The Spread of Improvement: Why Innovation Accelerated in Britain 1547-1851

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This working paper is a short overview of a much longer book project.

ABSTRACT

In the three centuries after the reign of Henry VIII, the British Isles emerged from civil wars, invasion threats, and religious strife to become the world's technological leader. Why did innovation accelerate? I studied the people responsible, the innovators themselves, using a sample of 1,452 people in Britain who innovated between 1547 and 1851.

The paper charts the emergence and spread of an improving mentality, tracing its transmission from person to person and across the country. The mentality was not a technique, skill, or special understanding, but a frame of mind: innovators saw room for improvement where others saw none. The mentality could be received by anyone, and it could be applied to any field – anything, after all, could be better.

But what led to innovation's acceleration was not just that the mentality spread: over the course of the eighteenth century innovators became increasingly committed to spreading the mentality further – they became innovation's evangelists. By creating new institutions and adopting social norms conducive to openness and active sharing, innovators ensured the continued dissemination of innovation, giving rise to modern economic growth in Britain and abroad.

INTRODUCTION

In 1547, the year that Henry VIII died, the British Isles peripheral to European technological development.[1] Glass-makers, for example, were said to be almost entirely lacking, and it would be some decades, despite the encouragement of the state, before foreign glass-makers could be enticed to bring their expertise.[2] Even England's textiles, its main export, were hampered by dyes of poor quality. A petitioner to the Crown in 1553 did not mince his words when discussing the state of the industry: "no man almost wyll meddle with any coullours of clothe touchinge wodde and mader [woad and madder] . . . that is dyed within this realme".[3] The bulk of the patent monopolies granted were to foreigners, to encourage them to bring their expertise, and to train the local population. The preoccupation was not with developing technologies that were new, but with simply keeping pace.

And yet, three centuries later, in 1851, the United Kingdom had become the world's technological leader. Over six million people – equivalent to almost a fifth of the country's population – flocked over the course of only five months to the Great Exhibition in Hyde Park, London, to celebrate the remarkable and rapid change.[4] Whereas in 1547 scarcely anyone in England had known how to make any kind of glass, let alone glass that was crystal-clear, in 1851 the venue for the Great Exhibition was the largest enclosed space on the planet, constructed with 300,000 of the largest panes of clear glass ever produced – a Crystal Palace.[5]

Britain's transformation from a technological backwater into an innovation superpower – an Industrial Revolution – was brought about by an unprecedented acceleration in the rate of innovation. [6] A student of the historian T.S. Ashton famously called the

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[1] I will use "British" throughout to refer to the British Isles: the geographical area that comprises today's United Kingdom and the Republic of Ireland. This is for the sake of convenience: the kingdoms of England and Ireland were united under one ruler from 1542, with Scotland added the personal union in 1603. England and Scotland were in 1707 officially united as the kingdom of Great Britain, and in 1801 Ireland was added to the official union to create the United Kingdom.
[2] Hulme, 'The Early History of the English Patent System', 127.
[3] Cholmeley, 'The Request and Suite, &c.', 9.
[4] Auerbach, *The Great Exhibition of 1851*, 1.
[5] Ibid., 32, 135.
[6] Although innovation's acceleration is commonly accepted, economic historians continue to debate how much the economy grew. See: Deane and Cole, *British Economic Growth 1688-1959*; Crafts, *British Economic Growth During the Industrial Revolution*; Crafts and Harley, 'Output Growth and the British Industrial Revolution'; Berg and Hudson, 'Growth and Change'; Temin, 'A Response to Harley and Crafts'; Crafts, 'Productivity Growth in the Industrial Revolution'; Clark, 'Macroeconomic Aggregates for England'; Broadberry et al., *British Economic Growth, 1270-1870*.

transformation a "wave of gadgets",[7] but this does not capture the breadth of industries affected. James Watt developed the separate condenser for steam engines and Richard Arkwright spun cotton with his water frame, but technological leaps occurred in nearly all industries, beyond the famous examples of cotton, iron, and steam.[8] It was also the age in which Edward Jenner developed vaccinations against smallpox, and in which John Bennet Lawes used superphosphate of lime as a fertiliser. Innovation accelerated in agriculture, medicine, brewing, furniture-making, photography, and even gardening.[9]

