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RESEARCH ARTICLE

# The Diffusion of Knowledge during the British Industrial Revolution

Gregori Galofré-Vilà

Universitat de València (Departament d'Anàlisi Econòmica), València, Spain,
Corresponding author: Email: gregori.galofre@uv.es

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**Abstract**

While technological progress played a central role in the British Industrial Revolution, statistical evidence on how inventors and entrepreneurs engaged in the process of technological innovation has typically received minor attention. In this paper I use quantitative methods to show that counties with a relatively high number of informal networks −in the form of Freemasonry, friendly societies, libraries, and booksellers− experienced more innovation as measured by new patents and exhibits at the 1851 Crystal Palace World's Fair. Qualitative evidence and propensity score matching suggest that the mechanisms highlighted here were an important part of British technological leadership. Economic factors cannot account for these patterns.

**Keywords:** industrial revolution; enlightenment; masonic lodges; innovation; technology

**JEL Codes:** J24; N13; O14; O33

## Introduction

Few areas of inquiry in social sciences are as important as understanding the causes and mechanisms that opened the floodgates of the British Industrial Revolution. Until recently, Allen and Wrigley's view, that the key ingredients of the Industrial Revolution were expensive labor and cheap energy (demanding labor-saving innovations), has attracted much attention. Other commonly accepted explanations in the literature have been Pomeranz's access to new markets owing to colonialism and good institutions that promoted (or did not confine) economic growth.[1]

In a series of works, Mokyr has identified the role and diffusion of ideas that took the technological lead. While there had been earlier waves of invention in the Islamic world or China, none snowballed into a world-changing industrial revolution. Britain was unique in creating "open science" and the transmission of ideas, as

[1]See Allen (2009), Koyama and Rubin (2022), Pomeranz (2000) and Wrigley (2010). For coal see Fernihough and O'Rourke (2021) and for institutions see North and Thomas (1973). See also Galofré-Vilà et al. (2018) and Galofré-Vilà (2018, 2020).

knowledge became a common resource creating an effective market for information to be spread. As Mokyr (2017: 24) says, "Cultural transmission [occurs] through socialization and learning in cultural processes."

Understanding how social and cultural actors turned ideas into progress during the Age of Enlightenment is vital for conceptualizing the development of the Industrial Revolution. Mokyr (2010a: 80) clarified that "enlightened ideas found expression in the myriad of friendly societies, academies, Masonic lodges, and similar organizations of people who shared beliefs and traded knowledge." Mokyr and Voth (2009: 27) also concurred that "Britain in the eighteenth century experienced an enormous growth in formal and informal social networks, through the growth of friendly societies, masonic lodges, and eating clubs … It can be argued that such informal institutions not only supported markets, but also helped Britain take the technological lead."

Kelly et al. (2022: 842) recently reviewed an "Enlightenment culture of improvement and empiricism through popular science demonstrators, coffee shop lecturers, and scientific societies" and Squicciarini and Voigtländer (2015: 1865) that "Scientific societies are a prime example for the emergence of scientific activity during the Age of Enlightenment." On the question of why the Industrial Revolution happened first in Britain and not elsewhere, Clark (2000: 443) made the point that in Britain the "broad membership of societies may have promoted a wider, more participatory Enlightenment than the brilliant but elitist cultural worlds found in France or Germany." Similarly, Mokyr (2010b: 10) also argues for a differential effect with respect to other countries: "Such networks exist in every society, but the ones established in the eighteenth century [Britain] were open and accessible to middle class men and thus were an ideal vehicle for the transmission of the information that supports reputational mechanisms."

This paper documents the mechanics by which access to knowledge blossomed into a process of industrialization and provides statistical evidence that these networks supported innovation.[2] I find that informal networks in the form of Masonic lodges, friendly societies, libraries, and booksellers had a sizable effect, and each one-standard deviation increase in these informal networks was associated with between one third to one half of one standard deviation of the dependent variable, being either new patents or exhibits at the 1851 Crystal Palace World's Fair in London. All these informal networks are presented in more detail in Section 3 while statistical evidence suggest that their effect is causal.

Naturally, this work is closely related to the literature focused on understanding the British Industrial Revolution. There are excellent surveys by Berg (1994), Clark (2014), Crafts (1995, 2011, 2021), and Mokyr (2009, 2021), and two strands within this broad literature are particularly related. One existing set of papers and books looks at the lives of famous inventors (Allen 2009; Meisenzahl and Mokyr 2012).[3] A second closely related set of work stresses the diffusion of the Enlightenment and the role of human capital during the British Industrial Revolution.

[2]While this paper argues in favor of Britain's capabilities to industrialize, it does not intend to play down other forces behind the British Industrial Revolution.

[3]See also Bottomley (2014), Dutton (1984) and MacLeod (1988).

This last agenda has been pushed by Mokyr in the last three decades —to which this paper contributes—,[4] and has been also expanded by Dowey (2017) and Kelly et al. (2014, 2020, 2023) —to whom this paper owes several ideas— and Squicciarini and Voigtländer (2015) —who have shown additional evidence from French societies—.[5] Dowey's (2017) doctoral work, titled *Mind Over Matter*, is of particular interest, as using a similar motivation and data yields congruent evidence: Local rates of invention during the British Industrial Revolution were responsive to the local prevalence of informal networks. Moreover, Dowey's doctoral work shows that access to knowledge during the Age of Machines was also positively correlated with the emergence of modern economic growth.

The rest of the paper continues as follows. The next section connects the pathways by which these private and informal networks promoted inventions. Section "Data" shows the data collection and Section "Empirical strategies" displays the empirical results exploiting cross-county variation using cross-sectional and panel level regressions and Section "Discussion" concludes.

## British informal networks

How did these mostly voluntary, private, and informal networks prove to be a locus for the exchange of scientific and technological information, spurring sustained economic growth? Conceptually, based on the work of Pearson and Richardson (2001) and others, private, voluntary, and informal networks emerged between members of local associations (like Freemasons, friendly societies, libraries, and coffee houses), and created informal arrangements (i.e., rules by which people behaved) with similar effects to public institutions,[6] facilitating the operation of markets and the use of scientific method. These forums represented the information networks of that time, where people would come in to have a coffee or a drink, share ideas, and get in contact with people from different disciplines; building bridges between those who knew things and those who made things.

