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Nicholas Crafts
University of Warwick

Nikolaus Wolf
Humboldt University Berlin

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Nicholas Crafts
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Nikolaus Wolf
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Abstract

We examine the geography of cotton textiles in Britain in 1838 to test claims about why the industry came to be so heavily concentrated in Lancashire. Our analysis considers both first and second nature aspects of geography including the availability of water power, humidity, coal prices, market access and sunk costs. We show that some of these characteristics have substantial explanatory power. Moreover, we exploit the change from water to steam power to show that the persistent effect of first nature characteristics on industry location can be explained by a combination of sunk costs and agglomeration effects.

Keywords: agglomeration; cotton textiles; geography; industry location

JEL Classification: N63; N93; R12

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1. Introduction

Cotton was a key sector in 19th-century industrialization. During the Industrial Revolution, the industry became remarkable for its technological progress and productivity advance. Both its raw material and its finished products were highly internationally tradable. It was also highly and persistently spatially concentrated. In 1800, the UK had 95 per cent of the world's spindles, in 1850 it had 69 per cent and in 1900 still 58 per cent (Farnie and Jeremy, 2004). The cotton industry accounted for 22 per cent of British industrial value added and 50 per cent of British merchandise exports in 1831; during the years 1780-1860 it sustained an average rate of TFP growth of 2.6 per cent per year while contributing about a quarter of the economy's total TFP growth (Crafts, 1985).

Within the UK, the industry was highly localized and increasingly so. In 1850, Lancashire accounted for 66 per cent of spindles and in 1903 even for 79 per cent (BPP, 1850: BPP, 1903). Given that the cotton industry witnessed substantial change in terms of power technology, mechanization and processing techniques, this locational persistence is all the more remarkable. This is, of course, well known and is a staple of accounts of the development of the industry. For example, Farnie (1979) devotes a lengthy chapter to discussion of the reasons for this phenomenon and its extensive historiography in which he identifies a number of plausible hypotheses but recognizes that the reasons for it are not fully agreed. In fact, there is no explicit quantitative analysis which provides an explanation for why so much of the UK industry was in Lancashire, why it stayed there and, at the same time, says why other areas of the UK which had at least some of the characteristics believed to be attractive to the industry were without a cotton textiles industry.

Explaining the location of cotton textiles in the 19th century is clearly an important task for economic history given the role that the industry played in industrialization. The fact that the cotton industry stands at the very beginning of British and later European Industrialization suggests that understanding the geography and spatial dynamics of this particular industry can shed light on the dynamics of industry growth more generally. Recent historiographical trends add value to such investigations. Two aspects stand out. First, there is the interest in location decisions sparked by the new economic geography and epitomized by the study of industrialization in Catalonia in Roses (2003) and models featuring the possibility of "geographical lock-in" such as Krugman (1991) or more recently Redding et al (2011). Second, there is the attention now being given to what economists might call 'directed technological change' (Acemoglu, 1998) in which both natural endowments and market demand conditions are seen as driving decisions to develop new technologies. Here the key reference is Allen (2009) with his emphasis on the role of cheap energy together with high wages in directing the development of textiles technology during the British

industrial revolution. In this context, understanding the interaction between factor prices, other locational characteristics and choice of locations assumes added significance.

In this paper, we try to account for the location of the UK cotton textiles industry in 1838 as revealed in the detailed statistical report resulting from the implementation of the Factory Act (BPP, 1839). This account was the most detailed ever published by the Factory Inspectors and gave information on the distribution of employment and the use of power not only at the county level for all parts of the UK (including Ireland) but also at the level of individual towns. It has already been used for a number of statistical analyses about the nature of the industry within Lancashire (for example, Gattrell, 1977; Rodgers, 1960). However, no study so far has attempted to shed light on the issue of the spatial distribution of the cotton industry across Britain.

The remainder of the paper is organized in six sections. In the following section 2, we briefly survey the literature on the origins of the British cotton textile industry and its geography. This section includes a discussion of the main hypotheses put forward in the historical literature on the geographical concentration of the British cotton industry. Next, in section 3, we discuss our empirical strategy and present a simple theoretical framework to guide our research. In section 4, we present and discuss our data on the cotton industry and potential explanatory variables. In section 5, we report estimation results for various specifications of this model, test two mechanisms that might give rise to geographical lock-in, and discuss the implications of these results before we conclude in section 6.

2. Literature Survey

A good starting point is the classic study by Farnie (1979, ch. 2). Here Farnie states that

"The original advantages of Lancashire comprised its poverty, its climate, its water supply, its textile tradition and its mechanical inventions. The acquired advantages included its supply of coal, machinery and labour, its access to the markets of Liverpool and Manchester, its low transport cost, and its auxiliary industries" (1979, p. 46).

In Farnie's elaboration of these original advantages, 'poverty' is understood as the low value of land in much of the county for agricultural purposes, 'water supply' primarily connotes the availability of fast-running streams that can provide water power and 'climate' relates in particular to humidity which was valuable in terms of the pliability of cotton fibers and the risk of breakages in the yarn.

Overall, this represents an argument that original natural advantages were later augmented by investment and culminated in agglomeration advantages.

Several of the points listed by Farnie have been highlighted by other writers. The importance of Lancashire's proto-industrial traditions is emphasized by Rose (1996) although she is careful to state that the emergence of rural manufacturing in impoverished upland areas with poor-quality agricultural land was not an automatic precursor. Nevertheless, she points out that there was an almost perfect geographic coincidence of 18th century fustian manufacture with the location of the modern cotton industry (1996, p. 15). This argument has resonance with Farnie's list of Lancashire's original advantages but gives a role to his acquired advantages in sustaining the location of the industry.

Many people have remarked upon the eventual tendency of the cotton industry within Lancashire to locate on the coalfield in an era when coal was very expensive to transport over land. Rodgers (1960) represents a very strong version of the argument that the location of the industry was basically determined by the price of coal, an important intermediate input, at least once steam power took over from water power in cotton mills. Von Tunzelmann (1986) cited estimates that the transport cost for coal was about 2.5p per mile in the early 1840s which would have doubled the pithead price for a location 10 miles away.

An important variant of this argument is that cheap coal mattered as a key permissive factor for the development of agglomerations and that agglomeration advantages were the real secret of Lancashire's success (Balderston, 2010). This claim resonates with ideas from Marshall (1919) and the new economic geography and the list of such advantages might be long including technological spillovers, the provision of specialized inputs, deep labor pools, and market access. One obvious feature of successful agglomerations is that they tend to bid up the price of labor but keep unit labor costs competitive through external economies of scale. The ultimate importance of agglomeration advantages for Lancashire's success is generally agreed, as is the observation that, as steam power superseded water power, the industry became more spatially concentrated even within Lancashire itself. This process of further spatial concentration and agglomeration entailed a shrinking of the industry's geographical spread rather than a move to completely new locations, although there were other areas with lower wages, cheap coal, access to ports, high humidity etc.

On the other hand, the nature of the original advantages resulting from climate and natural resources has proved contentious. In claiming that humidity was an important asset, Farnie was reasserting a traditional belief that had been strongly disputed and somewhat discarded following a

critical analysis by Ogden (1927). Ogden himself, along with Atwood (1928), argued that the real advantage was in the ready availability of soft water which was helpful for the finishing industries but also for the boilers of steam engines. In turn, this claim was vigorously attacked as a myth by Rodgers (1960), who stressed that pollution had negated any possible advantage from water quality.

Clearly, no-one is proposing that there is a single factor explanation for the dominance of Lancashire in cotton textiles. If anything, as with Farnie (1979), we are presented with a 'laundry list'. Only occasionally is there a sense of how much of an advantage or handicap a given attribute offered. For example, Farnie (1979, p. 49) suggested that Lancashire's natural humidity could be seen as the equivalent of a 10 per cent tariff. Rodgers argued that a mill located far enough from a coal mine that it paid twice the pithead price faced a cost penalty equivalent to a 20% wage increase (1960, p. 140) but that the annual saving from clean soft water for spinners and weavers was only equivalent to 5 per cent of the cost of fuel (1960, p. 142). We do not, however, find an analysis which carefully examines the trade-offs between different locations. This is unfortunate because, as we shall see, Lancashire does not appear to have been uniquely blessed with any one cost advantage other than, eventually, the 'acquired' benefits of agglomeration.

Nevertheless, the literature does provide important guidance as to how an empirical investigation of the determinants of the location of the cotton industry should proceed. Obviously, a number of factors which could mean that production costs differ across locations have been identified and, in principle, most of these hypotheses are testable, although, as we discuss below, data limitations constrain what can be done. Importantly also, it is clear that history matters and, in particular, this is underlined by the locational choices made when the industry switched from water to steam power. Understanding quite why history mattered is central to an account of Lancashire's dominance.

3. Empirical Strategy and Theoretical Framework

Our aim is to put these claims from historical narratives into a theoretical framework and confront them with statistical evidence. To this end, we follow the literature on location choice in the wake of McFadden (1978) and Carlton (1979) and consider the location choice of a profit-maximizing mill owner in 19th century Britain. As we will discuss in the next section, our data gives the location of a total of 1823 cotton mills documented in the Factory Return 1838, including spinning factories, weaving factories, and factories where both spinning and weaving was done. We distinguish between 148 locations covering all parts of the UK, namely all historic 118 counties (including Lancashire and distinguishing between the East, North, and West Riding of Yorkshire), and within the

county of Lancashire 31 areas roughly following the boundaries of Poor Law Unions. To this we add data on a set of location-specific characteristics, such as coal prices, geographic or climatic conditions and access to markets, which we describe in some detail below.

The fact that we use here only one cross-section of data has two implications for our results. First, we focus rather on the long-run determinants of location choice, because our data includes newly established mills as well as mills founded decades ago in the mid-18th century. Hence, our results will reflect the effect of different factors on a mill-owner's decision to produce at a particular location – by starting a new mill or by deciding to continue production in an existing mill. Second, some of our results will suffer from the effect of omitted variables that we cannot capture at this moment. In order to address this issue, we allow in our estimation for general region-specific variation in constants (region fixedeffects) and in the distribution of errors (heteroskedasticity).

In modeling location choice, we start with the assumption that a (current or prospective) mill owner can locate in one of J possible locations, where we treat the location choices as independent of one another. In particular we use a Poisson model, which is, as shown by Guimaraes et al (2003) observationally equivalent to conditional logit models, but much more tractable.[1] The profit to a firm i (=1,.., 1823) of locating in j (=1, …148) can be described with an unobservable latent variable π* as

$$\pi^*_{ij=} V_{ij} + \varepsilon_{ij}, \tag{1}$$

where the first is a deterministic part and the second a stochastic part. The deterministic part V_{ij} can be written as

$$V_{ij} = \beta x_j + \gamma z_{ir}. \tag{2}$$

In equation (2), the letter x denotes a vector of k ∈ $(1, \dots, K)$ location-specific variables and z a vector of possible industry characteristics. Given data constraints, we have to assume that γ=0 for all industry characteristics. The decision maker now selects one out of the J=148 mutually exclusive alternatives and we assume that the locations we observe in our data are those that maximize the profit π*. With this, the probability that we observe a cotton mill i at location j is

$$P_{ij} = P\left(\pi^*_{ij} > \pi^*_{ik} \forall k = 1, \dots J : k \neq j\right)$$

$$= P\left(\varepsilon_{ik} - \varepsilon_{ij} \leq V_{ij} - V_{ik} \forall k = 1, \dots J : k \neq j\right).$$

[1] We tried many more specifications with qualitatively very similar results.

