# The Industrial Revolution and the Origins of Modern Economic Growth: a New Look.

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Note: this talk relies on joint work with Morgan Kelly and Cormac Ó Gráda, as well as on joint work with Assaf Sarid and Karine Van der Beek.

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The following is based on joint work: Morgan Kelly, Joel Mokyr and Cormac Ó Gráda, "The Mechanics of the Industrial Revolution" *Journal of Political Economy,* Vol. 131, Issue 1 (2023) and Morgan Kelly, Joel Mokyr and Cormac Ó Gráda, *Why Britain: a New View of the Industrial Revolution*, forthcoming, Princeton University Press.

## The British Industrial Revolution remains the Defining Event of modern economic history

Significance:

1. Created the "Great Enrichment" --- the rising tide of *sustained* economic growth that has lifted boats world–wide and created the current prosperous world.

2. Created the "Great Divergence" --- European (really "western") economic leadership between c 1880 and 1980.

3. Created British economic and technological leadership between c 1780 and c 1880.

# Two separate questions:

"Why Europe" as opposed to "Why Britain."

Will deal here only with the latter.

This question is of great importance by itself.

In 1750 Britain was neither the largest, nor the richest, nor the most powerful nation in Europe.

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# How should we think of Britain's role in the Industrial Revolution?

One of my more justly neglected analogies is to compare the Industrial Revolution with the rise of Christianity. Here is what I rashly wrote in my youthful days of *sturm und drang*:

*"Examining British economic history in the period 1760-1830 is a bit like studying the history of Jewish dissenters between 50 B.C. and A.D. 50. At first provincial, localized, even bizarre, it was destined to change the life of every woman and man in the West beyond recognition and to affect deeply the lives of others… Although the center of the stage has long been taken over by others, Britain's place of honor in the history books is assured:* ***It will remain the Holy Land of Industrialism."***

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# What was the Industrial Revolution?

Above all, the Industrial Revolution was a *technological* event: some famous major inventions and a much larger number of "tweaks." A more encompassing definition would focus on *useful knowledge,* focusing on both science *and* technology and the interaction between them, which was the core of what I have called "the Industrial Enlightenment".

Change in the *primum mobile* of economic change: before the Industrial Revolution there was growth, but it was primarily "Smithian" in nature (i.e., driven primarily by trade and specialization). After 1800 it became more and more "Schumpeterian" (i.e., driven increasingly, though never exclusively, by useful knowledge).

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Hence we could think of the Industrial Revolution as something akin to what physicists call a "phase transition."

Yet it was much more.

Comparable to the Neolithic Revolution in its significance in economic history: if we depict the history of the world as a "hockeystick", the Industrial Revolution is the beginning of the upturn that raised living standards significantly and sustainably above subsistence levels for the bulk of the population (and not just a tiny elite), with everything that came with it.

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# There are other interpretations of the Industrial Revolution :

1. **Demographics**: The breaking of the "Malthusian Regime" that had kept much of the world's population at a high pressure equilibrium (Lucas, Galor).

2. **I.O**. : A change in the "mode of production" i.e., rise of the Factory System (Marx, Max Weber, Mantoux). Implied a rise in the ratio of fixed to circulating capital in manufacturing, basically mechanization (Orthodox formal Marxist definition, but also Hicks).

3. **Trade**: A growth in the importance of "formal" markets in both goods and factors. "Industrial Capitalism" (Karl Polanyi, "History of Capitalism" literature).

# But why Britain?

There is more or less a consensus why the Industrial Revolution happened first in **Europe and not in Asia** (and few would contest that in the end the difference between Britain and France/Germany/Belgium/Netherlands was dwarfed by the gap between Europe and China/India/Middle East), although the question is still a bit overdetermined.

But the precise causes of **Britain's precocity,** the main topic concerning me here, are still hotly contested. Here is a very partial list of the competing schools:

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# Traditional views of "why Britain?"

The **Geographical** School: Britain was blessed with minerals (above all coal but also iron, non-ferrous metals and fireclay) as well as being a hard-to-invade island with good ports and well-integrated markets. Emphasized by members of the carbonocentric school such as E.A. Wrigley and Pomeranz.

The **Institutional** School: it was above all "1688 and all that" --- North-Weingast (1989), Pincus-Robinson, Stasavage, Cox. Institutional change in the second half of the seventeenth century.

- Good governance and strong property rights. Constraints on the executive. Solved "commitment problem" without violence (North; Acemogu-Robinson).
- Strong contract-enforcement coupled with "coercion-constraining institutions", with deep medieval roots, Greif (2006) . Especially popular among political scientists and new institutionalists; less so with quantitative economists (e.g. Murrell, 2009; Sussman and Yafeh, 2006).

**Specific British Institutions:** English *poor laws* played a role (Solar; Kelly-O'Grada; Greif-Iyigun); Effective IPR's and functional *Patent system* (North; Bottomley, Howes and others). *Relatively weak guilds* (P. Wallis; Ogilvie; Doepke et al.) *Political Economy*: Nation controlled by rich men meaning no effective resistance to technological change. Britain was a "Civil Economy": informal networks in the "Associational Society" --- enhanced trust and cooperative behavior (Peter Clark). *Relatively rational taxation*: no internal tariff barriers.

The **Imperialist** School: Ghost acreage and ghost workers. Atlantic economy, slave trade, slavery. Britain exploited its colonies and other non-Europeans and got rich at their expense (e.g., Inikori; Parthasarati; Beckert) in a zero-sum setting. Popular in History departments and among "History of Capitalism" scholars. Pomeranz: heavy emphasis on ghost acreage.

The **Contingency School** (Crafts, 1977): Britain had been just lucky. Had the French Revolution not occurred, for instance, or had Nelson lost at Trafalgar, France could have overtaken it (François Crouzet).

**Induced Innovation** (Robert Allen): high wages + cheap energy in Britain stimulated labor-saving inventions in an endogenous growth setting (Acemoglu). At first popular among economists, but has become very controversial.

# More recent suggestions

**Cultural School:** The **Industrial Enlightenment** was a critical cultural change with profound economic implications. Britain had an enlightenment, but it was different from the Continental one: it was more pragmatic, applied, materialistic, focused on concrete problem-solving rather than radical institutional reform or abstract philosophy and mathematics.

Also: Britain was the most extreme case of McCloskey's "Bourgeois virtues" --- the growing appreciation and rising prestige of commercial and industrial activities: "Free innovation led by the bourgeoisie became at long last respectable" (McCloskey *Trilogy* Vol. II, p. 386).

**Psychological view** (Nicolas Baumard, 2018). Higher living standards in Britain before 1700, coupled to lower inequality, led to widespread changes in behavior and preferences according to "Life History Theory" --- richer people are more risk-taking, inclined to entrepreneurial behavior, innovative, more cooperative, more trusting and publicly-minded.

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# A New Approach

One way to look at dynamic processes in history is to recognize both negative and positive feedback loops.

Much of economic history before 1600 was characterized by *negative* feedback loops. What this implies is that the system tends to converge to a unique and stable equilibrium.

