“Engines of Growth”

On the Origins of the Industrial Revolution

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Where do Economists and Historians differ the most?

One interesting issue is: Eurocentricity.

Economists are unabashedly "Eurocentric" in that they recognize that modern economic growth started in Western Europe.

Historians feel this is somehow wrong and politically incorrect, but are not quite sure why: different interpretations.

I am squarely in the economist camp:

The British Industrial Revolution started a process of modern economic growth in Europe and its offshoots that was different from everything that had been experienced before, *anywhere.*

1. There was growth before 1800, but the acceleration was by a factor of ten!
2. Modern Growth is less variable and volatile, at least until 1914.
3. Modern Growth is less reversible and cannot be undone by disasters (even the horrors of the twentieth century).
4. 1-3 are explained by the fact that *technological progress* becomes the main driver of the process.
5. In this process, there are no obviously diminishing returns.

What we need to understand is: why and how this happened.

Everything else is commentary

Technological progress must be seen above all as something that happens to the *useful knowledge* controlled by people, and so it must be seen as originating in intellectual innovation.

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Here is the Great Dilemma of Modern Growth:

Following the influential work of North, Baumol, Greif, and Acemoglu-Robinson, most scholars have reached the conclusion that ***institutions*** played a central role in Europe's success (although the exact nature of their role is still being debated).

Institutions explain efficient allocations, investment, and commercial relations at arms length, more law-and-order, less rent-seeking, more markets, less redistribution.

But in those, Europe was not particularly exceptional: much of Asia had sophisticated, commercialized and monetized economies around 1600.

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Despite everything, it is hard to argue that by 1700 Europe has obviously superior institutions.

Yet the conditions that rendered it capable of a more powerful technological momentum were already in place.

While *technological* progress did not depend in any direct and simple way on *scientific* progress, it clearly depended on the broader concept of intellectual innovation.

What I propose in this talk is to build the bridge between the two: how did institutions affect technological progress in this age?

The first argument is that Europe developed between 1500 and 1700 a system that was highly suitable for intellectual innovation.

This is based on two assumptions:

- Intellectual innovation is often constrained by built-in resistance to it, through what one might call intellectual reactionaries.

- All intellectual innovation involves fixed costs, and so for it to be generated, innovators must expect some minimum audience whom they can hope to persuade.

To start with, in early modern Europe (ca. 1450-1750) there was a lot of resistance to innovation

That is in part because the physical world and the metaphysical world were closely connected; Cosmology and theology in the picture of the world that emerged were deeply intertwined and provided an intellectual foundation of the religious establishment.

Hence a lot of political power was riding on a stable image of the universe.

In the late Middle Ages, the intellectual innovations of the twelfth and thirteenth centuries had rigidified into a Ptolemaic-Aristotelian canon that became increasingly intolerant of deviants.

As a result many natural philosophers with new ideas got in trouble or feared it. In addition to the famous cases of Copernicus and Galileo, there are many others:

- The Brabant chemist Jan-Baptist Van Helmont had his book *De magnetica vulnerum* impounded and in 1624 the inquisition in the Spanish Netherlands began formal proceedings against him for ‘heresy and impudent arrogance.’
- In Naples, the philosopher Giambattista della Porta who had experimented with incubators for chicken hatching was accused in 1588 by the Inquisition of being ‘a sorcerer’ and had to abandon his work.
- A few famous “heretics” were executed (Miguel Servetus, Giordano Bruno).

Yet, overall, this suppression is remarkable for its almost complete failure

Even as Galileo "retracted" his views, the heliocentric view of the world had triumphed.

By 1650 or so, the forces of reaction have little taste and energy left for suppressing new ideas outside a few areas (mostly in southern Europe). This meant a much more open market for ideas in which progressive theories friendly to innovation could thrive.

How did this happen?

My argument is a variation on the famous "political fragmentation" hypothesis

First put forward by David Hume and Edward Gibbon.

Later resuscitated by, i.a. Douglass North and Eric Jones, and in political science especially by Jean Baechler.

