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Britain's leadership in the industrial revolution: chance or necessity?

An essay in economic history and methodology

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Abstract

The purpose of this work is to critically appraise the various contributions to the literature regarding the outbreak of the Industrial Revolution in England: was it a necessary development given its premises, or was it the result of fortuitous coincidences? Notably, following the path traced by influential scholars, we try to give an answer to the question *Why was Britain first?*. In our analysis, we also devote a significant space to understanding the main dynamics and features of technological change, exploring how it is influenced by institutions, culture, and markets. For these purposes, we decided to follow a deductive methodology, beginning with an overview on relevant definitions, then focusing on the main issue - the academic debate on the nature of technical progress, whether essentially deterministic or serendipitous - to finally conclude with a digression on the dynamics of technological development, particularly on the distinction between micro- and macroinventions.

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1 Introduction

"Rue des Immeubles Industriels - when was it built?"
– Walter Benjamin, *The Arcades Project*

The British Industrial Revolution can truly be regarded as *the* turning point that, more than any other, is responsible for the shaping of our frantic modern world. The chain of decisive events and the raw number of technological breakthroughs achieved in such a brief period - that is, a century more or less - appears, even to this day, impressive to say the least. Thanks to its many favorable conditions, Great Britain was able to break free from the long cycles of Malthusian stagnation, typical of pre-industrial economies, and surged swiftly and rather unexpectedly to become the leading power of the Western world.

To get a quick grasp on how much we are indebted to this peculiar process, just imagine a medieval Frenchman - say from A.D. 1300 - finally going to sleep after a tiring day working in the fields of his *seigneur*. If his well-earned slumber lasted, instead of a single night, some 450 years, he would still recognize his old reality upon waking up. Of course, he would feel rather confused, because a lot of fundamental inventions have already taken place: he would be dazzled by the striking power of firearms, and would be delighted to read the news from a much changed world on the many newspapers and *pamphlets* - if only he knew how to read. However, let him go back to sleep once more, thrilled by the discoveries of the last day, and do not disturb him until the dawn of 21st century. Now, we can safely say that he would not recognize his "beloved" society anymore. New materials, transoceanic instantaneous communications, roaring engines, and many other unheard-of things such as *social rights*!

The example above is meant to be a funny one, yet it is able to capture the essence of the Industrial Revolution(s): total, and irreversible, change. The new social and economic orders emerging from the process had nothing more to do with the old ones. Inevitably, though, the transition encountered some slow-downs, and did not affect every part of the globe in the same way. In this regard, it was an almost exclusively European phenomenon - not considering the American exception - until mid-20th century, and it appears to have been subjected to the usual cycles of expansion and shrinking typical of capitalist systems. Thence the emergence of the Great Divergence (Broadberry, 2021) between the developed nations and the others (notably, among those that were not able to keep up the pace there were major powers rich of history and cultural achievements, culture and successes such as China, India and the Ottoman Empire).

Alongside with the Great Divergence, it must be mentioned that even in Europe things did not go so well for everyone: those who thrived the most, and therefore reached the top spot in economic dominance, were the North-western nations, that is, the United Kingdom, Germany, France - although much later -, Belgium and the US, leaving the Eastern and Mediterranean economies backward and almost irrelevant on the world stage. This is the so-called European Little Divergence, to distinguish it from the bigger one among Europe and the rest of the countries, and from the other Little Divergence happening in Asia in the second half of 19th century (i.e. the rise of Japan during the Meiji period) (Broadberry, 2021).

It should be clear by now to the reader that the Industrial Revolution was neither a simple nor a brief process: it was the result of many deep-rooted changes, different layers of development converging over a span of decades. For these very reasons, an almost infinite set of interpretations has been provided by economic historians and cliometricians, each one accounting for a particular aspect of the matter. These explanations often focus on single factors, regarded as crucial for the beginnings and the outcomes of the transition; but since they differ so much, they are usually seen as mutually exclusive, or at least in sharp contrast with one another. Think of Watt's steam engine, for example: according to some scholars (Rostow, 1975, pp. 164–167), it has been the main driver of industrial mechanization and transports' revolution; others (the majority, nowadays, but it has not always been so) believe instead that the machine was a mere addition to a growth process started well in advance, caused by innovations which had already occurred in the textile sector (Landes, 1969; Davis, 1973).

In this work we try to discuss a great deal of these influential accounts, analyzing their strengths and their weaknesses, to better understand which seem to be the most convincing and reliable. In Section II, we will list the various definitions given of "Industrial Revolution" to find the most flexible and comprehensive ones; we will then give a brief overview of the features of the British environment that probably set the whole mechanism in motion, avoiding for the moment using a comparative approach with other countries. Section III will focus entirely on a most interesting controversy between scholars, notably Crafts, Landes and Rostow, concerning the allegedly stochastic nature of technical progress: was it a fortuitous case that it all started in Britain? Or was it the result of a more subtle, intrinsically deterministic combination of favorable factors? Following the debate, we will make some comparisons with France, the leading country on the continent, to try to understand why the Industrial Revolution happened here and not there. Section IV will delve further deeply into these questions, exploring the implications of technological progress, underlining the distinction between micro- and macroinventions and explaining in what invention differs from innovation. Section V will then conclude, summing up what we have learned.

2 Industrial Revolution: definitions and causes

"*My God, how big London is!*" – Bill Bryson, *Notes from a Small Island*

Many interpretations have been given over the years concerning the nature and the main dynamics of the Industrial Revolution.

As should appear evident, the debate on the causes of the first Industrial Revolution suffers from a huge issue: researchers have been trying to explain something whose definition itself is controversial. How can we reach a satisfactory analysis of a phenomenon, if we do not even know what that phenomenon really is about? Definitions are central in both social and hard sciences (think about mathematics), because they allow us to *deductively* build our research path, giving us an overview of what is important and what is superfluous, what is already clear and what must be clarified, which findings are coherent and which give a different perspective on the matter. The importance of the deductive method for the Social Sciences, and for Economics in particular, is not a new principle, of course, as it dates back to the work of J. S. Mill (Mill, 1836). In recent years, however, a growing feeling of skepticism has led to a widespread rejection of deduction as a fruitful approach to research, favoring in its place more quantitative, and thus more inductive, statistical tools. Such diffidence appears evident, for instance, in Landes (1994, p. 637), who states:"Optative history [i.e. alternative history, or "history as I would have liked"] is to be found whenever deduction takes precedence over induction, when the end (the result desired) determines as well as justifies the means"; and perchance this rebuttal of deduction is also at the basis of another, never-ending debate: the one on what makes an economic theory 'good'. For McCloskey (1994, pp. 38–52), persuasion is as much a significant factor for choosing among competing theories as it is empirical validity. A troubling conclusion quickly follows from such a view: that economic theories are little more than fairy tales, indeed with some kind of adherence to reality - which might also be fortuitous -, but with no scientific validity.

We have to strongly disagree with this vision. Deduction is the first approach to be adopted when taking on a question for the first time. It is fundamental to tidy up your mind, clarify the research questions, and formulate the right strategies to begin the investigation. And, as things stand, this approach is precisely what we need at the present moment to begin this exposition. The purpose of the next part is then to choose, among the load of definitions given by scholars, the one that we believe is most apt as an heuristic tool, to be used in the following sections of this work.

2.1 Definitions

The British Industrial Revolution has often been described as the chain of events that made possible for the Western world to achieve modern economic growth (in terms of GDP). This account has found wide agreement, especially after the precious insights by Rostow (1960) and Gerschenkron (1962). Kuznets (1966) gave us the best explanation of what we should consider as MEG: a discontinuity - with respect to the previous periods characterized by long cicles of limited growth, stagnation and shrinking - that allowed to produce huge growth rates, in a self-sustaining and self-enforcing way.

Rostow gave us a theory of stages for all countries undergoing a path of industrialization, with little if any differences, while Gerschenkron - later followed by Pollard (2000) - paid more attention to regional peculiarities, observing that it is never the country as a whole that "takes off", but rather specific parts of it. Although both of them provided a diachronic description of growing economies, Gerschenkron highlighted that it is possible for backward countries to *catch up* with the leader thanks to what he calls *substitute factors*, i.e. different conditions that in some particular contexts may be beneficial to the general development. This last idea has truly been successful in pushing forward comparative analysis.

Clearly, this definition is able to capture something valuable: the consequence of the Industrial Revolution; and yet it does not say anything about why the discontinuity happened, or how. In other words, it accounts for what came after, and not during, the Revolution. Not only: it may well be that GDP growth did not come from in-

Year	Agriculture	Industry	Services
1700	38.9	34.0	27.1
1759	36.8	33.9	29.3
1801	31.7	36.4	31.9
1841	23.5	45.6	30.9

Tab. 1: Sectoral share in labor force, Great Britain (Broadberry, 2021)

dustrial expansion at all (but, say, from increased agricultural efficiency or expanded trade). For these reasons, it does not seem to be very useful for our purpose. In addition, recent research (Crafts and Harley, 1992) effectively contested this vision, having shown that the total growth rate for the years 1760-1830 was actually much lower than what had been reported by previous estimates. In fact, as Mokyr (1999) sums up: since technological take-offs do not affect the entire economy, but just a few dynamic parts of it (Pollard, 2000), the aggregate-level consequences will only be felt after a very long time. In Britain, textiles, ore smelting, steam technology (and many others), were all truly expanding at an unprecedented speed; but they were, at least at the beginning of it all, just a small drop in the economic ocean. The effects of industrialization were only felt when the process was almost entirely complete, after the 1850s.

Moving forward, another interesting definition is the one given by Mathias (1969, p. 963), in terms of structural change: for him, the Industrial Revolution consisted of a "fundamental redeployment of resources away from agriculture". However brief, this formulation underlines a key development that was both the consequence and the cause of industrialization: the shift from cultivations to factories. Neither was this a short process, of course; but surely it is a fact supported by a great deal of data and quantitative analyses. As shown in the table below, the share of labor force employed in the agricultural sector decreases steadily and consistently starting from 1759 already. It is a major change, since farmers displaced from the fields need to pack up and move to nearby cities, where they can find employment in the new, flourishing industrial suburbs. Therefore, it becomes relatively easier for burghers to concentrate workers under the same roof, with low wages, poor standards of living and strict discipline; and thus, factories are born. By looking at tab. 1, it is also quite interesting to notice that, at least for what concerns the 18th century, the major share of the labor force that ceased working in the agricultural sector found employment in the services industry, not in manufactories. These latter experienced an astonishing growth (almost 9%) only in the first half of the 19th century.