Hence, the probability of observing location choice j for mill i depends on the distribution of the stochastic part ε, given the (observed) deterministic part V. Under standard distributional assumptions, the expected share of firms in location j can be written as

$$E(Share_j) = \frac{e^{xj\beta}}{\sum e^{xj\beta}} \quad (3)$$

To ease the interpretation of estimation results, Schmidheiny and Brülhart (2011) note that for the Poisson-estimator the elasticity of the expected number of firms in location j, $E(n_j)$, with respect to a change in the k-th locational characteristic x_k of region j is simply given by its coefficient in the profit function:

$$\varphi_{jj} = \frac{\partial logE(n_j)}{\partial x_{jk}} = \beta_{k.} \quad (4)$$

Hence, a one percentage change in characteristic k will lead to a β_k-percentage change in the number of firms expected to choose this location. We will make use of this property in our empirical analysis below.

The next step is to formulate hypotheses about locational characteristics that would matter for location choice. Some characteristics were highlighted in the historical literature on the cotton industry, including access to water power, humidity, and coal prices. The recent theoretical and empirical literature on location choice would call these "first nature" characteristics (because they can be treated as largely exogenous to choices) and, in addition, highlights "second nature" factors, notably access to markets and sunk costs. These latter are endogenous to location choices and arise from the interaction between locations. They are also crucial for an understanding of the dynamics of location decisions over time.

Let us start with the general framework proposed by Combes et al (2008, chapters 4 and 12). They show that in a standard model with monopolistic competition, transportation costs and several inputs, total profits for a firm located in j can be formulated as a function of three groups of factors: variable costs, fixed costs and benefits from market access. To keep things simple, we can assume that differences in variable costs mainly reflect differences in "first nature" characteristics between locations (such as coal prices), while variations in fixed costs and market access are endogenous to earlier location choices. Hence they reflect "second nature" characteristics. Optimal location choice therefore involves searching for the place that maximizes profits with respect to variable and fixed costs and benefits of market access:

$$Max(Profit_j) = Max[cm_j^{-(\sigma-1)} MP_j - F_j], j \in \{1, \dots, J\} \quad (5),$$

where m stands for the marginal costs of some input factor, c and σ are parameters (both >0), F stands for fixed costs and MP gives the benefits from access to markets that will increase in own market size and good access to neighboring markets. Head and Mayer (2004) estimate this model under the assumption that fixed costs are equal across locations and therefore can be neglected. They provide empirical evidence that both differences in variable costs and access to markets matter for location choice, which implies that there is scope for positive feedback effects or geographical lock-in as argued in Krugman (1991). The basic intuition for this is that earlier location choices can change the characteristics of a location, namely its own market size and the size of neighboring markets. Therefore, even if a location starts to become less attractive in terms of variable costs, the benefits from a large market can still outweigh this disadvantage.

We will follow their approach with some modifications. With their assumption regarding fixed costs, Head and Mayer (2004) do not take into account that a considerable part of the fixed costs are typically sunk costs in the sense that they have been incurred in the past (such as costs for a building), and they are location-specific so that they cannot be recovered upon exit (Motta and Thisse 1994). A simple reformulation of (5) can capture this idea:

$$Max(Profit_j) = Max[cm_j^{-(\sigma-1)} MP_j - F_j S_{ij}], j \in \{1, \dots, J\} \quad (6),$$

where S_{ij} is an indicator variable equal to some positive value bounded by 1 whenever the location of an existing mill is evaluated against a new location, and zero otherwise. In this formulation, some fraction of fixed costs will now matter for a firm that considers relocating, even if fixed costs are perfectly equal across locations.

In our context, consider the investment of a cotton mill owner into power equipment. A waterwheel installed in the past is tailor-made to the nearby river or stream and will have little or no resale value. However, a part of the old construction and machinery can be reused with the arrival of the new steam power technology or combined with it, saving the costs of relocation. For example, at the Quarry Bank Mill in Styal near Manchester, the first steam engines were installed in 1810 to provide auxiliary power to the existing water wheels and as a precaution against water shortages. After several decades the mill was still operational at its old location but nearly entirely steam powered. In addition, the waterway infrastructure (canals, weirs, water reservoirs) put in place for the old water-power technology remained useful for the new steam power technology as well for two reasons: first, because steam engines needed access to water for feeding boilers and condensing steam (Holden 1999), second because waterways reduced the cost of transporting raw materials and finished products (Maw et al. 2012).

More generally then, the existence of sunk costs will *dampen* the impact of current or prospective changes in the differences in variable costs and market access between locations and will *increase* the impact of past differences. To see this, consider a situation with only two possible locations (j= 1,2) at two different points in time (t=0,1) and treating market access as exogenous for simplicity (i.e. each firm is small relative to the local market). Initially (t=0), location 1 is more attractive than location 2, due to lower variable costs ($m_1 < m_2$) ceteris paribus, so that:

$$[cm_1^{-(\sigma-1)}MP_1 - F_1] > [cm_2^{-(\sigma-1)}MP_2 - F_2] \quad \text{or simply}$$

$$Profit_1(m_1) > Profit_2(m_2) \tag{7}$$

With (3) and (6), this will attract a larger share of firms to location 1. Now consider a reversal in variable costs in the next period (t=1), for example due to biased technological change that affects relative input prices. With this, we have $m_1 > m_2$ or $m_1 = (1+\Delta)\, m_2$. A mill owner who has chosen location 1 in t=0 will have to evaluate the benefit of moving to the lower cost location 2 against the cost of moving, which will now depend on the level of sunk costs. Let us define the operating profit as profit net of fixed and sunk cost. Then we can see that the critical value of sunk costs FS*, at which a mill owner is indifferent between relocating and staying, is increasing in the difference in operating costs due to the change in variable costs:

$$OpProfit_1(m_1) = OpProfit_2(m_2) - F_2S_{12}{}^* \quad \text{or}$$

$$OpProfit_1((1+\Delta)m_2) = OpProfit_2(m_2) - F_2S_{12}{}^* \quad \text{or}$$

$$F_2S_{12}{}^* = OpProfit_2(m_2) - OpProfit_1((1+\Delta)m_2) \tag{8}$$

Put differently, in the presence of positive sunk costs, a higher differential in (current and prospective) operating profits is necessary as an incentive for relocation (see Redding et al 2011). By the same token, past differences in operating profits can have a more persistent effect because more firms will stay at a location even after earlier cost advantages have disappeared.

To summarize, we see that there are three main types of locational characteristics that affect location choice: variable costs, fixed costs, and benefits from market access, which interact over time. In general, contemporaneous variation in all three types of factors should matter for location choice. However, past variations in operating profits can modify the impact of contemporaneous variation in variable costs due to two types of path dependency: first, there can be positive feedback effects due to market access as highlighted in new economic geography models in the wake of Krugman (1991). Second, sunk costs can introduce another form of hysteresis in location choice that

can delay relocation (similar to the mechanism discussed in Redding et al. (2011)). In the next section we now turn to empirical evidence on the effect of specific types of costs and market access effects.

4. Data on the Location of the British Cotton Industry and Its Potential Determinants

We seek to explain the location decisions which underlie the observed spatial distribution of mills and employment in the UK cotton textile industry in 1838. We consider employment in each county but also divide Lancashire into sub-divisions based on Poor Law Unions. Our dependent variable is derived from the Factory Inspectors' report for 1838 (BPP, 1839). Table 1 provides descriptive statistics for the location of cotton mills and their employment, maps 1 and 2 show the substantial geographical variation in concentration.

[Table 1 about here]

It is noticeable not only that much of the industry is in the North West, and a very high share in Lancashire alone, but that the industry is highly concentrated at the county level. In fact, many counties have no cotton textile employment at all. Of the 148 locations in our data set, the cotton industry is absent in 92 and even within Lancashire 10 of the 31 Poor Law Unions had no cotton mills and hence no cotton employment. On the maps (map 1 and map 2), areas with no cotton industry are green and most parts of Britain during the industrial revolution remain green throughout the century.

Turning to measurement of locational characteristics, we begin with aspects of what Farnie (1979) called "original advantages": poverty, climate, water flow, mechanical inventions, and water quality.

Farnie suggests 'poverty' as an attractor of cotton textiles. This makes sense in terms of a comparative advantage view of pre-industrial England where in the early stages textiles were most likely to be found in areas which were relatively unsuitable for agriculture and the value of agricultural land was low. This can be proxied by the land tax which was imposed in the 1690s for England and Wales and in the 1710s for Scotland and for which the valuations did not change thereafter (Ginter, 1992). Valuations are reported for the individual parish as well as at the county level in BPP (1844b). These have been converted to a tax rate per acre using the areas reported in Bartholomew (1904) and BPP (1862). As shown in map 3, there is a clear gradient rising from north to south, with show relatively low land-values for Lancashire compared with southern England.

Given that we lack comparable data for Ireland, we provide another measure for the suitability of land for agriculture: ruggedness of the terrain. Map 4 shows an index of average terrain ruggedness based on the data from GTOPO30 (US Geological Survey, 1996), a global elevation data set for a grid of 30 arc-seconds across the entire surface of the Earth. The data set was developed through a collaborative international effort led by staff at the US Geological Survey's Center for Earth Resources Observation and Science. The data is provided by Nathan Nunn and Diego Puga on http://diegopuga.org/data/rugged/, which we recalculated to match historical counties and Poor Law Unions. There is a rather tight (log-) linear relation between early 18th century land tax rates and average terrain ruggedness, with a correlation of -0.66. Therefore, we use ruggedness for which we have data for all of the British Isles rather than land tax rates as our proxy for the suitability of land for agriculture to capture Farnie's notion of poverty as an "original advantage".

To measure humidity, which Farnie (1979) regarded as the key aspect of climate, we use 20th-century data to measure levels of relative humidity in different locations. Our basic source is the gridded time-series dataset, CRU TS 3.0, published by the University of East Anglia Climate Research Unit (2008). This provides latitudinal and longitudinal data on vapor pressure and on mean daily temperature averaged over 1901-2006, which permits calculation of an estimate of relative humidity.[2] The data is shown on map 5. It is informative to see that the lowest estimated value of relative humidity is 83.5% - well above the 50-54% considered by Lander (1914) to be the minimum for cotton spinning. While levels of humidity do vary over the year and within a day, they typically stay well above this critical level at any time. Hence, our data on relative humidity suggest that there was no location in the UK that would not have met the required level; Lancashire observations are all very similar and lie within the range 86.3% to 89.8%, which is just below the average for all of the British Islands. The map shows that Lancashire has substantially *lower* levels of relative humidity than other parts on the Atlantic coast, notably western Ireland and the Southwest of England.

[2] To calculate the relative humidity utilized in this paper, we first calculate the dew point using the following equation:

$$T_d = \frac{243.5 * \ln\left(\frac{v}{6.112}\right)}{17.67 - \ln\left(\frac{v}{6.112}\right)},$$

where v is the actual water vapor pressure, in units of millibar. Because the dew point (T_d) decreases by about 1°C for every 5% decrease in relative humidity (RH), we can approximate the RH using the following equation from Lawrence (2005): $RH \approx 100 - 5(T - T_d)$, where T (temperature) and T_d are measured in degrees Celsius.

The availability of suitable water flows is another aspect of nature which we capture through modern data. We use data from the UK Hydrometric Register (2008), which provides basic statistical information on the average extent and volatility of water flows, based on 1,454 "gauging stations" across the UK in modern boundaries (including Northern Ireland but not the Republic of Ireland). Matching flow data for Ireland were obtained from Ireland's Environmental Protection Agency (EPA, at http://hydronet.epa.ie/) for 125 gauging sites. Most of the data is averaged over several decades, typically over periods of 30 to 50 years. For our purposes these data include two useful variables, namely the "mean flow" and the "q95". The former gives the average water flow of rivers in cubic metres per second over the measurement period. The latter gives the flow in cubic metres per second which was equaled or exceeded for 95% of the flow record. The mean flow data ranges from values of below 1 cubic metre per second up to more than 89 in England and even 165 if we include Scotland, with an average of 4 and 6 cubic metres per second for England and the UK, respectively. Data on "q95" show a range from near zero to more than 28 cubic metres per second in England (UK: 42), with an average of 0.85 and 1.1 metres per second in England and the UK, respectively. Mean flow and q95 values for rivers in Lancashire, including the Irwell, Darwen, Mersey or Ribble in Lancashire along which many of the early cotton mills were located, are typically above the English average. As shown in map 6, Lancashire has good access to rivers with high mean flow levels, but so have many other locations in the UK and Ireland.

