind the work regulations that Henry Ford imposed on his assembly lines" (Gimpel, 1976, 5). Early medieval monasteries innovated production methods that profoundly transformed agriculture, for example, planting orchards, grafting fruit trees, breeding livestock, improving wine- and beer-making, and inventing architectural solutions for heating and sanitation. They laid the groundwork for many of today's industries, such as breweries, wine-making, naturopathy, sanitation, engineering, and architecture, and they were progenitors of today's corporate organizational forms, such as functional and process organization, democratic co-determination, and assembly-line work (Kieser, 1987; McGrath, 2005; McGrath, 2007; Melville, 2012). As early precursors of today's universities, monasteries contributed significantly to the differentiation of artistic and scientific professions, for example by spreading handwriting to help coordinate their actions in far-flung monasteries Kieser (1987), by elaborating a vocabulary on economic and finanical issues Todeschini (2009), and by writing early textbooks, for example on double-entry bookkeeping

Kehnel (2012).

The first-mover advantage of monasteries—of leveraging organized labor through codified rule and bureaucracy—lasted into the eleventh century. Then, other and more specialized organizational forms emerged. In the twelfth century, craftsmen and traders began to form cooperative associations, which led to the emergence of guilds across Western and Central European cities Ogilvie (2019). Over time, these guilds displaced the monasteries' dominant position in production and trade. In parallel, the first universities emerged in the late eleventh and twelfth centuries and challenged the role of monastic schools, where monks and nuns had been teaching since the sixth century. Whereas the monastic schools were devoted to the study of liturgy and prayer, universities imparted knowledge in the liberal arts, law, medicine, and theology, and thus lay the groundwork for an increasingly worldly division of labor.

Our analysis considers monastery foundings from the eleventh century onwards, a period when the organizational solutions and technologies they implemented were well established and mature. Confronted with increasing competition from alternative organizational forms, monasteries nonetheless had to adjust to the changing requirements of the times. From the eleventh century on, a variety of Catholic orders emerged that specialized in a particular offerings, such as monastic orders (e.g., the Benedictines or Cistercians), canons regular (e.g., the Premonstratensians and St. Augustine), mendicant orders (e.g., the Dominicans and Franciscans), clerks regular (e.g., the Society of Jesus and Camillians), and congregations (e.g., the Redemptorists and Salvatorians) (Davidson, 1995; Dinzelbacher and Hogg, 1997; Ehrmann et al., 2013; Schmidtchen and Mayer, 1997; Schwaiger and Heim, 2008). These various orders specialized in particular offerings: Some focused on contemplation (e.g., Carthusians and Cistercians) whereas others interacted with the secular world by teaching (e.g., Jesuits and Salvatorians), proselytizing (e.g., Divine World Missionaries and White Fathers), or social work (e.g., Franciscans and Camillians). Within limits, they each experimented with a range of governance models to manage the division of labor more effectively: the Benedictines, for example, developed very elaborate organizational rule systems, whereas the Franciscans, defined fewer rules and pursued broader definitions of problem areas. The various orders adjusted their goals to the societal context: Military orders were founded during the crusades and in feudal times, mendicant orders constituted themselves in the times of poverty movements and urbanization, and the Salesians of Don Bosco were founded in 1859 against the backdrop of early industrialization Codina and Zevallos (1991).

This historic background motivates our considering the founding of a monastery in Europe between 1000 and 1900 CE as an incremental organizational innovation. From 323 to 1000 CE, a new S-curve on the view of work emerged in monasteries. By the eleventh century, this technology faced increasing competition from other, newly emerging organizational forms, such as guilds and universities. Confronted with increasing competition from these alternatives, Catholic orders and their monasteries specialized in the prevailing technology: in other words, they moved along the existing S-curve.

Fig. 3A depicts monastery founding rates over the period of analysis. It confirms that the diffusion of monasteries slowed after 1100, stagnated after 1200, and decreased continuously after 1500. In particular, the Reformation and secularization substantially weakened the population. Nevertheless, the monasteries always recovered from these drastic events by specializing in new, yet incrementally innovative, solutions, even if not with the same market dominance as they had enjoyed when they held a monopoly on the division of labor. Between 1000 and 1900 CE, monastery foundings introduced well-tried and tested specialized knowledge about production methods, products, and the organization of work and education into regions, thereby incrementally but noticeably transforming local economic development.

Publisher foundings as a general proxy for radical organizational innovations

By comparison, the emergence of publishing houses between 1500 and 1900 introduced a fundamentally new technological innovation, movable-type printing, which heralded radical societal change. The invention of printing substituted the existing technology of copying books by hand, which until then had mostly been done in monasteries. Suddenly, books and manuscripts could be produced and disseminated quickly, cheaply, and *en masse*. The new technology heralded feudalist Europe's transition to modernity (Febvre and Martin, 1976 [1958]; Luhmann, 2012 [1997]) and transformed entire sectors. For example, movable-type printing enabled the differentiation of the education system, the founding of newspapers, and emergence of new professions, such as those of publishers and journalists. Book printing also eroded existing activities, such as the sale of indulgences by the Catholic Church by facilitating the spread of the ideas of the Reformation. Thus, by leveraging the technology of movable-type printing, publishing house established a new S-curve that surpassed and upended the status quo based on hand-copied texts.

Fig. 3B illustrates the rate of diffusion of publishing houses in our data set. By the second half of the eighteenth century, publishing houses were spreading rapidly throughout Europe. This spread was accelerated by the industrial revolution of the nineteenth century. However, as the numbers of market entrants indicate, the market for publishing houses was not yet saturated at the end of the observation period. The founding of publishing houses can thus be taken as an indicator of a radical organizational innovation. Publishing houses brought fundamental new knowledge to a region, leading to new industries, applications, and vocations, and thus pervasively transforming that region's economic development.

Monastery foundings by newly established monastic and mendicant orders as proxies for incremental and radical organizational innovations

Furthermore, monasteries allow within-group comparisons of both more incremental and more radical organizational innovations. To consider radical and incremental subtypes of monastery foundings, we focus on the period between 1075 and 1600, that is, from the height of the Gregorian reforms to the eve of the Thirty Years' War. Throughout this period, several new orders were established that challenged the hegemony of the Catholic Church in different ways Todeschini (2009). Mendicant orders, for example, were founded in protest against the wealth accumulation of established orders such as the Benedictines. The mendicants' refusal to own property or pay taxes posed a serious challenge to the established Church. The radical nature of this idea is demonstrated by the fact that several of the lesser Mendicant orders were suppressed by the second council of Lyon in 1274, and the Church actively pressured the major Mendicant orders to relax the poverty requirements. A more incrementalist approach was pursued by the monastic reform orders, which were also founded in the twelfth and thirteenth centuries, most notably the Cistercians. Originating from internal efforts to reform the Benedictine Order, the Cistercians aspired to follow the Rule of Saint Benedict more closely and thus modified rather than challenged the established model (Jamroziak, 2015; Todeschini, 2009). We compare monastery foundings by newly established monastic reform orders, which pursued a moderate, incrementalist approach, against foundings by newly established mendicant orders, which took a more radical stance. Because the stated goals of Catholic orders evolved over time, we treat as innovative only foundings within the first 100 years of their orders' establishment.[2]

[2] For example, several of the mendicant orders began owning property after the Council of Trent loosened earlier restrictions in the mid-sixteenth century.

Table 1
Incremental and radical innovations by foundings of monasteries and publishers.

	Units	Innovation Incremental	Radical
Monasteries	3,165	3,165	-
Publishers	16,596	-	16,596

Published texts by contemporary Catholic authors and heretic or controversial authors as proxies for incremental and radical organizational innovations

Similarly, publishers can be differentiated into radical and incremental organizational subtypes. Some adopted a conservative approach of publishing texts by contemporary Catholic authors who remained overall aligned with or even defenders of the status quo. Others published texts by heretical and highly controversial authors of the times, notably Martin Luther. Such efforts were highly subversive of the status quo and radical in nature. Hence, the types of texts published by different publishing houses can serve as indicators of incremental or radical innovativeness. The database from which we inferred the founding years and locations of publishers also includes information on the authors of published texts. As an indicator of openness to radical texts and ideas, we identified 2,915 texts that had been authored by Martin Luther, whose writings augured one of the most radical societal shifts since the middle ages. As an indicator of more incrementalist positions, we identified 4,273 texts by the most prolific conservative Catholic authors of the period. Our selection includes controversialist theologians who were outspoken defendants of the Catholic doxy against the rise of Lutheran thought (Johannes Cochlaeus, Johannes Eck, Martin Eisengrein, Jerome Emser, Jodocus Kedd, Thomas Murner, Caspar Schatzgeyer, and Thomas Stapleton) and contemporary spiritual and intellectual leaders of the Catholic church (Manuel Alvares, Joseph Biner, Jacques Bénigne Bossuet, Stanislaus Hosius, Cornelius Lapide, Alfonso Maria de Liguori, Johann Adam Möhler, Franz Neumayr, and Domingo de Soto).