A slightly different interpretation, which is nonetheless similar to Mathias's, is the one provided by Solow (1970), and it views the Industrial Revolution as a transition from circulating capital to fixed capital, the process ultimately leading to a relevant increase in capital accumulation. This definition quite resembles the other because we can easily identify circulating capital with goods, such as raw materials and crops, produced and exchanged by agriculture. Fixed capital (e.g. machines, mines, infrastructures) is instead notoriously equated to industry. The Industrial Revolution starts with machinery and evolves alongside with it; that is something even the most skeptical would agree with, and so we may consider this argumentation a valid one. But the thing is, why did machines become available all of a sudden? True it is that Europeans had a long tradition in exploiting the power and efficiency of some famous mechanisms like watermills, windmills and clocks (Landes, 1983), but in the 18th century the sheer amount of new technological inventions overtook any expectation. In the iconic sentence reported by Ashton (1955), "a wave of gadgets swept over England". This reflection brings us to another influential vision of the British Industrial Revolution: the one advocated by what Mokyr (1999) calls "the Technological School". This school of thought, which finds among its adherents Mokyr himself and even more prominently Landes (1969), "considers changes in technology to be primary to all other changes and thus focuses on invention and the diffusion of new technical knowledge. Technology is more than just 'gadgets', of course. It encompasses techniques used for the organization of labor, consumer manipulation, marketing and distribution techniques, and so forth" (Mokyr, 1999, p. 8). Indeed,

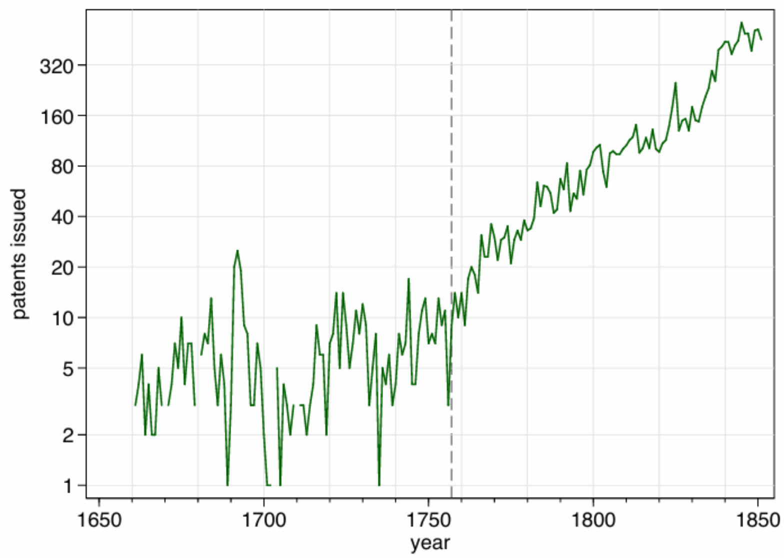

Fig. 1: Patenting rate in England (Sullivan, 1989)

it was technical progress that allowed for the rise of machines. It was only thanks to impressive engineering breakthroughs and sudden 'clusters' of inventions that industrialization was able to begin. Unthinkably slow production processes (e.g. those for textiles) were completely transformed, reaching revolutionary levels of speed and output capacity. It should be said that historians of technology have always been the most convinced supporters of the discontinuity hypothesis: for them, the Revolution marks the threshold to an entirely new reality, not just a 3% increase in GDP growth per year. It is the beginning of the alliance between science and production, a relationship we consider natural nowadays, but which by no means was taken for granted centuries ago. Quantitative studies (Sullivan, 1989; Sullivan, 1990) revealed sharp increases in the number of patents granted post-1750, as also shown in the graphic above, thus confirming this new path in technical advancement. Hence, it seems quite appropriate to explain structural change - and thus GDP growth - through better technology.

Lately, some other historians (Wrigley, 1988) have revisited one of the oldest and most influential accounts of the Industrial Revolution: the one originally provided by Nef (1932), which interprets the phenomenon primarily in 'energetic' terms (i.e. emphasizing the importance of the dramatic increase in coal consumption experienced in those years). More recent contributions take a fresh look at that theory, viewing industrial development essentially as a transition from a mostly organic economy to a predominantly mineral one. The truly revolutionary element was then the rapid appropriation of underground resources, which were essential for energy production and heating; this was necessary to ensure a more efficient allocation of surface lands, while also opening up an entirely new - and seemingly infinite - source for natural resource exploitation. A similar interpretation can also be found in Thomas (1980, p. 12), who additionally argues that Britain developed the Industrial Revolution not because it was "well endowed" with mineral resources - which it actually was - but because it was "ill endowed" in the most common energy source of the time: timber. The energy shortage threatened to become even harsher after the Treaty of Paris, signed in 1783, which gifted resource-rich America its independence. For Thomas, it was that critical bottleneck - confirmed by contemporary witnesses: "had it not been for foreign supply, scarcely a timber tree at this day would have been left standing upon the Island (Marshall, 1785, p. 2) - which strongly pushed for innovations towards alternative sources of power. In any case, it is worth noticing that the new energetic path was opened by such innovations. After all, "coal and iron had been in the British ground since the beginning of history" (Mokyr, 2009, p. 102); it was, once again, only the complementary development of new techniques that made coal exploitation possible.

That being said, some other views of industrialization remain to be mentioned. The first that we are going to analyze is still one of the most influential: it considers the Industrial Revolution as the product of dramatic and sometimes sudden social changes, either consciously driven by institutions or erratically determined by major domestic - or international - events. As a matter of fact, English society was left utterly modified by the tides of the Revolution. Abroad, the shaky monarchies of

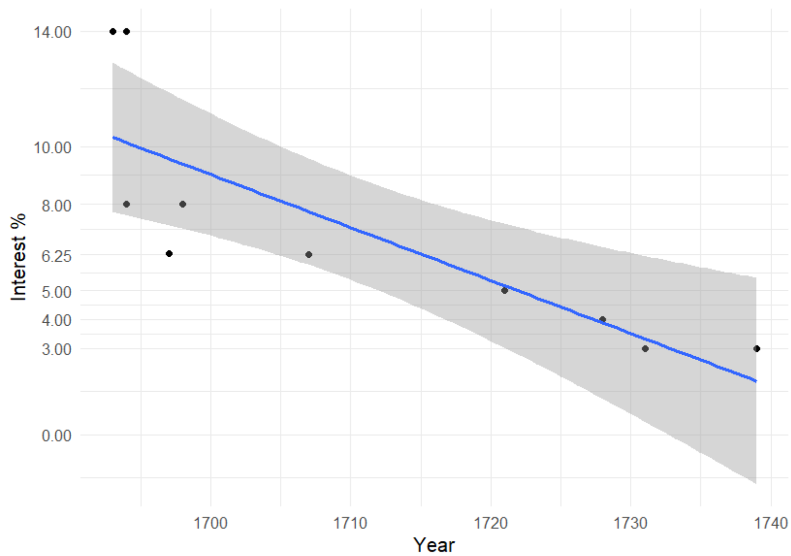

Fig. 2: Government long-term borrowing: interest rates 1693-1739, graphical visualization of data present in North and Weingast (1989, p. 824)

Europe regarded what was happening in England with apprehension, as a highly subversive and infectious disease (Milward and Saul, 1973, passim). The most feared danger was the construction of a whole new social order, with workers and burghers replacing the old classes of *ancien régime*; something that, ironically, on the continent became reality after another major earthquake: the French Revolution. In England, industrialization slowly laid the groundwork for the subsequent widening of suffrage, the decisive birth of *trade unions*, and the rise of the bourgeoisie, without any need for a violent political revolution, although social turmoil was inevitable, as demonstrated by the Peterloo Massacre and the many protests in favor of the Great Reform Act of 1832. One of the most acclaimed theories regarding the role of institutions in stimulating the Industrial Revolution is the one provided by North and Weingast (1989), who identify in the Glorious Revolution of 1688 the decisive milestone which set everything in motion. With the demise of the Stuart dynasty and the proclamation of the Bill of Rights, the king's powers were greatly reduced in favor of the Parliament. And with the birth of the new system, which saw the separation of the Crown's personal wealth from public finances, and with the consequent creation of the Bank of England in 1694, it was now credible that the State would actually repay all its debts and would not impose unpredictable and arbitrary taxation. Previously, Stuart kings frequently raised forced loans, promising high interest rates but typically failing to repay them by the due date. This, of course, made borrowing increasingly difficult, overstretching public expenses and blocking critical investments. In addition, erratic taxation - or sometimes even expropriation - made property rights less secure and generated widespread uncertainty. Instead, Parliamentary approval of new taxes and limits to interventions by the Crown in economic matters increased the country's fiscal reputation and allowed for higher borrowing, higher spending, higher taxes. Figure 2 illustrates this downward trend in interest rates applied to government long-term borrowing, dropping from a disastrous 14% in 1693 - just after the Glorious Revolution - to a strikingly low 3% by 1739.

As Mokyr (2009, p. 7) sums up, another foundative event for this view is "the emergence of formal, competitive, and impersonal markets in goods and factors of production". For Toynbee (1969, p. 58), "the essence of the Industrial Revolution is the substitution of competition for the medieval regulations which had previously controlled the production and distribution of wealth". The disappearance of guilds and forced serfdom surely went in the direction of a freer, self-determining market. Yet, it should be noted that, contrary to Smithian principles, seldom did the British government act in accordance with *laissez-faire* principles: it repeatedly granted monopolies and intervened heavily in the economy with protectionist regulations, that were lifted only when the Revolution had already made its course. Two examples of such regulations are the Corn Laws, abolished in 1846, and the Navigation Acts, definitely eliminated in 1849. Despite having shown that technological change might well include in itself the other definitions, for social change things seem to be a little different: the two aspects strike us as rather complementary, in the way new knowledge pushes society forward, and institutions sometimes effectively drive technical

research in the desired direction. For the moment, let us not jump into conclusions. More on this fruitful relationship will be added later on.
One last analysis, in terms of cultural change, remains to be addressed: it is the one provided by De Vries (1994), in terms of "Industrious Revolution". The concept is particularly useful for supporting the cause of those who believe that the British Industrial Revolution did not come out of the blue. In fact, for De Vries - who follows the path traced by so-called Early Modernists (feeling "an eagerness to remove the vestiges of crude modernization theory, with its traditional modern dualism and its linear historical models" (De Vries, 1994, p. 253)) - the Industrious Revolution constituted some kind of anticipatory signal to industrialization itself. He defines it as a change in cultural habits regarding working time and consumption of goods. People started working more and harder, placing less value than before on the utility of leisure time as the need for money income rose, and marketed goods (i.e. goods produced to be sold on the market) replaced direct consumption. As such, the Industrious Revolution constituted a mostly demand-side phenomenon, paving the way for those supply-side developments which the Industrial Revolution was composed of.

2.2 Causes

Having provided a quick overview on definitions, and having found that technological and social interpretations seem to be the most well-suited to describe what actually was going on in 18th century's England, it seems mandatory to say some brief words on those causal relations identified by the many generations of historians that worked on the topic.
First of all, the most obvious one, geographical features: since industrialization requires resources to exploit, it is fundamental to have plenty of them, at an affordable cost, and available at a rather short distance. England was rich in mineral deposits of coal and iron, had enough wood to maintain and expand the biggest trade fleet in the world, benefited from a temperate climate rich of waters, from navigable rivers -

essential for fast and cheap transport of raw materials - and from a strategic position overlooking the Atlantic ocean, surveilling trade routes from all over the world. Recent contributions (Caruana-Galizia, Hashino, and Schulze, 2021) highlighted how so-called "second nature geography" played a huge role as well, since it takes into account how economic agents interact with each other across space. Some examples may be, for example, efficient and capillary infrastructure, proximity to markets or agglomeration economies. Last but not least, Britain's insular position shielded it from the devastating conflicts that broke out on the continent ever so frequently. The advantageous natural defense provided by the English Channel, along with a restraint from participating in European matters when not strictly necessary, allowed the island to thrive even during centuries, notably the 17th and the 18th, plagued by wars and consequential economic breakdowns (Mokyr, 2009, p. 7).