Following the argument made by Ogden (1927), we also collected data on water quality, specifically on water hardness. Total permanent water hardness is defined as the concentration of calcium and magnesium ions expressed as equivalent of calcium carbonate (CaCO3), according to the following formula: Total Permanent Hardness (CaCO3) = 2.5(Ca2+) + 4.1(Mg2+). Data for average total water hardness for about 2,500 sites across the UK was kindly provided by the Environmental Change Research Centre, UCL.[3] We complement this data with information from the Irish Water Framework Directive (WFD) River Basin District Management Systems, Working Group on Groundwater Guidance (2005). The resulting pattern of water hardness is shown in map 7. Again, there is considerable variation in the data with Lancashire being characterized by moderately soft water.

To capture the idea of an earlier textile tradition as well as a location's technical capabilities to produce mechanical inventions, we use a novel data set on the location of patent holders, weighted

[3] This centre is funded by the Department for Environment, Food and Rural Affairs. We are grateful to Dr. Pete Smyntek, Queen Mary University London for giving us access to this data.

by their impact, which has been constructed by James Dowey.[4] The variable (TWRI) is a location-specific index based on the number of patents that people resident at that location hold, weighted by the number of times this patent was cited in other patent files. The patent data goes back into the early 17th century and includes all patents relevant to the textiles industry in a broad sense. Dowey shows that it is important to de-trend this data to take into account that older patents would have a higher probability of being cited independent of their technical importance. We use only patents awarded up to 1815 to limit endogeneity issues. The resulting variable shows that many regions of Britain produced innovators, with one concentration in the south and the centre of England and another in southern Scotland (see map 8). Before 1815, Lancashire was not a particularly innovative area, but it was near to regions with very high innovative activity.

Next, let us consider several factors, which Farnie (1979) termed the 'acquired advantages' relevant to decisions about where to locate the cotton industry. To start with, coal prices should be seen in this category for two reasons. First, because substantial effort is necessary to find and exploit a location's coal reserves and second, because the price of coal includes not only the geographical distance to natural coal resources but also the infrastructure in place to transport it. Cheap coal in Lancashire emerged as a supply response to industrial growth (Langton, 1979). Information exists for years close to 1842 and 1843 on coal prices paid by Poor Law Unions in England and Wales (BPP, 1843) and in Scotland (BPP, 1844a) and from Robert Kane (1845) for Irish regions. These data, displayed in map 9, show a very wide range. The highest price paid was 40 shillings per ton at Bradfield in Berkshire and in rural southern England it was not uncommon to pay 30 shillings or more. The lowest price was 4 shillings and 2d at Leigh in Lancashire but prices only marginally higher were recorded at Poor Law unions in Durham and Northumberland. Map 9 again shows the data at the county level and for Poor Law Unions within Lancashire.

A simple way to capture foreign market access for an industry that was so dependent on trade is to consider average distance to major ports weighted by the tonnage that they handled, based on the list of 12 principal ports in BPP (1854), as shown in map 10. Alternatively this might be simplified to distance to Liverpool or London, the 2 most important ports at the point where cotton took off. The literature on the location of the industry in Lancashire might even hypothesize that proximity to Liverpool would suffice given its ultimate dominance. It is obvious that measured in this way Lancashire is a county with excellent access to markets, but so are several counties closer to London.

[4] The original patent data are reported in Woodcroft (1854)(1862). We are very grateful to James Dowey for supplying us with his dataset. This will become publicly available after Dowey completes his Ph. D. dissertation.

Next, we explore the role of benefits from agglomeration in terms of a proxy variable, domestic market size. These advantages are generally thought to have been important in the 19th century cotton industry (Marshall, 1919; Leunig, 2003; Broadberry and Marrison, 2002). Following Krugman (1991) and Combes et al (2008) we can think of agglomeration benefits or external economies of scale as a function of the size of the industry in a given location and proximity to other producers in 1838. As a first approximation, market size is represented by distance-weighted employment (a market-potential type measure but leaving out own employment) based on the Factory Inspectors' Report (BPP, 1839). However, such a measure is directly related to the variable that we are trying to explain, namely the number of cotton mills and their employment in 1838. To limit this problem of endogeneity, we note that a location's access to overall population around 1800 is highly correlated (with a correlation coefficient of about 0.77) to agglomeration in terms of cotton textiles employment in 1838 but can be regarded as exogenous to the number of mills and employment a generation later (see figure 1). Map 11 shows the resulting measure of market potential approximated by population in 1801. South East Lancashire clearly scores very highly in terms of market potential.

Lancashire may have benefited from agglomeration but its corollary was high wages. If we wish to consider wage rates across the whole country, the only option for our period is to use the data on agricultural wages to reflect conditions in local labor markets. These were compiled by Bowley (1900). Lancashire was clearly a relatively high wage location in the late 1830s, certainly compared with many agricultural areas of the United Kingdom. High wages were no doubt an endogenous result of the concentration of the industry and a cost to be accepted because it was compensated by high productivity rather than an advantage per se.[5]

Table 2 illustrates this discussion. We see that the Lancashire locations (Manchester and Preston) were well placed compared with the average of other locations in most respects. On the other hand, few Lancashire observations were best-placed on any single characteristic. Turning to Lancashire as a whole, the county has the location with the best score in terms of market access and coal prices but not for anything else.

[5] Prior to the industrial revolution, Bowley's data show that in the 1760s Lancashire was a county with relatively low agricultural wages.

5. Empirical Results

a. Benchmark Results

In this section we fit a Poisson model for the location of the cotton textiles industry across the British Islands according to the Factory Returns for 1838, as discussed in section 3. We first estimate the expected number of cotton mills for each location as a function of locational characteristics as described above (Table 3, columns 1 and 2). Next, we estimate the expected number of employed persons in the cotton industry for each location (columns 3 and 4), before we estimate the expected number of employed persons per mill or average mill size, where in this last case the number of persons per mill is set to zero whenever there is no industry at a location (column 5). In each specification we add the (log of) the area of various locations in km^2 as a control to account for the fact that, if location choices were entirely random, smaller locations should always have fewer cotton mills than larger locations, ceteris paribus.

Consider the results in Table 3. A larger area seems to increase the likelihood of finding a mill and cotton industry employment but the effect is not always statistically significant, depending on the specification. A location's terrain as measured by its average ruggedness tens to have a large and significant effect. It is interesting to note that this effect is stronger for the location of mills but only weak for the expected number of employed persons or average mill size. If we interpret ruggedness as a measure of the unsuitability of land for agriculture, this lends strong support to Farnie's notion of poverty as an "original advantage".[6] Our next finding is quite revealing: higher levels of average relative humidity appear to reduce a location's attractiveness for the cotton industry, not increase it. This is not necessarily at odds with the argument that a minimum level of humidity is needed for the industry but it supports the view that this was not a binding constraint anywhere in the British Isles. Given that the effect is large and comes with the wrong sign (while not being significantly different from zero in any estimation), we suspect that humidity might be correlated with some other (unobserved) factors. Therefore, we also provide results after dropping the humidity variable, which remain largely unchanged (compare columns 1 with 2 and 3 with 4).

Next, we find that the availability of water power, measured here as proximity to rivers and streams with fast and steady water flow (q95) seems to exert a strong influence. In all specifications, we find that good access to water power increases a location's probability of having a cotton industry, and

[6] This interpretation is also suggested by the fact that ruggedness has an effect similar to that of land taxes, but with opposite sign. In an alternative specification (no shown) we re-estimated the model for all those locations, for which we have data on land taxes (all except Ireland) with similar results compared to the full sample. We next estimated the model replacing ruggedness by log(land tax), which again produced very similar results, except that the coefficient on land tax is strongly negative, as expected.

also that it increases the expected size of that industry. In contrast, the quality of water, specifically the total hardness of water does not matter much: the estimated coefficients are far from significant. This might be due to measurement problems because the quality of water varies substantially between neighboring locations, which we cannot capture perfectly. Still, the results do not support the idea of a strong and systematic effect of water quality on cotton textile location. Finally, we turn to the last aspect of Farnie's list of original advantages: a location's mechanical inventions. Our proxy, based on weighted patents issued before 1815, comes out with a strong positive coefficient, which is about as robust as our finding on access to water power. The elasticity of the expected number of cotton mills as well as the expected employment in any location with respect to this measure is between 70% and 80%. Obviously, there may still be an issue of endogeneity, if the incentive to innovate came from the existence of an industry, but we show at least that an earlier track record of innovation up to 1815 had lasting effects into the 1830s.

Turning to what Farnie (1979) termed the "acquired advantages", we first have a surprising result: a location's coal price has a negative but rather weak and typically insignificant effect on the expected number of cotton mills, notably on the probability of finding a cotton mill at all. This is interesting because in 1838, the share of steam power in total installed power (measured in horse power) was already about 54 per cent, and within Lancashire it was 73 per cent. Therefore, we might have expected to find a much stronger effect of the coal price. With regard to the argument in Balderston (2010), this might be affected by the way we measure market access, because in part the price of coal and the size of an agglomeration in the 1830s would be positively correlated.[7] What we find is that the probability of finding a cotton mill at all seems to be much more affected by access to waterpower than access to coal. In contrast, the results in columns 3, 4, and 5 show that coal prices had a strong impact on industry size, measured in terms of total employment and even more so employment per mill: high coal prices apparently put a clear limit on the growth of the industry.

Further, we find that distance to major ports did matter for the geography of the industry, after controlling for many other factors. This makes sense for an industry that was so heavily dependent on imported raw materials, and increasingly relied on foreign demand for its products. However, this effect is less robust than others, possibly because the location of large ports is again correlated with other factors such as market size. Interestingly, we see that the location of larger mills is much more strongly affected by distance to ports than mill location per se. This suggests that mills engaged in foreign trade (via both import and export markets) tended to be larger, which is in line with the recent literature on heterogeneous firms in international trade (Melitz, 2003; Redding and

[7] However, we do not find any positive but rather a (weak) negative correlation between market access (measured by our variable mp01) and coal prices.

Melitz, 2012). Finally, we explore the effect of the size of agglomerations on the expected number of cotton mills and industry size. Using the sum of distance-weighted population across locations as a proxy, we find that agglomerations make it more likely to find a mill and a higher employment in this industry (columns 1-4). However, we also find that agglomerations are associated with a smaller average mill size, which is in line with earlier findings by Broadberry and Marrison (2002) and Leunig (2003). A notable fact about Lancashire's cotton industry was its network of a large number of small but highly specialized and interconnected firms.

b. Robustness Checks and Extensions

As a robustness check, we rerun our Poisson model with two alternative regional aggregations. First, we test for pooling all 31 poor law unions in Lancashire into one observation, the county of Lancashire (Table 4a). Second, we rerun the model for the 31 poor law unions of Lancashire only (Table 4b).[8]

As shown in Tables 4a and 4b, our results are reasonably robust to changes in regional aggregation, with some interesting exceptions. If we pool over the Lancashire poor law unions, we find that ruggedness has no significant effect on the location of cotton mills, a negative effect on employment, but again no detectable effect on the average size of mills. Variation within Lancashire, which is substantial, overturns this result. Our result on access to water power in turn seems to be largely driven by variation across counties, similar to the coefficient on distance to ports. The positive coefficient on water hardness within Lancashire is very likely to be spurious, as our data show very little variation across Poor Law Unions.[9] In comparison, our findings on the effect of coal prices, innovative activity before 1815 and market access are rather robust to regional aggregation. Higher coal prices make it less likely that a location develops a cotton industry and notably limit the size of mills, while a strong tradition in innovation has the opposite effect. Good market access is a strong predictor for the development of an industry, but seems rather to increase the number of mills, while limiting their size, in line with our findings for the full sample.

