Access to Knowledge and the British Industrial Revolution: An Empirical Analysis

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Introduction

A satisfactory explanation of Britain's transition to modern economic growth during the Industrial Revolution must answer two questions posed by Crafts. Why did total factor productivity (TFP) growth accelerate gradually between the mid-eighteenth and mid-nineteenth century, and why did it remain slower during this period than the rates of TFP growth typically achieved by economies at or close to the technological frontier in the twentieth century? In the process, it must also uncover the mechanics of the discontinuity in technological progress that marked the transition to modern growth. (Crafts 1995, 1996).

There is an important role in such an explanation for the gradual fall in the cost of access to knowledge that was achieved during the Industrial Revolution through the blossoming of the institution of learned societies. From the mid-eighteenth to the mid-nineteenth century, Britain's network of learned societies – voluntary organisations that held regular meetings and lectures often on scientific and technological topics, and housed and published associated literature – grew markedly. As the Industrial Revolution progressed, each successive generation of individuals interested in scientific and technical knowledge were better connected to one another than the one before, and as a result, enjoyed a successively lower cost of access to knowledge to help them invent, improve and adapt technology. The resulting increase in the rate of flow of microinventions led to the gradual acceleration in the growth rate of TFP of Crafts' first question. At the same time, the institution of learned societies was only a prototype system for the discovery and dissemination of knowledge and was superseded in the late nineteenth and twentieth centuries by research-oriented universities and corporate research and development (R&D). When countries adopted these superior institutions they were able to achieve higher TFP growth than Britain was during the Industrial Revolution.

This paper quantifies for the first time the rise of the institution of learned societies within Britain during the eighteenth and early nineteenth centuries, and provides empirical evidence that it had a positive effect on technological innovation. The evidence arises from an analysis of the spatial covariation within Britain of learned society members in 1851 and the addresses of British exhibitors and prize winners at the Great Exhibition of 1851.

Theory and literature

Persuasive explanations have been proposed for the timing of the acceleration in technological change that characterises the Industrial Revolution that emphasise an increase in demand for technology[1] and the removal of political constrains to technological change[2]. However, even if one attaches very significant weight to such arguments there remains a role for a third approach that does not take it for granted that the capabilities required for technological innovation would necessarily be in adequate supply should a demand stimulus arise or a political constraint disappear. Given Mitch's finding that the supply of formal education did not rise significantly during the Industrial Revolution, and was not particularly high at the start of it (Mitch 1999), such research has focused on the informal institutions that may have determined Britain's capacity for technological innovation.

The main contribution to this research has been that of Mokyr, whose Industrial Enlightenment hypothesis argues that an intellectual culture conducive to technological innovation spread during the 18th century, which raised the growth rate of the knowledge-base from which new technology could be invented and developed[3], and lowered the cost of access to it (Mokyr 2002, 2005, 2009). Learned societies play a significant role in Mokyr's hypothesis, and the argument in this paper is guided by

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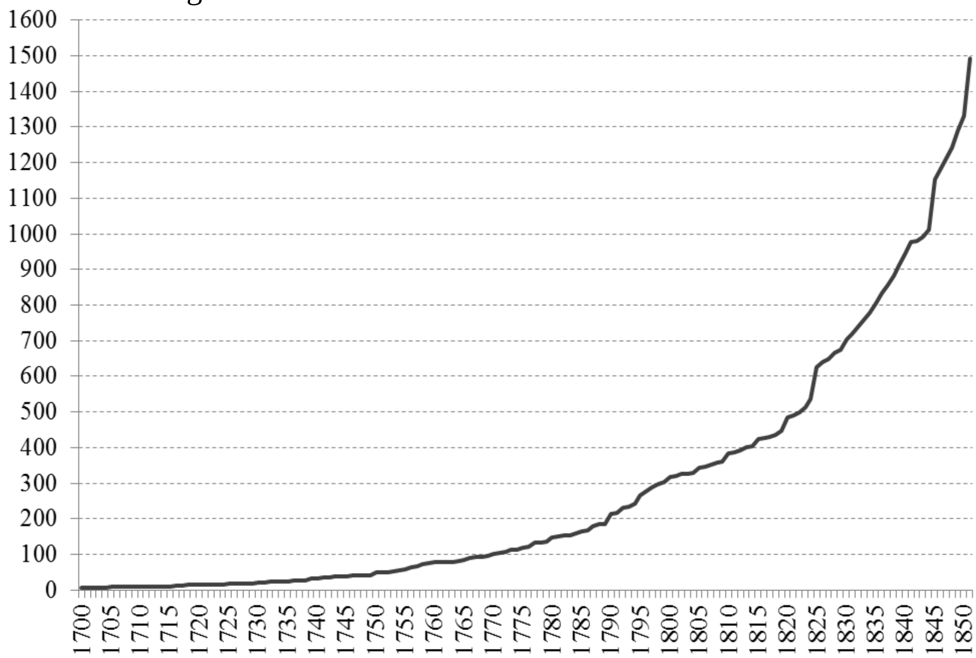
[1] Allen (2009)
[2] See Robinson and Pincus (2011)
[3] including but not limited to the scientific knowledge-base.