Two of those seem most persuasive:

1. *Malthusian Dynamics:* Positive productivity shock → Rising Incomes → Rising birth rates + Falling death rates → Population growth → Diminishing returns to fixed factor → Declining Incomes.
2. *Political Dynamics:* Positive productivity shock → Rising Incomes → increased local rent-seeking + poorer predatory neighboring states invading → higher taxes and war-related damage → worse incentives → Declining Incomes. Known as the **rapacity effect.**

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# The effect of negative feedback

These two effects supposedly kept the vast majority of the world's economies at lower level of incomes (close to "subsistence") (Galor, 2011; Clark, 2009).

Regions that were able to become more prosperous with high living standards eventually stopped growing and declined (Italy, south Germany, Low Countries).

Yet there were potential *positive* feedback loops, that created what is known as “Matthew Effects” at the level of the economy.

“For to every one who has will more be given, and he will have abundance; but from him who has not, even what he has will be taken away.”
— Matthew 25:29

And so long-term economic history can be seen as a horse race between negative and positive feedback mechanisms.

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# What kind of positive feedback loops can we identify?

1. Baumard's psychological "life history" theory: rising income → more entrepreneurship and willingness to take risk, more cooperative behavior and more trusting → rising incomes.
2. More standard nutritional poverty traps theory: low income→ malnutrition → cognitive + physiological stunting → lower income (and if nutrition improves, the cycle moves in the other direction).
3. Rising incomes → more demand for high income-elast. goods → urbanization and investment in human capital (since luxury goods demanded more skills) → urban amenities + investment in HK → rising productivity → rising incomes.

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I accept all these, but I am proposing an additional positive feedback loop.

4. Higher incomes → fewer people at a subsistence level of income → more intellectuals → more people who can spend time on thinking about and tinkering with "useful knowledge" → more technological progress → higher productivity

In short, the argument is this:

By 1700 or so, Britain was already a relatively rich country that had succeeded in raising income levels considerably above subsistence. But instead of a negative feedback loop setting in, the positive feedback loops dominated and created a Matthew Effect.

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By that time, the negative feedback effects had receded:

1. Malthusian mechanisms had weakened considerably in Britain and no longer played a role.
2. External predators were not a serious threat to an island nation with a powerful navy.
3. Internal rent-seeking was curbed (somewhat) by the growing power of Parliament that constrained the king (despite high taxes) and eventually by an Enlightenment ideology that objected to "corruption."

But how come Britain was already rich in 1700? Very strong performance in the century before the Industrial Revolution:

1. No fighting on British soil after 1649.
2. Integrated markets (no internal tariffs, good transportation).
3. Profits from Atlantic Trade (incl. slave trade)
4. Highly productive agricultural  sector

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**Tab. 3: Growth rates of real GDP, population and real GDP per capita, England 1270-1700 and Great Britain 1700-1870 (% per annum)**

| | Real GDP | Population | Real GDP per capita |
|---|---|---|---|
| *A. England* | | | |
| 1270s-1300s | -0.02 | 0.27 | -0.29 |
| 1300s-1350s | -0.64 | -0.52 | -0.12 |
| 1350s-1400s | -0.30 | -1.06 | 0.76 |
| 1400s-1450s | -0.06 | -0.21 | 0.15 |
| 1450s-1500s | 0.40 | 0.25 | 0.15 |
| 1500s-1550s | 0.51 | 0.65 | -0.14 |
| 1550s-1600s | 0.81 | 0.62 | 0.19 |
| 1600s-1650s | 0.41 | 0.51 | -0.10 |
| 1650s-1700 | 0.78 | -0.04 | 0.82 |
| 1270s-1700 | 0.22 | 0.04 | 0.18 |
| *B. Great Britain* | | | |
| 1700-1750s | 0.49 | 0.30 | 0.19 |
| 1750s-1800s | 1.21 | 0.77 | 0.44 |
| 1800s-1850s | 2.08 | 1.34 | 0.74 |
| 1850s-1870 | 0.12 | 1.54 | 0.58 |
| 1700-1870 | 1.31 | 0.84 | 0.48 |

*B. Accounting for growth of British GDP per capita*

| | GDP p.c. | Work days p.c. | Human capital p.c. | Capital p.c. | Land p.c. | TFI p.c. | TFP |
|---|---|---|---|---|---|---|---|
| 1340s - 1400s | 0.54 | -0.17 | 0.15 | 0.17 | 0.14 | 0.30 | 0.25 |
| 1400s - 1450s | -0.08 | 0.11 | 0.22 | -0.06 | 0.01 | 0.28 | -0.35 |
| 1450s - 1640s | -0.03 | 0.10 | 0.16 | 0.00 | -0.09 | 0.16 | -0.19 |
| 1640s - 1690s | 0.88 | 0.17 | 0.10 | 0.11 | 0.01 | 0.39 | 0.49 |
| 1690s - 1830s | 0.34 | 0.08 | 0.02 | 0.04 | -0.10 | 0.03 | 0.31 |
| 1830s - 1860s | 1.11 | 0.06 | 0.30 | 0.34 | -0.23 | 0.75 | 0.36 |

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# A lot of this was in agriculture

**Tab. 5: Sectoral annual growth rates of output, labor-force and labor productivity, England 1381-1700 and Great Britain 1700-1851**

| Period | Annual % growth: | | | | | |
|---|---|---|---|---|---|---|
| | Agriculture | | | Industry | | |
| | Output | Labor-force | Labor productivity | Output | Labor-force | Labor productivity |
| 1381-1522 | 0.01 | -0.01 | 0.02 | 0.27 | 0.10 | 0.17 |
| 1522-1700 | 0.38 | 0.25 | 0.13 | 0.73 | 0.66 | 0.07 |
| 1700-1759 | 0.79 | 0.22 | 0.57 | 0.63 | 0.31 | 0.32 |
| 1759-1801 | 0.85 | 0.44 | 0.41 | 1.54 | 0.97 | 0.57 |
| 1801-1851 | 0.74 | 0.64 | 0.10 | 3.00 | 1.74 | 1.23 |

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But most of this growth was driven by “Smithian” processes: better allocation of resources and gains from trade, both inter-regional and international.

After 1750, “Schumpeterian” processes become gradually more important: Innovation and productivity growth.

What drove that?

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# UTHC (Upper-tail human capital)

This is an argument about the upper tail of the human capital distribution (the "elite" of the population of skilled artisans).

Technological progress can occur "bottom up" from experience and cumulative learning by doing by artisans and farmers and other practitioners.

Or it can take place "top-down" from a small number of inventors and a larger (but still very small) number of people who make improvements and adjustments ("tweakers").

# The importance of elites

Adam Smith made this point well: he noted that "to think or to reason comes to be, like every other employment, a particular business, which is *carried on by very few people* who furnish the public with all the thought and reason possessed by the vast multitudes that labour." The benefits of the "speculations of the philosopher ... may evidently descend to the meanest of people" if they led to improvements in the mechanical arts (Smith, [1776] 1978, pp. 569–72, emph added).