For sure, the 'ever-sunbathing' British Empire was pivotal in the country's supply system. It generated continuous and inexpensive flows of multiple materials, crucial for newly born manufactories, while also constituting a competition-free market where finished products could easily be sold for profit. In spite of the high administrative and military costs required to maintain so great a number of colonies, and avoid them crumbling to pieces, it yielded perfectly wonderful returns for private investors. Although Thomas (1968) states that colonies were not beneficial for the country as a whole - since even investing in risk-free assets, which notoriously offer low-returns, would have produced almost double profit - it seems difficult to ignore the stimulating function they played for private initiative.

Concerning the institutional framework, Britain enjoyed even better conditions. The Glorious Revolution of 1688 transformed the nation into the first-ever constitutional monarchy, limiting the king's power and enabling enhanced participation in political affairs for the landed bourgeoisie and proto-capitalists. Burghers shaped the economy to their interests through protectionism and the gradual elimination of mercantilism and *rent-seeking*, which Mokyr (2009, p. 63) describes as "the use of political power to redistribute rather than create wealth". The Englishman's innate attitude for

business is almost proverbial, and for a reason; he revealed an exquisite taste for promising ventures, and often single-handedly delved into risky enterprises (on the contrary, in many other industrial systems, notably Germany and the US, industry almost always saw involved big actors such as corporations and *holdings*), giving birth to an original economic system called "individual capitalism". In addition, a rudimentary yet effective relief tool was offered by the old *Poor Laws*, dating back to Elizabethan times. They relied on local parishes to provide some basic services (mostly food and shelter) to those who had fallen into utter disgrace; this might have acted as a slight incentive to invest in risky undertakings. It is easier to make up your mind and put all your assets at stake, if you know you will be maintained - although at subsistence level - even if you fail.
Equally important, British fiscal stability baited foreign investments and provided favorable rates even for the heaviest of borrows. Then, as (Mokyr, 2009, p. 68) brilliantly summarizes,

> Britain did not need to outlaw guilds, abolish internal tariff barriers, or eliminate the "privileges" enjoyed by ruling classes on the Continent, legislate freedom of movement or occupational choice, release serfs, wholly reorganize the set-up of property rights over land to allow the rationalization of farming, and unify bewildering sets of different local weights and measures, to say nothing of laws and litigation procedures and hundreds of encumbrances, small and large, on the free exercise of commerce and industry.

In place of medieval guilds, Britons developed a reliable apprenticeship system, which was endowed with a significant degree of autonomy. It played a major role in the formation of a vast number of skilled engineers and craftsmen, and was crucial for the development of that famous British 'mechanical thought' so much praised and envied by foreigners. Nobility in England had been rather weak since the end of the Middle Ages, and privileges had almost completely disappeared by the end of the 17th century. In fact, the aristocracy had willingly transitioned to a more productive estate, that of great landowners devoted to the self-management of their assets. They were not a sclerotic class, but one keen to investments and efficiency-seeking. Property rights had been deemed sacred, and had been protected accordingly, ever since the publication of Locke's influential reflections on civil society and the role of the State; a crucial aspect in luring investors and rewarding innovators.

With regard to technological inventions, the first piece of legislation aimed at protecting intellectual property was the old *Statute of Monopolies*, granted by Parliament under King James I's rule as early as 1624: it prohibited many types of monopolies but more importantly established new patenting rights for novel inventions, in exchange for a fee, for a maximum period of 14 years (i.e. two generations of apprentices, since apprenticeship cycles lasted 7 years in average). Of course, by the middle of the 18th century the Statute had already been amended many times, but always in a more safeguarding sense for the private inventor. Arguably, the easiness with which legal changes took place and new social requests found quick answers by institutions, which modified themselves accordingly without much trouble, was owed to the peculiar legal order typical of Britain: the *Common Law*. A set of unwritten rules, derived from public habits and social conventions, particularly flexible in adapting to new issues emerging from the flow of times, although somewhat restricted by the concept of legal precedent. Having considered all these elements, it appears quite safe to agree on the fact that Britain benefited from an unrivaled synergy of advantages on the institutional side.

Another key factor which strongly pushed in the direction of structural change was the good state of the agricultural sector. Obviously, to allow a large industrial sector to grow - thus employing a majority of the workforce - it is necessary for agriculture to enjoy high productivity rates (high yields, low employment). A thriving agricultural sector means higher wages for peasants, creating an incentive to mechanization, and fosters a large market for industrial products, leading to a surge in demand. So, was Britain really advantaged in this sense? Yes, it was. Animal husbandry - notably a more capital-intensive subsector of agriculture since it requires significant investments to buy animals, continuous spending to maintain and replace them, while they provide their services for a long period of time - was relatively more important than crop cultivation as early as 1300, accounting for a remarkable total of 63.6% according to estimates by Broadberry, Campbell, and Leeuwen (2008, pp. 47–48). As a consequence, it provided British agriculture with a large number of self-reinforcing benefits: many animals meant abundant fertilizer; fertilizer led to higher yields; productive soils signified less land needed for grain, oats, and other edible crops; and more available land allowed for larger fodder cultivations, which in turn increased animal husbandry.

Furthermore, between 17th and 18th century, another process was underway: the *enclosure* of former common lands (the information that follows is drawn from a course held at Oxford University by Professor Brian A'Hearn, to whom the credit is due). Before that time, a typical medieval village was composed of the Lord's domains and the peasants' lands. Among the latter, one could distinguish between waste/common terrains - for pastures and woods - and arable terrains. In the arable fields, cultivations were not evenly distributed, but instead were organized into a great quantity of tiny strips, each dedicated to a single crop and owned by a single household (see fig. 2). This system was inefficient because of three major issues: (i) excessive exploitation of shared lands, (ii) poor coordination and scarce investments on maintenance, (iii) inefficiency in overseeing distant terrains and moving animals and equipment from place to place. Notwithstanding the problems it faced, this form of terrain division remained in place for centuries. Fenoaltea (1976) provides reasons to believe that this was due to an attempt to spread peak labor demand over time. In fact, if all crops of the same type were located in the same area, households would have had to hire external workers to avoid wasting harvest they had been unable to collect on their own, thus having to endure much higher costs than what was strictly necessary with the other method. Enclosures effectively managed to counter this 'scattering process', leading to the concentration of fertile terrain in the hands of big capitalist landowners. Although this transition did not increase agricultural

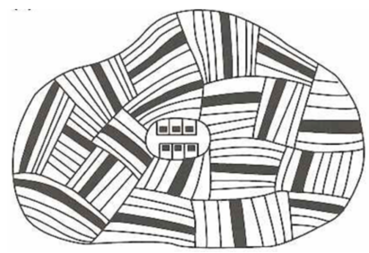

Fig. 3: Common field system with scattered strips (from prof. Brian A'Hearn, Oxford University)

efficiency by much, it acted as a fundamental driver of structural change towards manufactory: small landowners and poor peasants, who used to work in the common fields to get whatever they could for free, were kicked out of those properties and fell below subsistence level. This set of unfortunate events forced them to abandon the countryside and move to cities, seeking for better fortunes.

Many more definitions and causal factors could be cited, and each would deserve careful consideration and credit. However, it was not our purpose to exhaust the complexity of the debate in such a small number of pages. Our aim, it is worth repeating, was to quickly introduce the reader to the fundamental characteristics of the Industrial Revolution, putting him in the best position to understand and give his own interpretation of what will be discussed in the following two sections of this work. Notice that, even though we have underlined the most prominent causes that probably favored the phenomenon in analysis, in no way they should be regarded as conditions *sine qua non*, in whose absence no revolution would have occurred. We must interpret causal relations as mere *tendencies*, not as universally true and necessary laws. In Economics, and in Social Sciences in general, we cannot venture much beyond this limit. But we must not consider this boundary in a nihilistic way, as long as the explanations we strive to give pay respect to logical reasoning and common sense.

3 The Crafts-Rostow-Landes controversy

"*Philosophy is a battle against the bewitchment of our intelligence by means of language.*" – Ludwig Wittgenstein, *Philosophical Investigations*

In 1977, Nicholas Crafts (1977) wrote a most ingenious paper, taking on the common methodological approach adopted by the majority of economic historians in investigating the Industrial Revolution. That precise article provoked a heated debate on the matter, which gradually saw the involvement of some major academic figures in the field, such as Walt Rostow and David Landes, who provided insightful solutions to the problems raised by Crafts. In this section, we present a critical review of these articles, in chronological order, further extending the discussion and offering some new perspectives.

3.1 Crafts: *Some Thoughts on the Question, "Why was England First?"*

The thesis proposed by Crafts in this first paper is simple yet revolutionary: the habitual - almost ritual - question *Why was England first?* "is misconceived and should be discarded" (Crafts, 1977, p. 430). Notably, Crafts highlights the danger of incurring in *post hoc ergo propter hoc* fallacies by adopting such a comparative approach, and argues that economic and technological progress should primarily be regarded in stochastic terms. Let us analyze these two points more in depth.

First of all, a *post hoc ergo propter hoc* fallacy is a kind of logical mistake that involves the possibly spurious identification of a necessary causal relation between two (or more) events. The logical error resides in the fact that the latter event seems to necessarily require the former in order to happen, when in fact there might be no such requirement. In our context, Crafts believes that historians instinctively assumed *a priori* that the British economy was superior to all others, given its success in achieving the major innovations in steam and cotton. This would be an obvious mistake, as it is impossible to infer a specific cause from its supposed effect:

> Unfortunately, this contention that the result demonstrates the superiority easily leads to "explanations of Britain's primacy ... [which] consist mainly of a not very convincing sort of 'retrospective inference' ('something must have caused Britain's primacy in time, so presumably the earlier conditions overtly observable did') ". In other words, the favourability of certain conditions in England has been inferred from the result with the likelihood of post hoc ergo propter hoc fallacies. (Crafts, 1977, p. 433)

What are the consequences, as perceivable in the traditional literature, of this unjustified conclusion? Essentially, as Milward and Saul (1973, p. 23) put it, the result is that "the economic history of these [continental] countries have steadily been measured on the English model". Or, to repeat Crafts' words:

> This led to the presumption of English superiority and French inferiority, and to attempts to identify, by comparison with other economies, favourable features of the English economy. [...] An appropriate question to have asked [...] would have been, "Were there factors which made the probability of the onset of the Industrial Revolution high in eighteenth-century England ?" rather than asking, "What made France inferior?", the comparative economic historians' translation of "Why was England first ?" (Crafts, 1977, pp. 440–441)

The reference to France is not incidental. In fact, the French economy was the largest and the fastest-growing in continental Europe. For this reason, Crafts repeatedly uses it throughout its article as a counterfactual to the Industrial Revolution happening first in England. As we progress, we will discuss more in detail what the two economies were similar for and how they differed considerably.