Mokyr's theoretical framework[4]. As a result, the empirical analysis here also serves as a falsifiable test of part of Mokyr's theory. This is important because the main criticism of Mokyr's theory has been that it has previously lacked falsifiable evidence (Crafts 2011).

The growth of learned societies during the Industrial Revolution

What were the quantitative dimensions of the rise of learned societies in Britain during the Industrial Revolution? Were they large enough to suggest a plausible macroeconomic impact on technological change? Figure 1 presents the first comprehensive time series of learned societies in operation in Britain during the eighteenth and early nineteenth centuries.

Figure 1: *Learned Societies in Great Britain 1700-1851*



Between 1750 and 1850 the number of societies rose dramatically from 49 to approximately 1,500. This was a far greater increase than the increase in population, and between 1761 and 1851 the number of societies per 100,000 capita in Britain rose by an order of magnitude, from 0.6 to 7.2. A comprehensive (and previously unanalysed) survey of all existing learned societies in the British education census of 1851 reveals that mean membership was 164 (median: 86) with a standard deviation of 439. Earlier membership records, where they exist, suggest that membership numbers per society were not significantly different to this over the preceding century. On this basis, simply taking mean membership per society as constant over time implies that membership rose from around 8,000 in 1750 to 246,000 in 1851; or in per capita terms, from around 0.1 per cent of the population in 1750 to around 1.2 per cent of the population in 1850. Moreover, figure 2 shows that the growth of learned societies was a country-wide development. Each of the British regions had significant numbers of learned societies by 1850.

In theory, learned societies lowered the cost of access to knowledge by providing access to literature, facilitating connections between individuals through meetings and lectures, and establishing a national social network that helped individuals find relevant contacts. According to my estimates, in the aggregate, learned societies held about 15,000 lectures in 1851; and housed about 1.9 million books in their libraries. In purely quantitative terms, both longitudinally and spatially, the rise of learned societies during the Industrial Revolution was a major institutional development. It is not implausible to suggest that it could have had a macroeconomic impact.

Were the origins of the burgeoning learned societies sufficiently independent of industrialisation so that they can be thought of as a fundamental cause of technological change as opposed to a mere passive response to demand? Although many societies had idiosyncratic origins, including on some occasions demand from industry, two facts suggest that their growth was largely independent of industrial demand. First, the century in question saw the rise of the more general social phenomenon of voluntary associational societies, of which learned societies were just one part. Clark calls voluntary associational