My main point is that political fragmentation makes the suppression of intellectual innovation by incumbents hard to carry out because of coordination failure.

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The forces of reaction failed to coordinate

The reactionary Catholic powers (Pope, Habsburgs, Bourbons) were constantly at each others' throats, as were the reactionary Protestants.

As a result, innovative and original minds in this era could survive and prosper by playing one power against another and by being footloose.

When they feared suppression by the regime, they simply left.

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Even the Netherlands and Britain knew periods during which heterodoxy could be a dangerous occupation.

Both Thomas Hobbes and Hugo Grotius escaped hostile and oppressive government in the seventeenth century and found refuge in Paris. London and Amsterdam repaid France the favor on many subsequent occasions, most famously by the Netherlands hosting René Descartes and Pierre Bayle for many years.

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Many intellectuals became quite agile in maneuvering between rival political entities

The most famous examples of this in the early period were Martin Luther himself and his medical counterpart, the great medical troublemaker Paracelsus.

But many others, less famous:

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Three examples from different sub-periods:

1. **Bernardino Ochino** (1487-1564) highly controversial Siennese Franciscan monk and preacher, committed to free inquiry and controversy, and famous for an unusual eloquence. He alienated the Catholic Church, especially attracting the hostility of the reactionary hardline Cardinal Giovanni-Pietro Caraffa (later Pope Paul IV, 1555-1559). An equal-opportunity gadfly, Ochino also alienated most protestants. He was summoned to appear before the Roman Inquisition established in 1542 (one of the first “heretics” to be so persecuted) and fled to Geneva in 1547, eventually ending up in England, whence he was driven by the ascension of the intolerant Mary Tudor. Returning to Zurich, he was again expelled and ended up in Poland (at that time a relatively tolerant nation) but was banished from it in 1564 at the instigation of the papacy and died in Moravia. Among other things, he advocated divorce and was suspected of supporting polygamy

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2. Tommasso Campanella, (1568-1639), an Italian monk who studied astronomy, astrology, and occult philosophy and soon became skeptical of the Aristotelian orthodoxy. Accused from an early age of heresy by the Inquisition, his ability to play one power against another in fragmented Italy ran out when he was sentenced to life imprisonment in 1599 (for anti-Spanish activity rather than for heresy) and spent twenty seven years in a Neapolitan jail. His conditions there were sufficiently benign that he could write seven books in jail as well as a pamphlet defending Galileo during his first trial in 1616. He could accomplish this in part because the Emperor Rudolf, Duke Maximilian of Bavaria, and other Catholic notables were exerting influence to protect him. He was released from jail through the intervention of the Pope Urban VIII, but got in trouble again. He had succeeded, however, to endear himself to the French authorities (anxious to embarrass the Spanish), and made it out of Italy to France, where he was honored by the court of Louis XIII and eventually accepted even by the suspicious Cardinal Richelieu and died in Paris.

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Jan Amos Comenius (Komensky) (1592-1670) a precocious Enlightenment genius, who was early in life persuaded by the writings of Francis Bacon that the “millennium” could be achieved by advances in natural philosophy and applied his belief in progress in educational reform. A Protestant, he fled his native Moravia in the early years of the thirty-years war and settled in Poland in 1620 and then invited by another early Baconian, Samuel Hartlib, to settle in Britain, but once again had to flee because of the British Civil War. Via Sweden and Hungary he ended up back in Poland, but chased away by the outbreak of War, he escaped to Amsterdam in 1657, where he lived the rest of his life. Like many seventeenth century rebels and original thinkers, he took strong religious positions which often got him in trouble, but he survived repeatedly by fleeing in time, losing his family and his books in the process. One of the leading intellectuals of his age, he wrote the leading Latin language textbook of his generation was among others invited to become President of the newly founded Harvard College.

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Even those who did not flee persecution were often very footloose

E.g. Erasmus of Rotterdam, Christiaan Huygens, Leonhard Euler.