Crafts does not stop here. In his view, not only does the question under examination cause important biases in comparative studies, but it is also unanswerable on its own, because technical progress must be regarded as a stochastic, rather than deterministic, variable. Socio-economic deterministic explanations of technological advancements thus fail, in this sense, to portray the full picture, because they do

not recognize any room for chance in the development process. Why have many inventions not occurred earlier, despite high market demand and the availability of scientific knowledge for their implementation? Because inventions, although encouraged and focused by certain demand requests, are subjected to a certain degree of uncertainty on the supply side (Landes, 1994, p. 644). Take the example of cancer treatment: consumer demand is at its highest level - it will probably continue to grow significantly in the future - and modern science is in its best-ever shape; nevertheless, no resolutive cure has yet been discovered: perhaps it will be done thanks to a stroke of good luck? Furthermore, it is not uncommon for inventions to appear by mistake, without being intentionally sought; a phenomenon playfully referred to as the 'King Saul Effect', after the biblical figure of Saul, king of Israel[1] (Mokyr, 1990, p. 286). Classical examples to include in this cathegory might be, for instance, the discovery of fire, Fleming's penicillin, or Edison's phonograph.
In the Crafts article, we find an even more self-explanatory situation, that clarifies both points of his argumentation: that of a football match against two teams.

> An analogy would perhaps be to ask if Walsall's 2-0 defeat of Arsenal in their I932 F.A. Cup tie would justify the inference that Walsall was the better team in the sense that they would have emerged victorious a majority of times in a large sample of games. (Crafts, 1977, p. 434)

We do not know *ex ante* which team is the better, but we do know that team 2 won the game. Does this entail that team 1 generally plays worse? Of course not, because the outcome of the game might have been conditioned by unfortunate and unpredictable events. Hence, the conclusion that team 2 was superior is flawed.
Now, let us reflect on these points a bit more. On the one hand, Crafts' argument is methodologically valid, since it is designed to prevent scholars from jumping to risky conclusions and to avoid an excessive focus on British strengths (and continental

[1] Saul set out to search for lost donkeys, when he was unexpectedly crowned King by the prophet Samuel (1 Sam., ch. 9–10)

weaknesses). Indeed, the literature has often displayed such a tendency to ignore the different elements governing backward economies, as we have seen already when discussing Rostow and Gerschenkron: substitute factors have typically been seen as impediments, rather than as propulsive conditions, just because they were absent in the British economy, even though Britain was a completely different environment with entirely diverse prerequisites.

On the other hand, the conclusion that questioning why the Revolution occurred in Britain, and not in, say, France, is misleading *and should therefore be abandoned* seems quite like an unacceptable act of restraint towards Economic History and even more broadly for historians. One should never impose such restrictive limits on the field of research, especially when the research in that field actually *makes sense* and the boundary is instead only based on skeptical presumptions. Let us hereby clarify what we mean. There is a very dense passage in the article, where it is held that quantitative methods - like multiple regressions - fail to produce valid results when investigating *unique events* such as the Industrial Revolution, as it is impossible for the researcher to gather sufficient data to adequately estimate the parameters and error terms required to correctly run the regression. Now, a multiple regression equation is made up of four different parts: an dependent variable, some independent variables, the coefficients (or parameters) of the independent variable and, lastly, an error term.

$$Y = \alpha + \beta_1 X_1 + \ldots + \beta_n X_n + \epsilon$$

The parameters governing the influence of the multiple independent variables on the final regression outcome actually permit negative values, as correctly noted by Crafts (1977, p. 433) when he underlines the fact that a regression should take into account not only positive (i.e., economically speaking, stimulating factors) elements, but also *retardative* ones. An observation later retrieved by Mokyr when he affirms: "Whereas Britain had some institutions that fostered and encouraged growth, many others were more of an obstacle to than a support for economic development. Not all institutional elements in Britain worked to promote economic and technological

development. Although the eventual outcome was unprecedented growth, this took place *despite* rather than *because* of some of the institutional preconditions" (Mokyr, 2009, p. 25, italics in the text).
Not only; the presence of a margin for inaccuracy is what makes statistical regressions an intrinsically probabilistic tool: for specific values of the Xs, we can only infer probability distributions of Y but not its actual true value. So, how shall we interpret the error term, this annoying ϵ that constantly ruins our plans? By following the path traced by Crafts in his paper - a path he then swiftly decides not to take - we can assign to it two simultaneous explanations: error might be produced by both *ignorance* and *chance*. In fact, if we do not take into account every single independent variable related to the effect we want to explain (i.e. because we are not aware of all of them, and not because we do not want to), we get a biased estimate which does not reflect the relative impact of the variables that we ignored; and indeed, a certain degree of randomness is always present and cannot be eliminated, no matter how much we try. That being said, Crafts dismisses the whole reasoning by concluding that "it can be fairly claimed that the standard question is unanswerable" (Crafts, 1977, p. 434). But we would not be, and should not be, so hasty. No one has a remedy for chance, and random events are an inevitable part of history that can, at times, significantly influence and deviate the path of linear development; but ignorance is a defect that, given proper time, instruments and dedication, can be solved and substituted with clarity. After all, it is the historian's duty to search for causes hidden or forgotten in the mists of time. By posing a research question, one can focus its efforts and slowly reduce the relevance of the error term, leaving it to stochastic factors alone. Instead, by dismissing such a guiding inquiry, one appears to be surrendering their own role as an economic historian. Notwithstanding the undeniable impact of chance in history, historians, as much as economists, can freely reason in terms of general tendencies, without feeling the need to fit every instance into the scheme. A fair amount of randomness does not preclude explanation.

In the second section of his paper, Crafts adopts a very specific definition of the Industrial Revolution, which had originally been formulated by Davis (1973, pp. 311–313): “the Industrial Revolution had its immediate beginning in the cotton industry. [...] The events that were decisive were two in number; the invention of the spinning jenny by Hargreaves, and of the water frame by Arkwright”. This approach partially follows Landes’ pioneering work of 1969 (Landes, 1969), but further extends the conclusions with an unexpected twist, crucial for our discussion; that is, the decisive innovations were only *two in number*. As a consequence, when viewed in this way, the whole complex mass of the phenomenon gets reduced to a very limited set of sectorial advancements; and naturally, it becomes easier to account for the role played by stochastic factors when there are just a few notable (i.e. decisive) events to take into consideration. This perspective, as a matter of fact, aligns well with the example of the football game previously exposed: the entirety of the Industrial Revolution thus becomes a matter of a single game, which maybe was won, in spite of 85 exhausting minutes of annoying and senseless *tiki-taka* (to push the metaphor forward), only thanks to a fortunate goal scored after a sudden turnover – and well, who knows, perchance the other team had just missed an easy penalty. Once again, unfortunately, here we have another perfectly suited demonstration of how, with deductive reasoning, the conclusions utterly depend on the premises established before: if we change those preliminary assumptions, then the results will also differ by quite a large margin. So, the question is, do we agree on this ’restricted’ vision of the Industrial Revolution? No, since we have previously enumerated a vast amount of heterogeneous causes and concauses. The whole process cannot have been set in motion by only two of them, because that would mean ignoring all the other relevant factors which were nonetheless present. We will later examine how different scholars responded to Crafts on this point.

In any case, it is worth remarking that, even though this 1977 article was submerged by comments (many of which were skeptical or straightforwardly critical), the most important proposal advanced by Crafts, the one against an "in-principle bias" towards the other European economies, was correctly perceived and embraced by a majority of economic historians, to the point that the introduction of a recent work by Mokyr concludes: "When thinking about such questions, it is important not to succumb to 'hindsight bias'. By this I mean that when we know that a certain event occurred, we tend to view it as more or less inevitable and reinterpret all prior conditions as facilitating the outcome. After all, a lot of outcomes occur despite some prior conditions. [...] If Britain succeeded more than other European nations, it was because at that time she was better situated and equipped by comparison. But such differences were of degree, not essence, and they were fluid" (Mokyr, 2009, p. 12).

3.2 Rostow: *No Random Walk: A Comment on " Why was England First?"*

Just a year after Crafts had published his article, Walt Rostow wrote a brief, yet effective answer, stating that Crafts' arguments, though correct in principle, were actually unable to provide a satisfactory stochastic explanation of the outbreak of the Revolution in England. Notably, Crafts had failed - willingly or not - to confront "two lions in the path" (Rostow, 1978, p. 610): the sudden and consistent acceleration in the rate of British granted patents and the necessary appraisal of what Rostow refers to as 'innovational zeal'. Concerning the first point, the sharp bend upwards of the graph for England, shown in fig.1, is not met by a similar trend in France. In fact, the French rate remains stable - excluding normal fluctuations - throughout the entire 18th century (in the period 1796-98, the number of French patents was 8; in Britain, they were 69!) (Rostow, 1975, p. 176). Here, it is important to point out that Rostow's claim is somewhat misleading, as the patenting systems in the two countries where substantially different and far from perfect[2]: many inventions, even some of a considerable relevance, went 'under the radar', so to speak, especially

[2] Dutton (1984) believes that the imperfection of the British patenting system was actually optimal, as it sufficiently protected inventors' claims without being to strict or pervasive, thus avoiding a slowdown in progress and technical diffusion

in France, where the criteria for a successful patent grant were less clear and more stringent. Additionally, it is also interesting to stress that many of the patented inventions were not actually *invented* in England, but rather imported (from other countries were they had not found an appropriate practical application), perfected and finally introduced to the English markets: think for example of the Jacquard Loom, invented by Joseph Marie Jacquard in 1804 and quickly adopted and adapted by British textile manufacturers; the hydraulic press, widely used in Britain, following ideas and basic concepts previously developed by Blaise Pascal; or also Papin's steam engine of 1687, which possibly served as an inspiration for Savery's (McCloy, 1952). A rather famous proverb circulating in those years stated that "for a thing to be perfect it must be invented in France and worked out in England" (Wadsworth and Mann, 1931, p. 413). In this regard, British superiority might be identified in highly adaptive engineering skills, that proved profitable for inventors capable of donating different uses to previously useless machines. Mokyr, with his usual synthetic phrasing, asserts: "Invention was not equivalent to technological change. More was needed" (Mokyr, 1990, p. 240).

Regarding the second "lion", Rostow - but so will do Landes (1995, p. 645) - introduces an important distinction that will accompany us for the rest of this work: the subtle separation between invention and innovation. The observation is not particularly original, since it can be traced back to the work of Schumpeter (1939, passim); notably, while the act of invention is thought of as the precise moment of the idea, of the first creation of something new, innovation is intended as the introduction of the invention to the markets, where it is then subjected to a competitive selection process. In our context, Rostow specifies that, although France might have displayed a similar inventive capacity with respect to England, it certainly did not achieve the same results when it came to materially doing business with those inventions.

> In this matter of estimating innovative zeal, one must go beyond Hargreaves's spinning-jenny and Arkwright's water frame. One must look at the full range over which entrepreneurs were seizing on and applying new inventive insights, including agriculture, road and canal building, iron manufacture, and the steam engine, as well as cotton textiles. Here, evidently, we do not have orderly, even imperfect, statistical data. But we do have contemporary judgement and the conclusions of wise and careful scholars.(Rostow, 1978, p. 611)

This is a particularly crucial observation, also shared by Landes (1994, passim), as it involves those endogenous elements (e.g. engineering tradition, competitiveness of the markets, business mentality) that can hardly fit in a stochastic account of technical progress; this concept is precisely what will be discussed in Section 4.