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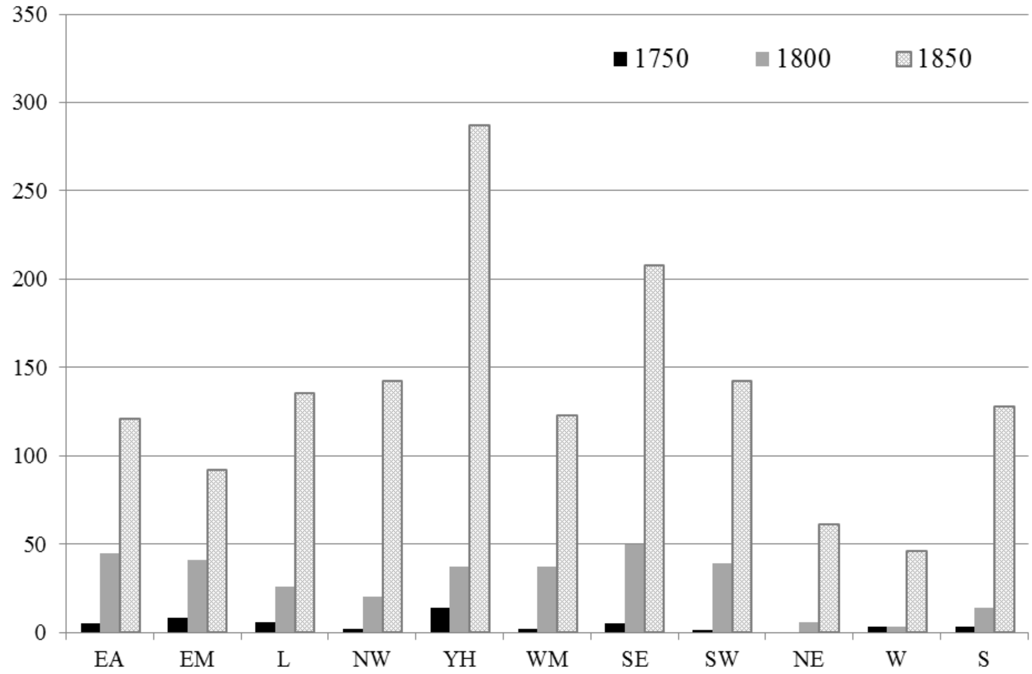
[4] As described in Mokyr 2002 ch 2.

societies the 'vectors of the Enlightenment' and estimates a rate of around 100 societies founded per decade at the start of the eighteenth century, rising to 1,000 per decade by the end of it[5]. Second, the geographical distribution of learned societies was far broader than that of industrialisation. A simple regression of learned society members per capita on industrial employees per capita in 1851 across British registration districts explains only 3.8 per cent of the variation. First and foremost, the engine of growth of learned societies in the eighteenth and early nineteenth century was Enlightenment culture, not demand from industry.

Figure 2: *Learned Societies by British region, 1700-1851*



Key: EA =East Anglia, EM = East Midlands, L =London, NW = North West, YH = Yorkshire and Humberside, WM = West Midlands, SE = South East (not London), SW = South West, NE = North East, W = Wales, S = Scotland.

The effect of learned societies on technological innovation: evidence from the 1851 Great Exhibition

Model and data

Did learned societies affect technological innovation? The empirical strategy I use to answer this question is based on the hypothesis that such an effect would be stronger in the locality of the learned society than further away. This follows naturally from Mokyr's theory of the cost of access to knowledge but is also analogous to the 'Marshall-Arrow-Romer knowledge production function', which is commonly used to empirically identify knowledge spillovers into technological innovation from corporate R&D or academic research in modern economies[6]. The basic strategy in such studies, as here, is to use regression analysis to test for spatial covariation between the regional knowledge input (typically regional research resources or expenditure; but in this case regional statistics related to learned societies) and a proxy for regional technological innovation.

Such a proxy for regional technological innovation is provided by the Great Exhibition of 1851, which was a major world exhibition of technology and industry held in London during the summer of that year. There were around 6,400 British exhibits admitted on merit from around 8,200 British applications, which were submitted via a process involving 330 regional committees. Of those admitted to the exhibition 30 per cent were awarded prizes for a combination of utility and novelty. Data on the addresses of exhibitors and prize-winners from the exhibition's catalogue provide a quality-filtered count of technological innovations across space, covering the whole of Britain. Using this data I produce exhibit and prize counts for the 656 census registration districts covering Britain.