By accessing these networks, not only inventors met with other inventors to share ideas, or directly investigated ideas in books, but often inventors and entrepreneurs met with businessmen and found opportunities to develop ideas and cooperate on the basis of personal relations and trust. As commented by Greif and Mokyr (2015) "British Masonic lodges and friendly societies … cemented commercial regulations and allowed investors to invest in projects they knew little about but whose entrepreneurs they knew personally and therefore felt they could trust." In this diffusion of Enlightenment culture, partnership and trust were key, as they created successful partnerships between innovators and entrepreneurs based on reputation, providing, an incentive for people to innovate in order to achieve the recognition of the groups.

To quote a famous example, James Watt improved the steam engine, which enabled the mechanization of factories and mills. Yet, he could only commercialize the invention after partnership with Matthew Boulton, a businessman. Both had

[4]Mokyr builds some of his work from Musson and Robinson (1968), Schofield (1963), Inkster (1991, 1998), Jacob (1997, 2014), and Jacob and Stewart (2004). For Mokyr's early work see Mokyr (1990a, 1990b).

[5]On human capital papers see for instance Galor and Moav (2004).

[6]Nevertheless, despite the fact they behaved similarly they were not enforced.

close links with freemasonry[7] and were well-known members of the Lunar Society of Birmingham. Watt also established close links and partnerships with other Freemasons like Erasmus Darwin, John Robison (the British physicist and mathematician) and John Roebuck, the founder of the Carron Ironworks, who later went into business with the already famous Watt to commercialize his lead chambers, which manufactured sulfuric acid. Similar connections can be found in other Freemasons, like Robert Stephenson (the designer of locomotives). Such links were additionally reflected in the wider Victorian culture, as Freemasons like William Hogarth (the artist) commissioned portraits for John Desaguliers, Martin Folkes, and Thomas Pellet. In fact, about half of the inventors referenced by Allen (2009) and Meisenzahl and Mokyr (2012) have Enlightenment connections.[8] Howes (2017) has also noted that around half of the innovators in his sample were members of important societies. Nonetheless, it is important to stress that beyond being connected at famed societies like the Royal Society, other links —like being a freemason, part of the same friendly society or frequenting the same library— were important for the transmission of ideas and extremely difficult to observe and document in historical settings.

Like the Reformation, the Enlightenment spread through literacy. Books, pamphlets, newspapers, and encyclopedias influenced an increasing number of inventors and businessmen. Together with cotton clothes, clocks and tableware, books were one of the goods that came into great demand in the mid-18th century. As Mokyr (2010a: 39) writes "the growth of scientific books and periodicals in the eighteenth century was impressive" as "these works were perhaps the prototype of a device meant to organize useful knowledge." Authors like John Sinclair and Arthur Young became famous for writing voluminous books on agriculture and Joseph Banks and Erasmus Darwin on plants and animals. On matters of new technology, Edmund Beckett Grimthorpe published his knowledge of watch making, and William Jones did the same of solar telescopes. The translation of foreign books into the English language was also important. For instance, Rudolph Ackermann translated Senefelder's work on lithography in 1818, thereby spreading the technique to Britain.

As the demand for books increased, their quality improved, forms of production became standardized and prices fell even more. The *Licensing of the Press Act* in 1694 had already begun to deregulate the printing industry and the prices of books plummeted in the early 18th century, before remaining for a long time at a plateau, rendering them increasingly accessible (van Zanden 2009).[9] As Allen (2009: 12) also comments, "the invention of printing sharply reduced the price of books, leading to much more reading for both useful knowledge and pleasure." By 1775, Britain had produced around 138 million books, more than in Germany (117) or the Netherlands (53). While it is true that literacy did not paint late 18th century

[7]Watt was a freemason in Scotland, and although Boulton was not, he was a close friend with other British freemasons like Erasmus Darwin. Darwin has been claimed to be the middle-man between Boulton and Watt and for instance, when Watt visited Birmingham, in the absence of Boulton, Small and Darwin showed him the Soho Manufactory.

[8]Indeed, there might be problems of sample selection as inventors may have ended up in the sample simply because of either publication or known membership (Meisenzahl and Mokyr 2012).

[9]For a dissenting view on the effects of licensing laws see Fielding and Rogers (2017).

Britain in an exceptional light (Mitch 1999), around two-thirds of the male population were still able to read, introducing a large number of people to new knowledge through books.[10]

People met and exchanged knowledge in public and private for a such as bookshops and libraries. Naturally, the spread of books and libraries as well as bookshops correlated: as books and journals circulated widely, libraries were developed, making the former easier and easier to access. As Mokyr (2010c: 39) further comments "the age of Enlightenment took a special delight in compiling books that summarized existing knowledge, added sophisticated and detailed drawings that elaborated the operation of technical devices, and placed these books in public libraries." However, libraries (whether public or private) not only stored knowledge, but actively sought to disseminate knowledge through organizing lectures, symposia, experiments, and public readings of texts like encyclopedias (Allen 2009; Squicciarini and Voigtländer 2015).[11]

In many ways, these places also connected and complemented famous societies. For instance Howes (2020: 24) reviews that "as the Society [of Arts] grew in its prestige, its members felt that it deserved a suitably prestigious venue. There were practical reasons for a new venue too. The number of members hoping to have their say very soon outgrew the living rooms, libraries, and coffee-house booths that the Society had commandeered." Outram (1995) also reviews that to promote the enlightenment culture, bookshops often offered magazines and books to be browsed by customers.

Did ideas transformed into patents? The British patent system emerged from the Statute of Monopolies (1624). It was the most expensive patent system among its contemporaries (Hancock 1850) and although patents may fail to capture innovation outside the patent system and probably have only a small role in most innovation, it is also possible to argue that many of the most important inventions of the Industrial Revolution can be found in patent filings (Khan 2020; MacLeod 1988; Moser 2005, 2013; Penrose 1951).[12] Indeed, following some of the inventors of the Industrial Revolution mentioned above, anecdotal evidence illustrates that patents could be connected to the workings of informal networks like Freemasonry. For example, James Watt patented a total of six inventions, most of them linked to the steam engine, including a "method of lessening the consumption of steam and fuel in fire-engines" (5th January 1769) and "a steam or fire engines for raising water" (12th March 1782), but also a new method of "copying letters" (14th February 1780). Later on, Matthew Boulton also patented an "application of the powers of water-mills, cattle-mills, and steam-engines" (8th July 1790) and an "apparatus for raising water and other fluids" (30th December 1797). A total of six patents were also filed by Robert Stephenson, including two on "locomotive steam-engines" (26th January

[10]Buringh and van Zanden (2009) also show that literacy rates in the 18th century were around 54% in Great Britain, 38% in Germany, 29% in France, 23% in Italy, and 8% in Spain; yet the British remained below the Dutch (85%).