After a while, the knowledge of mobility becomes internalized. Since their mobility is common knowledge, by 1700 the persecution of intellectuals becomes perfunctory even in extreme cases (e.g. Helvétius). Many rulers take the “if you can’t beat them” approach.

Political fragmentation was thus important

But it carried the risk that in an atomized world, if the audience for intellectual innovators became too limited, it would not be worth to invest into the costs of the research and writing for a very few.

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The solution: Intellectual unity within political fragmentation

Many of those intellectuals were "global superstars" whose market was the entire European intellectual community.

This community is widely recognized as the "Republic of Letters" (*Respublica Literaria*), a transnational community that communicated mainly through letters and publications.

It is easy to mistake a sense of belonging to the "Republic of Letters" as a form of personal loyalty to a transnational entity, but a loyalty to King or Republic did not conflict with their need for a large and international audience.

The Republic of Letters, in practical terms, was more of a market than an identity. By catering to a much larger market in terms of reputation and standing, the expected rate of return on producing new ideas increased.

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This allowed European Intellectuals to realize economies of scale despite the fragmentation

- Every potentially creative person could expect an audience much larger than his immediate neighbors, and indeed much larger than those who spoke his vernacular language.

- Every piece of knowledge, whether in mathematics, natural history, astronomy, or technology, was ***contestable***, and the market for ideas was never monopolized by an uncontestable orthodoxy.

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Moreover:

- Because they read each other's works, they had more giants on whose shoulders they could stand.
- Because they were all competing in the same market, they were incentivized to do better research and keep ahead of their rivals. Many famous priority fights (Leibniz-Newton), (Hooke-Newton) and not so famous (Jan Swammerdam vs. Reinier de Graaf).
- Equally important: there are economies of scale in *verification*: one knows that any new result is checked by many experts who are keen to find a mistake, so this increases trust in new findings even if they are hard to understand. [This is even more true today].

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The most important rule that emerged in this Institution was "Open Science."

Instead of trying to squeeze exclusionary rents out by keeping their knowledge private, intellectuals placed all intellectual innovations in the public domain, playing a signaling game, in which the most successful gained the prize: fame, patronage and (rarely) fortune.

Together with the invention of the printing press, this institutional change was of momentous importance.

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Most played the game with great aplomb, a few had to be coaxed to publish (Newton), a very few others refused and thus became the source of resentment of their colleagues (Flamsteed).

Above all, the transnational character of the Republic of Letters meant that for natural philosophers the audience and community of reference was much of Europe.

The people responsible for Scientific Development after 1600 included Italians, Germans, Frenchmen, Swedes, Dutchmen and Britons, who knew each other's works, translated and diffused it. It seemed the natural thing to do even if the political relations between the nations were often bad ("The sciences are never at War."). Some of these became intellectual superstars.

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Many scientists and intellectual innovators benefitted from “global” reputations:

- **Christiaan Huygens**
- **René Descartes**
- **Andreas Vesalius**
- **Gottfried Leibniz**
- **Cornelius Drebbel**
- **Jan Comenius**
- **Hugo Grotius**

Summary of argument:

Europe between 1500 and 1750 (at least), Europe has the advantages of political fragmentation without one of the worst disadvantages, which is atomized markets for ideas.

So why did things not move faster? In part, because it still suffered from the other cost of fragmentation (destructive war).

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Second argument about the connection between institutions and technological progress

This is an argument about the *diffusion and adoption* of new technology rather than invention itself.

The main theoretical point is that new technology is an *implementable* form of knowledge; much like, say, music, there is a very strong complementarity between those who first create the new knowledge (inventor) and those who implement it.

Great inventors are not enough

Implementers do not have to be very original and creative minds, but they should be skilled, dexterous, precise, and be able to read a blueprint.

Their skills, much of them "tacit knowledge" are needed to build, install, operate, and maintain the new designs (whether they be mechanical, chemical, or biological).

Moreover, they need enough tacit knowledge to ***tweak*** the technology to adapt it to local circumstances, differences in materials and fuels, etc.