Table 1 documents the number of foundings for each general organizational innovation type: the foundings of monasteries as an incremental organizational innovation and the foundings of publishers as a radical organizational innovation. Table 2 presents the operationalization of radical and incremental innovations for the monasteries. Table 3 provides an overview of the operationalization and number of radical and incremental innovations for the text dataset of publishers.

The temporal scale and granularity of the datasets vary substantially. We adopted a moving-window approach to highlight the broader trends in regional innovativeness by counting all foundings that occurred in a 21-year window centered on the focal year, that is, in the 10 years leading up to- and the 10 years following that year.

Processes of knowledge spillovers originating from clusters of creative people

Clusters of creative people taken from Schich et al. (2014) are used to measure the opportunities for domain-diverse encounters in a region and the attractiveness of this region in global mobility networks. For our purposes, these data have two decisive advantages. First, they measure the indirect processes of knowledge spillovers originating from clusters of creative people. In contrast to knowledge transfers, which capture direct knowledge flows between people or firms (Jandhyala and Phene, 2015; Reagans and McEvily, 2003), knowledge spillovers refer to the indirect benefits of being located in proximity to others (Breschi and Lissoni, 2001; Krugman, 1991). As such, they are difficult to identify and measure (for early examples and discussions of attendant measurement problems, see Acs et al., 1992; Audretsch and Feldman, 1996; Breschi and Lissoni, 2001; Jaffe, 1989; Jaffe et al., 1993). The foundings of monasteries and publishing houses clearly fall outside the activity domains of the creative individuals observed in the dataset from Schich et al. (2014); for example, fewer than 1% of these individuals were religious leaders (see Table 4 below). We can therefore be confident that

Table 3
Incremental and radical innovations by subtypes of published texts.

	# Units	# Innovation (1600-1900) # Radical	# Incremental
Catholic Authors			
Controversialists	1,087	-	1,087
Contemporary Intellectuals	3,186	-	3,186
Protestant Authors			
Martin Luther	2,915	2,915	-
Other Authors	1,066,537	-	-
Manuscripts (Total)	1,073,725	2,915	4,273

Table 2
Incremental and radical innovations by subtypes of monasteries.

	Units	Innovations (1075-1600) Incremental	Radical	Neither*	Before 1075	After 1600
Monasteries						
Nonreformist						
Aug. Canons Regular	209	-	-	189	11	9
Benedictine	448	-	-	312	86	50
Mendicant Orders						
Augustinian Mendicant	41	-	12	23	-	6
Dominican	77	-	39	22	-	16
Franciscan	304	-	66	76	-	162
Capuchin	134	-	18	7	-	109
Carmelite	92	-	23	30	-	39
Carthusian	250	-	15	204	-	31
Monastic Reformist						
Jesuits	38	-	-	24	-	14
Premonstratensians	198	117	-	73	-	8
Trappists	61	9	-	-	-	52
Cistercians	1,313	663	-	587	-	63
Monasteries (Total)	3,165	789	173	1,547	97	559

Note: *) Monasteries founded by Orders that had been established more than 100 years earlier are not considered in the analyses by subtype.

Table 4
Activity domains of notable creative individuals, 1000-1900.

Activity Domain	# individuals
Artists	
Fine Arts	66,598
Print & Graphics	34,200
Applied Arts	14,855
Performing Arts	3,228
Creative	4,160
#Artists	123,041
Worldly leaders	
Architecture	12,146
Academic (including education and health)	3,908
Governance (including politicians, lawyers, military, activists, and religious figures)	2,574
Business (including industry and travel)	1,053
#Worldly leaders	19,681
Others	
Notable but without specific assignment	21,916
Athletes	262
#Others	22,178
Total	164,900

Note: Data allow multiple category assignments per person.

these measures do not reflect direct knowledge transfers of people operating in the domain of the innovation (Breschi and Lissoni, 2001; Feldman and Kogler, 2010; Ponds et al., 2010). Second, for much of the period under investigation, historical records were sparse and only remembered people with special achievements or extraordinary skills. This is confirmed by numerous examples from our data set. For example, in 1500 the data include Martin Luther (credited with starting the Protestant Reformation), Michelangelo Buonarroti (remembered as a "renaissance man" for his talent as painter, sculptor, architect, poet, and engineer), Christopher Columbus (remembered for the first European contact with the Caribbean, Central America, and South America), and Lucas Vázquez de Ayllón (remembered as Conquistador and founder of the first European settlement on the territory of today's USA). Alongside these figures of universal historical importance, the data also includes artists, worldly leaders such as academics, politicians, lawyers, military, business and religious figures, and even some athletes. These notable individuals are remembered because their approach to work and life pushed the boundaries of social, cultural, and historical precedents in their respective fields, thus effecting novel and appropriate ideas, processes, and solutions Amabile (1996). As a measure of local creativity, their heterogeneity underscores the fact that creativity is a matter of degree Perry-Smith (2006). Although few people are remembered for transformative breakthroughs and radical ideas, many people are remembered for pushing the limits and making adjustments to existing solutions.

Opportunities for domain-diverse encounters

Using the biographical data on creative individuals taken from Schich et al. (2014), we measured opportunities for domain-diverse encounters in each region for each year of our analysis from 1000 to 1900 CE. We measured domain diversity in local networks under the assumption that creative individuals spent the first half of their productive lives in the place where they were born and the second half of their productive lives in the place where they died. For each region and year, opportunities for domain-diverse encounters are calculated from Eq. 2 on the assumption that creative individuals of domain groups including more than 15 creative individuals assign half of their interactions to members of their own group and the other half randomly to all domain groups ($h = 0.5$). Schich et al. (2014) assigned each creative individual to one or more of 11 activity categories. As these activity types largely overlap, we have grouped them into three broad domains: *artists, worldly leaders*, and *others* (see Table 4). To mitigate erratic swings in this variable for small networks, we smoothed measures across neighboring combinations of domain groups of different sizes.

The centrality of regions in the global mobility network

From the life-course trajectories of all notable individuals, we constructed mobility networks to measure the evolving centrality of regions over time and how this affected subsequent migration. In the global mobility structure, a tie connects both regions for the duration of the person's productive life (from 15 years of age until their death). For example, Michelangelo Buonarroti was born near Florence in 1475 and died in Rome in 1564. Our method assigns him to the Florentine social network of creative individuals from 1489 to 1526 and to the Roman social network for 1527 to 1564. In the global network, Michelangelo connects Florence and Rome from 1489 to 1564.[3] Fig. 2 illustrates the evolution of the global mobility structure over time.[4] For example, the global network in 1500 connected regions through the 1,398 individuals who were alive and of productive age that year, including Martin Luther (*1483 and †1546 in Eisleben near Halle, Germany), Michelangelo Buonarroti (*1475 in Caprese, Italy; †1564 in Rome, Italy), and Christopher Columbus (*1451 in Genoa, Italy; †1506 in Valladolid, Spain).

Mobility patterns offer a dynamically changing indicator of the relative attractiveness of regions for creative individuals over time. If people were born in one region but moved voluntarily to another during their lives, this indicates a preference for the latter. Of course, such reasoning does not hold in all cases, particularly as we observe only places of birth and death. Because we do not know why people moved from one place to another, we simply examine how many people moved between each pair of regions at each point in time. In technical terms, we constructed the global mobility network as an undirected network with edges that are weighted by the number of people connecting each pair of regions each year. We measure the relative importance of regions in the global mobility as its eigenvector centrality in the network Bonacich (1987), thus effectively weighting the centrality of a region by the centrality of the regions to which it is connected. Because eigenvector centrality is not defined for isolated regions that neither attracted nor originated creative individuals in a particular period, we added a negligible weight to existing and non-existing ties, thus creating a fully connected network.

Control measurements

We include numerous control variables to account for plausible alternative drivers of regional development. We account for the pre-existing innovation base of regions because it affects subsequent founding rates in predictable ways (Hannan and Freeman, 1977; Lomi and Larsen, 1996). We include lagged effects for the number of *innovations in the prior period*, that is, for the number of monasteries or publishing houses founded or for the number of texts published in the preceding period. We also control for the number of *units open at the start of each period* and for the number of *units closed in the prior period.* These measures capture local developments that affect the survival prospects of the organizational types, including church-internal dissension and

[3] Throughout his life, Michelangelo moved back and forth between Florence and Rome, with Rome increasingly important in his later years. For his Florentine commissioners, Michelangelo sculpted his David (1501) and painted the Doni Tondo (1503-1506), among many others. For his Roman commissioners, he carved the Pietà of St. Peter's Basilica (1499), painted the ceiling of the Sistine Chapel (1508-1512), planned the Piazza del Campidoglio (1536), designed the Dome of St. Peter's Basilica (1547-1564), and developed the Basilica of Saint Mary of the Angels and Martyrs (ca. 1555). In Schich et al.'s (2014) data, Michelangelo is recognized for accomplishments as artist (sculpture and painting) and as a worldly leader for his architectural contributions.

[4] As the data is sparse prior to 1408, for periods in which fewer than 300 notable individuals were alive, we added people who had lived in earlier times to construct the global mobility structure. In Figure 2, edges that represent the trajectories of individuals who are no longer alive are identified as dashed lines.