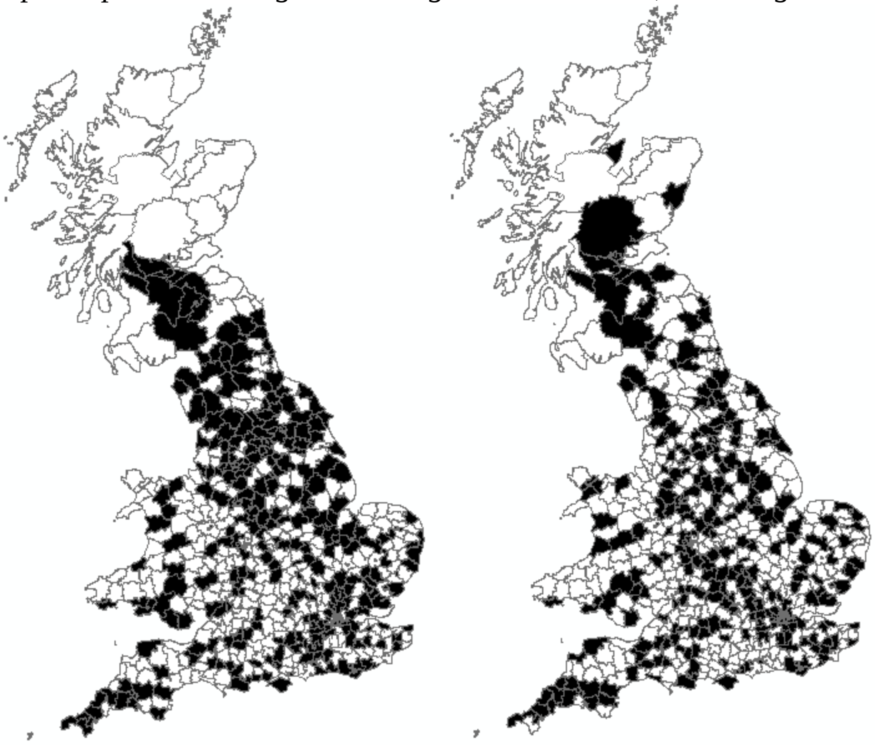
I calculate the main dependent variable of interest – learned society membership by registration district in 1851 – using the 1851 education census. As a first pass at investigating the spatial relationship

[5] Clark (2000)

[6] See Audretsch and Feldman 2003 for a survey.

between learned society membership and technological innovation, figure 3 shows learned society membership and exhibits at the Great Exhibition by registration district, both in per capita terms. It is clear from this picture that the two spatial distributions share some common patterns. The task at hand is to quantify this relationship and control as fully as possible for confounding factors.

Figure 3: *left map is learned society membership per capita in 1851. Right map is exhibits at the Great Exhibition of 1851 per capita. Black regions are higher than median, white regions lower than median.*



In order to control for the location of industrial production, which may be correlated both with technological innovation and learned society membership, first I stratify the innovation counts across 10 industrial sectors, producing counts of exhibits and prizes for 6,560 industry-regions. Then I calculate the size of the labour force employed in the secondary sector in each of the 10 industry sectors in each registration district, using occupational data from the 1851 census[7]. This enables me to produce within–industry sector estimates of the effects of the covariates, while controlling for the location of highly specific industrial activity. To control for other factors that may simultaneously affect the count of learned society members and the technological innovation count, I include population density and a proxy for the regional literacy rate, derived from the proportion of grooms in the registration district who signed their name on the marriage register in 1851, as recorded by the Registrar General. I include the size of the adult population in each registration district and a dummy for the London registration districts, to control for possible idiosyncrasies of the capital. Finally, to allow for knowledge spillovers and agglomerations operating over areas larger than registration districts I include spatial lag variables for the covariates. To create these variables, for each registration district I take the average value of the covariate in question across the registration districts that it shares a border with. I use the negative binomial regression model to fit the data due to its suitability for handling a count dependent variable, which gives the following specification:

$$y_{ij}^{k} = exponential\ (\alpha + \beta_1 MEM_{ij} + \beta_2 MEM_{i-1,j} + \beta_3 EMP_{ij} + \beta_4 EMP_{i-1,j} + \beta_5 DEN_i + \beta_6 DEN_{i-1} + \beta_7 LIT_i + \beta_8 LIT_{i-1} + \beta_9 POP_i + \beta_{10} LON_i + \delta_j + \varepsilon_{ij}) \quad (1)$$

where k = 1 or 2 and y_{ij}^{1} = exhibits in region i and industry j, y_{ij}^{2} = awards in region i and industry j, MEM_{ij} = number of learned society members in region i (/100), EMP_{ij} = employees in the secondary sector in region i and industry j (/1,000), DEN_i = population density in region i (persons per km^2), POP_i =