The evidence suggests that Europe had an advantage

W. Europe produced better craftsmen, engineers, armorers, millwrights, clockmakers, instrument makers, shipbuilders and so on than other societies.

As a result, it was able to build firearms that outperformed what non-European societies had, even when the latter possessed firearms, e.g. Ottomans, India, and later China. This, too, can be traced to the continuous warfare or threat of war in Europe (Hoffman, 2009, 2010).

Recent research shows that skill premia in Europe were lower than elsewhere (Van Zanden, 2009), which is likely to reflect differences on the *supply* side.

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The importance of skilled artisans

Europe's skilled workforce consisted of trained ***artisans*** whose human capital was central to its productive capability.

There is no question that in the 3-4 centuries before the Industrial Revolution these artisans were able to generate a **reasonable** amount of technological progress in a host of industries, mostly through small microinventions.

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It has been suggested (Grafe, 2009) that the European system of human capital transmission, with or without guilds, even if it was not very dynamic before 1750, assured that even tacit knowledge was *cumulative*. Moreover, many trained artisans were fairly mobile as “journeymen”.

This assured that Europeans did not have to reinvent wheels, and that very large differences in productivity would be competed away in the long run.

But the effect of artisans is ambiguous:

The human capital of skilled ***artisans*** was committed to the incumbent technology, which they obviously had a stake in and tried to protect.

They often tended to *resist* radically new technology through both legitimate and illegitimate means .

Moreover, artisans were organized in guilds, which often tried to limit entry and extract exclusionary rents.

By 1700 or so:

Europe had developed a substantial population of skilled artisans, especially in Britain and the Low Countries.

Whether or not they were literate, numerate, and educated, these workers embodied a great deal of practical skills and *savoir faire* with materials, motion, heat, moving parts, some chemicals, hydraulics, etc.

How did this happen?

Many of the master-artisans produced two things: both goods and the training of young workers, through master-apprenticeship relations.

“Learning on the Shop floor” was central to skill acquisition

Training occurred in Europe through apprenticeship.

Recent research has tended to place a heavy emphasis on the effectiveness of apprenticeship as an agent of technology (Humphries, 2003, 2010).

Yet we know that apprentice relations were the “mother of all incomplete contracts” and were rife with potential failures. The relationship lent itself well to exploitation and cheating on both sides, and the system could easily have unraveled.

What made apprenticeship contracts work (relatively) well in some parts of Europe?

In parts of Europe apprenticeship was regulated and supervised by craft guilds.

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Most scholars thought this was an impediment

Guilds were seen as rent-seeking institutions that crystallized incumbent technology to maximize exclusionary rents. They resisted innovation and thus should be seen as a "reactionary institution."

There is some truth to that; at the same time, much recent scholarship has recognized that they also played an important role in the intergenerational transmission of skills and "competence."

The revised view of the craft guilds is that they actually facilitated the diffusion and intergenerational transmission of skills and in some cases were agents of technological progress (e.g., Epstein and Prak, 2008).

But apprenticeship worked especially in places where guilds were weak such as the N'lands and Britain.

Clearly, whatever it was, the institutional basis for the creation of human capital in the form of skills and competence was an important element in the technological success of Europe and creates a critical link between the institutional explanation and the technological achievement.

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The Apprenticeship Contract needed enforcement

There were four routes to achieve that, and all four were used:

- Enforcement through craft guilds who could regulate the working conditions and supervise the training as well as demand proof of competence through a test or "masterpiece."(esp. Germany).
- Enforcement through local government as was the case in much of the N'lands (Davids, 2007)
- Enforcement through third party (for instance, go to court if the contract needed enforcement)
- Enforcement without third party, through reputation mechanisms or informal private networks.

Each economy used some combination of all four.

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Apprenticeship

In England, the Statute of A & A was passed in 1563 and not repealed till 1814. Yet this law had many exemptions and (like much legislation at this time was widely evaded). Even after its repeal, this mode of human capital formation remained dominant for many decades.

Contracts were enforced mostly through informal norms and reputation effects.