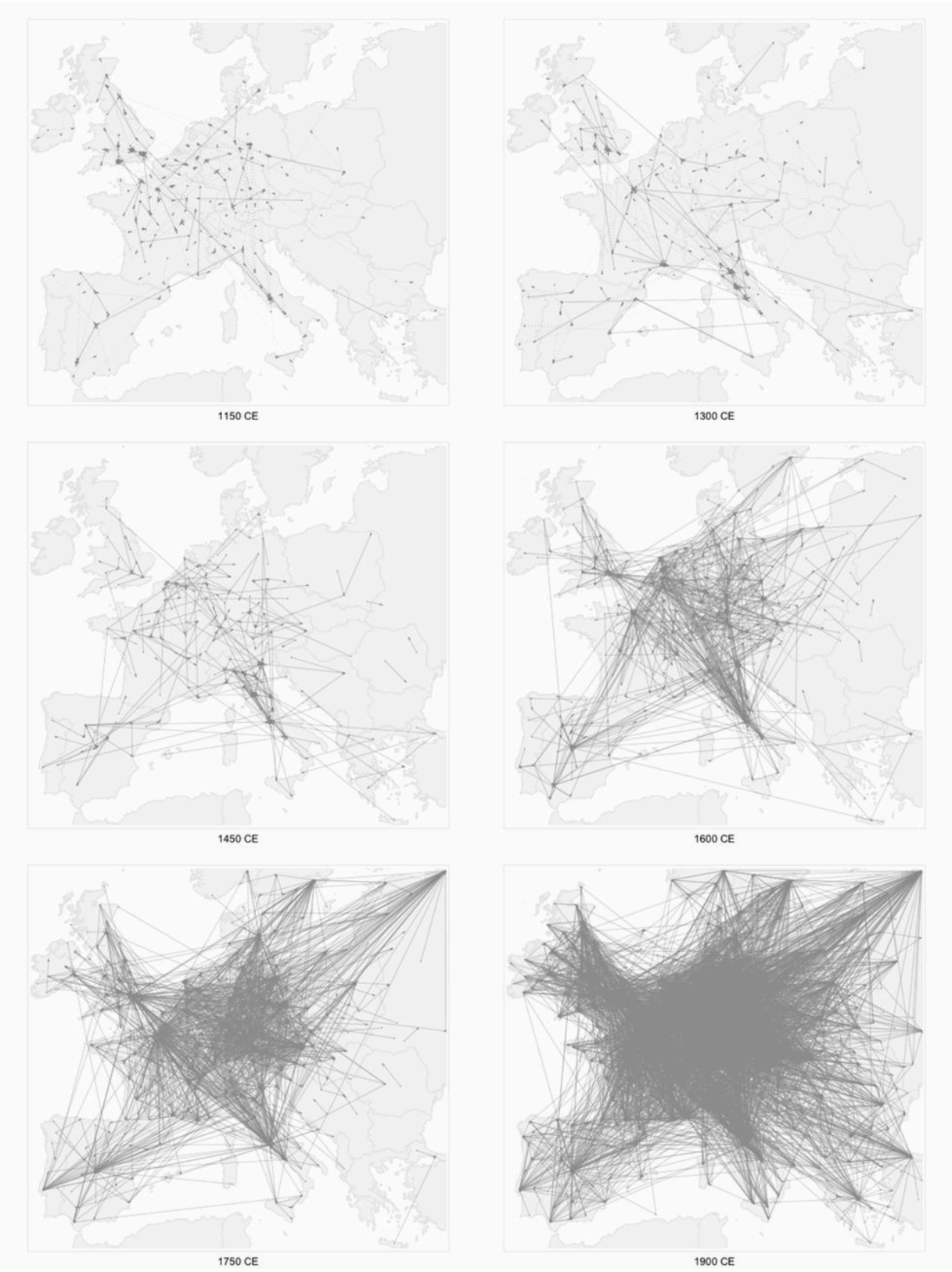

Fig. 2. The global mobility structure over time.

censorship efforts, among others. For the subanalyses of published texts, we added lagged variables for the *total number of texts published* in each region in the prior period.

To control for political stability, we added a binary variable for each year and region that identifies whether that region is located in a country that was involved in *wars or civil unrest* at the time. To construct this variable, we extended the coverage of the Conflict Catalog Brecke (1999), which lists 2,912 violent conflicts from 1400 to 1900. We

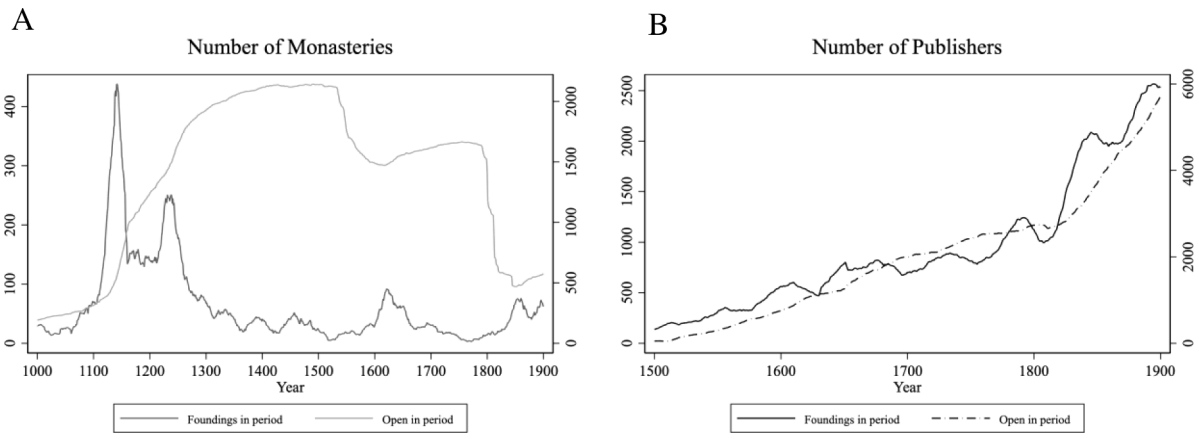

Fig. 3. Foundings of monasteries and publishers over time.

manually matched reported conflicts to present-day national boundaries using a historical atlas and set this variable to 1 for each year in which a region was involved in a conflict and 0 otherwise.

As a proxy for overall technological development, we constructed a variable for *travel speed*, as operationalized by the distance that could be traveled per day (in km, logged). Until the early nineteenth century, horse-drawn traffic allowed only moderate speeds, but these increased with improvements in road infrastructure in the eighteenth century and further accelerated with the invention of steamboats and railways around the mid-nineteenth century. As a measure of relative economic prosperity, we added *GDP per capita* as estimated for national levels by the Maddison project (Bolt and Van Zanden, 2013). The Maddison project provides country-level estimates for economic development and income levels for 169 countries in 50-year increments from 1000 CE to the present. We interpolated these data to generate annualized and regionalized control variables for relative economic development and population measures. We standardized this measure within-year to capture relative differences in wealth between regions as opposed to absolute changes in wealth over time. We further added two time-invariant controls: the distance of each region to the *nearest waterway* as an indicator for opportunities for river and seafaring trade, operationalized as the shortest distance from the nearest coastline or river with a catchment area larger than 5,000 km^2 European Environment Agency (2012), and whether a region is located in an *inaccessible, mountainous area*, a binary variable identifying whether the geometric center of a region is higher than 800m above sea level.

We incorporated city-specific estimates of *population size* compiled by Bosker et al. (2013). Population size indicates local economic prosperity, reflects changes in life expectancy due to changing hygiene standards and sanitation, and includes the possible effects of disease epidemics. When the bubonic plague wiped out half of the population in Europe in the 14th century, for example, plummeting population levels affected the power relations between peasants and their feudal landlords and, consequently, the overall organization of social life Levine (2006). Bosker et al.'s (2013) city-level data show an observable population decline in the decades after the plague (1347–1351). We added a dummy variable to identify *plague-affected regions* based on whether a local population declined by more than 5,000 inhabitants between 1345 and 1400.