[11]Along with public libraries, in private subscription libraries, visitors could access by paying a small fee.

[12]For instance, MacLeod (1988: 1) commented that "invention took place outside it and often in ignorance of it."

1833 and 7th October 1833) and another on a "mode of supporting the iron-rails for edge-railways" (11th December 1833).

Following this logic, in which local groups like Freemasonry, friendly societies, libraries, and booksellers provided means for knowledge sharing, thus having positive spillover effects for inventions, one may worry that these organizations could simply be a response to the Industrial Revolution. Indeed, as noted by Dowey (2017), the idea that these organizations were endogenous to the Industrial Revolution has a lineage going back to Marx and Engels (Engels 1895). However, later in the paper I provide qualitative and quantitative evidence to attenuate forces of reversal causality.

Beyond the above informal networks, there were also other ways in which different actors could spread innovation. Market integration and the transport revolution allowed people (and their ideas) to move faster throughout Britain reducing the cost of communication (Szostak 1991). As recently showed by Kelly et al. (2023), Britain was also well supplied with skilled artisans like craftsmen, masons, carpenters, watchmakers, and engineers (Walker Hanlon 2022; Kelly et al. 2014). While recognizing the existence of other potential pathways, in what follows I focus on the most salient informal networks that connected people and their ideas under reputational mechanisms and sharing knowledge and from those I could quantify using historical data. Yet, before quantifying their importance and delving into issues of reverse causality, it is first necessary to present the data collection and baseline correlations in the next two sections.

## Data

This paper combines several data sources for industrial Britain, all are available at the county-level, and some of them being hand-collected and digitized for the first time. The county is a good unit of analysis as for specific year or decade the of number inventors in more granular data (i.e., the municipality or parish level) would be small and often zero. Indeed, some variables like Masonic lodges, to the best of my knowledge, are only available at the county level. Main descriptive statistics on all variables are available in Table A1 (see supplementary materials) and their spatial heterogeneity is shown in Figure 1. Next, I briefly describe each one of them.

### *Patents*

Patent data include details on individual inventors (name and surname, place of residence and year that the invention was patented) and inventions (a short description of the invention).[13] I hand-collected all these details on British patents from the two-volume *Titles of Patents of Invention, Chronologically Arranged*, edited by Bennet Woodcroft (1854).[14] To also get a sense of the quality of the patents,

[13]See also Bottomley (2014, 2019), Griliches (1990) and Moser (2013).

[14]A reason for focusing on the 1750–1849 period is that patent laws were largely stable at this time (Dutton 1984). In 1852 there was an important reform act, which lowered the cost of patenting, leading to an increasing number of patents filed. On the origins and collection of the patents data, Woodcroft was hired by the Patent Office Commissioners in 1852 to compile a comprehensive index of all patents since 1617.

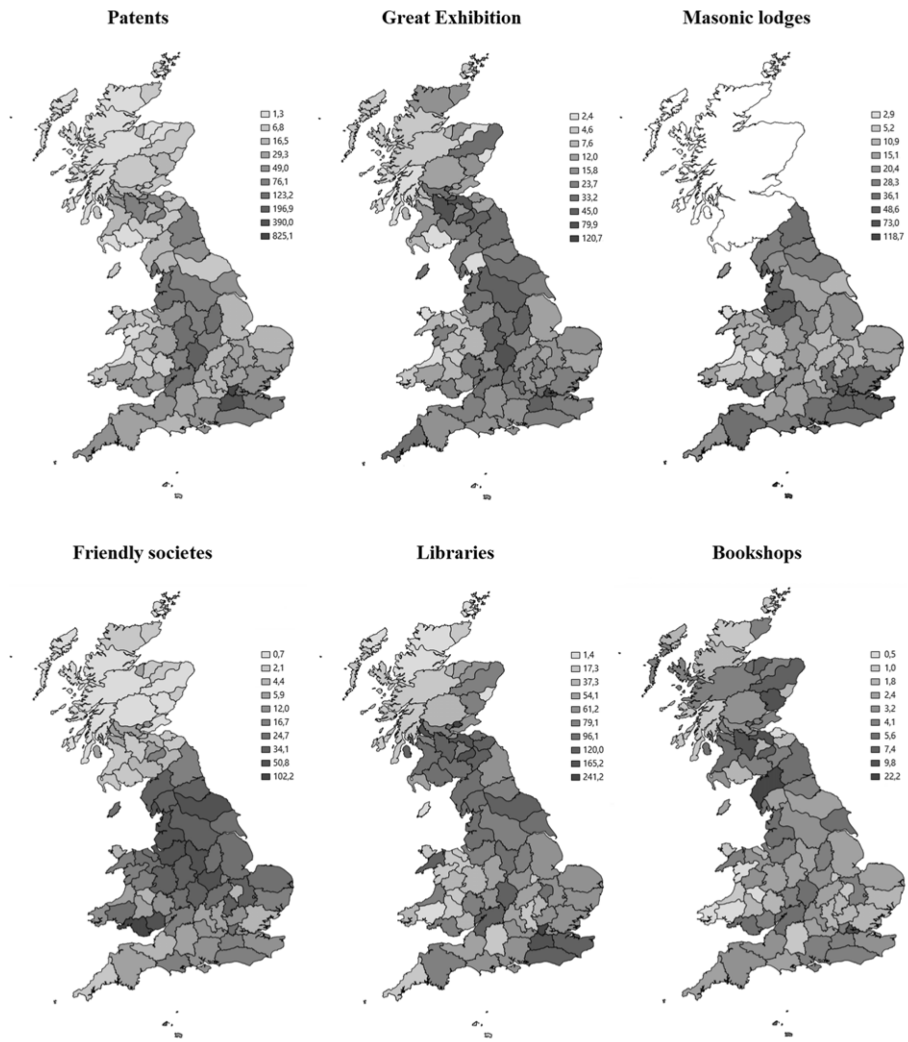


**Figure 1.** County-level variation on key variables.
Note: These maps show the number of patents, exhibits at the 1851 Crystal Palace World's Fair, masonic lodges, friendly societies, libraries and booksellers within each county. Data are for the period 1750 and 1849, with the exception of the Great Exhibition and Booksellers that are a cross-sectional for 1851. The white area in masonic lodges denotes lack of data for Scottish counties. All variables are expressed in per capita terms.