Finally. Rostow concludes his short paper with an ingenious remark: he dismisses Crafts' metaphor of the football game, not because of its logical conclusion (again, that no causes can be inferred from the effect), but because it is inadequate for portraying what truly happened during the Industrial Revolution. In his interpretation, rather than a matter of a single decisive match, this last was a "large sample of games" (Rostow, 1978, p. 612), a yearly championship of repeated encounters among the teams. And it was won, and by a great margin, by the smaller nation.

3.3 Landes: *What room for accident in history?: explaining big changes by small events*

In 1993, at Hull, David Landes delivered his Tawney Lecture, which was later published on *The Economic History Review* the following year (Landes, 1994). It begins with a strong critique of what he calls "optative history", that is, a form of historical research based on counterfactuals and ideological views. An example of it, with which he illustrates the concept, would be the revisionist vision against the European world dominion which started in the 18th century : Why was it Europe that took the lead? Could it not have been, for instance, China, which on many occasions had displayed, in the previous centuries, far superior scientific knowledge, cultural tradition, and military might? (Jones, 1981). Surely, the reader has already noticed the similarity of this counterfactual interrogation to the one posed by Crafts (1977). And indeed, this article by Landes is centered on a vigorous rebuttal of the ideas proposed by the latter. In Landes' opinion, "history as accident" is just another form of optative history: "a little nudge, and it could have, should have, gone the other way" (Landes, 1994, p. 637).

What observations does Landes make in his paper? Firstly, that to state that innovation - as well as every social and intellectual achievement - results from a stochastic search process is not to say that it is *random*: "the simultaneity of certain inventions [*clusters* of inventions] [...] is evidence of the influence of demand and the connivance of supply" (Landes, 1994, p. 645, footnote).

> In general terms, the flow of innovation is not a stochastic process. This is not to say that there are no elements of chance. [...] But to say that the details are stochastic is not to say the process as a whole is one of chance, a random walk. Note that this combination of general tendency and random detail is characteristic of just about all social action and historical developments and of economic processes in particular (Landes, 1994, p. 651)

Secondly, that the possibility for a backward country to "get lucky" and win the race for innovation, though mathematically conceivable, is most improbable: "I know of no examples". This point he makes seems weaker: Crafts could easily respond by arguing that Landes is not aware of such instances because he is still perpetrating *post hoc ergo propter hoc* fallacies; since the country won the race, Landes tries to find elements that explain the victory (and reasons for the other country's loss) and, having found them, he assumes that that country was not just lucky, but superior indeed; and yet, perhaps, it might have been a perfect example of a lucky country that was helped by 'Fate'. In these cases, examples are useless, as they can be used to support either explanation. Landes also tries, rather ineffectively, to contest the statement by Milward and Saul (1973, p. 30) – accepted and reported by Crafts - that measuring the performance of continental economies “against a British yardstick” is a methodological fault, as it causes and underestimation of the former and an overestimation of the latter. For this purpose, Landes simply argues that “all comparison – and we cannot do without comparison – means measuring against the characteristics or performance of others” (Landes, 1994, p. 644). Which certainly is true, but unfortunately the point was another one: not really the presence of a measure for comparison – which, as Landes says, is inescapable - but rather the strongly biased nature of that “yardstick”.

Except for these last two arguments, the criticism Landes moves to Crafts is actually effective: the fifth section of his paper is utterly devoted to the confutation of numbers advocating for France parity - or even superiority – with respect to England, effectively proving that they are incomplete and heavily biased upward. Without entrapping ourselves in such technical discussions, the important thing to stress is the conclusion reached in the end: that “one has to make sense of numbers, and numbers have to make sense” (Landes, 1994, p. 646). Even when those who propose them invite the readers to embrace caution in using them, it is often a useless warning, as numbers *per se* seem more reliable than words. Having said that, Landes launches a vehement invective against the credulity displayed by modern economic historians, eager to draw revolutionary conclusions from unexpected quantitative estimates, in spite of a great amount of widely accepted, comprehensive accounts supporting just the opposite conclusions. He even comes to the point of proposing to weigh quantitative estimates on a "scale of robustness", assigning a sort of reliability index to each number. It is, one might say, the expected critique moved by a traditional historian, when he finds himself on the defensive because of the advent of new mathematic research tools, and of new perspectives. Crafts, in a following paper, pours fuel on the fire: "He [Landes] takes the opportunity to pour scorn on old data and to indulge his anti-cliometric prejudices while characteristically failing to offer estimates of his own" (Crafts, 1995, p. 592). But we do not view it this way: the one expressed by

Landes is a sincere apprehension towards the bulimic appetite displayed by mathematical methods, when they are adopted to investigate humanities such as History. True, the one branch we are presently concerned with is Economic History, and - as the name itself suggests - this last discipline is an hybrid of some sort, were numbers and functions actually need to play a role; but digits cannot, must not, replace the tidy and careful study of contemporary sources; they should not thoroughly substitute humanistic approaches with quantitative ones. Landes is not being reactionary. He is being sensible, and careful, in recommending caution when dealing with controversial data.

In any case, the most interesting part of this paper is the actual analysis of the differences between England and France. Notably, the factors Landes takes into consideration would belong - to follow the classification introduced in Section 2 - to the category of those socio-cultural elements which were decisive in supporting the introduction of new technologies. According to him, not only was Britain richer in engineering skills, but also used them differently than France: particularly, the English pursued quantity; the French focused on quality. British innovations in the textile sector were primarily related to wool and cotton, two products for which market demand was always high among all social classes, from the poorest to the wealthiest; in contrast, French industry specialized in silk, a high-quality good closely tied to the consumption habits of the declining nobility. Even though the production share of French silk rose to quite significant levels, it could still arguably be considered a 'niche' good when compared to British sales volumes. Landes reports two other examples, related to a manufacturing branch for which France has always been renowned: clockmaking.

> The British engaged in batch production using extensive division of labour; the French relied on a chosen *horloger de la Marine*, who made one chronometer after another. The British [...] made thousands; Louis Berthoud made 300 in a lifetime. (Landes, 1994, p. 650)

In many ways, a caring attitude towards the quality of niche goods, which physiologically drives up prices, is oxymoronic to the concept of the Industrial Revolution, which instead involves an extensive increase in quantities at cheaper costs. The nature of the privileged goods must also be considered: in the textile sector, the one where the Revolution began, Britain industrialized wool and cotton manufactories; France, went on to pursue improvements in the production of silk fabrics. On the one side, necessary goods; on the other, luxuries. "The French did not lack for talent or knowledge; but they were moving along different lines"(Landes, 1994, p. 652).

> In the last years of the Old Regime, the French government, troubled by the domination of the Swiss watch manufacture [...] solicited from the leading watchmakers of Paris plans for the large-scale, mechanical manufacture of watches based on production of interchangeable parts. [...] Their [clockmaking *Parisiens* artists'] primary concern was not the vision, but rather the danger. How was one to engage in such an operation, which would have the effect of substituting impersonal, embodied knowledge for personal skills, without empowering workers to take the secret to other employers or set up in business themselves? In the event, nothing happened. The government filed the reports away; the Paris watch trade continued to devote itself to making the finest pieces (as with chronometers); and the Swiss, with cheaper labour, ran off with the spoils. (Landes, 1994, p. 650)

This account is crucial for many aspects, the first of which being the overprotective attitude adopted by *ancien régime* institutions towards artisans and farmers. That surely limited the competitiveness of markets, and significantly slowed down the transition to an industrial economy. Of artisans, we have already spoken. Regarding the other social class, Milward and Saul (1973, pp. 43–51) tell us how the French government defended peasants from excessive demands imposed by the nobility and prohibited the expropriation of crop fields, since farmers accounted for the biggest share of tax revenues (the clergy and the aristocracy, as it is widely known, did not pay any taxes, thanks to ancient feudal privileges, which were only abolished

in 1789). Secondly, the example shows the reactionary behavior of French artisans, hostile to an enlargement of craft knowledge and keen to maintain the personal, quasi 'familiar' nature of the production system. In this sense, the statement by (McCloy, 1952, p. 191) seems perfectly fitting: "Private business of eighteenth-century France thus was more to blame than the government for failure to pursue invention".
Landes concludes his article by stating what he calls "a golden rule of historical analysis" (Landes, 1994, p. 653). That is, *big processes call for big causes.* The complexity of large events - and the Industrial Revolution may well be considered to fit this category - requires an equally complex explanation. It is not possible to assign the primary causes for the Revolution to only two major inventions occurred in the textile sector, as Crafts does in his paper. Multiple causes, "of shifting relative importance", "combinative dependency" of productive factors, "temporal dependency" of progressive innovations (Landes, 1994, p. 653); all of these elements must be adequately addressed by a satisfactory casual explanation. If this last lacks anyone of the conditions stated above, it must be regarded as incomplete.

4 The debate on the nature of technological development: fortuitous or induced?

"*Fortune favors the prepared mind*" – Louis Pasteur

Up to now, we have investigated how the process of the Industrial Revolution has been interpreted by different scholars, identified the most probable causal relations behind its outbreak and its subsequent take off, and finally focused our attention on a heated debate regarding the role of accident in technical advancement. Across all these research questions, we have found that the ultimate explanatory factor, and as such, the core of the issue, is technological change; more specifically, by now, we should have started asking ourselves: how does this change happen? What are its necessary determinants, if any? Is a deterministic vision of science and technology adequate, not only theoretically but also empirically? And finally, then, why was Britain actually first? To these central interrogations we try to give an answer in the section that follows.