# The classic statement of UTHC

"There hath not been wanting in all ages and places great numbers of men whose genius and constitution hath inclined them to delight in the inquiry into the nature and causes of things, and from those inquirys to produce somewhat of use to themselves or mankind. But their Indeavours having been only single and scarce[ly] ever united, improved, or regulated by Art, have ended only in some small inconsiderable product hardly worth naming. But though mankind have been thinking these 6000 years and should be soe six hundred thousand more, yet they are and would be...wholly unfit & unable to conquer the difficultys of natural knowled[ge]. ***But this newfound world must be conquered by a Cortesian army, well-disciplined and regulated, though their numbers be but small."***

Robert Hooke, 1666

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This is a crucial argument about the Industrial Revolution: Much of the progress was generated by relatively few people; of course not just the 5-6 names that were venerated by Victorian hagiographers (Watt, Arkwright etc)  but a larger group, perhaps 2-3 percent of the labor force.

Who were these people? Some of them were intellectuals: "natural philosophers" (= scientists), who tried to take insights from chemistry (such as it was), physics, applied math, botany and so on and make production better. Some of them were entrepreneurs: clever businessmen who connected with people with new ideas and made them work. Some were inventors, people who thought "outside the box" or solved problems through a combination of luck and tenacity. A few were physicians, applied mathematicians, architects, surveyors, and such.

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# Competence as a key component

One critical component were high-skill artisans. Engineers, mechanics, colliers, coal-viewers, clockmakers, ironmongers, lens-grinders, and so on.

Inventiveness and original out-of-the-box thinking counted for a lot, but what may have mattered more is something I will call **competence**.

Competence may have been the key difference between James Watt and Leonardo Da Vinci.

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# Competence and the Industrial Revolution

**Competence** is defined here as the high-quality workmanship, tools, and materials needed to implement an innovation; that is, carry out the instructions embodied in the "recipe" for the technique. Someone had to execute the blueprint with a high level of accuracy (low level of tolerance), scale them up, and to install, adapt, operate, maintain, repair the machinery, and make it operate under a variety of circumstances.

Beyond those, competence often involved minor improvements, adjustments, and refinements (tweaks) of a technique, which may not have qualified as a "microinvention" stricto sensu. The artisans behind them were the "tweakers and implementers" that constituted the second line of attack after the great and not-so-great inventors (Meisenzahl and Mokyr, 2011).

# The upper tail of human capital: technical competence

Before and during the Industrial Revolution it was widely observed that British craftsmen were more skilled and had been better trained than anywhere else.

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## Successful mechanization and technological progress depended on these skills

James Watt himself said as much: “what is the principal hindrance to erecting engines? It is always the smith work.”

*What made his Soho works a success is having people at his side who could do the technical heavy-lifting: not just hall-of-famers like* ***William Murdoch*** *and* ***John Wilkinson****, but trained mechanics like* ***John Southern****, a highly competent engineer known for the invention of the graphical indicator diagram an instrument that was essential in computing the amount of work done in an expansive steam engine, or* ***James Lawson****, an outstanding engineer and manager and an astute observer of economic conditions in the kingdom.*

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# Can a larger endowment of skilled artisans explain British precocity?

## Brief digression: Tacit vs. codifiable knowledge

**Skills and competence** have been described by Michael Polanyi in his classic work on the topic as “the observance of a set of rules not known to the person following them.”

Tacit knowledge of any kind is likely to be transmitted through personal contact: by observation, memorization, and imitation. Hence, Polanyi argued, “An art which cannot be specified in detail cannot be transmitted by prescription, since no prescription for it exists. It can be passed on only by example from master to apprentice.”

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## Historians of Technology have realized the importance of competence.

John R. Harris, a historian of the iron industry in the Industrial Revolution, insisted that technological competence was to a large extent an instinctive *savoir faire* and a form of tacit knowledge that could only be taught by personal contact and example over many years. The British skilled worker was the repository of this tacit knowledge.

The iron workers and coal mine engineers absorbed the skills needed to work with coal and iron in John Harris's words "with the sooty atmosphere in which they lived rather than ever consciously learned" and would find it hard to express even what needed to be explained.

# The tacit-ness was important

1. It could not be taught in “engineering schools” or other formal institutions; it had to be acquired almost entirely through personal contact, that is from masters to apprentices.

2. It could not be easily diffused across space except through people moving about, engaging in learning, emulating, and often what we would call “industrial espionage.”

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# Implication of UTHC for the Industrial Revolution

**Proposition:** Britain may have had an absolute advantage in *both* inventing and implementing inventions, but it had a comparative advantage in "tweaking and implementing." Its "ingenious mechanics" were far better than any other economy in Europe.

Yet this is precisely what counted in those years.

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But if true, these high skills were the result of a channel of *positive feedback.*

Part of it was on the demand side.

On the eve of the Industrial Revolution Britain was rich and had a (relatively) equal income distribution.

Hence it had a relatively large “middling class” (less unequal income distribution and a high-wage commercialized economy), which generated a demand for upmarket “middle-class” consumer goods requiring high-skill and accuracy: clocks, watches, musical instruments, fancy toys, telescopes, as well as high-end ceramics, fancy furniture, and up-market textiles.

The skills deployed in these industries spilled over --- at least up to a point --- to the dynamic high-skill industries in the Industrial Revolution.

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Moreover, if the higher living standards and better nutrition of the *average* person in Britain was *even moderately higher* than in France or elsewhere on the Continent, affecting either cognitive  or physical capability, this would have far-reaching implications for the density in the *upper tail of the human capital* distribution.

The important part was not necessarily the mean or median quality of the workers but the size and quality of the upper tail of the distribution.

If the average quality of British workers (physical and/or cognitive) was even slightly higher than that of the European Continent, the density in the upper tail of the distribution would be dispropor-tionately larger.

This is a standard property of symmetrical statistical distributions: small differences in means (leaving the standard deviation the same) would imply a much larger than proportional increase in the size of the upper tail.

For example, in a normal distribution with $\mu = 100$ and $\sigma = 10$, an increase of 1 percent in the mean would lead to a 50% increase in the density above $4\sigma$.

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# But what is the evidence for the relative superiority of British craftsmen?

But this is history: evidence is everything.

How do we “know” this?

The evidence comes in 4 different parts.

# Evidence for the superiority of British artisans (1)

For one thing, contemporaries, both on the Continent and in Britain, said so.

**Jean-Baptiste Say,** France's leading student of Adam Smith, wrote in 1803 that Britain's wealth was due to "the wonderful practical skills of her adventurers [= entrepreneurs] in the useful application of knowledge and the superiority of her workmen" (Say, [1803], 1821, Vol. 1, pp. 32–33).

The great engineer **John Farey** (1791-1851), who wrote an important treatise on steam power, testified at a late stage of the Industrial Revolution that "the prevailing talent of English and Scotch people is to apply new ideas to use, and to bring such applications to perfection, but they do not imagine as much as foreigners" (Great Britain, 1829, p. 153).

But how do we know this is "causal"?

## **To make sure that high skills were a cause and not purely a consequence, we need to show that it *preceded* the Industrial Revolution**

This belief goes back to **Daniel Defoe** decades before the Industrial Revolution.