I matched each patent to Woodcroft's list of citations in technological and legal publications using the *Reference Index of English Patents of Invention, 1617–1852* (Woodcroft 1862) and to Nuvolari et al. (2021)'s classification of industries.

While patent data provide a unique window into the development of technology during the Industrial Revolution, as already noted, they may fail to capture innovation outside the patent system. Moreover, it is also possible to argue that comparability across time is difficult to assert since greater number of publications appeared in later years. The system was also often criticized for neglecting radical inventions,

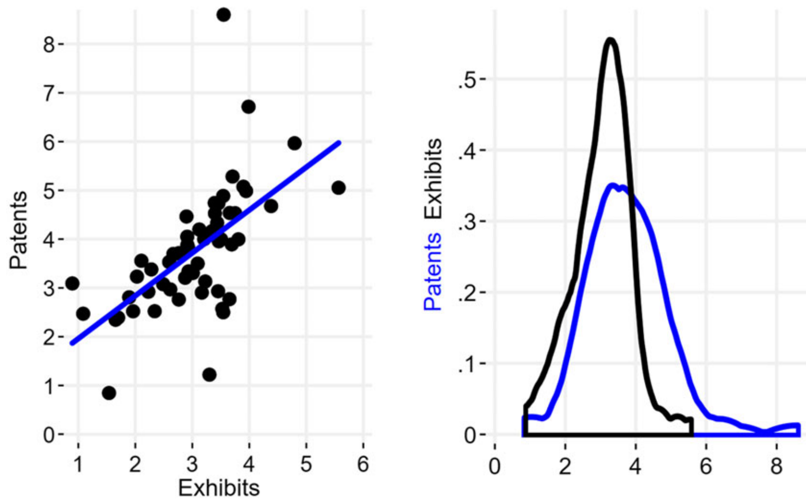


**Figure 2.** Unconditional correlations between patents and exhibits and their distribution.

and sometimes what survived from guilds, also saw patents as an unfair obstruction to the course of their business. For instance, MacLeod (1988) notes that clockmakers bolstered their successful resistance to various patents. Nonetheless, despite being an imperfect measure of innovation missing important dimensions of technological innovation, as Moser (2013: 23–24) points out, "in the absence of economy-wide data on the quantity of innovations, patent counts have become the standard measure of innovation."

### *1851 Crystal palace World's fair*

In an effort to absorb some of the limitations of the patent's data, I also use data from the *1851 Crystal Palace World's Fair in London.*[15] Data from the Exhibition have kindly been shared by Petra Moser. The 1851 Fair was the first prominent worldwide technology exhibition. It housed 17,062 exhibitors and attracted more than 6 million visitors. The dataset lists the name of the inventor, its residence, type of invention, prizes awarded, and the industrial classification for the invention. Naturally, as Figure 2 shows, there is a close correspondence between those who patented or were at the Crystal Palace. This fact emphasizes the importance of cultural factors and systems of collective inventions outside the patents system.

A potential caveat of this source is that public awareness of the exhibition may have been enhanced by the libraries of Masonic lodges, and membership in some groups may have given prospective exhibitors an advantage beyond better capabilities for technological innovation. However, it does not seem that ultimately informal networks were a formal contact point (Cantor 2012; Message and Johnston 2008), and the number of local committees was large (330) and spread throughout Britain. Davis (1999) has also shown how some committees treated mechanics' institutes

[15]For details see Moser (2005).

with suspicion given their reputation for harboring radical political views. Given that the exhibition was widely advertised via the national media, and Prince Albert's involvement lent it star power, people became aware of its occurrence. In any case, this is just a cross-sectional dataset for 1851, missing inventions as we move away from that year.

### Freemasonry

Through its roots lay in the brotherhoods of medieval stonemasons, Freemasonry is a network that offers male sociability exalted by mythology and ritual. Thus while Freemasonry's origins are lost in the unrecorded history of medieval times, it formally organized in London around in the early 18$^{th}$ century. As a fraternal organization, Freemasonry unites men (and later on women) who, though of different religious, ethnic or social backgrounds, share a belief in the fatherhood of God and the brotherhood of mankind. Freemasonry described itself as "a system of morality, veiled in allegory and illustrated by symbols", being fraternal organizations that acted as an allegorical guide for the moral and spiritual improvement.[16]

The local organizational unit was the Lodge. These were places supervised by a regional Grand Lodge. Yet, Grand lodges had only limited jurisdiction, giving space to each lodge to be independent, and thus they did not necessarily recognize each other as legitimate. The Lodge met regularly to approve minutes, elect new members, and perform ceremonies. As Burt (2003: 659–660) notes, overall "Freemasonry was highly 'business friendly' . . . the formalized dining and socializing activities that followed every lodge meeting presented exceptional opportunities for networking between individual and firms."

Data on Masons' lodges including their historical dates and meeting places from 1717 to 1894 are collected from *Lane's Masonic Records* available in the Museum of Freemasonry. This source allows for the creation of panel data, with the list being first published by the United Grand Lodge of England in 1895, listing all lodges established by the English Grand Lodges from the foundation of the first Grand Lodge in 1717.

### Friendly societies

Friendly societies were groups of mostly working men who pooled their savings so that they could support themselves and each other in difficult times (Gorsky 1998; Gosden and Heather 1961; van Leeuwen 2016). According to Cordery (2003: 1): "These collective-self-help organisations provided working people with the security of mutual insurance alongside opportunities for regular, ritual-based sociability." They constituted the largest set of voluntary associations in Britain, and by 1900 they reach about 6 million members (Cordery 2003). Data on the location of lodges, with the number of members belonging to each one and days when the meetings of each lodge took place are from a previously untapped data source: *The List of the Lodges composing the Independent Order of Oddfellows, Manchester Unity of the*

[16]For further details on how the Freemason movement spread during the Industrial Revolution, see Bullock (1996), Burt (2003), Clark (2000), and Jacob (1991, 2014). For details on how it came out of the Mason's Guild and morphed into a society of gentlemen and members of the upper bourgeoisie, see Jacob (1981).