While we think that our findings are plausible, let us highlight several important issues. To start with, so far we have neglected contemporary wages as a determinant of industry location. This may seem odd, given that wages would clearly account for a much higher share in total costs than, for example, energy costs (see for example Kane 1845, p. 64). A first intuition would suggest that locations with lower wages should be particularly attractive to the industry and this may indeed have been one of Lancashire's original advantages.

[8] We also re-estimated our model with logit, probit and conditional logit with qualitatively very similar results.
[9] To be precise, the finding is entirely driven by the Poor Law Union of Clitheroe.

For a mill owner in 1838, however, low wage labor could only be accessed in areas where the cotton industry was small or non-existent, in other words, only by foregoing agglomeration benefits. Table 3 shows that agglomeration exerted a strong positive effect on the location of cotton textiles. Theory predicts that successful agglomerations will pay higher wages and in modern data areas with high market potential pay more (Head and Mayer, 2006). Data from the 1906 *Earnings Enquiry* show that higher wages were paid to operatives in districts with larger cotton employment (Broadberry and Marrison, 2002). A simple OLS regression suggests that the pattern of wage increases across locations is strongly positively affected by the size of the cotton textile industry.[10] So, we can reasonably conclude that wages were endogenous to the size of a location's industry and that the estimated impact of market potential in Table 3 incorporates a dampening effect of higher wages which offsets the pure productivity effect of agglomeration.

Given that wages are endogenous and cotton wage data are not available for 1838, we have included regional dummies in estimating the equations in Table 3, which should control for differences in wage levels that are not captured by other variables. The implication is that when considering the magnitude of locational advantages we will not be able to examine the effects of counterfactual changes in wages. But, in any event, that would not be an appropriate use of a single-equation model which is not designed to capture the general-equilibrium effects on wages consequent on a significant re-location of the cotton industry.

A related issue is due to the fact that we consider a very dynamic industry, characterized by substantial technological change and probably by high rates of firm entry and exit. To explore its location patterns, we use only one (albeit very detailed) cross-section of data, 1838. In particular, we argued in section 3 that market access and sunk costs can give rise to a geographical lock-in or path-dependency where previous cost advantages (for example, good access to water power) continue to exert an influence, even though technological change seemingly had rendered them irrelevant.

To address this issue, let us focus on one very particular finding from Table 3: we find that access to water power exerts a strong influence on the location and size of the cotton industry in 1838, while we know that at this time already more than half of all power (measured in hp) in the cotton industry was generated by steam engines. To make the point more explicit, we use the same set of variables as in table 3 above to estimate in Table 5 the expected number of steam engines across locations.

[10] For an OLS regression we find: ln(wage1830/wage1770) =0.384 (0.019) +0.067 (0.011)lncottonmills; n = 148, R^2 = 0.14.

We find that the effect of access to water power on the probability of finding steam engines in the cotton industry is comparable to the effect of this factor on the probability of finding a cotton mill (Table 5, column 1). We find this even after we control for all the other variables discussed in section 4 (Table 5, column 2). Clearly, this cannot reflect any direct effect of water, but suggests that other, indirect channels matter. In our theoretical section 3, we argued that three types of factors should affect location choices: variable costs, fixed costs (due to the effect of sunk costs), and benefits from market access, which interact over time. The benefits from having good access to water power in 1838 should have become more limited, while the benefits from having good access to coal should have become much more important. Moreover, we would expect to see this effect most strongly for the location of steam engines in the industry.

What then explains the strong effect of water on steam engines? We argued that past variations in operating profits (such as better access to water decades ago) can modify the impact of contemporaneous variation in variable costs (better access to coal in 1838) due to two types of path dependency. First, there can be positive feedback effects because of market access, as highlighted in new economic geography models since Krugman (1991). Second, sunk costs can introduce another form of hysteresis in location choice that might delay relocation. Our proxy for agglomeration benefits based on population in 1801 in neighboring regions does not eliminate the significant coefficient on water power (compare Table 5, column 1 and 2). To investigate further, we can introduce a more direct measure using access to the employment in the cotton industry in 1838 in neighboring regions (ignoring endogeneity problems for the moment). As shown in Table 5, column 3, this reduces the estimated coefficient on water power somewhat but it stays positive and highly significant. In the presence of an endogeneity bias, the continuing effect of water power would be understated so we can conclude that path dependence due to agglomeration does not really explain our finding.

Next, a simple way to approximate the level of sunk costs in power equipment is to use the number of waterwheels used in the cotton industry. This should capture the idea that water power exerted an indirect effect on the location of steam engines because it had promoted the installation of waterwheels and auxiliary investment such as buildings and of course spinning or weaving machinery using power equipment. Insofar as these can be re-used with steam engines (as was the case at Quarry Bank Mill in Styal for example), their presence might dampen the incentive to relocate away from a location in response to contemporaneous differences in variables costs, like coal prices. As shown in Table 5, column 4, there is indeed strong evidence for such a mechanism via sunk costs. Controlling for the number of waterwheels, which should capture the essence of the

mechanism, the coefficient reflecting the predictive power of access to water power for the number of steam engines across locations stays positive but it becomes statistically insignificantly different from zero. Finally, if we combine the two mechanisms, the coefficient gets even smaller. Hence, we conclude that our results on the role of "original" and "acquired" advantages using cross-sectional data reflect much more than the contemporaneous variation across locations in 1838, including also some relevant interactions over time.

c. Discussion

Clearly, Lancashire's dominance of the cotton textiles industry was not based on having the best position with regard to any of Farnie's 'original advantages' and, in turn, none of these was a sufficient condition for cotton textiles to be present in 1838 (see our maps and table 2). For example, much of Scotland was better placed with regard to 'poverty' and water power, most of Ireland in terms of humidity. Softer water was to be found in parts of Wales. Yet, most of these locations had no cotton mills. Often, however, they were remote, being quite far away from big population centers and large ports.

If there was a necessary condition for having a cotton textiles mill in 1838, a cheap source of power is the nearest candidate. Only 20 mills out of 1823 (7 of which were in Ireland) were situated in locations where both the price of coal was above average and also water flow was below average. Proximity to population and ports did not prevent a complete absence of cotton mills in Bedfordshire, Berkshire and Buckinghamshire each of which had high coal prices and weak water flows.

It seems that the spatial concentration of the cotton industry in Lancashire has to be explained in terms of a good position in terms of a combination of first and second nature geography. In terms of what Farnie called 'acquired advantages', in 1838 Lancashire benefited from cheap coal, proximity to ports, and also excellent market access, which made it much more attractive to mill owners than the Celtic Fringes of the British Isles. Table 6 uses our regression results to explore these points and to provide some quantification of Lancashire's advantages. Using model 4 of Table 3, we investigate counterfactual changes in cotton textile employment to the statistically significant characteristics of Manchester and Preston.

We consider first the implications of counterfactuals in which observed characteristics are replaced one at a time by the sample average observation for the variable. The results for both Manchester and Preston show that for each of coal price and market access there would be a very sizable reduction in employment of the order of 50 per cent or more. In contrast, ruggedness has relatively

weak effects and, for Manchester, the direction of change is the opposite. In terms of water power, as historians of the Lancashire cotton industry are well aware, Preston was a favored location but Manchester was not. The counterfactual prediction is that with average access to water power employment in Manchester would have increased significantly but in Preston it would have decreased appreciably. Reducing textile inventiveness (TRWI) to the sample average has a big effect on Manchester's cotton employment but a more muted one for Preston (a smaller place).

Turning to the counterfactuals where a 10 per cent change is imposed on the independent variables, the most striking result is the strength of the impact of changes in market access compared with the other characteristics. For both Manchester and Preston, in terms of total cotton employment, a 10 per cent increase in market access adds considerably more than the sum of a 10 per cent adverse change of all the other 4 characteristics takes away. Since market access effects were becoming stronger over time as the size of the industry grew while most other characteristics would change relatively little or not at all, the picture is of an industry that had become increasingly 'locked in' to its existing heartlands. Nevertheless, good market access could be offset by other disadvantages. For example, for Preston if each of water power, coal price and textile inventiveness had been only average the model predicts cotton employment would have been close to zero and there are places even within Lancashire itself with better market access than Preston but no cotton mills.

Comparing the impacts of 10 per cent changes in different variables reveals something about their relative strength and the tradeoffs that choice of location entailed. For example, Table 6 shows that a 10 per cent rise in coal price could be offset by a 44 per cent increase in water flow, a 15 per cent rise in textile inventiveness, being 28 per cent more rugged, or by a 1.6 per cent improvement in market access.

These results give qualified support to the emphasis the Rodgers (1960) placed on coal prices as a key variable for the location of the cotton industry without endorsing his claim that it dominated everything else. It might also be noted that, as the industry became more spatially concentrated over time, some locations lost their mills. Based on the data in Solar and Lyons (2011), we can identify observations in our data set for which there was no mill in 1838 but where there is evidence for cotton textiles at an earlier date. Exit is positively (negatively) correlated with high coal prices (textile inventiveness).

Finally, there is an important caveat as to what this methodology cannot do. The counterfactuals show, at best, what would be the implications in 1838 of taking away Lancashire's advantages. They do not provide estimates of the total impact that the 'original advantages' had on the location of the

industry. Indirect, legacy effects working through accrued agglomeration benefits in the form of sunk costs or otherwise obviously mattered but are not accounted for in Table 6.

6. Conclusion and Outlook

We have shown that the location of the UK cotton textiles industry in 1838 was positively related to the availability of water power, to ruggedness of terrain, to having a history of textile invention to proximity to ports, and to market access. We have found that lower coal prices do not have a significant effect on the probability that there was a cotton mill in a given location but do have a strong impact on employment in the cotton industry and on the size of mills. We have not found evidence to support the hypotheses that humidity and access to soft water were favorable locational characteristics.

These results largely vindicate the claims made by Farnie (1979) and do buttress his argument that Lancashire's dominance of cotton textiles was based both on 'original' and 'acquired' advantages. Thus, in the former category, our evidence is supportive of the roles played by 'poverty', 'water supply' and 'textile tradition' and, in the latter category, by agglomeration benefits, cheap coal, and access to foreign markets. We do not, however, agree with Farnie's emphasis on the value of a humid climate. Our results are consistent with the view of Rodgers (1960) that locations further away from coalfields were at a significant disadvantage in the age of steam power but we do not accept that coal prices dominated everything else.

An interesting aspect of our results is the relationship that they highlight between the original geography of the industry and its subsequent location. One way that this emerges is that we have found a strong correlation between access to water power and the use of steam engines. This seems to be explained by the impact of the sunk costs of earlier investment in equipment such as waterwheels. We have also found strong evidence for the agglomeration benefits of locating near to other producers which eventually acted to 'lock in' the industry to its heartlands. Here is a channel through which original advantages could have legacy effects in much later periods even though their initial relevance had evaporated.

This paper has interrogated the evidence provided by one cross-section. While the results provide considerable insight into the determinants of the location of the cotton industry, obviously, there are some important limitations on what can be inferred especially in the presence of endogenous variables. A valuable next step using panel data will be to analyze the evolution of the industry over

the remainder of the nineteenth century as it became even more spatially concentrated and reliant on steam power.