Throughout the period of our investigation, three major events affected the standing of the Catholic Church in society, and thus monastery foundings in particular. (1) The Western Schism arose in response to church-internal disputes about the identity of the pope and where he was to reside. In 1305, the newly-elected pope Clement V moved his court to Avignon, where it resided until 1377 (Zutshi, 1995). The return to Rome by Gregory XI in 1378 marked the beginning of a 40-year period of political turmoil in which there were two, at times three, declared popes at once—one in Rome, one in Avignon, and one in Pisa (Kaminsky, 2000). To account for these shifting geopolitical affiliations with the Catholic Church, we added a variable for *distance from the Vatican* and measure the shortest distance from Rome, Avignon, or Pisa, depending on where the nearest Vatican was located at each time. (2) The Protestant Reformation, which began in present-day Germany in 1522, challenged the accumulation of wealth by the Catholic Church. The Catholic Church experienced a profound decline in authority that affected both existing monasteries, many of which were expropriated or closed, and the prospects of new foundings Knowles (1968). In England, Ireland, and Wales, for example, King Henry VIII disbanded monasteries in the 1530s; in Denmark, King Frederick I issued an edict to appropriate church holdings in 1527; King Gustavus Vasa followed suit in Sweden in 1528; and in 1572, the Dutch revolt established the Calvinist Church as the sole recognized church of the Netherlands. We identified exact years in which Reformation-affected regions converted to Protestantism using data compiled by Rubin (2014). For each region and year, we included a binary variable, *Reformation*, to identify whether one or more cities in that region had been reformed. (3) During the Enlightenment period of the eighteenth and nineteenth centuries, several secularist and anti-clericalist movements took hold in various parts of Europe. These movements were accompanied by widespread seizures of church properties and dissolutions of monasteries Beales (2003). In Austria and Belgium, the *Edict of Idle Institutions*, issued by Joseph II in 1780, outlawed contemplative monastic orders. In France, religious orders were dissolved at the outset of the French Revolution (1789). In Germany, the territorial restructuring during and after the Napoleonic Wars (1803–1815) included broad annexations of Church properties. For each region and year, we coded a dummy variable to account for whether or not *secularization* had occurred.

Table A.1 in the Appendix presents descriptive statistics of all variables.

Analysis

The hypotheses are tested using panel regression models with fixed-effects specification for each region and year. For all models, a Hausman test indicates that a fixed-effects specification is preferred over random-effects specification. We additionally report the results of generalized method of moments (GMM) estimates of linear dynamic panel data models, which provide less biased standard errors. As our dependent measures of innovation are overdispersed counts and bounded on 0, we log-transform each count with 1 added to avoid taking a logarithm of 0. The distribution of the resulting variables satisfies the normal distribution assumption of regression models. For graphic illustrations, we convert the measurements back to their original scales. We include linear and quadratic terms for network size and subsequently introduce

Table 5
Opportunities for domain diversity within local environments and innovativeness.

	Monastery foundings (ln)		Publisher foundings (ln)	
	(1)	(2)	(3)	(4)
VARIABLES	Model 1a	Model 1b	Model 2a	Model 2b
Opp. domain-diverse encounters	-0.0276***	-0.111***	0.0200***	0.0711***
	(0.00246)	(0.00933)	(0.00417)	(0.0169)
Opp. domain-diverse encounters(sq)		0.0960***		-0.0576***
		(0.0104)		(0.0185)
Open at start (ln)	-0.0435***	-0.0435***	0.199***	0.200***
	(0.00111)	(0.00111)	(0.00354)	(0.00355)
Opened in prior period (ln, 1-year lag)	0.156***	0.156***	0.307***	0.307***
	(0.00186)	(0.00186)	(0.00389)	(0.00389)
Closed in prior period (ln, 1-year lag)	-0.0415***	-0.0411***	0.0285***	0.0283***
	(0.00186)	(0.00186)	(0.00316)	(0.00316)
Network size (ln)	-0.00578***	0.00181	-0.0695***	-0.0781***
	(0.00171)	(0.00190)	(0.00379)	(0.00470)
Network size (ln, sq)	-0.00118***	-0.00193***	0.0327***	0.0338***
	(0.000293)	(0.000304)	(0.000650)	(0.000737)
Local population (ln)	0.00602***	0.00606***	-0.000466	-0.000638
	(0.000622)	(0.000622)	(0.00188)	(0.00188)
GDP per capita (scaled)	0.00986***	0.00986***	-0.0142***	-0.0144***
	(0.000736)	(0.000736)	(0.00143)	(0.00143)
Travel speed (ln)	0.00922	0.00882	0.00579	0.00599
	(0.00940)	(0.00940)	(0.0125)	(0.0125)
Distance Vatican (ln)	0.0215***	0.0213***	—	—
	(0.00256)	(0.00256)		
Reformation	-0.0572***	-0.0563***	-0.0124**	-0.0124**
	(0.00205)	(0.00206)	(0.00582)	(0.00582)
Secularization	-0.0104***	-0.0108***	0.0869***	0.0871***
	(0.00306)	(0.00306)	(0.00426)	(0.00426)
War, civil unrest	0.00272*	0.00321**	-0.0120***	-0.0120***
	(0.00142)	(0.00142)	(0.00261)	(0.00261)
Isolated region	-0.0190***	-0.0147***	-0.0263***	-0.0324***
	(0.00197)	(0.00203)	(0.00475)	(0.00515)
Plague-affected region	-0.0182***	-0.0185***	—	—
	(0.00432)	(0.00432)		
Distance from waterway (km)	—	—	—	—
High altitude (>800m)	—	—	—	—
Year dummies	included	included	included	included
Constant	-0.0309	-0.0300	-0.0468	-0.0410
	(0.0761)	(0.0761)	(0.0992)	(0.0992)
Observations	298,231	298,231	132,731	132,731
R-squared (within)	0.173	0.173	0.517	0.517
Number of regions	331	331	331	331

Note: Regression with fixed-effects specification for region and year. Standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

	Monastic reform foundings (ln))		Mendicant reform foundings (ln)	
	(5)	(6)	(7)	(8)
VARIABLES	Model 3a	Model 3b	Model 4a	Model 4b
Opp. domain-diverse encounters	-0.0238***	-0.106***	-0.00119	-0.00629
	(0.00255)	(0.0177)	(0.00118)	(0.00494)
Opp. domain-diverse encounters(sq)		0.110***		0.00579
		(0.0141)		(0.00545)
Open at start (ln)	-0.00911***	-0.00923***	0.00260***	0.00266***
	(0.000762)	(0.000762)	(0.000673)	(0.000674)
Opened in prior period (ln, 1-year lag)	0.254***	0.253***	0.184***	0.184***
	(0.00246)	(0.00246)	(0.00249)	(0.00249)
Closed in prior period (ln, 1-year lag)	0.00144	0.00198	0.00384	0.00391
	(0.00371)	(0.00371)	(0.00394)	(0.00394)
Network size (ln)	0.0290***	0.0321***	0.000188	0.000340
	(0.00197)	(0.00200)	(0.000907)	(0.000918)
Network size (ln, sq)	-0.00593***	-0.00461***	0.000484**	0.000521**
	(0.000517)	(0.000585)	(0.000238)	(0.000241)
Local population (ln)	0.00444***	0.00444***	0.00175***	0.00175***
	(0.000313)	(0.000313)	(0.000143)	(0.000143)
GDP per capita (scaled)	0.00866***	0.00864***	0.00631***	0.00630***
	(0.000489)	(0.000489)	(0.000230)	(0.000230)
Travel speed (ln)	—	—	—	—
Distance Vatican (ln)	0.00822***	0.00805***	0.000585	0.000578

(*continued on next page*)

Table 5 (*continued*)

	Monastic reform foundings (ln))		Mendicant reform foundings (ln)	
	(5)	(6)	(7)	(8)
	(0.000851)	(0.000851)	(0.000393)	(0.000393)
Reformation	-0.00199	-0.00109	-0.00192*	-0.00190*
	(0.00228)	(0.00228)	(0.00106)	(0.00106)
Secularization	—	—	—	—
War, civil unrest	0.00436***	0.00467***	0.00580***	0.00581***
	(0.00125)	(0.00125)	(0.000575)	(0.000575)
Isolated region	0.00796***	0.0107***	0.00153*	0.00164*
	(0.00180)	(0.00183)	(0.000833)	(0.000840)
Plague-affected region	—	—	—	—
Distance from waterway (km)	-0.000153***	-0.000156***	-3.12e-05***	-3.12e-05***
	(1.95e-05)	(1.95e-05)	(8.97e-06)	(8.97e-06)
High altitude (>800m)	-0.00214	-0.00214	-0.00345***	-0.00345***
	(0.00180)	(0.00180)	(0.000832)	(0.000832)
Year dummies	included	included	included	included
Constant	-0.0746***	-0.0749***	-0.00872***	-0.00872***
	(0.00675)	(0.00675)	(0.00312)	(0.00312)
Observations	174,106	174,106	174,106	174,106
R-squared (within)	0.1486	0.1492	0.0287	0.0287
Number of regions	331	331	331	331

Note: Regression with fixed-effects specification for region and year. Standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