*Friendly Society* which was published in 1880. While other fraternal insurance organizations boomed in the 19th century, the Oddfellows was created in 1810, and it was the largest voluntary organization in the English-speaking world. In 1900, the organization had around 820,000 members only in Britain (Downing 2015).[17]

### Libraries

The location of over 30,000 libraries (by name, category, and year of operation) in Britain prior to 1850 are taken from the *Alston's Library History Database*.[18] Robin Alston who was Professor of Library Studies at University College London, constructed a panel based on over 1,500 published studies that referenced British libraries. A potential caveat is that Alston's data are based on a survey derived from first mention, so its chronology does not necessarily reflect the precise year of foundation. However, when used it in the cross-sectional analysis I pooled the data into a large time-span and in the panel data I organized the data into decadal windows. Libraries were inclusive and, on average, members borrowed around 20 books per year (Kelly 1992). Roughly, the library movement started in the 1720s and flourished in the second half of the 18th century. However, whereas public libraries grew rapidly at this time, the number of private libraries remained fairly stable.

### Booksellers

Finally, the location of booksellers can be derived from the occupation census of 1851. This is a cross-sectional dataset for 1851 with the location of the booksellers at the county level. After the passage of the *Licensing of the Press Act* in 1694, which deregulated the printing industry, the prices of books fell, and this was accompanied by a proliferation of libraries and booksellers, lowering the cost of codified access to knowledge via newspapers, magazines, pamphlets, and books (Porter 2000). Clark's cost of living index shows that the real price of books fell by around 30% between 1750 and 1850.

### Additional control variables

I also use the following control variables. The latitude and longitude of each county's location (by the county's centroid) is used to control for spatial autocorrelation (Voth 2021). I also created a dummy if the county had access to sea, and zero otherwise (i.e., land-locked county). I control for coalfields using the data from Fernihough and O'Rourke (2021), originally using the map from *Les Houillères Européennes* and created a dummy if the area of the county included more than 5% of coalfields' terrain.[19] Additionally, using data from Kanefsky and Robey

[17]And an additional 9500 dotted around the British Empire plus a million more in North America.

[18]See Robin Alston's *Library History Database* available at Institute for Historical Research (University of London).

[19]Basically, using the digitalized maps from Fernihough and O'Rourke (2021), I calculated the area of coalfields within each county (in percentage). The results are not sensitive if I use other thresholds (10% or 15%). For the original source see *The Atlas châtel et dollfus. Les houillères Européennes* published by the Société de Documentation Industrielle.

(1980), I use the number of steam engines up to 1800 according to the county in which they were constructed. Other adjustments include the number of schools (adding private and public schools) as a share of the total population using data from the educational census of 1851, and the occupational force with the number of people working above the age of 20 as a share of total occupation. Spatial distributions of these variables are available in Figure A1 (see supplementary materials).

## Empirical strategies

### Main results

Considering Figure 1 it is possible to see a close association between counties with a greater share of informal institutions and inventions located in the West Midlands and Greater London, and less of them in Scotland or Wales. At the county level, there seems to be a close positive association between the number of informal networks in the form of Masonic lodges, friendly societies, libraries, and booksellers and the level of inventions (proxied either by the number of patents or exhibits at the 1851 Great Exhibition). Nonetheless, I next go beyond the graphical evidence and explore these correlations more rigorously and implement some empirical strategies to limit biases due to endogeneity and unobservables in the following way:

$$\log INV(a)_c = \alpha + \beta_1 \log \mathrm{Network}(b)_c + \Lambda' \mathrm{X_c} + \mathrm{e_c} \tag{1}$$

where *INV* is the number of inventions in county *c* (per capita and in logs). As defined by (*a*), inventions take the form of *patents* or *exhibits* at the 1851 Crystal Palace World's Fair.[20] The main explanatory variables are the *information networks* being defined by (*b*) as the number of Masonic lodges, friendly societies, libraries, and booksellers ($b = 1, \ldots, 4$).[21] All available at the unit of county *c*, in per capita terms, in logs, and if they are available for different years, the count of all patents are restricted to the period 1750 and 1849. Additionally, $\Lambda' \mathrm{X_c}$ are county-level socioeconomic and demographic controls and $\mathrm{e_c}$ is the error term, with robust standard errors clustered at the county level. I also standardize data to have a mean of zero and a standard deviation of one so coefficients across models are directly comparable.

Table 1 shows the most parsimonious results (unconditional correlations) along with those conditional on a range of factors, and also using propensity score matching on the same correlates (using two neighboring counties).[22] In the absence of a fully random assignment, I use the propensity score matching methodology to find similar observable characteristics of non-treated counties. Since I do not have a typical zero-one treatment variable for the informal networks, I construct an individual indicator that equals one/zero when the informal network (i.e., the per capita number of masonic lodges, friendly society lodges, etc.) is above/below the median value.

[20]In order to assign each inventor (either patenting or presenting an exhibit at the 1851 Great Exhibition) to their respective county, I used the details of their place of residence. Hence, in each case, individuals were geocoded based on their address and grouped by discrete regional units (counties).

[21]Similarly, I geocoded the location of each Masonic lodge, friendly society, library and bookseller, and then assigned its county based on its location.

[22]The results are not sensitive if I use three or more neighboring counties.