Britain's acceleration of innovation was not just a wave of innovations; it was an increase in the number of people who innovated – the men and women in the upper tail of the population's distribution of talent, who pushed the technological frontier (see Figure 1).[10] This paper introduces a new sample of 1,452 people, active in the British Isles, who became innovators between 1547 and 1851 (an exercise for which there is ample precedent).[11] It includes all of the celebrated names, like Richard Arkwright or James Watt, but also captures hundreds of the lesser-known or near-anonymous marginal improvers and tinkerers, both expert and amateur.

Innovators are sometimes distinguished by importance, labelled "macro-" and "microinventors", or "stars" and "tweakers".[12] But this sample does not do so. Assigning significance in such a manner can be biased by prevailing narratives about the Industrial Revolution, and is done with the distorted lens of hindsight. Of course, some innovators were more financially successful than others, or have since received longer-lasting recognition. Some were more prolific, or were better at advertising their achievements. But all of the people in the sample improved things. The aim is to understand why they became innovators, rather than passing judgement on their eventual impact.

Innovation is a process with many steps, from noticing an opportunity for improvement, to designing a solution, implementing it, and then adjusting it further. Many people likely only noticed opportunities and never bothered to record or exploit them –

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[7] Ashton, *The Industrial Revolution, 1760-1830*.
[8] Unless otherwise stated, biographical details about innovators are taken from their respective entries in the online *Oxford Dictionary of National Biography*.
[9] Mokyr, *The Enlightened Economy*.
[10] Mokyr, 'Long-Term Economic Growth and the History of Technology', 1157.
[11]See, for example: (Allen, 2009, pp. 242–271; Khan, 2015; Khan and Sokoloff, 1993, 2004; MacLeod and Nuvolari, 2006; Meisenzahl and Mokyr, 2011)
[12] Allen, *The British Industrial Revolution in Global Perspective*; Mokyr, *The Lever of Riches*; Meisenzahl and Mokyr, 'The Rate and Direction of Invention in the British Industrial Revolution'.

unfortunately, they very rarely, if ever, become known to us. The men and women in the sample were therefore those who at the very least put pen to paper, voiced their ideas to others, or implemented their designs. But the designers, the implementers, and the tweakers were all still innovators. Note, however, that innovators were not always entrepreneurs (although they often were). Following on from Joseph Schumpeter, innovation has taken on a meaning distinct from invention, to refer to the development of improvements to be sold on the market.[13] But for the purposes of this paper I define innovation according to the more popular usage, as a catch-all term for improvements that are both physically tangible (usually referred to as inventions) and intangible (such as Alanson's technique of washing hands before operations).

Note, also, that innovators were not scientists (then called natural philosophers). Science is the practice of advancing our *understanding* of the world, whereas innovation is the distinct activity of *improving* the world, in the sense of contriving or implementing new objects and ways of doing things. Innovators often exploited knowledge of nature's laws, famously so in the case of vacuums and steam engines, but what distinguished them from natural philosophers was that they applied their understanding towards improvement. Sir Isaac Newton is included in the sample for his invention in 1669 of a reflecting telescope, not for his celebrated contributions to our understanding of physics.

The sample is the largest of its kind: it fully incorporates older lists,[14] and adds almost six hundred new names from a variety of other sources.[15] The additions include innovators who appeared in the ODNB since the older lists were compiled or who had otherwise been accidentally omitted;[16] innovators mentioned in works that have in general brought attention

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[13] Schumpeter, *Business Cycles*, 80–85.

[14] Allen, *The British Industrial Revolution in Global Perspective*, 269–71; MacLeod and Nuvolari, 'The Pitfalls of Prosopography'; Meisenzahl and Mokyr, 'The Rate and Direction of Invention in the British Industrial Revolution'. Although the sample includes many names from pre-existing lists, some who feature in those lists were omitted. Many, for example, only started innovating after 1851. Others were excluded for being hoaxes or frauds (like Samuel Alfred Warner, who in 1819 convinced the British government that he had invented an invisible shell). Still others were excluded, despite being British-born, for never innovating in Britain. And lastly, some names were excluded because they were not innovators at all, but rather patent agents.