4.1 Micro and Macroinventions

The article by Landes we have just finished analyzing was published almost twenty years after the one written by Crafts, in 1977. By that time, Crafts' views on the topic had already shifted by quite a significant margin. Indeed, he had smoothed his positions on the role played by accident in the context of the Industrial Revolution, ultimately acknowledging - that is, explicitly - a decisive importance to economic and institutional factors in the shaping of the major trajectories of technical development (Crafts, 1986). In a new paper (Crafts, 1995), although he coherently remarks, one more time, that an evident British superiority remains yet to be proven, he accepts Landes' criticism on the weakness of growth potentiality estimates for France, by recognizing that Britain actually was advantaged in some crucial aspects for the effectiveness of productive investments, notably GDP per head, literacy rate, and urbanization. In this sense, he agrees with Landes; and yet, he immediately makes sure to precise that better growth potential does not "equate to being the more likely to make the decisive inventions in cotton", the true "nub of the issue" raised in 1977 (Crafts, 1995, p. 594): the presence of chance thus prevents any *ex ante* prediction. In a later passage of the same paper, Crafts refers to a conceptualization, useful for his purposes, recently set out by Mokyr (1990), regarding the relative importance and different impacts of inventions: in this context, one must distinguish between *microinventions* and *macroinventions*. As every word in the definition provided by Mokyr is important, we report the entire paragraph below:

> I define microinventions as the *small, incremental steps* that improve, adapt, and streamline existing techniques already in use, reducing costs, improving form and function, increasing durability, and reducing energy and raw material requirements. Macroinventions, on the other hand, are those inventions in which a *radical new idea*, without clear precedent, emerges more or less *ab nihilo*. In terms of sheer numbers, Microinventions are far more frequent and account for most gains in productivity. Macroinventions, however, are equally crucial in technological history. 1(Mokyr, 1990, p. 13, italics added)

In addition, Mokyr defines an invention as "an increment in the set of the total technological knowledge of a given society" (p. 10) and technology not as "something that somehow 'exists'" but rather as "something we know, and technological change should be regarded properly as a set of changes in our knowledge" (p. 276). Macroinventions, then, are revolutionary intuitions that dramatically expand, in ways which are often unpredictable, the body of social knowledge. Notice how Mokyr argues that they emerge ab nihilo, that is, 'out of the blue', as they have no clear predecessor and as they typically require inspiration - along with an irreducible element of luck - in determining the time and place of their realization: they "do not seem to obey obvious laws, do not necessarily respond to incentives, and defy most attempts to relate them to exogenous economic variables. Many of them resulted from strokes of genius, luck, or serendipity" (p. 13). This vision aligns perfectly with the thesis proposed by Crafts which we have just finished analyzing. Microinventions, on the contrary, are incremental improvements to existing technologies, usually achieved by means of learning-by-doing and inventive effort. As such, they are highly sensitive to economic variables: incentives, relative factor prices, aggregate demand for the output and the possibility of employment (p. 13). Furthermore, they tend to create a sort of path dependency, since every new small upgrade builds upon the cumulative mass of previous ones, and cannot diverge by much (otherwise, they would be regarded as macro, not micro, inventions), though a great amount of subsequent improvements can often lead to completely modified results with respect to the original technique. Just consider airplanes, or cars: the macroinvention was their initial conceptualization, their first prototype, we might say; the vehicles and aircrafts we have today are the final outcomes of the long series of microinventions that have occurred over the course of the years.

Just like inventions and innovations are not substitutes but rather complements, so too are macro and micro inventions: "Without subsequent microinventions, most macroinventions would end up as curiosa in musea or sketchbooks". And at times, the inventor of the micro-improvement gets more celebrated than the creator of the original idea, as the story of the steam engine (where Watt's separate condenser secured his name to posterity, while Thomas Newcomen is too easily forgotten by History classes) proves. On the other side, "without novel and radical departures [macroinventions], the continuous process of improving and refining existing techniques would run into diminishing returns and eventually peter out" (p. 13).

Through these distinctions, Crafts emphasizes that the favorable conditions of the British economy for technical progress were related only to a higher probability (comparative advantage, Mokyr would call it) of developing microinventions, but not macroinventions, which were actually generated in a large amount on the continent, too. And yet, Britain happened to be lucky, and got the right macroinventions at the right time. From then on, Crafts argues, it was easier for Britain to maintain its leadership, thanks to what he calls the "learning advantages of primacy"

(Crafts, 1995, p. 596). But had France developed these inventions before England, perhaps it would have benefited from those advantages in such a way it would prevent British domination of exports, despite suffering of a comparative disadvantage in microinventions. Predictably, Landes views it in a different way. After criticizing the statement which describes microinventions as emerging 'ab nihilo' - which as a matter of fact is problematic, and in many ways counterintuitive, as we will see -, he proceeds to refute this last assumption by affirming that "had [macroinventions] occurred elsewhere, it would have been the British who would most quickly have developed them" (Landes, 1995, p. 599), thanks to the superior pool of engineers Britain was endowed of - an element, this last, which would find Mokyr (1990, Ch. 10) in agreement. In any case, he remarks, "it is not the subsequent superiority of the British textile industry that tells us about Britain's chances for technological change (Crafts's bugbear of post hoc, ergo propter hoc), but its previous development". The advantages of primacy for France would not have prevented the Industrial Revolution from happening in England first. Naturally, this assumption makes sense only if we do not identify the Revolution with the mere appearance of one or two notable inventions.

In stark contrast to the theorization proposed by Mokyr and Crafts, another renowned economic historian, Robert Allen, reinterpreted the distinction between micro and macroinventions in a more deterministic framework, leading the two concepts to produce markedly divergent conclusions. In a book (Allen, 2009) already regarded as a classic in the discipline, he proposes a novel vision of macroinventions, which, yes, he understands as important breakthroughs with no clear precedent, but which also decisively cause major shifts in factor proportions (in the case of the British Industrial Revolution, these inventions were mostly labor-saving, being designed to reduce the amount of workforce needed and as well shorten production times); since their profitability ultimately depends on relative factor prices (i.e. wages and, say, the price of coal or the price of a machine such as the jenny) and on the dimension of the interested market, these macroinventions will be adopted only in those countries where economic conditions are favorable enough. Moreover, as inventions of a certain relevance not solely require brilliant ideas, but must also undergo a long process of expensive realization and collaudation - often with high fixed costs to be paid in advance - the inventor will commit to building such a machine only if he anticipates sufficient demand for it, once introduced to the markets. In a previous work, Allen (2001) had provided estimates accounting for an early divergence in European wages starting around 1500, with salaries in Northern countries - led by England - rising much more steeply than in Mediterranean nations. Building on this analysis, Allen is then able to conclude that, having England experienced high wages, cheap energy, and relatively cheap capital for much of the previous centuries, "the Industrial Revolution was invented in Britain [...] because it paid to invent it there" (Allen, 2009, p. 2).

Using Allen's approach, inventions can be understood less as stochastic — and therefore unpredictable — phenomena and more as results of a purposeful search process. For this reason, they tend to align with economic laws and incentives, making their occurrence more predictable under specific conditions. On the contrary, microinventions, which result from localized learning and small, experience-based enhancements, are not easily foreseeable, because they tend to be Hicks-neutral (i.e. they leave factor proportions unaltered), being primarily directed at improving factor efficiency. Allen also suggests, rather controversially, that such improvements are not necessarily the results of the mechanical efforts of professional engineers, but also frequently emerge from the work of 'outsiders', that is, individuals not familiar with inventive activity, as they can more easily imagine different solutions from the ones which compose the current engineering 'paradigm' - in the sense of Thomas Kuhn (1962). Note that the unpredictability of microinventions does not concern their appearance, which is instead certain to eventually occur, but rather their direction, their path of improvement. Fig. 4 illustrates the difference among micro and macroinventions in Allen's work through a graphical visualization.

In a later paper, Crafts (2010, p. 160) makes an important observation in the at-

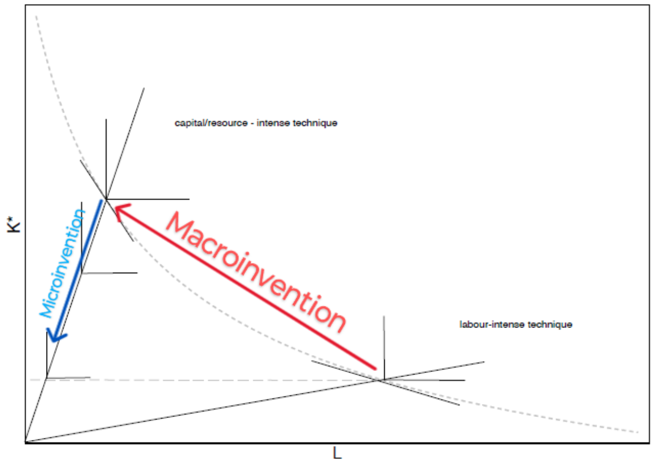

Fig. 4: Macroinventions follow changes in relative factor prices (isocost lines), while microinventions reduce the inputs needed to obtain a given output without altering the capital to labor ratio. See Nuvolari and Tanimoto (2021, pp. 323–324)

tempt to explain the radical differences in the interpretations provided by Mokyr and Allen. Cleverly, he distinguishes three main stages in the innovation process, notably: (i) the idea, (ii) the R&D phase, (iii) the incremental improvements. According to Crafts, the differences between Mokyr and Allen can be explained as such: Allen considers macroinventions as the sum of stages (i) and (ii), and microinventions as (iii), whereas Mokyr intends macroinventions solely as stage (i) and microinventions as (ii) and (iii). The decisive - and controversial - moment thus seems to be the R&D process, which by both authors is understood as dependent on economic forces, but for one it must be included in the "idea" phase, while for the other it should be seen as the "material realization" of the inventor's earlier idea. By including stage (ii) in the first part of the process, macroinventions inevitably become driven by market demand and incentives; in opposition, by attributing it to the microinventions phase, macroinventions instead become serendipitous, springing from sudden and unpredictable subjective inspiration. Tab. 2 compactly summarizes the two views.

Historian	Invention type	Stages	Sensitive to economic forces
Allen	Macroinvention	Idea + R&D	Yes
	Microinvention	Incremental improvement	No
Mokyr	Macroinvention	Idea	No
	Microinvention	R&D + Incremental improvement	Yes

Tab. 2: A summary of Mokyr and Allen's views as exposed by Crafts (2010)

Recent quantitative studies have focused their efforts in the attempt to find evidence supporting either of these claims. In particular, a paper by Nuvolari, Tartari, and Tranchero (2021) reports a careful appraisal of British patent data, through which the validity of the 'micro-macro' distinction is assessed. The findings reveal statistical trends coherent with a serendipitous vision of macroinventions, as they actually did not historically display any time-clustering trend, whereas microinventions seem to have followed previous advancements and to have exhibited sufficient correlations with economic incentives (à la Mokyr). However, the estimates also point to a labor-saving bias for macroinventions, in accordance with Allen's deterministic account of Britain as a 'high wage economy'. Lastly, the results contest Allen's argument on the importance of outsiders in the innovation process, showing how the unique "positive predictor of macroinventions is an engineering occupation" (Nuvolari, Tartari, and Tranchero, 2021, p. 15, tab. 10), while the impact of supposedly external contributions seems to have been fairly limited. This is a particularly relevant result for our purposes, as it demonstrates the importance of possessing at least basic engineering knowledge, either formally (i.e. through dedicated training or apprenticeship) or informally (learning-by-doing and observation), for facilitating mechanical improvements. The conclusions drawn in the paper, then, appear to align well with the one suggested by Crafts (2010):

> Mokyr and Allen are emphasizing complementary dimensions of macroinventions. More precisely, they are pointing to two necessary, but not sufficient, conditions for the occurrence of macroinventions. [...] Both favorable contingencies and investment and research efforts were simultaneously necessary for a successful macroinvention. For example, if we consider the case of James Watt's separate condenser, one can easily point to the flash of inspiration during the usual Sunday walk in May 1765 and to the more than ten years of experiments before the development of a satisfactory engine (Nuvolari, Tartari, and Tranchero, 2021, p. 17)

4.2 'Outsiders' and technical development

Let us now dwell on the 'outsiders' point a little more. This aspect is relevant to a stochastic theory of technical progress, as it challenges the conception that an engineering education and a working background predominantly devoted to inventive activities are unavoidable prerequisites for creating new machinery. Some people, it is sustained, simply had the right ideas in the right place and at the right time, wether through mere luck or personal ingenuity (though we doubt that such an ample set of 'right' occurrences can be entirely explained by means of fortuitous coincidences). Patrick O'Brien wrote a most interesting and well-documented paper supporting this 'indispensable men' interpretation, focusing on the case study of Edmund Cartwright, "a clerical gentleman who switched careers in mid-life to become one of England's greatest mechanical engineers" (O'Brien, 1997, p. 225). O'Brien correctly points out that Cartwright did not receive any form of mechanical education during his years at Oxford University, where he primarily studied the required subjects to become a clergyman. His interests were mainly related to poetry and literary matters, and his familiar background, a rather wealthy gentry family endowed with landed property, did not include any example of engineers or inventors. He truly was an 'outsider', without a doubt. The crucial turning point, the fatal event supposedly decided by chance which suddenly drove him towards "an all absorbing interest in mechanical exploration" (p. 205) took place in 1784: he overheard a conversation about the remarkable changes provoked by the machines invented by Arkwright and others, and he immediately came up with the idea of creating a device able to automate the weaving process, the phase of textile manufacturing which follows spinning. And thus, the first idea for the power loom was born; the first patent was granted the following year.