**Table 1.** Cross-sectional impact of informal networks on patents and exhibits

| | Patents | Exhibits | Patents | Exhibits | Patents | Exhibits | Patents | Exhibits |
|---|---|---|---|---|---|---|---|---|
| | Masonic lodges | | Friendly societies | | Libraries | | Booksellers | |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| Unconditional correlations | 0.496*** (0.177) | 0.396** (0.165) | 0.508*** (0.088) | 0.263*** (0.099) | 0.445*** (0.134) | 0.362*** (0.101) | 0.326*** (0.096) | 0.473*** (0.105) |
| Conditional correlations | 0.461** (0.184) | 0.366** (0.140) | 0.131* (0.078) | 0.007 (0.121) | 0.314** (0.122) | 0.216** (0.096) | 0.325*** (0.086) | 0.428*** (0.092) |
| Propensity score matching | 0.542* (0.301) | 0.571** (0.242) | 0.640*** (0.218) | 0.154 (0.220) | 0.575*** (0.222) | 0.478** (0.193) | 0.535** (0.213) | 0.646*** (0.225) |
| Observations | 58 | 58 | 90 | 90 | 90 | 90 | 90 | 90 |

*Note*: Outcome variable is either the number of patents or the number of exhibits at the 1851 Crystal Palace World's Fair within each county, per capita and in logs. The main explanatory variables of informal networks are the number of masonic lodges, the number of friendly societies lodges, the number of libraries and booksellers within each county (all in per capita terms and in logs). Models for each informal network and outcome variable are estimated independently. Data are restricted to the period 1750 and 1849, with the exception of exhibits at the 1851 Crystal Palace World's Fair and booksellers that it is a cross-sectional for 1851. Conditional correlations use the following control variables: the latitude and longitude of each county's location (by the county's centroid), a dummy if the county had access to sea, a dummy if the county included more than 5% of coalfields' terrain, the number of steam engines (in per capita and in logs), the number of schools (also per capita and in logs), and the labor force (i.e., the number of people working above the age of 20 as a share of the total occupation also in logs). Due to potential issues on balance and overlap, PSM models are estimated only with the following controls: a dummy if the county had access to sea, a dummy if the county included more than 5% of coalfields' terrain and the number of schools (also per capita and in logs). The number of counties for masonic lodges is 58 instead of 90 as data for Scottish masonic lodges are missing. Coefficients report the results standardized variables to have a mean of zero and a standard deviation of one, so the size of coefficients across models are directly comparable. Robust standard errors are clustered at the county level, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

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This shows more clearly if counties have the same rate of inventions if they had lower/higher levels of informal networks once they are matched on their observables. Moreover, since the effect of informal networks may come at different parts of the distribution, I also explore the effects with different cutoffs of the distribution.[23]

In all cases, informal networks accurately predict the number of British inventions, even after considering the intrinsic characteristics of the counties. Indeed, I find that these networks had a sizeable effect, and each one-standard deviation increase in these informal networks was associated with between one third to one half of one standard deviation of the dependent variable. Regarding the results using propensity score matching, I explore issues of balance and overlap with variance ratios and standardized differences (unreported here). After exploring with different models, I had to drop some controls relying only on coalfields' terrain, access to sea, and the number of schools (per capita and in logs), as otherwise there is the risk that the regression adjustment in some models rely on extrapolation.

### Robustness checks

Some robustness bolsters these findings. In Table A2 (see supplementary materials), I display results in absolute numbers (without per capita terms) and in logs to ensure that population's measurements are not driving the story. In Table A3 (ibid.), I add division/regional dummies to mop up much of the division level differences such as religion and employment, and to get more precision in the point estimates, in Table A4 (ibid.) I bootstrapped the standard errors with 100 repetitions. In Table A5 (ibid.), I also weight the regressions by the level of population to eliminate undue influence from smaller counties or the 'London effect'. I also control for potential outliers and sample stability and remove one county at a time (unreported here). Using data from the *Tables of the Revenue, Population, Commerce of the United Kingdom*,[24] in Table A6 (ibid.) instead of measuring friendly societies by the *Order of Oddfellows*, I used data from the number of friendly societies filed by the clerks of the peace from 1793 to 1832. In all cases these additional models lead to no material change in the baseline findings.

### Addressing sources of endogeneity

Despite previous correlations show that different ways to measure inventions or informal networks hint at the same result (i.e., the existence of these networks largely predict the rate of invention), there is still the threat of endogeneity and that these organizations could be simply a response to the Industrial Revolution. Yet, it seems unlikely that this is driving the story. The legal system and public markets did not incentivize innovation. English fees for patenting were very high (£145 in 1845, or £18,786 in today's money) and £380 (£49,231 in today's money) for full British coverage (Bottomley 2014).[25]

[23]For instance, instead of splitting the sample by those above/below the median value, considering only those above different percentiles. Results are not sensitive to these alternative cutoffs (unreported here).

[24]Available in Volume 2, pages 16–17.

[25]In order to adjust historical values to today's money, I used the Office for National Statistics' composite price index.

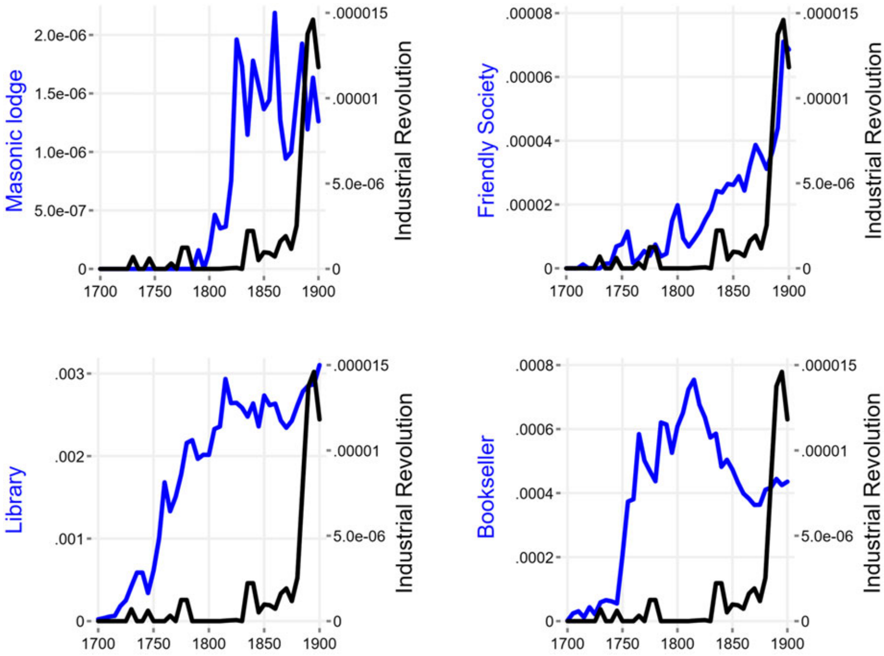


**Figure 3.** Keywords in British-language text.
Note: This figure shows mentions of some words in British-language texts between 1700 and 1900, using the Google Books' tool of Ngram Viewer. Data are in percentages.