Defoe wrote in 1726 that “the English ... are justly fam’d for improving Arts rather than inventing” and elsewhere in his *Plan of English Commerce* that “our great Advances in Arts, in Trade, in Government and in almost all the great Things we are now Masters of and in which we so much exceed all our Neighbouring Nations, are really founded upon the inventions of others.” (Defoe, [1726–27], 2001, p. 162).

**Jean Ryhiner**, a Swiss manufacturer visiting Britain, famously remarked in 1766 that “for a thing to be perfect it has to be invented in France and worked out in England.”

# The French were painfully aware of the skill gap

In the late 1780’s (following the 1786 Eden Commercial Treaty) one French author wrote despondently: “We have set the French workmen to grips with the English workman. It is the combat of a naked man against an armed man and it has the outcome we may expect and the victory cannot be disputed. Is no resource left to us?”

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# Invention vs implementation

By 1800 the fame of Huntsman, Watt, Crompton, Cartwright, Smeaton, Jenner and many others had put to rest the notion that the British had no original creativity to "invent" themselves.

Needless to say, British inventors made a lot of inventions; but it never dominated inventiveness as much as it did in implementation driven by competence.

This is consistent with the idea that they had an *absolute* advantage in both inventing and implementing, but a *comparative* advantage in the latter.

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Table 11: Inventions and innovations per country 1750 – 1950, % of total

| | *Total* | *Great Britain* | *France* | *Germany* | *USA* | *Other* |
|---|---|---|---|---|---|---|
| 1750 – 1775 | 30 | 46.7 | 16.7 | 3.3 | 10.0 | 23.3 |
| 1776 – 1800 | 68 | 42.6 | 32.4 | 5.9 | 13.2 | 5.9 |
| 1801 – 1825 | 95 | 44.2 | 22.1 | 10.5 | 12.6 | 10.5 |
| 1826 – 1850 | 129 | 28.7 | 22.5 | 17.8 | 22.5 | 8.5 |
| 1851 – 1875 | 163 | 17.8 | 20.9 | 23.9 | 25.2 | 12.3 |
| 1876 – 1900 | 204 | 14.2 | 17.2 | 19.1 | 37.7 | 11.8 |
| 1901 – 1914 | 87 | 16.1 | 8.0 | 17.2 | 46.0 | 12.7 |
| 1915 – 1939 | 146 | 13.0 | 4.1 | 13.0 | 58.6 | 11.3 |
| 1940 – 1950 | 34 | 2.9 | 0.0 | 6.7 | 82.4 | 8.0 |

Source: Giovanni Gozzini, *Un'idea di giustizia. Globalizzazione e ineguaglianza dalla rivoluzione industriale a oggi* (Turin 2010) 25.

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# Evidence for the superiority Britain’s artisans (2)

Technical superiority can be inferred also from knowledge flows: Britain was the first and most successful adopter of many inventions made overseas, long before the country of the inventor was able to deploy them successfully.

Among them were mechanical linen-spinning, chlorine bleaching, soda-making, food canning, the Jacquard loom, and paper-making machinery (all invented in France), the Voltaic pile (invented in Italy), the telegraph (the basic idea of which came from Denmark).

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# More evidence of the superiority of British skills

Moreover, throughout the eighteenth century, the French (and much of the rest of the Continent) engaged in massive industrial espionage in Britain trying to smuggle out equipment and ideas.

Another indication is that a stream of continental inventors traveled to Britain to have their ideas developed, tweaked, and hopefully produced at a large scale and commercialized.

Best-known: Aimé Argand.

Argand oil lamp, c. 1786

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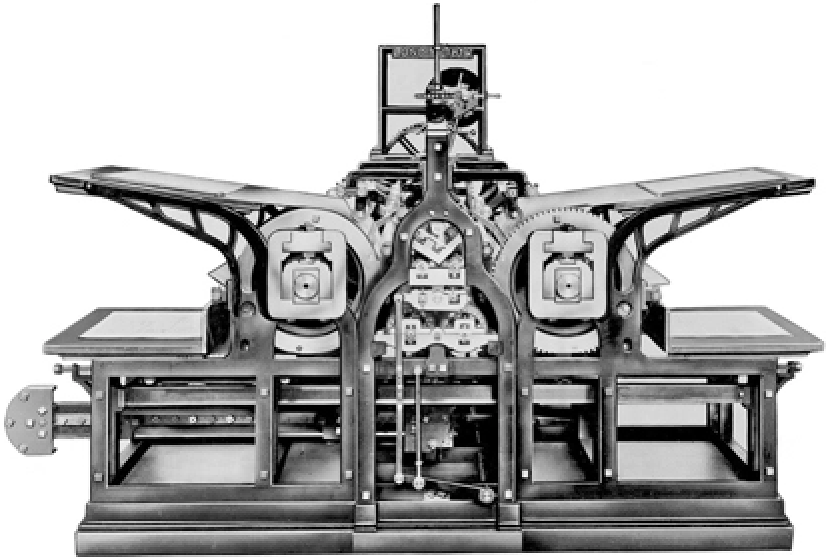
# One more example:



**Friedrich Koenig, 1774-1833, a Saxon inventor, made a number of major improvements to printing presses, invented a high-speed steam-powered press. But had to come to England to find the skilled workers to develop and scale-up his ideas, lived in London from 1806 to 1817.**

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# Evidence for the superiority Britain's artisans (3)

Policy evidence: The mercantilist mindset of the eighteenth century realized that Britain had an advantage here, and the British government responded to this superiority by the (largely ineffective) prohibition on the migration of artisans and exports of machinery (first passed in 1719 and repeatedly amended).

*In the early 1780s no skilled artisan or manufacturer was legally free to leave Britain or Ireland and enter any foreign country outside the Crown's dominions for the purpose of carrying on his trade. Textile printing workers were even forbidden to leave the British Isles, the implication being that other workers could at least travel within British possessions. It was an offence, moreover, to entice artificers or manufacturers to emigrate to foreign parts. It became illegal to export or to prepare to export to any place outside Britain and Ireland any pre-industrial or industrial textile, metal-working, clock-making, leather-working, paper-making or glass manufacturing equipment.*

(Jeremy, 1977)

There is a consensus that neither of those mercantilist measures were enforced very effectively.

But they indicate that informed and powerful people in the eighteenth century clearly thought that this advantage was a source of power and prosperity for Britain, and did not want their enemies to catch up with them.

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# Evidence for the superiority Britain's artisans (4)

To transfer tacit knowledge,  people had to migrate.

The smoking gun here was that Britain exported mechanics, engineers, and skilled workmen to every part of the Continent to install, operate, and maintain the new machinery developed in Britain.

The Continent imported British engineers and skilled manufacturers on a large scale, knowing full-well that they represented cutting-edge tacit know-how (Henderson, 1956).

The emigration of high-skill British artisans and engineers in the eighteenth and early nineteenth century was notable, and as it predated the Industrial Revolution, these were not just skills that had been accumulated in the Industrial Revolution itself.