[15] For the key findings of this paper, I provide the relevant figures that were found using the innovators mentioned in each of the older lists.

[16] An unsurprising occurrence, because the ODNB, reliant as it is on thousands of different contributing authors, does not describe innovators or innovations systematically, instead often using more ambiguous terms such as "new designs" or "improvements".

to relatively neglected industries;[17] innovators mentioned in the histories of other neglected areas that nonetheless experienced considerable innovation, such as brewing, coachmaking, medicine, and map surveying; [18] innovators mentioned in *A History of the Royal Society of Arts*, which emphasised industries where patenting was less common;[19] and innovators mentioned in Autumn Stanley's *Mothers and Daughters of Invention*, which specifically sought to list female innovators.[20] The sample also provides a fuller picture of innovation before the "classic" period of the Industrial Revolution by including innovators of the late sixteenth and early seventeenth centuries.[21] It therefore covers the longest span of time. The sample is, moreover, the most closely researched: it goes beyond the use of biographical dictionaries to also include information found in biographies, memoirs, letters, newspapers, genealogical records, and other archival sources. This research has allowed for the recovery of information about hundreds of hitherto near-anonymous innovators. The paper thus provides the most detailed and comprehensive portrait to date of the innovators responsible for the British Industrial Revolution. By examining their lives, we may discover why they became more numerous.

IMPROVEMENT AS A MENTALITY

How was innovation's acceleration caused? Some argue that property rights became more secure such that innovators felt confident enough to invest in improvements;[22] or that the patent system developed such that innovators could reveal their secrets and still profit from them;[23] or that people in Britain were particularly skilled or well-educated so that

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[17] Berg, *The Age of Manufactures, 1700-1820*; Berg, *Luxury and Pleasure in Eighteenth-Century Britain*; Bruland, 'Industrialisation and Technological Change'; Mokyr, *The Enlightened Economy*.
[18] Sumner, *Brewing Science, Technology and Print, 1700-1880*; Gilbey, *Early Carriages and Roads*; Magner, *A History of Medicine*; Hewitt, *Map of a Nation*.
[19] Between 1765 and 1845 patented innovations were not (officially) allowed to win prizes issued by the Society. Its history is therefore a rich source of the names of non-patentees, and it generally emphasises industries where patenting was uncommon, such as agriculture, agricultural machinery, horticulture, non-electric telegraphy, and textile design, as well as mentioning those people whose improvements had humanitarian aims. Wood, *A History of the Royal Society of Arts*.
[20] This brought the total number of female innovators to 15: still only 1% of the total, but far higher than the one or two names who tend to feature in other lists. Stanley, *Mothers and Daughters of Invention*.
[21] I checked for earlier names in the sources used by the pre-existing lists, and also included innovators mentioned in works that discuss Elizabethan and Stuart science and technology: Jenkins, *The Collected Papers of Rhys Jenkins*; Harkness, *The Jewel House*.
[22] North and Thomas, *The Rise of the Western World*.
[23] Bottomley, *The British Patent System during the Industrial Revolution 1700–1852*.

innovators could more easily get their designs implemented;[24] or that British society started to accord dignity to the middle classes so that more people felt able to "have a go";[25] or that demand was structured in such a way as to make important innovations particularly profitable.[26] And so on. All of the above factors assume the same thing: that innovation has always been among a given person's set of choices. Their implicit claim is that, other than in mid-eighteenth century Britain, save for a few short-lived "efflorescences",[27] choosing innovation had simply not been worth it.