Furthermore, as I show next in Figure 3, mentions of "Masonic lodge," "friendly society," "library," and "bookseller"[26] in the corpus of British-language texts (i.e., books, magazines, etc.) using the Google Books' tool of *Ngram Viewer*, spiked in the second half of the 19th century preceding mentions of the British "Industrial Revolution." Beyond showing that the mentioning and the notoriety of informal networks in the corpus of British-language texts spiked in the second half of the 19th century, preceding mentions of the Industrial Revolution, in Figure A2 (see supplementary materials), I also show that these networks were already of significant (and growing) magnitude around 1760–1780, which is when the British Enlightenment was at its peak and the Industrial Revolution was just getting on the way.[27]

The work from Cox (2020) also emphasizes how the patent system fostered access to knowledge after 1734, which is similar in spirit to this paper. Additionally, other authors have made similar claims. Clark (2000: 7, 488) opined that "clubs and societies were not some kind of Darwinian outgrowth of the Industrial Revolution" and that "in Britain [innovations] were created by a complex set of economic, social, political, and cultural conditions which were already in place before the Industrial Revolution." Dowey (2017: 4) also argues that informal networks were "largely exogenous to industrialisation, rooted instead in the intellectual developments of the Scientific Revolution

[26]Results are not sensitive if I use its plural form or modifications of the terms.
[27]I would like to thank Referee 2 for this suggestion.

and European Enlightenment." Furthermore, Gorsky (1998: 499) makes the point that friendly societies were not the result of the Industrial Revolution, as "a chronology premised on industrial discontinuity cannot account so satisfactorily for … the existence of fairly high levels of mutual aid in some agrarian counties and older manufacturing centres." The bottom line here is that there is also an important literature arguing that the direction of causality moves from these informal associations to the Industrial Revolution (and not the other way around).

### Panel data with fixed effects

Beyond cross-sectional models, I next use variables that recorded the time dimension and explore panel data with a range of fixed effects. Using the time dimensions when available,[28] I use the following equation:

$$\log PAT_{\mathrm{c,d}} = \alpha + \beta_1 \log \mathrm{Network}\big(Mason/Libraries\big)_{\mathrm{c,d}} + \lambda_{\mathrm{c}} + \delta_{\mathrm{d}} + \mathrm{e}_{\mathrm{c,d}} \quad (2)$$

where *PAT* is the number of patents in county *c* and decade *d* (per capita and in logs). I use separate models to estimate the effect Masonic lodges or libraries have as the main explanatory variables (also per capita, in logs and bounded by the period from 1750 to 1849). I also add county-level fixed effects ($\lambda_c$) and time (i.e., decadal) fixed effects ($\delta_d$), with the error term and standard errors being clustered at the county level. I standardize data to have a mean of zero and a standard deviation of one. In columns 4 and 5, I use division-by-time fixed effects (i.e., division specific decade trends and division by decade fixed effects) that mop up time-varying factors at the division level, such as division wide policy changes and preferences on goods, absorbing much of the division level differences.

Results in Table 2 using panel data with standard (i.e., county and decadal) fixed effects are also statistically significant, displaying the expected positive sign and coefficients are quite stable across specification. In comparison with those in Table 1, it is possible to observe how the size of coefficients is reduced by 10–20%, but this is simply because panel data allows for more precision and the inclusion of fixed effects. The change in the number of observations between Masonic lodges and libraries is due the lack of Scottish data for Masonic lodges. When I add the division-by-time fixed effects p-values remained sufficiently low to retain predictive value.

### Mechanisms

So far, I have measured inventions by the number of patents and exhibits at the 1851 Crystal Palace World's Fair, but both variables possess further qualitative details that allow for a better identification in the data. Since I have the number of citations for each patent, I also created a dummy for counties which are at the top 10-decile of citations of their patents. Here citations refer basically to mentions in technical journals and books, reports, and law commentaries. I also linked my dataset of patents

[28]For instance, while masonic lodges or libraries recorded the time dimension (along with its spatial distribution) the *Crystal Palace World's Fair* is just a cross-sectional for 1851 (only recording its spatial distribution in 1851).

**Table 2.** Panel impact of informal networks on patents

| | (1) | (3) | (4) | (5) |
|---|---|---|---|---|
| Masonic lodges | 0.080*** (0.028) | 0.127** (0.053) | 0.120** (0.055) | 0.146*** (0.055) |
| Observations | 928 | 928 | 928 | 928 |
| $R^2$ | 0.741 | 0.575 | 0.591 | 0.638 |
| Libraries | 0.212*** (0.041) | 0.328*** (0.120) | 0.301** (0.121) | 0.328** (0.147) |
| Observations | 1,440 | 1,440 | 1,440 | 1,440 |
| $R^2$ | 0.657 | 0.519 | 0.530 | 0.599 |
| Decade fixed effect | ✓ | ✓ | ✓ | ✓ |
| County fixed effect | – | ✓ | – | – |
| Division fixed effect | – | – | ✓ | ✓ |
| Division specific decade trends | – | – | ✓ | – |
| Division by decade fixed effects | – | – | – | ✓ |
| County-level clustering | – | ✓ | ✓ | ✓ |

*Note*: Outcome variable is the number of patents within each county, per capita and in logs. The explanatory variables of informal networks are the number of masonic lodges and the number of libraries within each county (in per capita terms and in logs). Models for each informal network and outcome variable are estimated independently. Data are restricted to the period 1750 and 1849. A range of time and region fixed effects are added as stated in the table. The difference in the number of observations when using masonic lodges or libraries is simply because data for Scottish masonic lodges are missing. Coefficients report the results standardized variables to have a mean of zero and a standard deviation of one, so the size of coefficients across models are directly comparable. Robust standard errors are clustered as stated in the table, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

with the data from Nuvolari et al. (2021) that display the number of times each patent is mentioned in a set of sources (and not just in Bennet Woodcroft's *Reference Index*) as well as the number of sources that mentioned each patentee. For inventors at the 1851 Crystal Palace, I also created a dummy for counties that received an award for exceptional inventiveness (about two thirds of the counties). These honors were awarded by international panels and ranked exhibits according to their "novelty and usefulness."[29] Results in Tables A7 and A8 (see supplementary materials) on the quality of inventions[30] and Tables A9 and A10 (ibid.) on industrial use show that not just its quantity (even after per capita adjusted), but informal networks are also a good predictor for the quality of the inventions.