	Published Catholic Authors (ln)		Published Luther's Texts (ln)	
	(9)	(10)	(11)	(12)
VARIABLES	Model 5a	Model 5b	Model 6a	Model 6b
Opp. domain-diverse encounters	-0.00943***	-0.128***	0.0115***	0.0316***
	(0.00310)	(0.0110)	(0.00277)	(0.00977)
Opp. domain-diverse encounters(sq)		0.142***		-0.0241**
		(0.0125)		(0.0112)
Published in prior period (ln, 1-year lag)	0.602***	0.601***	0.632***	0.631***
	(0.00230)	(0.00230)	(0.00234)	(0.00234)
All texts in prior period (ln, 1-year lag)	0.0217***	0.0209***	0.0212***	0.0214***
	(0.000628)	(0.000632)	(0.000547)	(0.000552)
Network size (ln)	0.0181***	0.0243***	0.00206**	0.00104
	(0.00115)	(0.00128)	(0.000991)	(0.00110)
Network size (ln, sq)				
Local population (ln)	-0.000216	-4.99e-05	-0.00226***	-0.00229***
	(0.000708)	(0.000708)	(0.000584)	(0.000585)
GDP per capita (scaled)	-0.00184**	-0.00164*	-0.000232	-0.000259
	(0.000920)	(0.000921)	(0.000791)	(0.000792)
Travel speed (ln)	0.00304	0.00222	-0.0131	-0.0130
	(0.0101)	(0.0101)	(0.00909)	(0.00909)
Distance Vatican (ln)	-0.000470	-0.000548	0.0117***	0.0117***
	(0.00208)	(0.00209)	(0.00167)	(0.00168)
Reformation	-0.0110***	-0.0103***	-0.00494**	-0.00508***
	(0.00237)	(0.00238)	(0.00196)	(0.00196)
Secularization	-0.00853***	-0.00839***	0.0430***	0.0430***
	(0.00324)	(0.00324)	(0.00288)	(0.00288)
War, civil unrest	0.00915***	0.00947***	0.00505***	0.00498***
	(0.00190)	(0.00190)	(0.00167)	(0.00167)
Isolated region	0.0143***	0.0168***	-0.00740***	-0.00779***
	-0.000216	-4.99e-05	-0.00226***	-0.00229***
Plague-affected region	—	—	—	—
Distance from waterway (km)	-8.02e-05*	-9.26e-05**	1.56e-05	1.75e-05
	(4.54e-05)	(4.55e-05)	(3.65e-05)	(3.65e-05)
High altitude (>800m)	0.00954**	0.00897**	-0.00772**	-0.00763**
	(0.00415)	(0.00416)	(0.00333)	(0.00334)
Year dummies	included	included	included	included
Constant	-0.109	-0.106	-0.0128	-0.0135
	(0.0812)	(0.0811)	(0.0727)	(0.0727)
Observations	132,731	132,731	132,731	132,731
R-squared (within)	0.2301	0.2308	0.2467	0.2468
Number of regions	331	331	331	331

Note: Regression with fixed-effects specification for region and year. Standard errors in parentheses.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

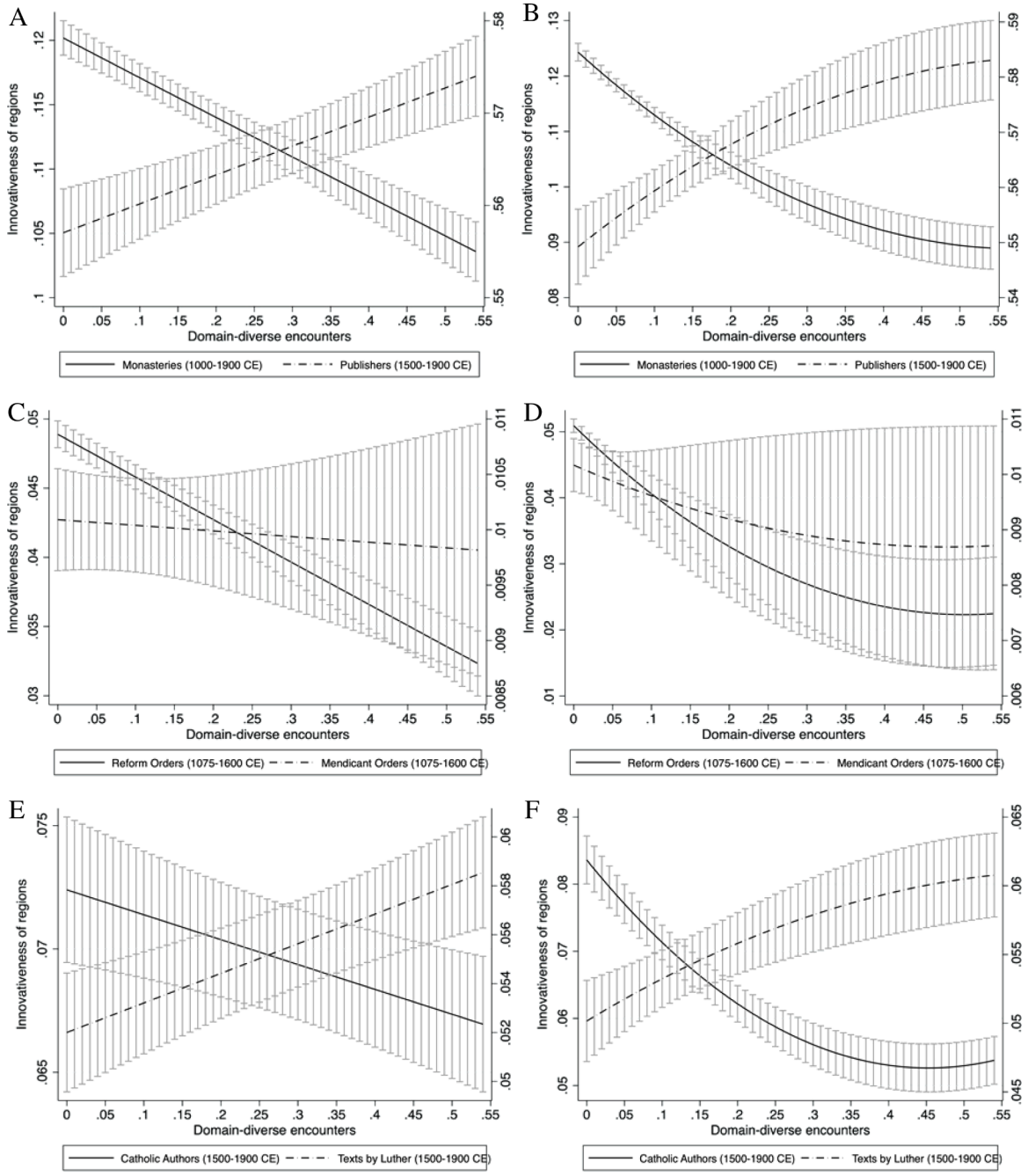

Fig. 4. Marginal effects of opportunities for domain-diverse encounters and innovativeness of regions
Note: Marginal effects as predicted in Table 5. To facilitate comparisons, predicted marginal effects of incremental and radical innovations are combined in one graph with two y-axes with radical innovations on the right y-axis.

a quadratic effect for opportunities for domain-diverse encounters, because social network measurements mostly impact outcomes in a nonlinear way. Finally, to test for hypothesis 3, we implemented a lagged variable design to assess the effect of a region's eigenvector centrality in the global mobility structure on opportunities for domain-diverse encounters in the region 50 years later. The time lag of 50 years ensures that creative individuals responsible for establishing the centrality of the region have been replaced by the next generation presented with opportunities for domain-diverse encounters in this region. We control for a region's eigenvector centrality at the time of the measurement of opportunities for domain-diverse encounters in this region.

Empirical findings

Table 5 reports the findings of the regression models with fixed-effects specification for each region and year to test Hypotheses 1 and 2. Models 1a-6a report the linear effect of local opportunities for domain-diverse encounters on the degree of radical and incremental innovation in these regions. Models 1b-6b add quadratic effects for opportunities for domain-diverse encounters. Figs. 4A-F illustrate the predicted marginal effects for the linear and quadratic models. The figures combine the predicted marginal effects of incremental and radical innovations in one graph with two y-axes. Table A2 in the appendix report the GMM estimations of linear dynamic panel data for the linear effects of opportunities for domain-diverse encounters on local

innovativeness.

In Hypothesis 1, we proposed that regions with high opportunities for domain-diverse encounters foster radical innovations. In line with this prediction, the results indicate that radical innovations were most likely to occur in regions with high opportunities for domain-diverse encounters. Foundings of publishing houses (Model 2, Fig. 4A/B) and publications of Lutheran texts (Model 6, Fig. 4E/F) were each most likely in domain-diverse environments. However, we do not find evidence of the hypothesized effect for monastery foundings by newly established mendicant orders (Model 4, Fig. 4C/D). The results suggest that opportunities for domain-diverse encounters did not have a marked effect on foundings by mendicant orders. These reported findings are consistent between the fixed-effects models of Table 5 and the GMM specification in the Appendix. Furthermore, the quadratic models indicate that regions with low opportunities for domain-diverse encounters have low chances to come up with radical innovations (Model 2b/6b, Fig. 4B/F). We tested the validity of our estimations over time. Consequently, establishing a publishing house early in the observation period may be a better proxy for radical innovations than doing so at the end of the period, by when the technology had become established and mature. Fig. A1/B in the Appendix shows consistent findings for foundings of publishing houses in the year 1500, when the technology emerged and in 1900, when publishing houses were spreading rapidly throughout Europe. Indeed, Fig. A1/B suggests that publishing houses were more likely to be founded in domain-diverse regions in 1900 compared to 1500.