Inter alia, this will allow investigation of issues relating to the nature of technical change during and after the Industrial Revolution. The Lancashire agglomeration was central to the long-run success of British cotton textiles which were increasingly spatially concentrated in an area characterized by high wages and cheap coal. This emerging geography intensified the rationale identified by Allen (2009) for technological progress whose factor-saving bias was energy-using and labor-saving. So, an analysis of 'directed technical change' in the cotton industry over the course of the nineteenth century would seem to offer an excellent opportunity to explore Allen's hypothesis in greater depth.

References

Acemoglu, D. (1998), "Why Do New Technologies Complement Skills? Directed Technical Change and Wage Inequality", *Quarterly Journal of Economics*, 113, 1055-1089.

Allen, R. C. (2009), *The British Industrial Revolution in Global Perspective*. Cambridge: Cambridge University Press.

Atwood, R. S. (1928), "Localization of the Cotton Industry in Lancashire, England", *Economic Geography*, 4, 187-195.

Balderston, T. (2010), "The Economics of Abundance: Coal and Cotton in Lancashire and the World", *Economic History Review*, 63, 569-590.

Bartholomew, J. G. (1904), *The Survey Gazetteer of the British Isles*. London: George Newnes.

Becker, S., Ekholm, K., Jäckle, R. and Muendler, M-M. (2005), "Location Choice and Employment Decisions: A Comparison of German and Swedish Multinationals*", Review of World Economics***,** 141, 693-731.

Bowley, A. L. (1900), *Wages in the United Kingdom in the Nineteenth Century*. Cambridge: Cambridge University Press.

Broadberry, S. N. and Marrison, A. J. (2002), "External Economies of Scale in the Lancashire Cotton Industry, 1900-1950", *Economic History Review*, 55, 51-77.

Carlton, D. (1979), "Why New Firms Locate Where They Do: an econometric Model", in W. Wheaton (ed.), *Interregional Movement and Regional Growth*. Washington, DC.: Urban Institute, 13-50.

Combes, P-P., Mayer, T. and Thisse, J-F. (2008), *Economic Geography*. Princeton: Princeton University Press.

Crafts, N. F. R. (1985), British Economic Growth during the Industrial Revolution. Oxford: Clarendon Press.

Dixit, A. and Stiglitz, J. (1977), "Monopolistic Competition and Optimum Product Diversity", *American Economic Review*, 67, 297-308.

Farnie, D. A. (1979), *The English Cotton Industry and the World Market, 1815-1896*. Oxford: Clarendon Press.

Farnie, D. A. and Jeremy, D. (2004), "The Role of Cotton as a World Power, 1780-1990", in D. A. Farnie and D. Jeremy (eds.), *The Fibre that Changed the World: the Cotton Industry in International Perspective, 1600-1990s*. Oxford: Oxford University Press.

Fujita, M., P. Krugman and A. Venables (1999), *The Spatial Economy. Cities, Regions, and International Trade*, Cambridge, Mass.: MIT Press.

Gatrell, V. (1977), "Labour, Power and the Size of Firms in Lancashire Cotton in the Second Quarter of the Nineteenth Century", *Economic History Review*, 30, 95-139.

Ginter, D. E. (1992), *A Measure of Wealth: the English Land Tax in Historical Analysis*. Montreal: Queen's University Press.Guimaraes et al. (2003)

Guimaraes, P., Figueirdo, O. and Woodward, D. (2003), "A Tractable Approach to the Firm Location Decision", *Review of Economics and Statistics*, 85, 201-204.

Head, K. and Mayer, T. (2004), "Market potential and the Location of Japanese Investments in the European Union", *Review of Economics and Statistics*, 86, 959-972.

Head, K. and Mayer, T. (2006), "Regional Wage and Employment Responses to Market Potential in the EU", *Regional Science and Urban Economics*, 36, 573-594.

Holden, W. (1999),"Water Supplies to Steam-Powered Mills", *Industrial Archaeology Review*, 21, 41-51.

Kane, Robert (1845), *The Industrial Resources of Ireland*, Dublin: Hodges and Smith.

Kerridge, E. (1985), *Textile Manufactures in Early Modern England*. Manchester: Manchester University Press.

Krugman, P. (1991), "Increasing returns and Economic Geography", *Journal of Political Economy*, 99, 483-499.

Krugman, P. (1995), *Development, Geography and Economic Theory*. Cambridge, Mass.: MIT Press.

Lander, C. H. (1914), *Ventilation and Humidity in Textile Mills and Factories*. London: Longmans, Green and Co.

Langton, J. (1979), *Geographical Change and Industrial Revolution*. Cambridge: Cambridge University Press.

Lawrence, M. G. (2005), "The Relationship between Relative Humidity and the Dewpoint Temperature in Moist Air: a Simple Conversion and Applications", *Bulletin of the American Meteorological Society*, 86, 225-233.

Leunig, T. (2003), "A British Industrial Success: Productivity in the Lancashire and New England Cotton Spinning Industries a Century Ago", *Economic History Review*, 56, 90-127.

Marshall, A. (1919), *Industry and Trade*. London: Macmillan.

Maw, P., Wyke, T. and Kidd, A. (2012), "Canals, Rivers, and the Industrial City: Manchester's Industrial Waterfront, 1790-1850", *Economic History Review*, 65, 1495-1523.

McFadden, D. (1978), "Modeling the Choice of Residential Location", in A. Karlquist et al. (eds), *Spatial Interaction Theory and Residential Location*. Amsterdam: North-Holland, 75-96.

Melitz. M. J. (2003), "The Impact of Trade on Intra-Industry Reallocations and Aggregate Industry Productivity", *Econometrica*, 71, 1695-1725.

Melitz, M. J. and Redding, S. J. (2012), "Heterogeneous Firms and Trade", NBER Working Paper No. 18652.

Motta, M. and Thisse, J.-F. (1994), "Does Environmental Dumping lead to De-Location?", *European Economic Review* 38, 563-576.

Ogden, H. W. (1927), "The Geographical Basis of the Lancashire Cotton Industry", *Journal of the Manchester Geographical Society*, 1927, 8-30.

Redding, Stephen, Daniel M. Sturm, Nikolaus Wolf (2011) "History and Industry Location: Evidence from German Airports," *The Review of Economics and Statistics*, vol. 93(3), pages 814-831.

Rodgers, H. B. (1960), "The Lancashire Cotton Industry in 1840", *Transactions of the Institute of British Geographers*, 28, 135-153.

Rose, M. B. (1996), "Introduction: the Rise of the Cotton Industry in Lancashire to 1830", in M. B. Rose (ed.), *The Lancashire Cotton Industry: a History since 1700*. Preston: Lancashire County Books, 1-28.

Roses, J. (2003), "Why Isn't the Whole of Spain Industrialized? New Economic Geography and Early Industrialization, 1791-1910", *Journal of Economic History*, 63, 995-1022.

Schmidheiny, K. and Brulhart, M. (2011), "On the Equivalence of Location Choice Models: Conditional Logit, Nested Logit and Poisson", *Journal of Urban Economics*, 69, 214-222.

Solar, P. M. and Lyons, J. S. (2011), "The English Cotton Spinning Industry, 1780-1840, as Revealed in the Columns of the *London Gazette*", *Business History*, 53, 302-323.

University of East Anglia Climatic Research Unit (2008), *CRU Time Series High Resolution Gridded Datasets*. Available from http://badc.nerc.ac.uk/view/badc.nerc.ac.uk ATOM datent 1256223773328276

Von Tunzelmann, N. (1986), "Coal and Steam Power", in J. Langton and R. J. Morris (eds.), *Atlas of Industrializing Britain*. London: Methuen, 72-79.

Woodcroft, B. (1854), *Titles of Patents of Invention Chronologically Arranged, 1617-1852*. London: Eyre and Spottiswoode.

Woodcroft, B. (1862), *Reference Index of English Patents of Invention, 1617-1852*. London: Eyre and Spottiswoode.

Official Publications

BPP (1839), Return of All the Mills and Factories.

BPP (1843), Account of the Prices of the Prices of Articles of Consumption at the Poor Law Unions throughout England and Wales.

BPP (1844a), Report of the Poor Law Commissioners for Scotland.

BPP (1844b), Return Showing the Annual Value of Real Property in each parish of Each County.

BPP (1844c), Occupational Abstract: 1841 Population Census.

BPP (1850), Return of the Number of Cotton, Woollen, Worsted, Flax and Silk Factories subject to the Factories Acts in the United Kingdom.

BPP (1854), Vessels and Tonnage at Each of the 12 Principal Ports of the United Kingdom.

BPP (1862), Poor Law Unions: a return of the Area and Population .

BPP (1903), Cotton Factories.

UK (2008) Hydrometric Register.

Appendix

Table 1: The Location of the Cotton Industry in 1838[1]

		Number of Cotton Mills	Share in UK in %	Employment	Share in UK in %
England	North-West	1533	84.1	211454	81.1
	…of which Lancashire	1125	61.7	152145	58.3
	North, North-East and Central	45	2.4	5806	2.0
	South-West	1	0.1	29	<0.1
	South-East	19	1.0	942	0.4
Wales		5	0.3	1010	0.4
Scotland		196	10.8	36918	14.2
Ireland		24	1.3	4622	1.8
United Kingdom		1823	100	260781	100
Herfindahl-Index of Concentration Lancashire, 31 Poor Law Unions [Normalized]		0.106 [0.076]		0.117 [0.088]	
Herfindahl-Index of Concentration England, 41 Counties [Normalized]		0.519 [0.507]		0.520 [0.508]	
Herfindahl-Index of Concentration UK, 118 Counties [Normalized]		0.404 [0.398]		0.371 [0.366]	

Source: Factory Inspectors' report for 1838 (BPP, 1839).

[1] North West is Cheshire, Derbyshire, Lancashire, and Yorkshire WR. North is Northumberland, Cumberland, Durham, Westmoreland, North East is Lincolnshire, Nottinghamshire, Yorkshire ER and Yorkshire NR. Central is Warwickshire, Leicestershire, Northamptonshire, Huntingdonshire, Rutland, Cambridgeshire, Bedfordshire, Buckinghamshire, Oxfordshire, Hertfordshire, Middlesex, Berkshire. South East is Norfolk, Suffolk, Surrey, Essex, Kent. South West is Cornwall, Devon, Dorset, Gloucestershire, Hampshire, Herefordshire, Somerset Staffordshire, Worcestershire, and Wiltshire.

Table 2: Characteristics of Different Locations, c.1838

	Manchester (Lancashire)	*Preston (Lancashire)*	*Full Sample Average*	*Lowest*	*Highest*
Market Access (proximity measure to cotton employment, 1838)	10215	7143	3541	782 (Kerry)	20110 (Chorlton, Lancs.)
Market Access (proximity measure to population, 1801)	112	89	73	29 (Caithness)	125 (Chorlton, Lancs.)
Distance to major ports (km)	185	196	310	182 (Warrington, Lancashire)	630 (Caithness)
Coal Price 1842/43 (d/ton)	64	89.5	173.5	64.0 (Leigh, Wigan, Manchester, Lancs.)	369.6 (Hertfordshire)
1690 Land Tax (d/acre)	126.65	4.69	9.81	0.04 (Sutherland)	252.55 (Middlesex)
Ruggedness (Index)	24.8	46.4	42.2	1.6 (Norfolk)	148.7 (Stirlingshire)
Q95 (m^3/ sec)	0.5	4.4	1.11	0.02 (Oxfordshire, Anglesey)	5.82 (Montgomeryshire)
Relative Humidity (%)	88.26	88.25	89.081	83.486 (Banff)	96.394 (Fermanagh)
Water Hardness (mg/litre)	15.212	15.212	36.903	1.79 (Cromarty)	132.41 (Huntingdonshire)
Textile Inventions (Index)	33.6	6.55	4.8	0 (21 locations)	239.8 (Middlesex)
Agricultural Wages ca 1770 (d/day)	13	13	11	5 (Kings County)	20 (Kent)
Agricultural Wages ca 1830 (d/day)	25.3	25.3	18	6 (Longford)	27 (Kent)

Sources: see text.