Now, let us focus on some important details, the first one being the entrepreneurial attitude displayed by the former priest; a demeanor recognized and shared also by his close friends, who expressed wishes of the kind "may you weave your webs of gold", or "remember when you grow very rich that we were friends before" (p. 207, 209). These hopes were explicitly nurtured by Cartwright himself, whose desire for monetary compensation for his ingenuity was so strong that he presented requests for several more patents, and he even decided to set up a textile factory near his Doncaster home. Unfortunately, the story of Cartwright is also one of business failure, as he spent much of his personal wealth (which he happened to possess thanks to his family's wealth and his respectable profession as a member of the Anglican church) in costly - and often unremunerative - ventures: his patents were constantly eluded, and the revenues he obtained for his mechanical investments were never sufficient to cover his high expenses. This entrepreneurial fiasco, despite promising mechanical successes, serves O'Brien as an example of how stubbornness and a personal will to succeed, to defy the odds, were sometimes more important to advances in technology than economic incentives. Frankly, we are not convinced. Indeed, the institutional failure to protect Cartwright's inventions was related to the 'imperfect' nature of the British patenting system mentioned earlier (Dutton, 1984), imperfections which nevertheless, more often than not, did not preclude adequate compensation for clever tinkerers who had been skilled in innovating (Arkwright and Watt's economic success being, in this regard, a perfect counter-example). Not always did the system work, but surely it did serve as a powerful incentive. In Britain, inventors generally did well financially, not so much in France (Mokyr, 1990, p. 254). This was enough to fuel the stubbornness of an ingenious man; we argue that, regardless of the twists of fate, things would have gone differently without such incentives.

Interestingly, then, the British Parliament awarded Cartwright a prize of £10,000 for his ingenuity, an unusually generous sum for a known Radical, granted by a Tory government during a dire and expensive wartime period (O'Brien, 1997, p. 219). Just for the sake of making a comparison, in contemporary France the State was not as attentive to stimulating innovations in the productive sectors of the economy, instead absorbing the energies of intellectuals primarily on military purposes: Lazare Carnot, excellent engineer and member of the Academy of Sciences, became an officer of the Committee of Public Safety and played a pivotal role in organizing the war effort, but only at the expense of his studies on the heat engine; Antoine Lavoisier, the father of modern chemistry, instead of public esteem was rewarded with an execution for treason during the Terror: traditional accounts of the trial have the judge state "La République n'a pas besoin de savants" ("the Republic has no need of scientists") (Naszályi, 2005). Fairly self-explanatory[3]. It might not be completely fair to draw general assumptions from such a limited pool of examples, especially because also in France existed instances of wealthy inventors (with Joseph-Marie Jacquard being a notable one) and some effective research prizes, but the overall tendency was already clear to contemporary observers and so should be to us. Inventors in England had simply better chances of making it to the top.

A couple more quick considerations. First of all, even though it was Cartwright who got the idea and the initial conceptions for the power loom, he immediately set out to employ a smith and a carpenter to build the machine (O'Brien, 1997, p. 208). Being an outsider, he would not have had any chance of building such a device without the help of professionals. But fortunately, as we have already pointed out many times, Britain had a large pool of engineers and skilled mechanics available, so that the first

[3] It should be said, though, that in Prerevolutionary France pensions were routinely awarded to the inventors of socially useful devices, and a few prizes were offered for special projects, as the example of saltpeter proves (Multhauf, 1971). In 1795, then, a reward amounting to 12,000 francs was promised by the Directoire for research on food preservation; a prize which was won in 1809 by Nicolas Appert (Mokyr, 2009, p. 137)

mental constructs could actually find their material realization. With no engineers, no power loom would have seen the light of day, despite Cartwright having had the right ideas. Secondly, a more general observation. Since the beginning of human history, technical change has obeyed different dynamics, often complex and not always coherent, but one evident trend can be recognized without much difficulty: the increasing need for new inventors to possess a highly specialized background and an excellent education to be able to achieve something remarkable. In the Middle Ages, almost all inventions were made by sheer luck, either by mistake or by fortunate coincidences. Serendipity was responsible for almost every new discovery. But today, the role played by chance is much reduced, also because of the incredible costs which have to be endured when venturing towards new technology, and individuals count much less than before. Invention has become a collective effort, which can be undertaken only by governments or large corporations: as things currently stand, there seem to be no possibility for a priest to invent a fusion reactor. For what concerns our matter of analysis, things are a little more complicated, as it is no obvious at first glance at which point of the scale of inventive activity the First Industrial Revolution can be situated. Serendipity appears to have been somewhat important. To answer this tricky question, we need to find out how many industries began their growth during the Industrial Revolution, without the need for serendipitous macroinventions. Was a major invention necessary to start growth for an industrial sector? Or instead, many manufactories saw their production take off even without huge technical breakthroughs? In brief: was technical progress pervasive or concentrated?

4.3 The pervasiveness of technological development in the British economy

As we have discussed in Section 2, Rostow (1978) criticized Crafts' interpretation (Crafts, 1977) of the Industrial Revolution through a clever *escamotage*: he reinterpreted the metaphor of the rush towards industrialization as a football match, suggesting instead that it should be viewed as an entire championship rather than

a single game. In our opinion, this critique has the purpose of underlining a certain 'narrowness' implicit in the perspective adopted by Crafts, drew from Davis (1973), for which "the events that were decisive were two in number; the invention of the spinning jenny by Hargreaves, and of the water frame by Arkwright". For Rostow - and Landes -, not only did Britain achieve spectacular production growth in textiles and iron smelting, but also in many other industrial sectors, which grew steadily but silently, unnoticed both by contemporaries and by later accounts. Even though the role of cottons and woolens cannot be underestimated, given the rapid growth in productivity, the large size of the sector, and the inelasticity of demand, there was more to the Industrial Revolution than iron and fabrics. In Peter Temin's enlightening words, "Crafts' revolution, being composed of only a few elements, could easily have been different. Landes' thorough-going revolution required society-wide preparation" (Temin, 1997, p. 7). Here, then, we try to persuade the reader that technical change in Britain was pervasive and continual, rather than limited to a few specific sectors of the economy, through some examples of fast growing industries which needed no macroinventions to see their output volumes skyrocket.
Kelly and Ó Gráda (2016) argued, against the view of a 'narrow' Industrial Revolution, that advances in the manufactory of silver watches "support the view of a more broadly based advance across many manufacturing sectors" (p. 1743). Already in *The Wealth of Nations*, Adam Smith had recognized the fast decline in watch prices, a decrease he estimated to reach as much as 95%. The fall had clearly been determined by technical progress, as wages had remained more or less constant during the period examined and so had done the quality of watches. Smith's claim was likely a little too ambitious, yet Kelly and Ó Gráda quantified[4] an annual decrease rate in watch prices of approximately 1.3% from 1685 to 1810, which equates to a fall of 75% over the span of a century (See fig. 5). This drastic surge in production is attributable to a finer division of labor, superior hand and machine instruments,

[4] For their purposes, Kelly and Ó Gráda used data on the value of stolen watches, from the trial records of Old Bailey for theft.

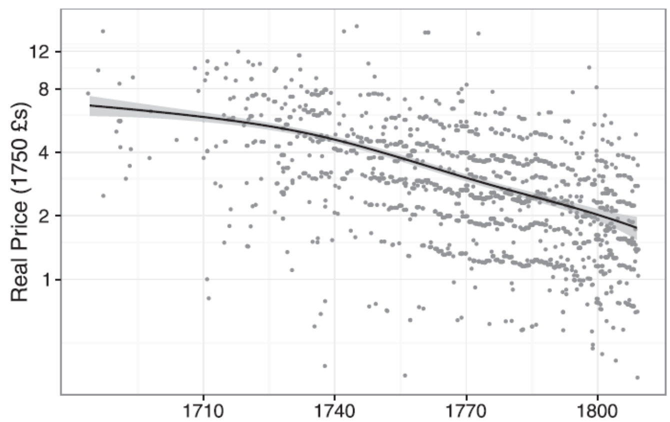

Fig. 5: Yearly value of silver watches as desumed by Old Bailey trials (Kelly and Ó Gráda, 2016, p. 1734)

and better metals. Output growth was predominantly driven by anonymous small improvements. Notice how this growth begins in later 17th century, supporting the claim of an early Industrial Revolution - and remember what was mentioned above regarding De Vries (1994) and the Early Modernists. Finally, Kelly and Ó Gráda put some emphasis on the prosperity of the British market, which stimulated innovation and the division of labor while being able to absorb such a dramatic increase in production volumes. This focus on demand is typical of deterministic accounts, whereas supply-side arguments are more commonly associated with stochastic theories of technological growth.

Other dynamic industries were brass and copper, ship-building, paper-making, railways, gas lighting, hats, chemistry (for an exhaustive survey, see Mokyr, 2009, p. 131-144). The first chemical enterprises emerged during this same period, and they were able to solve a longstanding issue in textiles dyeing: bleaching (Park and Glouberman, 1932). The complementarity of the two processes explains why bleaching became so fundamental during the Industrial Revolution: "granted that machines increased the output of cotton tremendously [...] of what use was the increased supply if the subsidiary processes of bleaching and dyeing were so slow and poor that the whole operation was appreciably retarded?" (p. 1143). As in many occasions, the invention was made on the Continent: the application of chlorine properties to bleaching was first realized by Claude Berthollet. When they heard the news concerning the ideation of the new process, James Watt and Matthew Boulton traveled to Paris just for the sake of gathering more information; little time passed, and already British industrialists - among whom was Watt's father-in-law - had devised an efficient technique for large-scale application. A few years later, Charles Tennant produced bleaching powder, an outstanding success, and the previous technique[5] quickly disappeared (Mokyr, 2009, p. 133). Once again, the French invented, and the British profited.

In 1783, the *Académie des sciences* offered a prize for a method to produce soda from sea salt. In 1791, Nicolas Leblanc invented and patented such a procedure, and opted to build a factory and embark in the soda business. The French Revolution completely shattered any dreams of success: the prize was never awarded, the factory was shut down in 1793, and a decree from the Committee of Public Safety revoked the patent's secrecy, in order to promote "a widespread revolutionary manufacture of soda" (Gillispie, 1957, p. 162). Having become a matter of public dominion, the 'know-how' for synthesizing soda rapidly spread to Britain, where chemical plants for the purpose opened in Liverpool and Glasgow. In 1850, Britain was producing three times the French total output.