Hypothesis 2 predicted, conversely, that regions with low opportunities for domain-diverse encounters will foster incremental innovations. The findings provide clear support for this hypothesis. Monastery foundings in general (Model 1, Fig. 4A/B), foundings by newly established reform-oriented monastic orders (Model 3, Fig. 4C/D), and publications of contemporary Catholic texts (Model 5, Fig.e 4E/F) were each most likely to occur in regions with diminished opportunities for domain-diverse encounters. These reported findings are consistent in both the fixed-effects and the GMM specifications. The quadratic models also show that incremental innovation is rarely found in environments that offer frequent opportunities for domain-diverse encounters (Model 1b/3b/5b, Fig. 4B/D/F). Again, we tested the validity of our estimations over time. After all, it is conceivable that establishing a monastery early in the observation period is a better proxy for incremental local innovativeness than doing so at the end of the period when the technology has fully matured and the region is saturated. Again, Fig. A1/A in the Appendix shows consistent findings for monastery foundings in the year 1000, before the diffusion rate slowed, and in 1500, after the diffusion rate had slowed. Indeed, Fig. A1/A suggests that monasteries in 1000 were more likely to be founded in regions with few opportunities for domain-diverse encounters than were monasteries in 1500.

The control variables in Table 5 each show plausible coefficients given each innovation's position in the lifecycle of its underlying technology. A pre-existing innovation base diminished the likelihood of activity based on established technology (i.e., monastery foundings) but increased the likelihood of activity based on emergent technology (i.e., publishing houses and texts). Innovativeness benefited overall from political stability and positive economic development, albeit in different ways and to different degrees. Whereas monasteries thrived in regions of high economic development, publishers were founded in less prosperous regions. Innovations were overall more likely to occur in populated regions. One exception is publications of Luther`s texts, which were more likely to occur in sparsely populated regions. Unsurprisingly, innovative activity declined in plague-affected regions. Further, monastery foundings by reform orders and publications of Lutheran texts occurred far away from the Vatican. Reformation-affected regions were less likely to host subsequent innovations. Secularization had a positive effect on foundings of publishing houses and publications of Lutheran texts, whereas foundings of monasteries and publications by contemporary Catholic authors were less likely to occur in secularized regions.

Table 6
Effect of lagged eigenvector centrality on opportunities for domain-diverse encounters.

VARIABLES	(1) Model 1a	(2) Model 2b	(3) Model 2c	(4) Model 2d
Opp. domain-diverse encounters				0.962***
				(0.00483)
Eigenvector centrality (50-year lag)		-0.135***	-0.237***	-0.145***
		(0.00693)	(0.0135)	(0.0303)
Eigenvector centrality (50-year lag, sq)			0.148***	0.133***
			(0.0166)	(0.0353)
Eigenvector centrality	0.0627***	0.148***	0.181***	-0.0631*
	(0.00552)	(0.00705)	(0.0137)	(0.0363)
Eigenvector centrality (sq)			-0.0487***	0.0497
			(0.0166)	(0.0388)
Local population (log)	0.0192***	0.0192***	0.0193***	-0.00576
	(0.000510)	(0.000510)	(0.000510)	(0.0107)
GDP per capita (scaled)	-0.0113***	-0.0110***	-0.0108***	-0.00262
	(0.000598)	(0.000598)	(0.000599)	(0.00192)
Travel speed (log)	0.00585	0.00549	0.00534	0.00131
	(0.00773)	(0.00772)	(0.00772)	(0.00363)
Plague-affected region (0/1)	-0.0309***	-0.0306***	-0.0301***	0.00295
	(0.00356)	(0.00355)	(0.00355)	(0.00972)
Distance Vatican (km, log)	0.00189	0.00209	0.00145	0.00429
	(0.00210)	(0.00210)	(0.00210)	(0.00541)
Reformation (0/1)	0.0934***	0.0924***	0.0924***	0.0108
	(0.00164)	(0.00164)	(0.00164)	(0.00966)
Secularization (0/1)	-0.0738***	-0.0719***	-0.0716***	0.00370
	(0.00245)	(0.00245)	(0.00245)	(0.00803)
War, civil unrest (0/1)	0.0155***	0.0155***	0.0155***	-0.000367
	(0.00117)	(0.00117)	(0.00117)	(0.000861)
Isolated region (0/1)	-0.220***	-0.220***	-0.220***	0.00535*
	(0.00120)	(0.00120)	(0.00121)	(0.00281)
Constant	0.469***	0.472***	0.479***	—
	(0.0626)	(0.0625)	(0.0625)	
Time dummies	included	included	included	included
Observations	298,231	298,231	298,231	297,900
R-squared	0.529	0.529	0.530	
Number of regions	331	331	331	331

Note: (Col. 1-3) Regression with fixed-effects specification for region and year. (Col. 4) Regression with GMM specification for dynamic panel models. We performed a variety of tests for unit roots in panel datasets including the Breitung, the Fisher-type and the Hadri test. These tests consider the null hypothesis that the series contains a unit root, and the alternative that the series is stationary. All tests were significant at the usual testing levels. Therefore, we reject the null hypothesis and conclude that the series is stationary. Standard errors in parentheses.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

We now consider whether the results are in line with the evolutionary dynamic of regions predicted in Hypothesis 3. Because creative individuals are attracted by innovative regions, we postulated that opportunities for domain-diverse encounters decrease as regions increase in eigenvector centrality. Table 6 reports the results, and Fig. 5 illustrates the predicted marginal effects of the eigenvector centrality of a region on its opportunities for domain-diverse encounters 50 years later. The results support Hypothesis 3 by showing a strong and significant decrease between the prominence of a region in the global mobility networks of creative individuals and the opportunities within this region to encounter individuals from different domains. Again, the reported findings are consistent in both the fixed-effects and the GMM specifications. From Fig. 5, we note that the confidence interval of this effect increases with the eigenvector centrality of regions. This finding suggests that variance in opportunities for domain-diverse encounters increases in hubs of creativity. This seems consistent with our theory predicting that the downturn of central and attractive regions is a time-

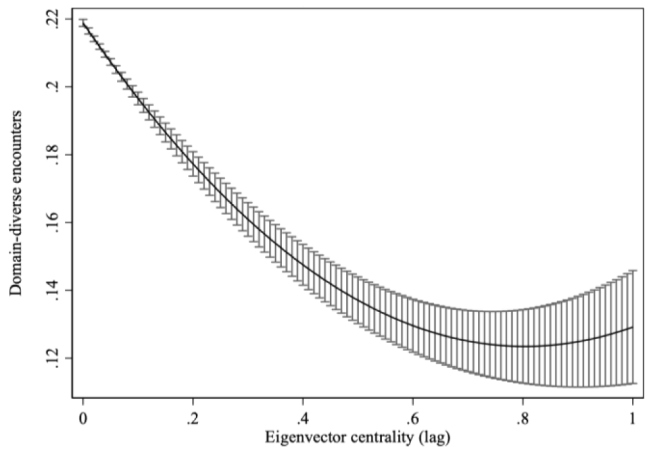

Fig. 5. Marginal effect of lagged eigenvector centrality on opportunities for domain-diverse encounters
Note: Marginal effects as predicted in Table 6, Col. 3 (95% confidence intervals).

delayed phenomenon and that the onset of decline can vary by decades. As we model only one time-lag, of 50 years, this observed increase in variance seems plausible.

To further substantiate these effects, we consider the evolution of the eigenvector centrality of three exemplary regions in the global mobility network over time: Rome, Venice, and London. Fig. 5 depicts how the eigenvector centrality of these regions changed over time. In each case, there were peaks in eigenvector centrality, but none of these were permanent. Rather, these peaks are consistent with the regions' innovation history: Renaissance Rome was known for its painters and artists, whereas mercantile Venice drew traders. London experienced two booms: thirteenth-century London rose to become the most important trading center of the Hanseatic League, and nineteenth-century London drew industrialists in great numbers. The figure shows that after their centrality peaks, all regions disappear again from the mobility focus of creative individuals.

Fig. 6.

Discussion

By integrating network mechanisms that operate at the local and global levels, this study has offered a life-cycle perspective on the dynamics of regional clusters of creativity over time. This study thus contributes a creativity-based perspective on the relative rise and decline of regions over time. Prior life-cycle theories of regional development have generally explained the uneven spatial distribution of innovations by changes in the underlying knowledge conditions of regions (Bathelt et al., 2004; Boschma and Lambooy, 1999; Cooke et al., 1997; Dosi et al., 1997; Iammarino, 2005; Lazzeretti and Capone, 2017; Marsili, 2001; Maskell, 2001). Broadly, this literature suggests that individuals and firms benefit from collocating because proximity allows them to share specialized resources and learn tacit or "locally sticky" knowledge from one another. Corresponding life-cycle arguments consider that these added benefits of collocation diminish or even become negative over time, for example, if learning induces members of a cluster to lock into solutions that are locally optimal at best (Martin and Sunley, 2003; Menzel and Fornahl, 2010). Although these studies have generated important insights into the dynamics of regional innovativeness, they have not considered or tested how social network mechanisms foster or impede creativity-related spillovers at local and global levels. As a step towards addressing this gap in the literature, we have elaborated and tested one such set of micro–level mechanisms, which explains how the dynamic evolution of local and global networks of creative individuals affects local creativity and regional innovativeness. The main contributions of our study can be summarized in three key points.