Table 3: Poisson Model of Cotton Industry Location, Britain 1838

Dep. Var.:	# of cotton mills (all variables)	# of cotton mills (excl. humidity)	# of employed persons in cotton mills (all variables)	# of employed persons in cotton mills (excl. humidity)	# of employed persons per mill (excl. humidity)
	(1)	(2)	(3)	(4)	(5)
Model	Poisson	Poisson	Poisson	Poisson	Poisson
Ln(area)	0.145 (0.186)	0.198 (0.118)*	0.193 (0.175)	0.238 (0.118)	0.088 (0.084)
Ln(ruggedness)	1.249 (0.462)***	0.898 (0.193)***	0.580 (0.375)	0.328 (0.168)*	0.133 (0.138)
Ln(relative humidity)	-34.917 (24.551)	-	-27.197 (17.963)	-	-
Ln(q95)	0.314 (0.035)***	0.282 (0.035)***	0.255 (0.043)***	0.207 (0.053)***	0.311 (0.154)**
Ln(totalhardness)	-0.031 (0.13)	0.035 (0.257)	0.023 (0.043)	0.070 (0.426)	-0.199 (0.252)
Ln(TWRI)	0.788 (0.032)***	0.717 (0.069)***	0.804 (0.030)***	0.753 (0.062)***	0.038 (0.054)

Table 3: Poisson Model of Cotton Industry Location, Britain 1838 (continued)

	(1)	(2)	(3)	(4)	(5)
Ln(Coalprice)	-0.426 (0.745)	-0.411 (0.673)	-1.081 (0.651)*	-1.046 (0.537)*	-1.551 (0.272)***
Ln(weighted Dist)	-3.823 (0.962)***	-1.778 (1.420)	-3.292 (1.302)**	-1.472 (1.821)	-5.219 (1.357)***
Ln(MP1801)	4.405 (1.073)***	4.603 (1.109)***	4.561 (0.845)***	4.773 (1.039)***	-2.733 (1.207)**
Constant and Region dummies	yes	yes	yes	Yes	Yes
# of Obs.	148	148	148	148	148
Pseudo R2	0.762	0.741	0.760	0.745	0.299
Log Pseudolikelihood	-869.203	-944.963	-123258.55	-131045.49	-7722.47
Note: robust standard errors in parentheses, * indicates significance at the 10 percent level; ** significance at the 5 percent level; *** significance at the 1 percent level.					

Sources: see text.

Table 4a: Poisson Model of Cotton Industry Location, 118 Counties of Great Britain

Dep. Var.:	# of cotton mills	# of employed persons in cotton mills	# of employed persons per mill
Model	Poisson	Poisson	Poisson
Ln(area)	-0.131 (0.186)	0.065 (0.163)	0.084 (0.264)
Ln(ruggedness)	-0.573 (0.443)	-0.979 (0.324)**	-0.059 (0.214)
Ln(q95)	0.769 (0.403)*	0.910 (0.279)***	0.477 (0.206)**
Ln(totalhardness)	-0.374 (0.342)	-0.258 (0.341)	-0.226 (0.200)
Ln(TWRI)	0.684 (0.301)**	0.258 (0.178)*	-0.022 (0.201)
Ln(Coalprice)	-2.752 (0.842)***	-3.278 (0.396)***	-1.903 (0.362)***
Ln(weighted Dist)	-1.703 (2.125)	-0.506 (2.674)	-5.832 (1.456)***
Ln(MP1801)	4.143 (0.783)***	5.384 (0.906)***	-3.390 (1.401)***
Constant	11.032 (14.929)	5.959 (19.876)	63.181 (17.277)***
# of Obs.	118	118	118
Pseudo R2	0.950	0.947	0.326
Log Pseudolikelihood	-296.965	-43595.905	-6328.562
Note: robust standard errors in parentheses, * indicates significance at the 10 percent level; ** significance at the 5 percent level; *** significance at the 1 percent level.			

Sources: see text.

Table 4b: Poisson Model of Cotton Industry Location, 31 Poor Law Unions of Lancashire 1838

Dep. Var.:	# of cotton mills	# of employed persons in cotton mills	# of employed persons per mill
Model	Poisson	Poisson	Poisson
Ln(area)	-0.295 (0.319)	-0.085 (0.291)	0.315 (0.192)*
Ln(ruggedness)	3.011 (0.933)***	2.095 (0.722)***	0.082 (0.281)
Ln(q95)	0.201 (0.167)	0.021 (0.129)	-0.017 (0.101)
Ln(totalhardness)	2.793 (1.030)**	1.556 (0.971)*	0.254 (1.101)
Ln(TWRI)	0.476 (0.266)*	0.754 (0.276)***	0.391 (0.197)**
Ln(Coalprice)	-1.111 (0.732)	-1.412 (0.756)*	-1.462 (0.612)**
Ln(weighted Dist)	-13.239 (13.225)	-0.618 (10.618)	6.662 (5.846)
Ln(MP1801)	2.517 (3.225)	3.769 (3.140)	2.100 (2.621)
Constant	48.613 (80.332)	-11.657 (67.220)	-36.340 (40.123)
# of Obs.	31	31	31
Pseudo R2	0.712	0.772	0.286
Log Pseudolikelihood	-328.263	-34345.758	-970.676

Note: robust standard errors in parentheses, * indicates significance at the 10 percent level; ** significance at the 5 percent level; *** significance at the 1 percent level.

Sources: see text.

Table 5: The persistent effect of water power: sunk costs and market access

Dep. Var.:	# of steam engines in cotton industry				
	(1)	(2)	(3)	(4)	(5)
Model	Poisson	Poisson	Poisson	Poisson	Poisson
Ln(area)	0.071 (0.009)***	0.249 (0.138)*	0.189 (0.057)***	-0.342 (0.193)**	-0.182 (0.123)
Ln(ruggedness)	-	0.254 (0.248)	-	-	-
Ln(q95)	0.210 (0.035)***	0.255 (0.044)***	0.181 (0.041)***	0.073 (0.053)	0.032 (0.029)
Ln(totalhardness)	-	0.186 (0.407)	-	-	-
Ln(TWRI)	-	0.761 (0.072)***	-	-	-
Ln(Coalprice)	-	-1.062 (0.557)*	-	-	-
Ln(weighted Dist)	-	-0.792 (1.379)	-	-	-
Ln(MP1801)	-	5.707 (0.949)***	-	-	-
Ln(MPCotton38)	-	-	0.585 (0.233)**	-	0.655 (0.584)
Ln(Waterwheels)	-	-	-	0.535 (0.067)***	0.474 (0.210)***
Constant and Region dummies	yes	Yes	yes	Yes	Yes
# of Obs.	148	148	148	148	148
Pseudo R2	0.462	0.744	0.473	0.729	0.738
Log Pseudolikelihood	-52638.51	-24995.51	-51619.61	-26476	-25671.53

Note: standard errors in parentheses, * indicates significance at the 10 percent level; ** significance at the 5 percent level; *** significance at the 1 percent level.

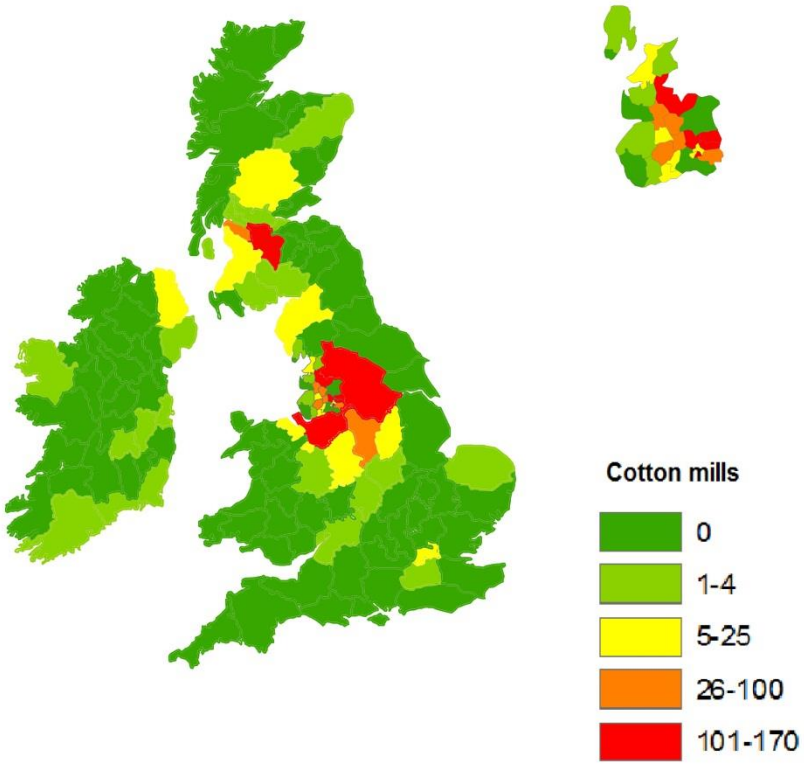
Sources: see text.

Table 6. Counterfactuals.

		Manchester			Preston		
		Orig. Variable	Change in Variable	Cotton Employment	Orig. Variable	Change in Variable	Cotton Employment
Actual data 1838		-	-	39363	-	-	8061
Benchmark Prediction (Table 2, column4)		-	-	30645	-	-	10021
Counterfactuals: predicted employment effect with **sample average**	Ruggedness	24.852	42.181	36450	46.416	42.181	9711
	Q95	0.5	1.11	36199	4.4	1.11	7532
	TWRI	33.583	4.847	8040	6.555	4.847	8263
	Coalprice	64	173.530	10790	89.5	173.530	5012
	Market Access 1801	111.758	73.230	4073	89.286	73.230	3890
Counterfactuals: predicted employment effect of a **10% increase** of…	Ruggedness	24.852	27.337	31618	46.416	51.057	10339
	Q95	0.5	0.55	31258	4.4	4.84	10221
	TWRI	33.583	36.941	32859	6.555	7.210	10669
	Coalprice	64	70.4	27735	89.5	98.45	9069
	Market Access 1801	111.758	122.934	48299	89.286	98.2156	15794
Counterfactuals: predicted employment effect of a **10% decrease** of…	Ruggedness	24.852	22.368	29604	46.416	41.774	9681
	Q95	0.5	0.45	29981	4.4	3.96	9804
	TWRI	33.583	30.224	27688	6.555	5.899	8318
	Coalprice	64	57.6	*34218*	89.5	80.55	11191
	Market Access 1801	111.758	100.582	18532	89.286	80.358	6060

Sources: see text.