# This phenomenon can already be observed before the Industrial Revolution

*Especially telling was the migration to France of the clockmaker Henry Sully, the founder of the Paris Societé des Arts in the 1720s. John Holker, the renegade Jacobite, became inspector general of French manufactures in 1756 and repeatedly recruited skilled workers in England and deployed them in France; Michael Alcock, a Birmingham toy- and button manufacturer who moved to France (1756) and built a large manufactory of ironware in La Charité sur Loire and brought in English technicians to maintain the equipment.*

# How many skilled workers migrated from Britain to the Continent?

One witness before the Parliamentary committee of 1824 estimated that in the years 1822 and 1823 alone, 16,000 artisans moved from England to France (Great Britain, 1824, p. 108); this seems exaggerated, but a year later another estimated the *stock* of English workers in France at that time at 15,000-20,000 workers (Great Britain, 1825, pp. 37, 43). Modern scholarship thinks it's probably somewhat smaller (Bensimon, 2011).

Many others went to Belgium, Germany, and the Habsburg Empire.

British emigrant engineers and mechanics built factories, railroads, and operated machinery in France, Germany, and the Habsburg Empire. But could be found everywhere on the Continent.

The pioneers of the Industrial Revolution in the Low Countries had names like Thomas Ainsworth, John Hodson, and William Cockerill.

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# Here is one more example :

**John J. Hughes, 1814-89, a Welsh ironmaster, founder of the town of Yuzovka, today Donetsk and a center of the heavy iron industry in the Eastern Ukraine.**

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## To sum up the argument so far:

Britain's leadership in the industrial transformation of Europe was rooted in an artisanal elite, who had the technical competence to design, build, operate, maintain, and continually improve the increasingly sophisticated machinery that began to appear in the mid-eighteenth century.

Without this pre-existing pool of mechanical expertise—ranging from watch- and clock-makers to millwrights, tool-makers, and foundry men—inventors like Arkwright and Watt would no more have been able to turn their ideas into usable technologies than Leonardo da Vinci had been in the fifteenth century.

It is this kind of obstacle that delayed an Industrial Revolution on the Continent and explains British leadership.

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# Two more issues

1. Do we have any systematic data to test the hypothesis of the importance of skilled labor to the Industrial Revolution?

2. How can we explain Britain's advantage in technological competence?

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# Testing the skills hypothesis on English data

One can test the prediction that the degree of industrialization in 1831 (or 1851) depended on the availability of skills. However, the supply of skills may itself be potentially endogenous: new industries associated with the Industrial Revolution encouraged inward migration of skilled workers in the decades before or caused workers in traditional industries like millwrights and blacksmiths to become specialized machine builders.

We therefore can use a second set of predictions—that in the eighteenth century these skills accumulated in low-wage areas that were conducive to the accumulation of mechanical skill—to instrument for potentially endogenous skills.

# The problem: data

The natural challenge comes in measuring the availability of mechanical skill at the beginnings of industrialization (since obviously the later data are endogenous).

However, the 1851 census details the numbers of workers in each occupation *broken down by age*. By examining elderly men (aged sixty and over, most of whom would have been apprenticed around age 14 in the late 1790s) we can get an idea of the distribution of the availability of skill at an earlier stage of the Industrial Revolution.

For nearly every county and every skill, the number of these men with a particular skill residing in a given area closely matches the number with the skill born in that county, suggesting that most of these men were apprenticed locally and that inter-county migration was not large enough to confound the analysis.

# The raw correlation with Industry in 1831 looks like this:

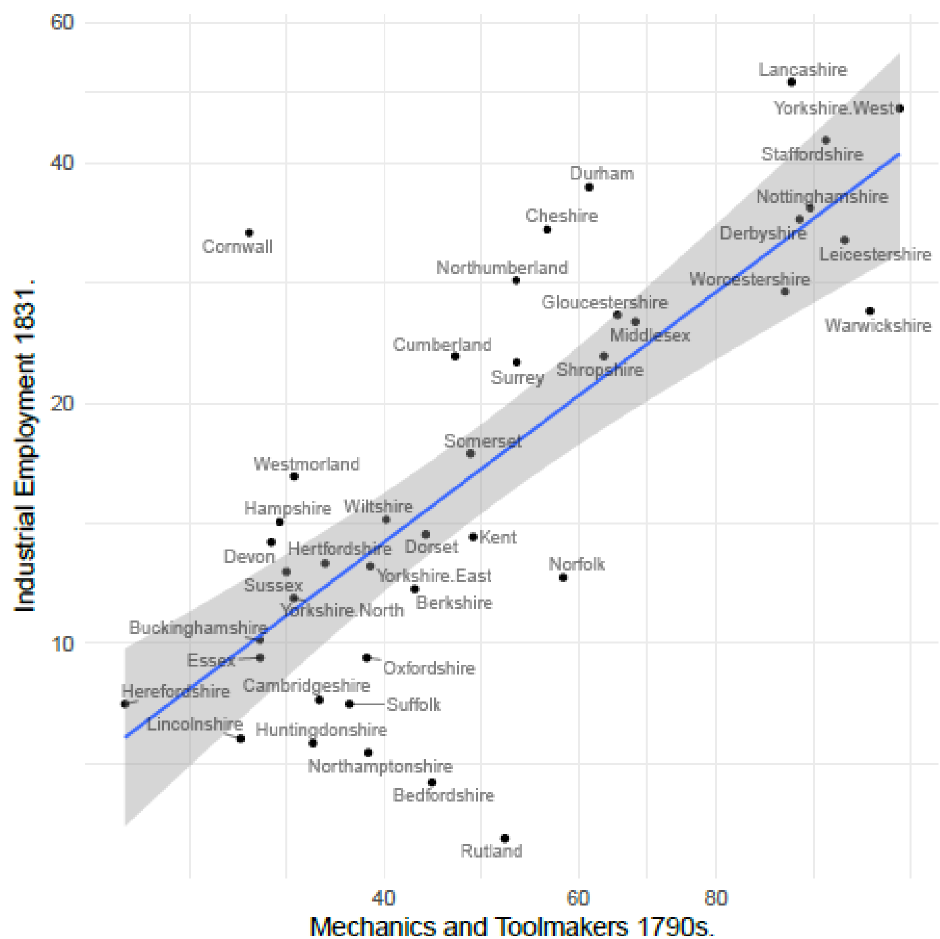


Figure 4: Share of mechanics and toolmakers in labour force in late 1790s versus industrial employment in 1831: logarithmic axes.