Apprenticeship survived both the repeal of the Statute in 1814 and the abolition of guilds after 1791 on the Continent.

The apprenticeship system worked well in Britain, as we shall see, and helps explain the precocity of the British economy.

The "technological ancien régime"

By itself, a supply of highly skilled artisans cannot bring about an Industrial Revolution. Artisans largely tended to reproduce existing technology and improve it on the margins.

However, when the artisanal system was combined with radical new insights, it could move forward at much faster speed.

The artisanal system supplied the crucial workmanship and materials necessary to produce a new piece of equipment or process over and over again. Without competent workmen, inventors would not have had the same economic impact.

This underlines the important complementarity between true inventors and skilled craftsmen.

The difference between Leonardo Da Vinci and James Watt :

John Wilkinson, 1728-1801 (painted by Gainsborough 1776)

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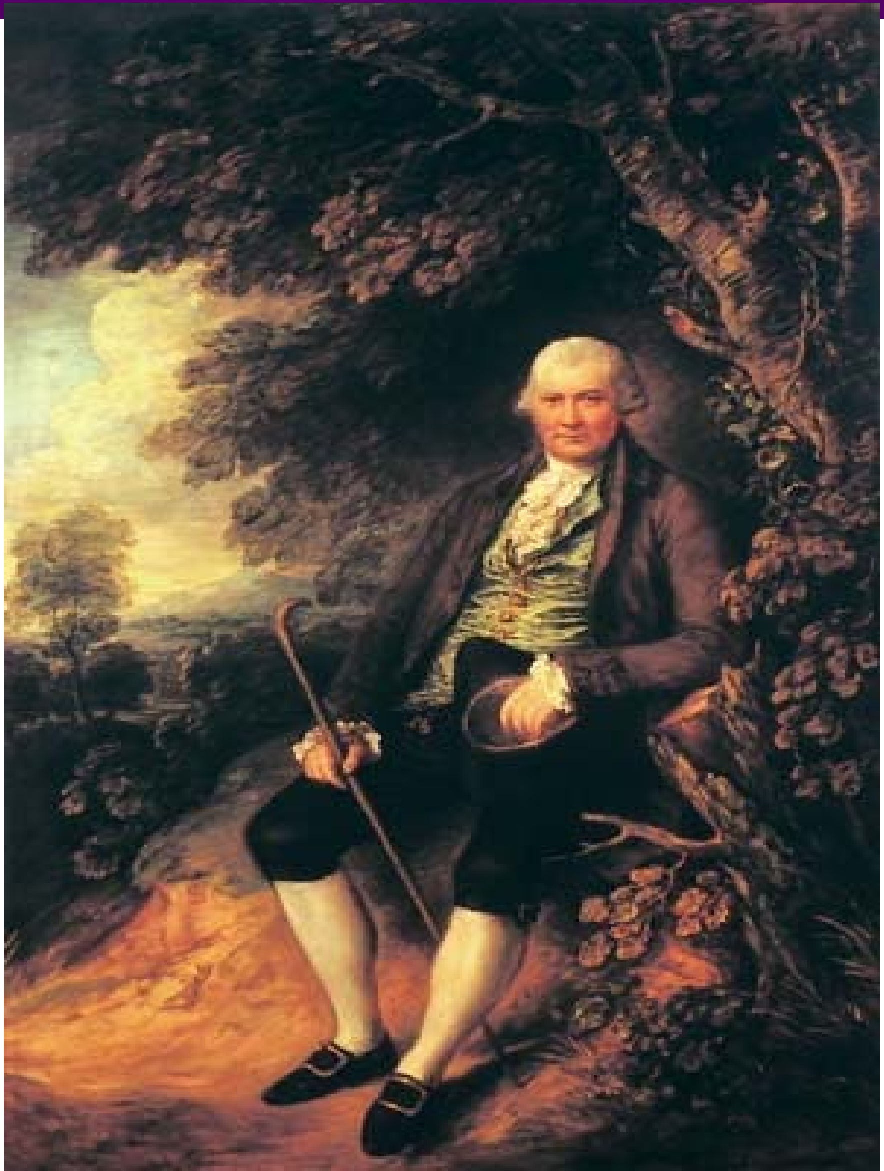

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Precocious Albion: why was Britain First?