[7] I am grateful to Leigh Shaw Taylor for providing me with the occupation data from the 1851 census, collected for the Occupational Structure of Britain Project at the Cambridge Group for the History of Population and Social Structure.

population in region *i (/10,000)* , LIT_i = male literacy rate in region *i*, LON_i = London dummy, δ_j = industry sector fixed effect, ε_{ij} = random error, and variables with *i-1* subscript are spatially lagged variables. Standard errors are clustered by registration district to allow for errors to be correlated within registration districts from one industry sector to the next.

Results

There is strong evidence that learned societies had an effect on regional technological innovation. Coefficients in table 1 are reported as semi-elasticities, so the first column tells us that an extra 100 learned society members in a registration district was associated with a 6.3 per cent rise in exhibits and a 7.1 per cent rise in prizes. Given that the standard deviation of learned society membership in a registration district is 746 this suggests, for a one standard deviation rise in learned society members, an economically significant 47 per cent rise in exhibits (7.46 times 6.3 per cent) and 53 per cent rise in prizes (7.46 times 7.1 per cent). Coefficients on learned society membership across the four regressions are highly statistically significant. They are also quite robust to controlling for spillovers from neighbouring districts, falling only from 6.3 to 6.2 per cent for exhibits and from 7.1 to 6.7 per cent for prizes. Coefficients on non-spatial lag controls are mostly of expected sign and statistically significant.

Table1: *Econometric results*

Dependent Var:	Exhibits	Exhibits	Prizes	Prizes
Spatial lags:	*No*	*yes*	*no*	*yes*
MEM_{ij}	.063***	.062***	.071***	.067***
	(.000)	(.000)	(.000)	(.000)
$MEM_{i-1,j}$		-.007		-.011
		(.399)		(.403)
EMP_{ij}	.067***	.062***	.072***	0.70***
	(.000)	(.006)	(.000)	(.001)
$EMP_{i-1,j}$		.020		.015
		(.386)		(.639)
DEN_i (x1,000)	.040***	.055**	.052***	.052*
	(.002)	(.026)	(.002)	(.070)
DEN_{i-1} (x1,000)		-.013		.043***
		(.620)		(.000)
LIT_i	.022***	.029***	.014**	.020***
	(.000)	(.000)	(.033)	(.007)
LIT_{i-1}		-.011		-.010
		(.119)		(0.294)
POP_i	.68	.72*	.38	.48
	(.106)	(.095)	(.429)	(.331)
LON_i	1.21***	1.36***	1.11***	.94**
	(.000)	(.000)	(.001)	(.011)
N	6,520	6,430	6,520	6,430
Pseudo R^2	0.18	0.18	0.21	0.21

Coefficients are semi-elasticities. Industry sector fixed-effects included. Standard errors clustered by registration district. *p*-values in parentheses (* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$)

Conclusion

As quantified in aggregate here for the first time, the rise of learned societies during the British Industrial Revolution was a major institutional development concerning the cost of access to knowledge in Britain. I have shown empirically that the institution had an impact on technological innovation and argued that its origins were mainly independent of industrialisation – hence it should be thought of as a causal factor in the timing of the Industrial Revolution.

The pattern of trend TFP growth in Britain since the eighteenth century is supportive of the argument that the cost of access to knowledge was a binding constraint to modern economic growth which was lifted by institutional progress concerning access to knowledge. The prototype knowledge economy of learned societies was a nineteenth century institution that produced a nineteenth century growth rate of TFP. This was a higher growth rate than the eighteenth century, before the institution gained a foothold, and a lower growth rate than the twentieth century when it was replaced by corporate R&D and research universities, which worked better.

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