Since for all patents and exhibits I can identify the type of invention, I also modify the outcome variable to be the number of inventions in each industrial use. Here, I used the types of industries as classified by Moser (2005) and Nuvolari et al. (2021) with a total of 16 industries displaying 128 regression results. Moreover, since as already noted both the patent data and the Crystal Palace exhibits have their

[29]Basically, juries awarded Council Medals, Prize Medals, and Honorable Mentions, and I combined all of them into a single category called "award." Results are not sensitive if I combine honors or study them independently. For details on awards see Haltern (1971).

[30]Given the nature of these outcomes, these models are estimated by a logistic regression.

shortcomings, regressions at the level of industry help to uncover the mechanisms behind the relationship between informal networks and inventions and the types of inventions bolstered by these networks.

Table A11 (see supplementary materials) shows that the effects of the informal networks changed with the nature of technological progress. For instance, informal networks mostly connected with new innovations in the sectors of chemicals, construction, food, engines, instruments and paper and also metallurgy and textiles. Other industries like furniture, leather, hardware (including locks and grates), and military are less well predicted by informal networks. As one might expect, there are differences on the effects on inventions by type of network, with Masonic lodges being the network that strongly correlates with innovations in construction, or booksellers predicting inventions in the paper and bookbinding sector. Differences also appear by the way they are proxied (patents or exhibits), but overall a clear picture of the above industries emerges with close links with the existing literature on the inventions during the Industrial Revolution. For instance, Meisenzahl and Mokyr (2012: 444) noted that "Outside the familiar tales of cotton textiles, wrought iron, and steam power, there were improvements in many aspects of production, such as mechanical and civil engineering, food processing, brewing, paper, glass, cement, mining, and shipbuilding."

As an additional robustness check in the industry analysis, I can also replicate the baseline cross-sectional results of this paper by adding industry fixed effects (Table A12, see supplementary materials). Here, industry fixed effects account for industry specific innovation intensities. This is important as arguably machinery is inherently more technology-intensive than other industries like for example the paper industry.

A final test I do is that following the literature on technological spillovers, the association between these informal networks and innovation, for being valid, need to rest on the assumption that local informal networks would influence innovation by proximity (i.e., Masonic and friendly society lodges or libraries had local coverage), where the cost of access to knowledge and the rate of innovation would be spatially mediated. Whether innovation from informal networks was driven by proximity can be tested in the data, and would emphasize the importance of cultural factors and systems of collective inventions. Taking distances between inventors of the same patent,[31] I find that inventors would be more likely to live closer than further away given that social networks are spatially embedded (unreported here). Indeed, more than three quarters of the inventors of the same patent resided within the same county or the contiguous one.

## Discussion

Britain's economic precocity in the 18th century changed the world allowing it to depart from Malthus and the embrace of poverty and premature death. Clearly, the movement from a narrow event into a globally transformative historical force

[31]Inventors of the same patent simply reflects that one invention was developed by one or more inventors and I take the distance (in km) between these inventors. Distances between pairs of inventors are calculated as the crow flies (i.e., the Euclidean distance between two counties based on the county's centroid).

needed something other than the momentum of steam and cotton or the Atlantic trade. Rising efficiency in production techniques moved in tandem with a new intellectual culture: the Enlightenment. This new culture developed a belief in the capability of what they called "useful knowledge" to advance the state of humanity. They did not just believe in progress, but showed a roadmap in whereby it was to be achieved.

Along with Mokyr's books *The Enlightened Economy* and *Culture of Growth*,[32] scholars have explored how these ideas rapidly spread into other countries, with the rise of the West. Yet, a missing stage in this logic is how ideas disseminate, in the first place, in 18th century Britain. Along with the Royal Society and other prominent societies (Howes 2020), informal networks were spread throughout the country in the mid-18th century. This paper described and quantified how these informal networks, in the form of Freemasonry, friendly societies, libraries, and booksellers boosted new ideas. It finds that informal networks in the form of Masonic lodges, friendly societies, libraries and booksellers had a sizable effect, and each one-standard-deviation increase in these informal networks was associated with between one third to one half of one standard deviation of the dependent variable, being either new patents or exhibits at the 1851 Crystal Palace World's Fair in London.

Despite showing evidence that informal networks distributed useful knowledge and the Enlightenment's belief in progress, some questions remain unanswered. For instance, did these informal networks matter to the real economy? There is a significant consensus among scholars from Joel Mokyr and Nicholas Crafts to David S. Landes to Deirdre McCloskey that the Industrial Revolution constituted the transition of an economy driven by Smithian process (i.e., based on the widening of markets, the division of labor, and the expansion of trade) to one in which growth and development were driven by knowledge. That is, until the Industrial Revolution, economic growth was cyclical and could happen almost anywhere in the world, but the Industrial Revolution elevated technological progress in Britain and changed the entire dynamic of economic history, a "phase transition", as it were (Mokyr 2021).

Consequently, in explaining the evolution of that knowledge, it stands to reason —even if this is uncertain and a question that remains unanswered here— that access to and diffusion of knowledge played a major role. If this is so, then it is also attractive to speculate that the mechanisms highlighted here were not simply an important part of British technological leadership but were part of the subsequent economic growth. As Alfred North Whitehead (1925: 96) believed, "The great invention of the nineteenth century was the invention of the method of invention", turning it from an occasional event to a steady part of the economy. Other relevant questions might be: Did these informal networks behave similarly in other places? Are these networks that changed the world 250 years ago still visible today? What remnants do we have of those cultures?

**Supplementary material.** To view supplementary material for this article, please visit https://doi.org/10.1017/ssh.2022.49

[32]See Mokyr (2009, 2017).

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**Gregori Galofré-Vilà** is Ramón y Cajal Fellow and Assistant Professor at the Universitat de València.

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