Another branch that saw remarkable expansion due to its interrelation with industries like textiles was the mechanical sector. "Mechanical engineering was a core activity of the Industrial Revolution, [...] generating a disproportional share of innovations" (Mokyr, 2009, p. 138). It was a sector which heavily relied on mechanical intuition and self-training, either acquired by means of apprenticeship or through workshops, two types of informal learning-by-doing where Britain was particularly strong. Notably, the expansion of output volumes and the ever growing need for

[5] Before chlorine, fabrics had to be exposed to sunlight for long periods of time, usually with the chemical interaction of stale urine: a process known as 'grassing'

new machines led to the birth of two wholly new productive sectors, the one of 'machine makers' and the one of 'machine tools producers', through two simultaneous processes which have been defined by Rosenberg (1963) as "vertical disintegration" and "technological convergence". While the first phenomenon refers to the sequence: (i) machines self-produced by users, (ii) machines autonomously produced by specialized industries, (iii) machine tools manufactories split off from machine makers; the second one concerns the elasticity of usage of these machine tools, which with a fairly restricted amount of modifications could be adapted to the needs of many different applications. Although Rosenberg's account is specifically referred to the American environment, its conclusions are general enough to be applied, without too many difficulties, to the context of the British Industrial Revolution, as it has been shown in a pioneering study by MacLeod and Nuvolari (2009), which also contains estimates of the share of mechanical engineering inventions in the total number of patents (this share reached almost 30% by 1820-1829; not exactly the figure of a negligible sector!).

To conclude, a final study should be mentioned, both for its simplicity and its effectiveness. Temin (1997) wrote a paper directly aimed at assessing the validity, respectively, of Crafts' and Landes' theories (as we have discussed many times now, the former being narrow, the latter broader). To do so, he adopts a Ricardian model based on trade data, available in great quantity and detail. The reasoning proceeds as follows: as Crafts (Crafts and Harley, 1992) postulates growing agricultural, mineral and textile sectors, with all the other manufactories being stagnant, a Ricardian analysis would recognize a comparative disadvantage for Britain in the manufacturing branch of the economy; this naturally implies, in accordance to the basic economic principle of international division of labor, that Britain should have been a net importer of manufacturing goods, while being *per contra* a net exporter of textiles, iron and agricultural goods. With these simple assumptions, Temin proposes an empirical test to solve the controversy: if trade data showed that other manufacturing goods were generally exported, then the 'pervasive' approach would

Export	Total value (£)	Export	Total value (£)
Brass and copper	1,830,793	Plated wares, jewels and watches	286,738
Machinery and millwork	970,077	Linens	4,694,567
Arms and ammunition	505,096	Manufactories/Total exports	85%
Hardwares and cutlery	2,556,441	Other/Manufactories	34%

Tab. 3: Some exportation goods with their aggregate value in pounds for years 1850-52; percentage shares of manufacturing goods out of total exports, and of manufactories other than iron and cottons/woolens out of total manufactory production (avg. for years 1794-1856) (Temin, 1997, Tab. 2 and 3)

be confirmed; if, instead, they displayed prevalent importations, then crafts' vision would probably be the correct one[6]. The results of the model are clear: "Britain maintained a clear comparative advantage in a wide variety of manufacturing industries throughout the first half of the nineteenth century. [...] There is no hint that these other commodities were being pushed off the list of exports by the growth of cotton exports" (p. 26). In fact, Britain exported almost any kind of manufacture, and mostly imported food and raw materials. These important results, which seem to confirm the pervasive interpretation of the Industrial Revolution, are summarized in Table 3. "Technical change was hardly uniform, but it was widespread. Britain became the workshop of the world, not just the cotton factory of the world".

4.4 A proposal for a taxonomy of theories

We are now approaching the end of our exposition. To conclude properly, we would like to offer the reader what could be defined as a clarifying taxonomy of the various theories encountered during the discussion. Specifically, the classification will be

[6] Even more relevantly, the clearest indicator would be the marginal rate of change in imports/exports, which Temin names "the path of trade": "was Britain losing manufacturing exports at the margin or gaining them"? (p. 21) As commonly happens in economic analysis, absolute values are usually less informative than marginal variations for assessing shifts in key variables.

designed to discriminate between theories on the basis of two criteria: the number of relevant elements identified as explanatory causes of the British Industrial Revolution (their *range*, or *scope*), and the extent to which chance plays a role in these theories (their *degree of determinism*). The classification also aims to follow a sort of 'hierarchy of scholarly influence', as it presents first those interpretations which have progressively been abandoned by scholars over the years, and later the ones which are, at the present moment, the most influential and discussed.

One of the oldest ways of analyzing the Industrial Revolution is the '*heroic*' approach which, for its naivety, can be presented more as a suggestive narration rather than a proper historical theory. In this perspective, innovations are solely attributed to the inspiration of a genius, endowed with extraordinary capacities for intuition and discovery. One paradigmatic example might be found in Smiles (1874). Usher (1929, p. 60), who defines this school of thought as "transcendentalist", states that "these explanations are essentially unhistorical" because "the emergence of novelty is treated as inexplicable" and "elements of mysticism become involved". These contributions can be regarded as the quintessential stochastic interpretations, as individual biographies are seen as all that matters, and invention is merely achieved "by a process of revelation [...] that admits of no analysis" (Usher, 1929, p. 61). No wonder that this approach has been abandoned by modern historians.

Other theorizations, more historical yet equally unsatisfactory, entirely forsake the biographical emphasis, and instead prefer to list "a large number of favourable factors, as, for example, does Kranzberg (1967)" (Crafts, 1977, p. 430). These factors belong to a wide (often excessively broad) range of social, cultural, economic, political and technological fields, with none of them seen as superior to the others: no single element stands out significantly from the rest. Crafts ironically defines these accounts as adopting a "*laundry-list*" approach. The fundamental work by Ashton (1955) can also be included among such theories.

Some scholars, on the contrary, have even gone so far as to reject the concept of 'Industrial Revolution' altogether. This wave of skepticism experienced a remarkable increase after the publication of estimates - notably those by Crafts (1986) - which negated fast economic growth as a consequence of industrialization (*gradualism*). Clark (1986, p. 39, 66) wrote that "there was no 'Industrial Revolution', historians have been chasing a shadow". We have already extensively discussed the uselessness of such a perspective which deliberately ignores, by investigating aggregate values, regional changes clear and manifest to every contemporary eye. The Industrial Revolution continues to be a useful abstraction, notwithstanding the many flaws of generalization (Berg and Hudson, 1992), but since this 'iconoclastic' vision exerted significant influence in the last years of the 20th century, it must be included in our taxonomy.

Then there are *single-factor theories*, which mainly try to explain the occurrence of the Industrial Revolution through a single specific characteristic of the British economy, usually one that was lacking in the continental environment. Be it the abundance of coal, the constitutional monarchy, or the apprenticeship system, they tend to excessively emphasize the role played by those elements, and not seldom do they deliberately ignore the diverse favorable features typical of other economic systems, as correctly underlined by Milward and Saul (1973, Introduction). Wrigley (1988), North and Weingast (1989) and Toynbee (1969) can all be included in this category. They are valid and insightful theories, yet they would benefit from a proper synthesis, which could link the diverse aspects together in a more comprehensive framework.

Finally, there are two other classes of theories, both of which successfully recognize the relative impact of a broad set of factors, rather than simply focusing on a single determinant, by assigning to each element different weights based on their relevance in their reciprocal interaction. *complex-and-thus-stochastic theories*, nevertheless, maintain that it is impossible to reach an ultimate causal explanation, regardless of how meticulously the research may have been conducted, and thus they tend to view progress as a stochastic (i.e. casual) variable. They are skeptical of general laws and afraid of hindsight bias, highlighting through historical examples the ever-changing

Theory type	Authors
Heroic	Smiles
Laundry-list	Kranzberg and Ashton
Gradualist	Clark
Single-factor	Wrigley, Toynbee, North
Complex-and-thus-stochastic	Crafts, early Mokyr
Complex-yet-deterministic	Allen, later Mokyr, Landes

Tab. 4: A taxonomy of theories.

nature of social development. Although they generally accept that some preconditions facilitate progress, they ultimately address development as an intrinsically random phenomenon. Based on what we have previously said, we can safely include in this classification the contributions of Crafts (1977) and the early Mokyr (1990).

On the other side, *complex-yet-deterministic theories* believe in the eventuality of reaching a perfect – or, better said, almost perfect – understanding of why it all happened, when it happened, where it happened. Obviously, this is the most ambitious methodological approach to the study of the Industrial Revolution (and economic history in general), and for this reason it is also the most prone to criticism and mistakes: it might as well be described as the *high risk, high reward* approach. Despite its fragility - one can always find in these explanations innumerable flaws produced either by incomplete understanding or by uncertain causal linkages - this approach is probably the most apt as a heuristic tool: it stimulates every kind of speculation, maintains that it is possible to find coherent answers through empirical research, and does not impose any limits to intellectual research. If one general trend can be discerned within the discipline of Economic History in recent years, it will be the net prevalence of these theorizations above all others. Today, the most influential and discussed contributions are those by Allen (2009) and Mokyr (2009) which, however different they may be, are nevertheless firmly situated on a deterministic pathway. Older works like Landes (1969) and Rostow (1960) also belong to this category.

5 Conclusions

"*There was an Industrial Revolution and it was British*" – Max Hartwell

With this, we conclude our essay. We hope it has been useful in helping readers better understand the essence and the underlying dynamics of the British Industrial Revolution. In Section 2.1, we examined various definitions given by the literature on the concept of Industrial Revolution, and we stressed how the technological interpretation appears the most fruitful, in heuristic terms, to be pursued. A discussion on this particular topic would not be complete without a brief overview on the fundamental drivers of industrialization, and this we provided - far from being exhaustive - in Section 2.2. Having then focused our analysis on technological change, we presented the points of view belonging to three influential scholars who, in a heated debate featuring parries and ripostes going on for over twenty years (and still not solved), argued that advances in techniques occur, respectively, serendipitously or deterministically. To solve such a tricky controversy, which has often been described as a 'dialogue among the deaf', we delved deeply into the nature of technological development, addressing the difference between micro and macroinventions, the role that outsiders can play in the discovery process and, most importantly, its pervasiveness throughout the whole British economy during the Revolution, in contrast to accounts which maintain it to have been concentrated and limited to a very small sample of innovative industries. We wish our readers to acknowledge how every step of our study has actually been functional to reach the conclusion that, ultimately, it was not the product of chance that the Industrial Revolution "took off" where it historically did. Through many examples of smaller industries experiencing significant growth without the need for serendipitous macroinventions, we believe to have strengthened the position of those who refuse to conceptualize the Industrial Revolution as a matter of a single 'football match' among already developed Nations - notably England and France in our concern - and who instead prefer to view the entire process more as a 'whole championship', where the significant victories have been achieved by Britain in many different moments, in many different fields. Thus, we refuse the interpretation of the Industrial Revolution as a unitary and *unique* phenomenon, and we desire to convey the overall complexity of the process. No single event decided the course of British industrialization. Instead, it was the steady flow of incremental improvements, for which Britain was so well endowed, that over the course of a century introduced modernity into the traditional world.

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