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# Textile Employment in 1851

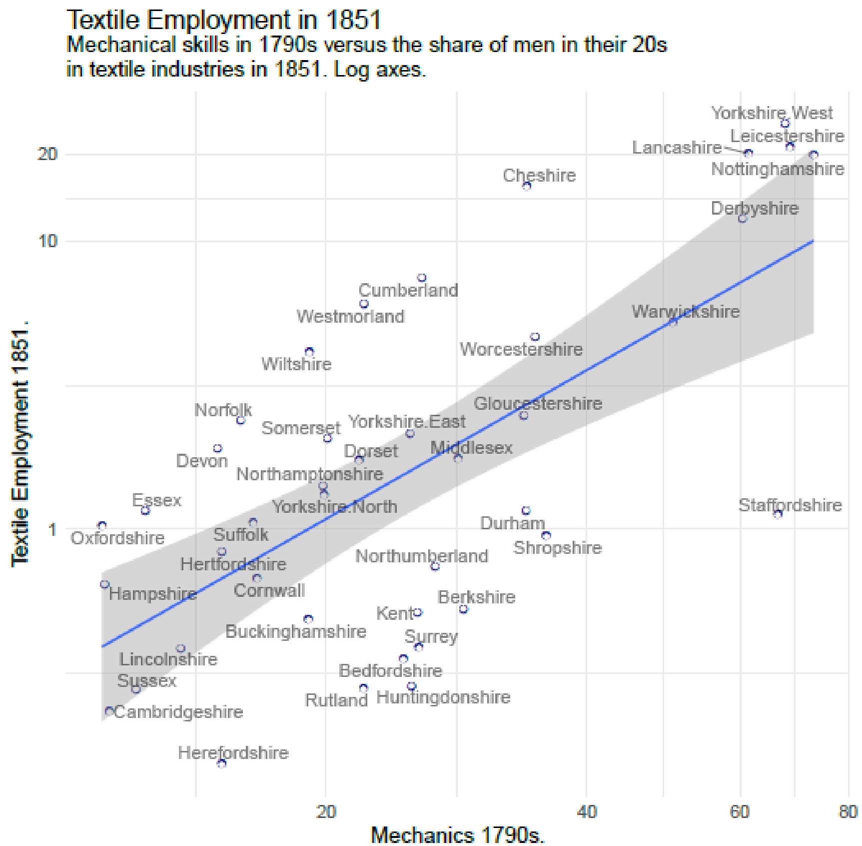


Figure 1: Supply of mechanical skill in the 1790s as a predictor of textile employment in 1851

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# Looking at the determinants of the size of manufacturing:

| | | | | |
|---|---|---|---|---|
| (Intercept) | −1.916* | −1.431* | −2.271*** | −0.335 |
| | (0.754) | (0.669) | (0.356) | (0.759) |
| Water.Flow | 0.338*** | 0.284*** | 0.290*** | |
| | (0.069) | (0.062) | (0.051) | |
| Coal | −0.040 | 0.015 | | 0.151 |
| | (0.084) | (0.074) | | (0.075) |
| Mechanics | 0.549*** | 0.522*** | | |
| | (0.133) | (0.115) | | |
| Toolmakers | 0.493*** | 0.532*** | | |
| | (0.131) | (0.114) | | |
| Sheet.Metal | 0.153 | 0.037 | | |
| | (0.096) | (0.090) | | |
| Metal.Products | −0.072 | −0.022 | | |
| | (0.082) | (0.073) | | |
| Cornwall | | 0.972** | 1.029*** | 1.317*** |
| | | (0.282) | (0.240) | (0.315) |
| Skilled | | | 1.059*** | 0.960*** |
| | | | (0.086) | (0.139) |
| $R^2$ | 0.808 | 0.860 | 0.857 | 0.754 |
| Num. obs. | 40 | 40 | 40 | 40 |
| RMSE | 0.279 | 0.242 | 0.231 | 0.303 |
| Moran | 0.143 | 0.023 | 0.047 | 0.000 |
| BP | 0.348 | 0.997 | 0.880 | 0.869 |

Dependent variable is log of number of industrial workers per 10,000 workers in 1831. Skilled is the sum of mechanics and toolmakers. Rutland excluded. Moran is the p value of a Moran test for autocorrelation. BP is the p value of a Breusch-Pagan test for heteroskedasticity.

**Table 1: Determinants of Industrial Employment in 1831: Ordinary Least squares.**

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The main problem with this result is that the skill data reflect a reality of the 1790s and thus may still be endogenous.

To try to deal with that, we instrument skills with three variables that we think may work here:

1. Size of cottage industry as approximated by agricultural wages.
2. Population growth before the mid-eighteenth century, as regions with cottage industries experienced higher birth rates, and workers from agricultural counties were attracted to upland areas where they could supplement income from farming with part-time manufacturing.
3. Cost of apprenticeship (as approximated by the costs of watchmaking apprenticeships).

# 2SLS results (First stage)

| | | | |
|---|---|---|---|
| Intercept | 10.294*** | 8.869*** | 3.349 |
| | (2.132) | (1.858) | (2.912) |
| Wage 1760s | −0.978* | −0.700 | 0.626 |
| | (0.481) | (0.417) | (0.683) |
| Apprentice Cost 1750-80 | −0.738** | −0.736*** | −0.451* |
| | (0.216) | (0.184) | (0.211) |
| Population Growth 1700-50 | | 1.453*** | 1.175** |
| | | (0.383) | (0.379) |
| Coal Proximity | | | 0.281* |
| | | | (0.119) |
| $R^2$ | 0.337 | 0.530 | 0.596 |
| Num. obs. | 39 | 39 | 39 |
| RMSE | 0.370 | 0.316 | 0.297 |
| Moran | 0.408 | 0.384 | 0.310 |
| BP | 0.093 | 0.568 | 0.284 |

Dependent variable is log of number of mechanics and toolmakers born in a county per 100,000 workers over age 60 in 1851. Excludes Rutland and Westmorland which recorded no watchmaking apprentices. All variables other than population growth are in logs. Standard errors in parentheses. Moran and BP are the p values of a Moran test for spatial autocorrelation, and a Breusch-Pagan test for heteroskedasticity respectively.

Table 2: First Stage Regression: Determinants of the supply of mechanics and toolmakers.

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# Second Stage 2SLS

| | | | |
|---|---|---|---|
| (Intercept) | −1.780* | −2.023*** | −2.629*** |
| | (0.689) | (0.536) | (0.457) |
| Skilled | 1.183*** | 0.974*** | 1.163*** |
| | (0.176) | (0.137) | (0.118) |
| Water.Flow | | 0.322*** | 0.274*** |
| | | (0.064) | (0.054) |
| Cornwall | | | 1.094*** |
| | | | (0.252) |
| N | 39 | 39 | 39 |
| RMSE | 0.371 | 0.284 | 0.235 |
| Sargan | 0.657 | 0.519 | 0.252 |
| Wu-Hausman | 0.358 | 0.898 | 0.077 |
| Weak instruments | 0.000 | 0.000 | 0.000 |

All variables are in logs with standard errors in parentheses. Skilled denotes the sum of mechanics and toolmakers and is instrumented using wages in the 1760s, population growth 1700-1750, and the median cost of becoming an apprentice watchmaker 1750-1780. Cornwall is a dummy for that county. The table reports p values of an F test for weak instruments, a Wu-Hausman exogeneity test, and a Sargan test of over-identifying restrictions.

Table 3: Second Stage Regression: Determinants of Industrial Employment in 1831: Instrumental variables.

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What is notable in Tables 1 and 3 is the strong explanatory power of a small number of variables: the availability of water power and the supply of mechanics and toolmakers explain nearly all of the variance (over 85 per cent) in industrial employment. The data here are spatial but a Moran statistic (the spatial analogue of the Durbin-Watson statistic) does not indicate substantial correlation in residuals so long as water rather than coal is treated as the energy source.

The data on skilled workers clearly indicate that there is good reason to believe that even at the level of English counties, skills drove industrialization.