First, we have formulated a testable theory that explains how local clusters of creativity emerge, flourish, and decline over time. This theory connects the insight that social environments are conducive to individual creativity (Perry-Smith and Mannucci, 2017; Perry-Smith and Shalley, 2003) with the observation that creative individuals are attracted to regions in which they can express their creativity, and in doing so contribute to the creativity of other individuals in their region. We have highlighted how radical and incremental innovativeness are affected by particular facets of networks of creative individuals, notably by size, composition, domain homophily, and the migratory flows of creative individuals between regions. We have presented a quantifiable measure for the likelihood of serendipitous creativity-enhancing encounters in local environments. This measure underscores a life-cycle theory of the rise and subsequent decline of regional clusters of creativity over time. The presented framework highlights the importance of serendipitous encounters across domains, particularly in nascent stages of regional development. Such encounters can establish a basis for radical innovativeness and change. The framework also acknowledges the importance of encounters within domains as a precondition for the transmission of domain-specific knowledge that is needed for incremental innovations that build upon an established knowledge base. Both views come together in a life-cycle theory of regional clusters of creativity.

Second, this study is the first to test for network mechanisms of localized knowledge spillovers on a scale that is large enough to capture

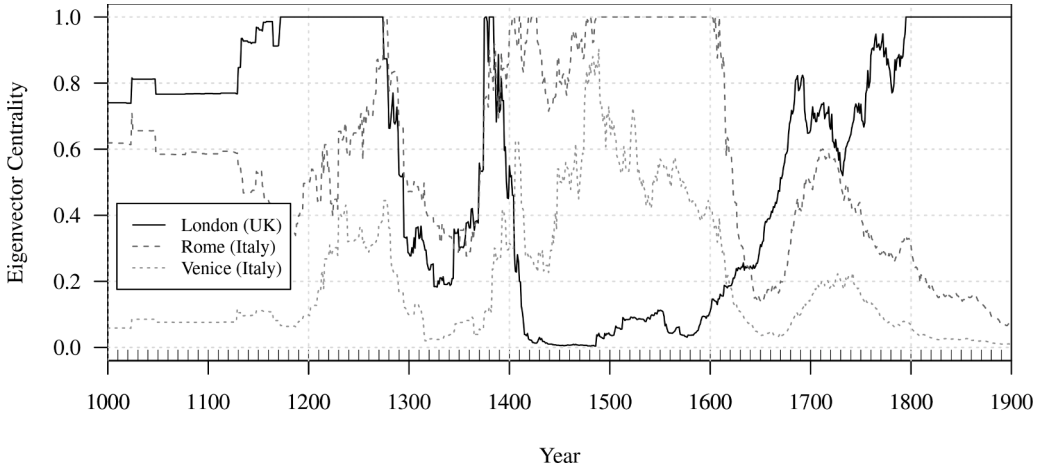

Fig. 6. Change in eigenvector centrality of select regions.

Table A1
Descriptive statistics and bivariate correlations.

ID	Variable	Mean	SD	Min	Max	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1)	Domain diversity	0.15	0.27	0	1	–	–	–	–	–	–	–
(2)	Monastery foundings	0.19	0.64	0	10	-0.06	–	–	–	–	–	–
(3)	Publisher foundings	1.27	10.49	0	532	0.07	0.00	–	–	–	–	–
(4)	Monastics ref. foundings	0.05	0.33	0	9	-0.07	0.58	-0.02	–	–	–	–
(5)	Mendicant ref. foundings	0.01	0.13	0	5	-0.02	0.35	0.00	0.03	–	–	–
(6)	Contemp. Catholic authors	0.30	10.09	0	1,218	0.01	0.01	0.13	0.00	0.00	–	–
(7)	Texts by Martin Luther	0.21	5.38	0	490	0.04	-0.01	0.12	-0.01	0.00	0.04	–
(8)	Isolated region (0/1)	0.52	0.50	0	1	-0.60	0.04	-0.13	0.07	0.02	-0.03	-0.04
(9)	Active network size (log)	1.01	1.42	0	8	0.51	-0.03	0.34	-0.08	-0.02	0.08	0.06
(10)	Local population (log)	2.71	1.94	0	8	0.36	0.03	0.17	-0.04	0.02	0.04	0.03
(11)	GDP per capita (scaled)	0.01	1.00	-3	8	0.02	0.13	0.01	0.04	0.07	0.01	0.01
(12)	Travel speed (log)	4.89	0.75	5	8	0.21	-0.02	0.15	-0.04	-0.02	0.02	0.02
(13)	Distance waterway (km, log)	27.32	24.69	0	193	-0.06	-0.07	-0.05	-0.03	-0.02	-0.01	-0.01
(14)	High altitude (>800m)	0.08	0.27	0	1	-0.02	-0.01	-0.03	-0.01	0.00	0.00	-0.01
(15)	Distance Vatican (km, log)	6.85	0.58	3	8	-0.01	-0.04	0.01	0.01	-0.01	-0.01	0.00
(16)	Reformation (0/1)	0.26	0.44	0	1	0.38	-0.06	0.17	-0.08	-0.02	0.04	0.04
(17)	Secularization (0/1)	0.06	0.24	0	1	0.17	0.00	0.16	-0.04	-0.02	0.02	0.04
(18)	War, civil unrest (0/1)	0.42	0.49	0	1	0.27	-0.08	0.07	-0.10	-0.02	0.01	0.03

ID	Variable	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
(1)	Domain diversity	–	–	–	–	–	–	–	–	–	–
(2)	Monastery foundings	–	–	–	–	–	–	–	–	–	–
(3)	Publisher foundings	–	–	–	–	–	–	–	–	–	–
(4)	Conservative monasteries	–	–	–	–	–	–	–	–	–	–
(5)	Mendicant monasteries	–	–	–	–	–	–	–	–	–	–
(6)	Contemp. Catholic authors	–	–	–	–	–	–	–	–	–	–
(7)	Texts by Martin Luther	–	–	–	–	–	–	–	–	–	–
(8)	Isolated region (0/1)	–	–	–	–	–	–	–	–	–	–
(9)	Active network size (log)	-0.75	–	–	–	–	–	–	–	–	–
(10)	Local population (log)	-0.50	0.56	–	–	–	–	–	–	–	–
(11)	GDP per capita (scaled)	-0.05	0.05	0.15	–	–	–	–	–	–	–
(12)	Travel speed (log)	-0.30	0.51	0.27	0.00	–	–	–	–	–	–
(13)	Distance waterway (km, log)	0.06	-0.07	-0.10	-0.13	0.00	–	–	–	–	–
(14)	High altitude (>800m)	0.00	-0.04	-0.03	0.13	0.00	0.12	–	–	–	–
(15)	Distance Vatican (km, log)	0.06	-0.09	-0.20	-0.04	0.02	-0.05	-0.15	–	–	–
(16)	Reformation (0/1)	-0.48	0.54	0.29	0.01	0.26	-0.11	-0.09	0.14	–	–
(17)	Secularization (0/1)	-0.26	0.42	0.28	0.00	0.65	-0.05	0.01	-0.01	0.28	–
(18)	War, civil unrest (0/1)	-0.35	0.30	0.29	0.01	0.08	-0.05	0.02	-0.03	0.35	0.16

long-term trends in the rise and decline of regions. Although researchers have long argued that social networks contribute to differences in the innovative performance across regions, to our knowledge, this is the first study that measures indirect, localized spillover effects over a 900-year period. The six analyses presented at the local level yield consistent results for how local network composition affects regional innovativeness as measured by a range of proxies. As foundings of Catholic monasteries and of publishing houses alike fall outside of the activity domain of the creative individuals that populate the mobility structure, they reflect the indirect effects of the agglomeration of creative individuals on the innovativeness of regions. Throughout the study period of 900 years, we observed the emergence, stagnation, decline, and re-emergence of regional centers of knowledge production and creativity across Europe. While not without challenges, drawing on historical data over this long period has allowed us to estimate time-lagged statistical models that minimize identification problems of "imprinting" that arise when unobserved conditions in a region affect both the dependent variable, here regional innovativeness, and the independent variables, here local and global network structures (Audretsch and Feldman, 2004; Henderson, 2007; Tappeiner et al., 2008). Our findings suggest that the mobility patterns of creative individuals have had strong indirect impacts on regional innovativeness.

Third, we have combined creativity theory with social network theory to present a life-cycle framework of the rise and subsequent decline of local clusters of creativity. This framework explains the rise, maturation, and decline of local clusters of creativity as the combination of individually rational decision-making processes with unplanned social externalities. Creative individuals are attracted to innovative regions in which other creatives have been successful before them, and they prefer interactions with similar others. At the same time, radical innovations are fostered by opportunities for domain-diverse encounters. This explains both why some domain-diverse regions become hubs of radical innovations and why the innovativeness of these hubs declines over time. This general pattern has policy implications. It suggests that policymakers should exercise caution in planning and coordinating clusters of innovative activity (Hospers, 2006; Martin and Sunley, 2003; Sorenson, 2018). In particular, it suggests the value of facilitating opportunities for unplanned social encounters between domains.