In general, there is good evidence that British workers around 1750 were already the most skilled and sophisticated in Europe.

Moreover, recent work has shown that there is a sharp increase in the number of apprentices in mechanical and high-skill occupations in the British midlands, indicating that the system was responsive to the growing demand for competence (Van Der Beek, 2011).

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The result of the superiority of British skills:

"[The English] cannot boast of many inventions but only of having perfected the inventions of others ... for a thing to be perfect it must be invented in France and worked out in England"

Jean Ryhiner (Swiss industrialist), 1766

Most others agreed:

"the English ... are justly fam'd for improving Arts rather than inventing… 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"

Daniel Defoe, c. 1726

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This turned out to be nonsense:

British invention was, of course, of great importance.

All the same, its technological success was based on its ability to build, install, run, and maintain new equipment and techniques. Foreigners invented important things as well, but in the majority of cases they came to Britain to exploit their inventions. A main reason: there they could find the skilled workers needed to carry out their plans and designs.

Most significant evidence here:

Through the second half of the eighteenth century and the first half of the nineteenth, many thousands of British engineers, technicians and mechanics migrated to the Continent as engineers, mechanics, technical consultants etc.

This tells us two things: First, that British precocity was indeed dependent on this human capital advantage. Second that it spread reasonably fast to the rest of Western Europe, which industrialized rapidly after 1815, since the rest of the Continent could first capitalize on and then imitate British competence.

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Two famous examples of this:

- **John Holker, 1719-86.**

Jacobite refugee: set up a textile manufacturing plant in 1752 in St. Sever, a Rouen suburb. He recruited many of his skilled workers in Britain, despite the risks. These skilled British workers would then be used to train French workers.

Worked as technical adviser to Daniel-Charles Trudaine (head of the French *bureau de commerce*) for decades. Submitted a scheme to the French government, probably with its strong encouragement, for the creation of a post that would encourage the seduction of workers from England, together with equipment, and, in the long term, would employ agents to continue this activity, and would then spread the industrial espionage beyond cotton.

- **Aaron Manby (1776-1850).**

  English engineer, built the first iron steam ship that was seaworthy. In 1822 he a partner named Daniel Wilson set up a large engineering firm in Charenton (near Paris). This firm employed a number of other British engineers and skilled workers, as well as 200-250 French workers in mostly unskilled positions. The experts testifying before Parliament Committee in 1824 agreed that his French workers could not perfect their machinery without British expertise.

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By the early1820s, it was estimated by contemporaries that there were 15,000-20,000 skilled British workers in France alone.

They were hired to install and run sophisticated and expensive machinery, as well as supervise and train French workers.

Similar workers were active in Germany, the Low Countries, the Habsburg Empire and Scandinavia.

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Summary:

I have suggested two mechanisms to connect institutions to *modern* (technology-led) economic growth, through the complementarity of intellectual innovation and competence.

There are others that still need to be investigated:

- IPR's and the emergence of patent laws (see Mokyr, 2009)
- Insurance and Poor Law institutions (Solar 1995; Greif, Iyigun and Sassoon, 2011).
- War and the spillover from investing in military technology.
- Direct encouragement by government through patronage and military procurement (e.g. Board of Longitude; Portsmouth naval yards).
- Informal institutions and trust-supported innovation, for instance through K-mkts.
- Informal or formal but non-coercive institutions that invested in infrastructure through "subscriptions."

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Engines of Growth vs. Steering Wheels

Recent research has returned to Carbonocentric explanations of economic growth (Wrigley, 2009; Allen, 2009). Yet while cheap fuel (or high labor costs) might have imparted a direction on the trajectory of technological progress, its speed and power were determined by the engine.

That engine was, above all, determined by institutions and the cultural beliefs that underpinned it.

Thank you.

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