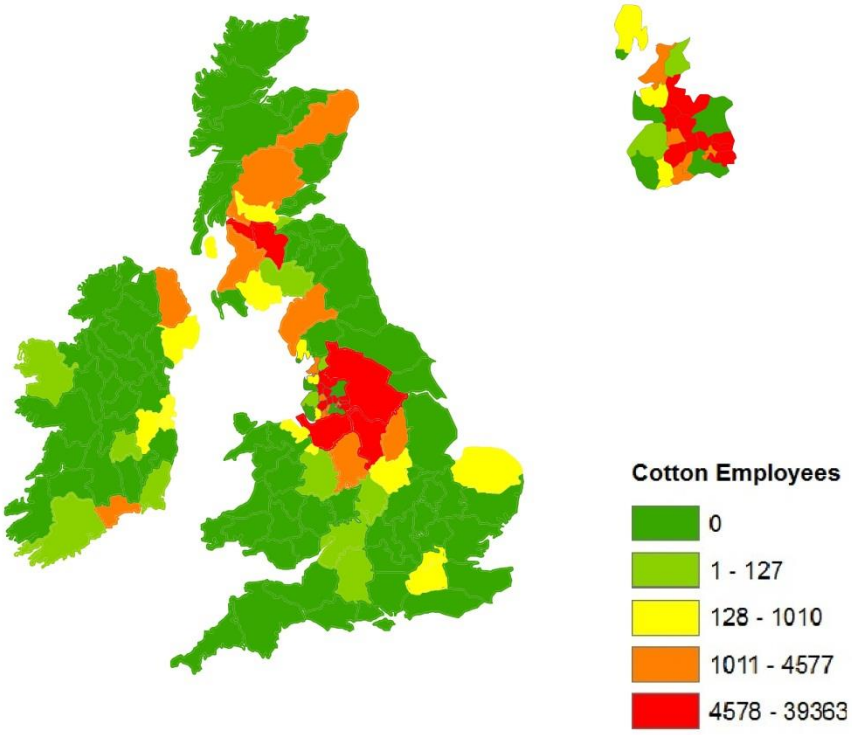
Map 1: the location of cotton mills in Britain 1838



Note: the inlay in the right upper corner shows Lancashire and its 31 Poor Law Unions.

Source: own map based on Factory Inspectors' report for 1838 (BPP, 1839).

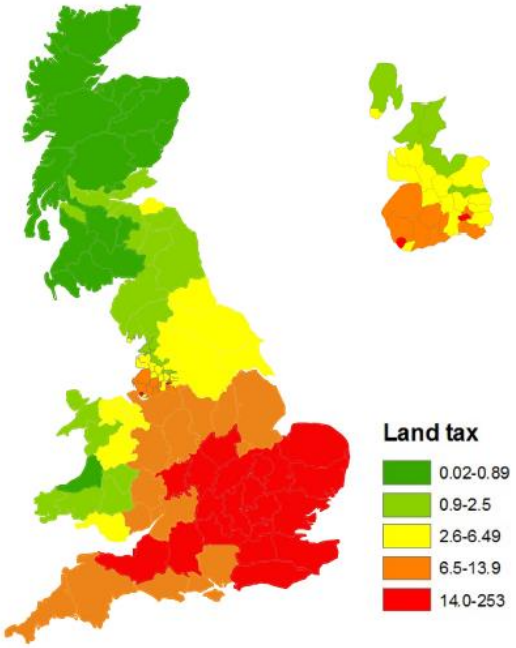
Map 2: the location of employment in the cotton industry in Britain 1838



Note: the inlay in the right upper corner shows Lancashire and its 31 Poor Law Unions.

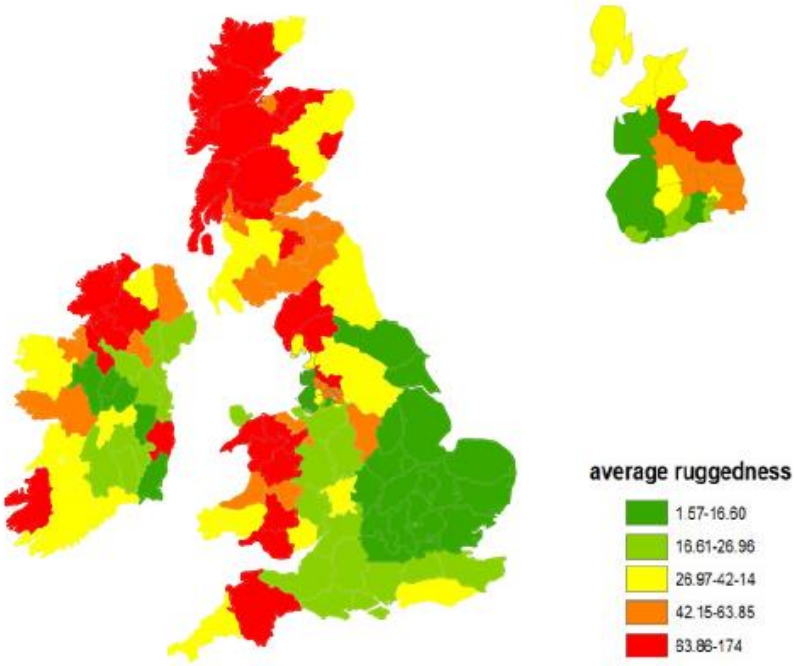
Source: own map based on Factory Inspectors' report for 1838 (BPP, 1839).

Map 3: land taxes in England, Wales and Scotland (shilling per acre, ca 1700)



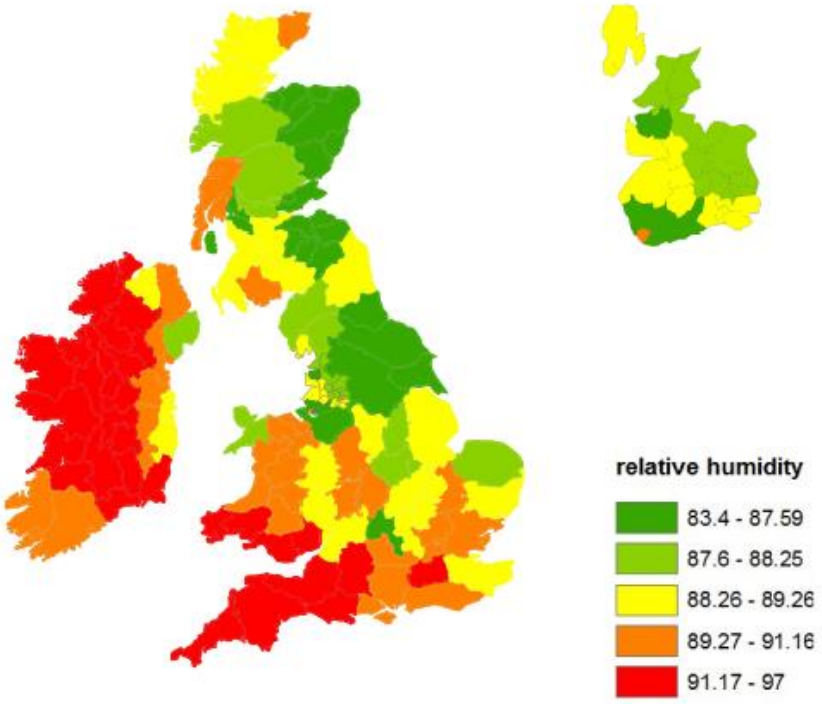
Sources: see text.

Map 4: average ruggedness of terrain



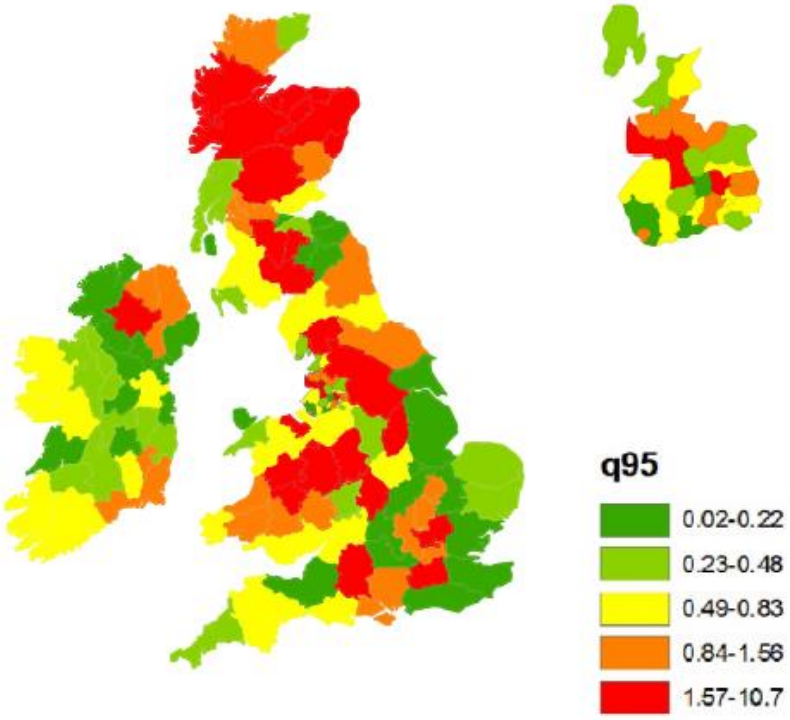
Source: see text.

Map 5: average relative humidity in %



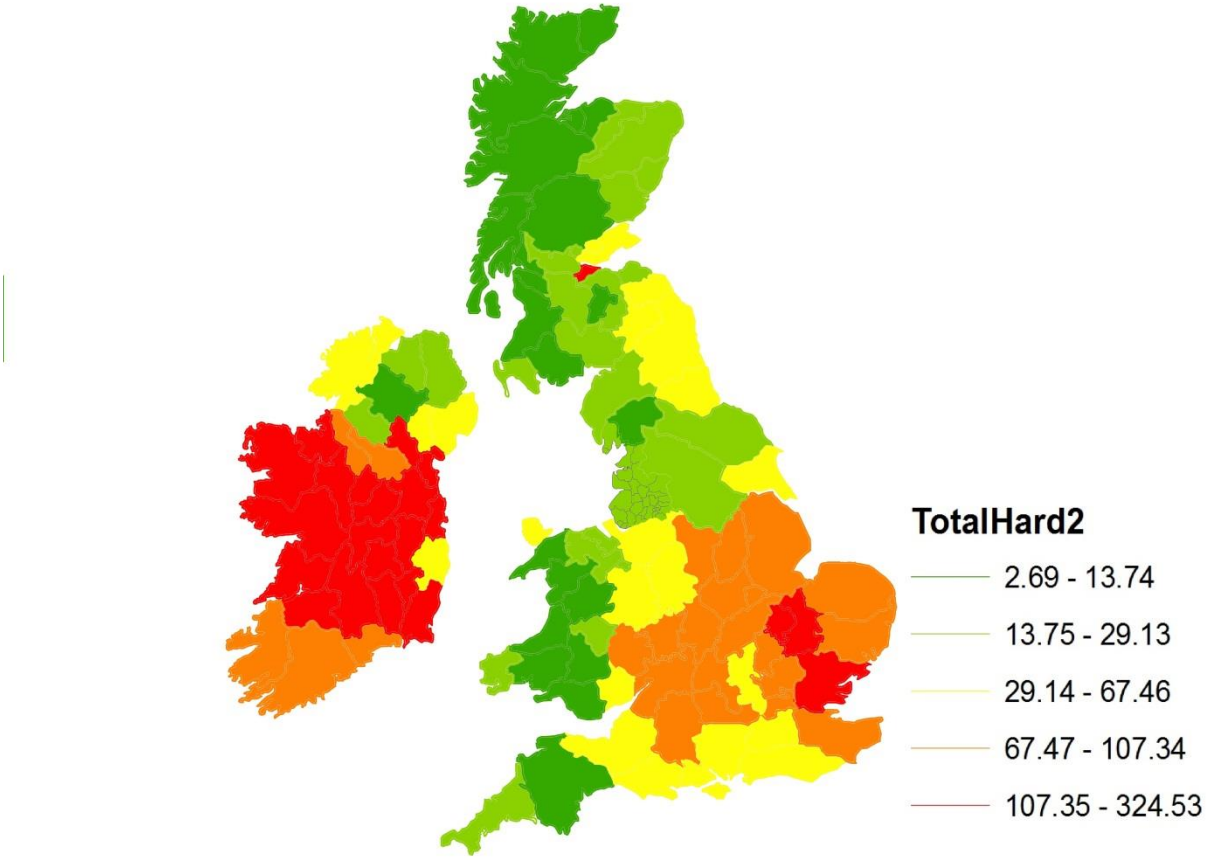
Sources: see text.