Our study suggests several avenues for future research. The life-cycle theory indicates that our empirical findings generalizes beyond the historical cases that we have presented. It predicts a decline in innovativeness over time for all regions that have produced radical innovations. This raises the question of whether this theory also applies to the knowledge-intensive societies of today. The diffusion rates of innovations have accelerated due to communication and transport technologies, and the life-cycle spans of technologies have surely decreased since the late Middle Ages. One might thereby argue that the fact that major contemporary centers of innovation have remained unchanged in recent decades detracts from our account of long waves in the geography of innovation. We would respond that it takes decades, if not centuries, to observe regional change of the scope that we have studied in this paper. On such a timescale, we observe an ongoing shift in innovation activity away from Western-industrial societies toward China, Russia, India, and Israel. Even at an accelerating rate, we would expect these dynamics to be accompanied by analogous patterns in today's knowledge-intensive societies: The stickiness of localized knowledge entails that creative solutions cannot be imported cheaply via modern media and over long distances. They require social relations and local

Table A2
Opportunities for domain diversity within local environments and innovativeness (GMM estimation).

	Monasteries found. (ln) (1)	Publishers found. (ln) (2)	Monastic ref. found. (ln) (3)	Mendicant ref. found. (ln) (4)	Publ. Catholic Authors (ln) (5)	Publ. Luther's Texts (ln) (6)
VARIABLES	Model 1a	Model 2a	Model 3a	Model 4a	Model 5a	Model 6a
L.foundings (ln)	1.002***	0.974***	0.996***	0.979***		
	(0.00818)	(0.0174)	(0.00682)	(0.0380)		
Open at start (ln)	-0.0151**	-0.0521**	-0.0207***	-0.0414		
	(0.00679)	(0.0225)	(0.00327)	(0.0324)		
Closed in prior period (ln)	0.0105	-0.0500***	0.00840	0.0323		
	(0.00742)	(0.0108)	(0.0156)	(0.0649)		
L.published (ln)					1.138***	1.149***
					(0.0228)	(0.0257)
Opp. domain-diverse encounters	-0.0687**	0.0292**	-0.0557**	-0.000772	-0.0268***	0.120**
	(0.0326)	(0.0126)	(0.0225)	(0.0257)	(0.00860)	(0.0543)
Network size (ln)	-0.0423***	-0.120***	0.0252	-0.0134	0.0947***	0.152***
	(0.0146)	(0.0443)	(0.0298)	(0.0401)	(0.0303)	(0.0476)
Network size (ln, sq)	0.00628**	0.0241***	-0.0128	0.00310	-0.0143***	-0.0202***
	(0.00317)	(0.00809)	(0.00985)	(0.0138)	(0.00468)	(0.00570)
Local population (ln)	0.00705	0.0368**	0.0123***	0.00541	0.0122	0.0216
	(0.00805)	(0.0170)	(0.00422)	(0.00497)	(0.0174)	(0.0274)
GDP per capita (scaled)	0.114*	-0.000204	-0.0966	0.132	0.00113	-0.000420
	(0.0653)	(0.00143)	(0.230)	(0.647)	(0.00127)	(0.000948)
Travel speed (ln)	-0.00112	0.000310	0.0261	-0.0245	-0.0278**	-0.0246
	(0.00295)	(0.00358)	(0.0262)	(0.262)	(0.0124)	(0.0160)
Distance Vatican (ln)	0.00236	—	-0.00194	-0.00283	—	—
	(0.00802)		(0.00358)	(0.00360)		
Reformation	-0.00209	0.0100	-0.00378	-0.00405	0.00990	0.00630
	(0.00483)	(0.00655)	(0.00607)	(0.00733)	(0.00784)	(0.00850)
Secularization	-0.0127	-0.00775	—	—	0.0101	-0.0180
	(0.0247)	(0.00979)			(0.0107)	(0.0120)
War, civil unrest	-0.00579	0.000884	-0.00344*	0.000268	-0.000821	-0.000788
	(0.00480)	(0.00128)	(0.00190)	(0.00207)	(0.00120)	(0.00111)
Isolated region	-0.0706***	-0.0830***	-0.0264**	-0.00422	0.0688***	0.111***
	(0.0201)	(0.0311)	(0.0123)	(0.0136)	(0.0221)	(0.0349)
Plague-affected region	0.00699	—	0.00221	0.00110	—	—
	(0.00634)		(0.00248)	(0.00266)		
Distance from waterway (km)	0.00315	—	-0.00388	0.00493	—	—
	(0.00253)		(0.00445)	(0.0540)		
High altitude (>800m)	-0.278	—	0.0875	-0.0207	—	—
	(0.350)		(0.243)	(3.405)		
Year dummies	included	included	included	included	included	included
Observations	297,900	132,400	173,775	173,775	132,400	132,400
Number of regions	331	331	331	331	331	331

Note: Regression with GMM specification for dynamic panel models. Standard errors in parentheses.
We performed a variety of tests for unit roots in panel datasets including the Breitung, the Fisher-type and the Hadri test. These tests consider the null hypothesis that the series contains a unit root, and the alternative that the series is stationary. All tests were significant at the usual testing levels. Therefore, we reject the null hypothesis and conclude that the series is stationary.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

practices to transfer this knowledge. In this respect, we expect that the argument of this article holds for today's societies as well. This calls for testing the effects of local network diversity on regional innovativeness in contemporary settings. It requires further research on how the diversity of contacts affects the likelihood of radical and incremental product, process, and social innovations, and whether opportunities for domain-diverse encounters predict where particularly influential innovations occur.

Second, our measures of innovativeness consist of event counts that do not consider differences in regional impact. Obviously, monasteries differed substantially in their size and impact on the local economy, publishers differed in the scale of their operations, and published texts differed in the number of copies brought into circulation. Unfortunately, records are insufficiently detailed to operationalize the relative importance of entities, and so our study has focused on the incidence of incremental and radical innovations. It remains to be seen whether opportunities for domain-diverse contacts also predict particularly influential cases of innovations.

Third, the datasets used in this study are restricted to the centuries before the onset of globalization. Subsequent changes in patterns of travel and communication might suggest that the proposed social mechanisms of knowledge spillover may also have evolved dramatically. However, much of the literature on localized knowledge spillovers relies on the stickiness of knowledge, suggesting that comparable mechanisms should be observable today.

That said, the theory presented here suggests that our empirical findings can be generalized beyond the historical case. Regions that are central in the global mobility structure yet diverse in their local composition seem best equipped to foster radical innovations. They exhibit both the knowledge stock and the opportunities for high levels of creativity and innovativeness. However, this state of heightened creativity and innovativeness is transient. As hotspots of creativity attract ever more creative individuals, local processes of consolidation set in, and contact diversity diminishes over time. Although consolidated regions still foster the incremental innovations that build on an established and growing knowledge base, their capacity to foster radical, disruptive

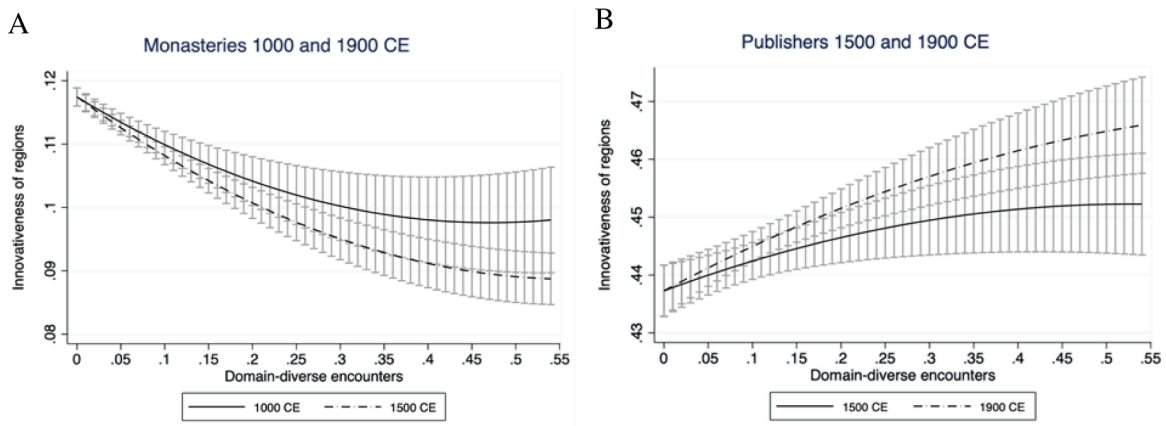

Fig. A1. Marginal effects of opportunities for domain-diverse encounters and innovativeness of regions for different time periods
Note: Marginal effects as predicted in a regression with fixed-effects specification for region and year, similar to Table 4, Col.s 1 and 3. An interaction between opportunities for domain diversity within local environments and year has been added.

innovations declines along with the likelihood of serendipitous contacts between domains. Over decades, regions may continue to innovate, but it is only a matter of time before disruptive changes occur elsewhere, in a new up-and-coming region on the periphery .

Credit author statement

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix

Table A1, A2 and fig. A1

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