The importance of water power is interesting because of the finding by Mokyr, Sarid and Van der Beek (2019) that millwrights were a crucial source of skills for the modern textile industry. This is consistent with micro evidence (Cookson, 2018, pp. 73-76; Byron, 2017, pp. 87-91).

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# We then perform some tests on other variables that traditionally have been put forward as explanations.

| | | | | | |
|---|---|---|---|---|---|
| (Intercept) | −2.912* | −2.783*** | −2.325*** | −2.278*** | −2.058*** |
| | (1.328) | (0.505) | (0.368) | (0.363) | (0.395) |
| Skilled | 1.041*** | 1.028*** | 1.061*** | 1.064*** | 1.042*** |
| | (0.094) | (0.088) | (0.087) | (0.093) | (0.087) |
| Water.Flow | 0.282*** | 0.303*** | 0.276*** | 0.291*** | 0.287*** |
| | (0.053) | (0.051) | (0.055) | (0.052) | (0.050) |
| Cornwall | 1.017*** | 1.027*** | 1.047*** | 1.027*** | 1.004*** |
| | (0.244) | (0.237) | (0.244) | (0.244) | (0.240) |
| Literate | 0.171 | | | | |
| | (0.340) | | | | |
| Potential | | 0.118 | | | |
| | | (0.083) | | | |
| Nutrition | | | 0.059 | | |
| | | | (0.089) | | |
| Booksellers | | | | −0.007 | |
| | | | | (0.041) | |
| Lawyers | | | | | −0.055 |
| | | | | | (0.045) |
| $R^2$ | 0.858 | 0.865 | 0.859 | 0.857 | 0.863 |
| Num. obs. | 40 | 40 | 40 | 40 | 40 |
| RMSE | 0.234 | 0.228 | 0.233 | 0.234 | 0.230 |

Dependent variable is the number of industrial workers per 10,000 workers in 1831. All variables are in logs. Standard errors in parentheses.

Table 4: Impact of other Factors on Industrial Employment in 1831.

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# Traditional explanations work less well:

- Literacy (convicts sent to Australia)
- Market potential (purchasing power weighted by inverse distance).
- Nutrition quality (Horrell and Oxley measure)
- Booksellers (James Dowey)
- Lawyers in the 1730s (Aylett).

Looking at the regression results in Table 4, it can be seen that none of these additional variables adds much explanatory power above and beyond skilled labor and water power, and in every case the coefficient of the proposed variable is low.

# How large was the Upper Tail Human Capital

This result provides support for the UTHC view of technological progress. But how big was this upper tail?

A small back-of-the-envelope shows why: Out of over 700,000 men aged over 60 in England and Wales in 1851, only 2,680 were or had been mechanics and 1,539 were tool makers: about 0.4 per cent and 0.2 per cent of their age cohort respectively. Assuming that fifty per cent of adult men in the early nineteenth century survived from their late teens into their early sixties, we are talking of somewhere around 8,000 men. Adding millwrights would add another 1550 skilled artisans at most. Assuming Shaw-Taylor's estimate of 40% in the secondary sector and a population of c. 6 m. in 1760, we are looking at at most 2-2.5% of the adult male labor force in industry.

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# Finally: What explains this British superiority?

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# The big question is why: where did this skill supply in Britain come from?

Part of it was due to the **focusing devices** from a number of high-skill sectors determined in part by geography and in part by demand:

- Coal- and other mining
- Shipbuilding, and shipping
- Instruments
- Clock- and watchmaking (Kelly and O Grada, 2017).
- Millwrights (Mokyr, Sarid and Van der Beek, 2021).

Many of the identifiable engineers and skilled technicians we know of came from these sectors.

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Very recent work (Hallman, Hanlon, and Rosenberger, 2023) comes up with a clever way of demonstrating this mechanism:

They construct innovation networks (which show technological spillovers using patent data) for both Britain and France for the first half of the eighteenth century. They show three things:

1. The French and Britiah networks themselves were fairly similar.
2. The networks mattered and had a causal impact of innovation.
3. Britain concentrated on technologies that were far more centrally located in the network and therefore its technological progress could benefit from for more spillovers. These industries were machinery, iron, coal, and shipbuilding (among others).

They were also skill-intensive, especially coal.

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# The supply of mechanical competence: Apprenticeship

One thing we need to keep in mind is how engineering and skilled artisans were produced in the past.

Masters of the craft produced both the products and human capital for youngsters by training apprentices.

The quality of training was crucial to the level of skills available to society, especially for the very best mechanics.

# In Britain, apprenticeship had become a market commodity

Modern research by Patrick Wallis, Chris Minns, Tim Leunig, and others has shown that the British market for apprenticeship worked better in many ways than elsewhere (see also Ben Zeev, Mokyr, and Van Der Beek, 2017; De la Croix, Doepke and Mokyr, 2017; Mokyr, 2019).

It is telling that even after the famous Statute of Artificers, which had regulated the institution of apprenticeship since 1563 was repealed in 1814, apprenticeship remained a central feature of British vocational training.

# Apprenticeship was a complex transaction

It requires a long-term non-repeated transaction between two parties with asymmetric information and strong incentives for both sides to cheat and behave opportunistically. “The Mother of all incomplete contracts”.

Enforcing that contract effectively was an important part of human capital formation.

In much of Europe that task was left to the guilds, but over time guilds became increasingly rigid and conservative and in many areas actively resisted innovation.

In Britain, apprenticeship worked better that elsewhere, largely because guilds lost much of their power in the seventeenth century, and apprenticeship contracts became self-enforcing through reputation mechanisms and a greater culture of cooperation in a "polite nation" on which disputes were settled and arbitrated.

This too can be easily seen to connect to individualism and generalized morality. Masters and Apprentices care about their reputation in the community and not just in their extended families.

When needed, a master/apprentice dispute could be settled by a local magistrate or JP.

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# A civil economy in a civil society

The apprenticeship contract in Britain played out "in the shadow of the law" --- and in the eighteenth century there is good evidence of a gradual growth in reliance on formal legal institutions and the growing importance of lawyers in contract enforcement.

In short, as was true for much of British commercial activity, the apprentice transaction was located in a *"civil economy"* --- in which effective market transactions could take place because of a common expectation that contracts would be honored and enforced and disputes be resolved satisfactorily in high probability.

Opportunistic behavior still took place but was both economically and socially costly.

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# Its effect on skills and human capital

The net outcome was a flexible and effective training system that produced competent and agile craftsmen and engineers, one that responded to market forces, and stood Britain in good service as long as tacit knowledge and technical competence were the keys to technological agility and innovation (Wallis, 2008; Leunig et al., 2011; Ben Zeev, Mokyr and Van der Beek, 2017).