Map 6: Mean flow data at gauging stations in the UK and Ireland



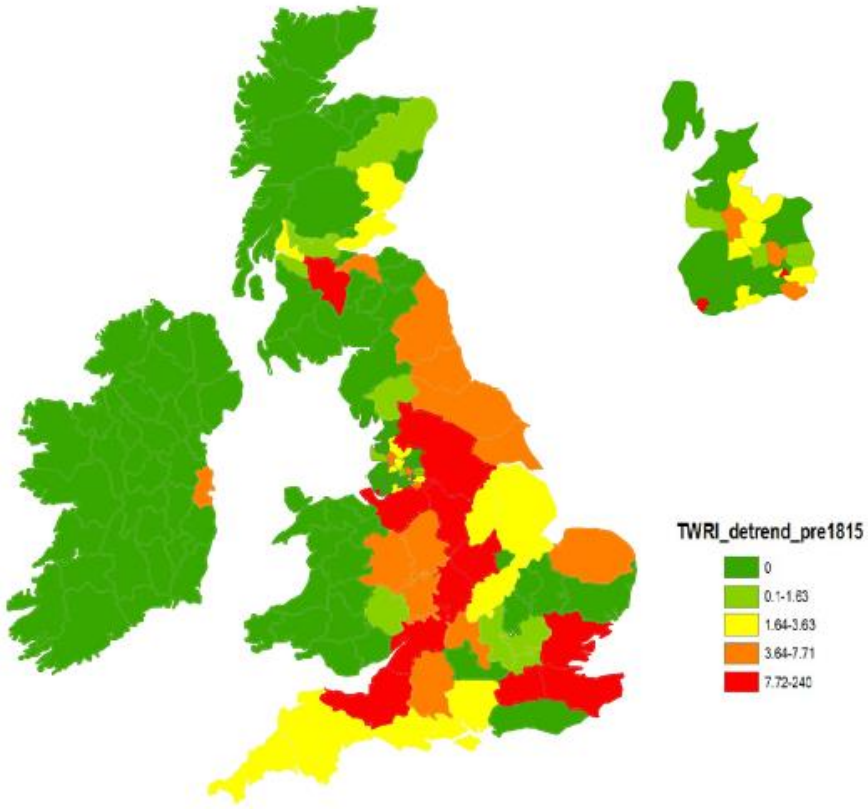
Source: see text.

Map 7: Water Hardness



Sources: see text.

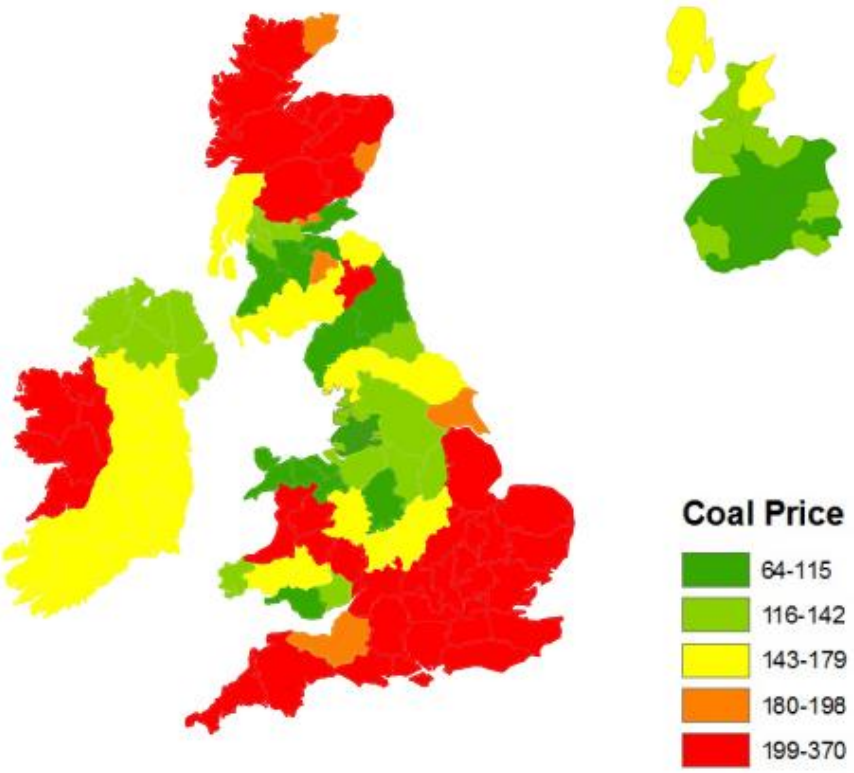
Map 8: Index of Patents, weighted by citations (up to 1815)



Note: the inlay in the right upper corner shows Lancashire and its 31 Poor Law Unions.

Source: see text.

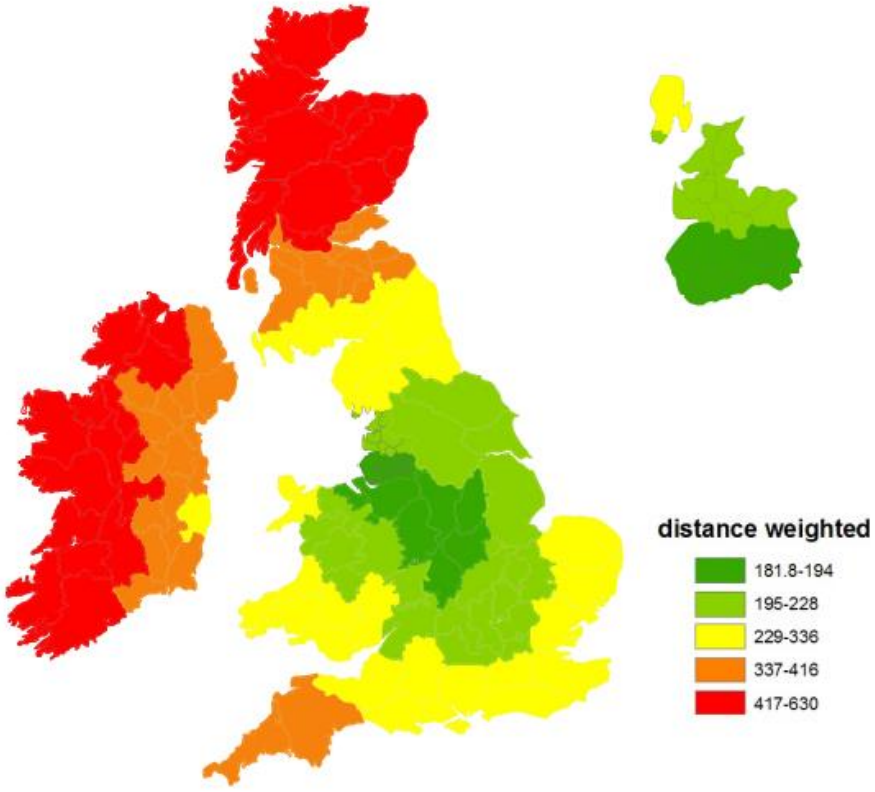
Map 9: British coal prices (shillings per ton, around 1842)



Note: the inlay in the right upper corner shows Lancashire and its 31 Poor Law Unions.

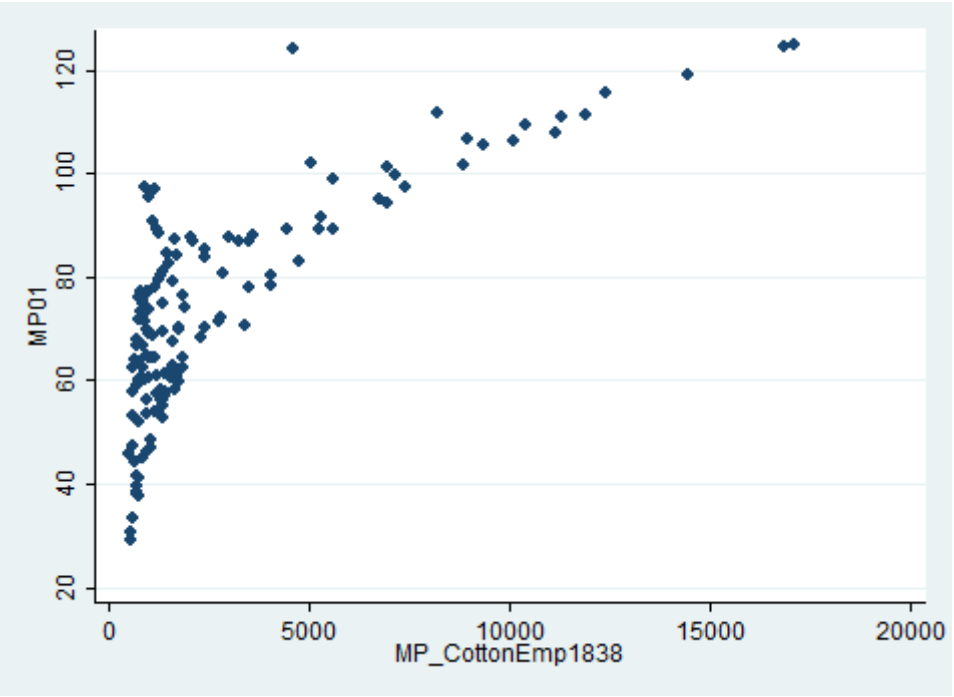
Source: see text.

Map 10: Distance to main ports, weighted by tonnage (1850s)



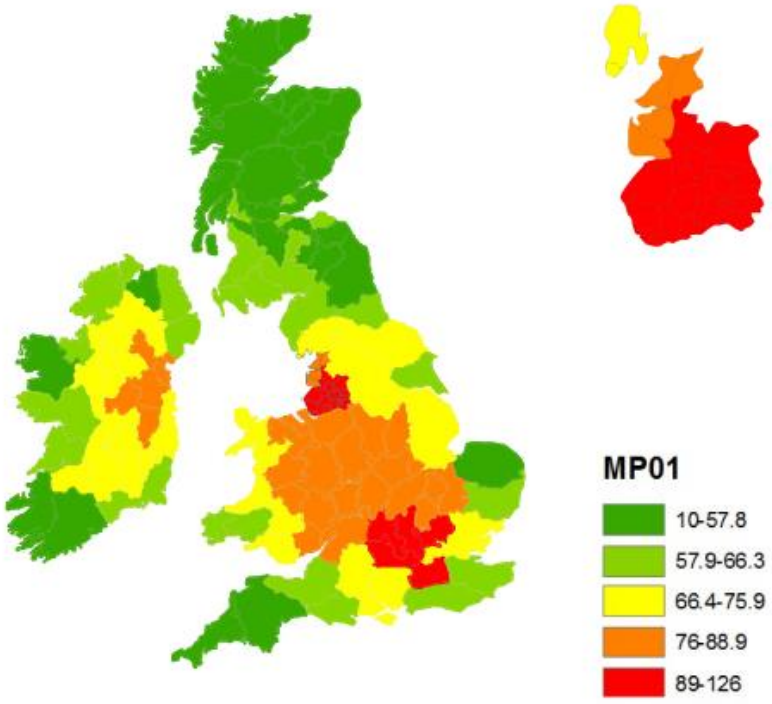
Source: see text.

Figure 1: Scatterplot of Market Potential (population 1801) and Market Potential (cotton textiles employment 1838)



Source: see text.

Map 11: Market-potential (access to population in 1801, weighted by distance)



Sources: see text.

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