# In sum:

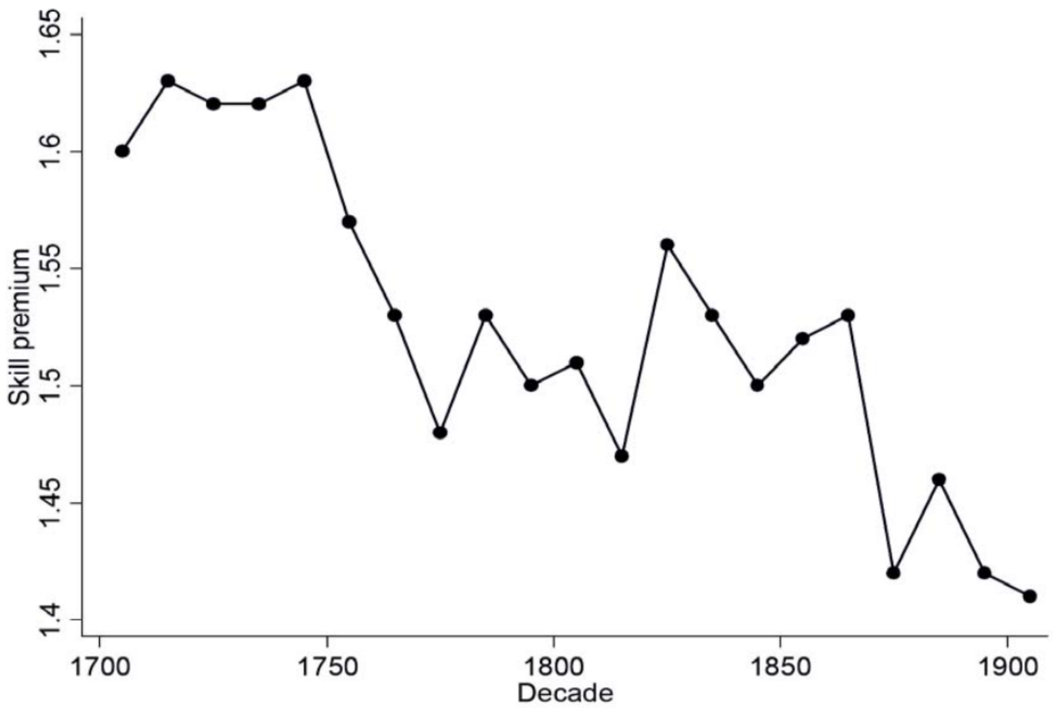
As argued above, Britain may have had a major advantage on other nations not because it had better science (it did not) nor because it had more inventors (it might have) but because it had better craftsmen and mechanics.

And it had better craftsmen because it was better at supplying them.

The supply of skilled labor was, in the longer run, highly elastic and responsive to technological shocks (Ben Zeev, Mokyr, and Van der Beek, 2017).

The most decisive evidence in favor of the elastic supply of high-skill labor in eighteenth century Britain is the absence of any rise in the skill-premium during the Industrial Revolution.

**Figure 3. Skill Premia, 1700-1910**




Source: Clark (2007).

**Epilogue:**

# Why did Britain lose its dominant position?

The nature of technological progress changed over the course of the eighteenth century.

In the second half of the eighteenth century most technological advances were still made by dexterous polymaths or clever engineers, with only an occasional dependence on science.

However, over the next decades the dependence on formal science increased, as the low-hanging fruits of tinkering had been picked and further advances depended on major breakthroughs in scientific understanding.

# England had no advantage in scientific or intellectual UTHC

Eighteenth-century English science, while not unimpressive in its own way, did not produce intellectual superstars like Bacon or Newton, as opposed to France which produced Lavoisier, Laplace, Ampère, Coulomb, and Sadi Carnot, as well as better mathematicians and philosophers.

To be sure, the **Scottish** Enlightenment, of course, was next-door.

It probably mattered little that many of the scientific breakthroughs occurred on the Continent, since the British had access to it. All major publications (and many minor ones) were translated and readily accessible.

(E.g. Lavoisier's pathbreaking *Elements* which saw four English editions between 1790 and 1799).

# What this meant is critical to an understanding of the Industrial Revolution in Europe

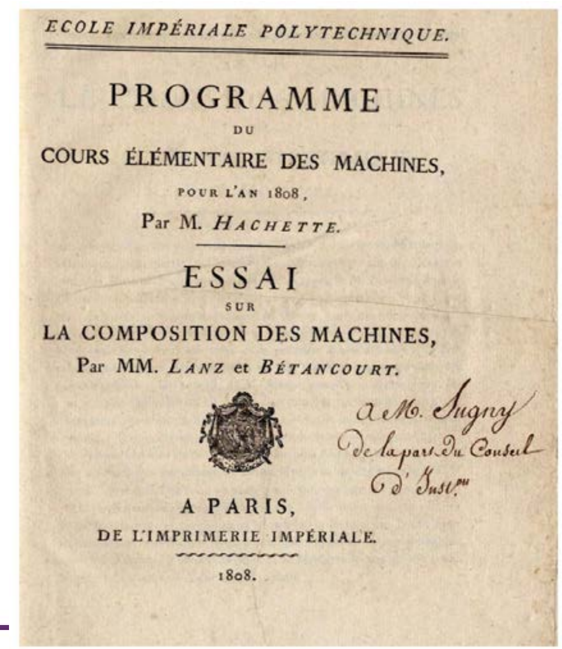
As long as useful knowledge that drove the engine of progress was mostly tacit and artisan-based, Britain had the advantage.

But as knowledge became more codified and more formal (“science-based”). other continental countries, which had equally good or better scientists, became more competitive and in the last third of the nineteenth century Britain has to deal with stronger competition from France, Germany, Switzerland, Belgium and eventually the USA.

## The decline of tacitness eventually meant the decline of British technological leadership

Over time technical competence became increasingly less tacit and more codifiable as formal engineering-science books started to appear and become more accessible. Interestingly enough many of these books were written in French; the French were more comfortable with codifiable and formal knowledge. E.g. the work by Agustín de Betancourt:

*This work was translated into English twice and reprinted as late as 1840 and taught in engineering schools all over Europe. In Britain engineers learned their trade from other engineers as apprentices; in France engineering schools taught from mathematically sophisticated textbooks (Cardwell, 1994, p. 205).*

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## Yet the gradual growth in the importance of science was critical to the historical dynamic

Over the course of the nineteenth century, the input of rapidly-advancing formal science became crucial: chemistry, electricity, metallurgy, thermodynamics and many other parts of formal knowledge made the 2nd Industrial Revolution possible .

As this process advanced, Britain's advantage in tacit skills and competence became less decisive, and it increasingly had to share technological leadership with other countries.

These countries had more developed formal research institutions and better universities teaching science and formal knowledge. Britain's lead was eroded by 1914.

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As a result, Britain lost it technological leadership in the last third of the nineteenth century, which led to much hand-wringing and navel-gazing in Britain. Big literature of whether Victorian Britain “failed” somehow.

What is not fully acknowledged with all the wailing about “Britain’s climacteric” and “Britain’s Decline” (which is coming back in the post-Brexit disastrous performance of the British economy) is this:

# The significance of the British achievement

“What ultimately matters is the irreversibility of the events. Even if Britain's relative position in the developed world has declined in recent decades, it has remained an urban, sophisticated society, wealthy beyond the wildest dreams of the Briton of 1750 or the bulk of the inhabitants of Africa or Southern Asia in our own time.

Britain taught Europe and Europe taught the world how the miracles of technological progress, free enterprise, and efficient management can break the shackles of poverty and want. Once the world has learned that lesson, it is unlikely to be forgotten.”

# Thank you!

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