The problem with this assumption is that the absence of innovation before the eighteenth century was not always for want of opportunity. Easy solutions to technological problems could go unexploited for centuries, even millennia. Take John Kay's flying shuttle, which is today famous for improving the efficiency of weaving cotton. What makes the invention so extraordinary is that it could easily have been developed centuries prior. Bennet Woodcroft, a nineteenth century compiler of patent records, expressed his astonishment that the use of shuttles on a horizontal loom had been "performed for upwards of five thousand years, by millions of skilled workmen, without any improvement being made to expedite the operation, until the year 1733". And all Kay had added was some wood and some string – it was an improvement that required no new materials, nor any advanced scientific knowledge. It was also first applied to weaving wool, which had been one of England's major exports since the thirteenth century, and which by the sixteenth century had become its largest.[28] As for institutions, the patent system offered little protection: the invention was immediately pirated by Kay's competitors to little avail. He was even forced to move to France, amid threats from weavers to his property and even his life.

Rather than asking why the flying shuttle was invented in 1733, we should ask why it was not invented centuries earlier: one of the most revolutionary innovations of the Industrial Revolution was a minor adjustment to an ancient industry, applied to an ancient technology, using ancient materials, and applying no new scientific knowledge. Kay thus faced no special incentives, even innovating successfully *despite* some significant costs.

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[24] Kelly, Mokyr, and Ó Gráda, 'Precocious Albion'.
[25] McCloskey, *Bourgeois Dignity*.
[26] Allen, *The British Industrial Revolution in Global Perspective*.
[27] Goldstone, 'Efflorescences and Economic Growth in World History'.
[28] Broadberry et al., *British Economic Growth, 1270-1870*, 144.

Kay's flying shuttle is not alone in having been low-hanging fruit, for centuries unpicked. The same is true of Lewis Paul's carding machine, of Richard Arkwright's water frame, and of many of Edmund Cartwright's improvements to textile machinery. Albeit famous for their later effects on the cotton industry, their patents often list applications to silk, linen, hemp, hair, and wool – not just cotton.[29] They again involved simple additions, using no new materials, to technologies that were ancient. To echo Woodcroft, how many hundreds of thousands of skilled people must have carded, spun, and weaved, under innumerable institutional and market conditions, before Paul, Arkwright, Cartwright and their ilk saw room for improvement?

The persistence of such unpicked low-hanging fruit is further demonstrated by the number of British innovations that had been anticipated elsewhere, sometimes by hundreds or thousands of years. Chinese innovators had developed multispindle spinning wheels and treadle looms as early as the eleventh century. By 1690 they had even contrived a "proto-Bessemer converter", which would not be developed in Britain until the 1850s.[30] The seed drill of 1701, for which Jethro Tull would become famous (and have a rock band named after him), was another remarkably simple improvement to an ancient industry: agriculture. It, too, had been anticipated in China before the third century; and it was even used in Mesopotamia in the 3rd millennium BC. The technology did not appear in Europe, let alone in Britain, until the sixteenth century.[31] Of course, many of the innovations of the Industrial Revolution did require prior scientific or technological advances. But the above examples demonstrate that innovation could fail to occur even when all of the incentives were in place.

I suggest that innovation is not always among a person's set of choices, but is instead a practice that is received: when people do not make improvements, it is often simply because it never occurred to them to do so. Incentives matter too, of course. But before they can even take the costs and benefits of innovation into account, people require an improving mentality. Such a mentality was not an abstract ideal, nor was it a skill: it was a lens through which to see the world. It was a frame of mind through which processes and products appeared imperfect, and in need of bettering. Henry Dircks, a nineteenth century inventor, expressed it thus: "No work of art appears perfect . . . it may possibly be made lighter, stronger, more efficacious, or be done away with altogether. The man whose mind is thus constituted

[29] Woodcroft, *Alphabetical Index of Patents*, 11, 94, 431.
[30] Mokyr, *The Lever of Riches*, 220–21.
[31] Needham and Bray, *Science and Civilisation in China*, 258–71.

becomes an Inventor".[32] As a mindset, the improving mentality was much like how a devotee of Karl Marx might at the root of every social problem see the effects of capitalist exploitation; or how a libertarian might everywhere see the hand of an overbearing state. But it was not necessarily ideological: it was also similar to how a rock climber might view a wall as something to clamber over rather than as a barrier.[33] The improving mentality was thus not any particular expertise or understanding – it was *a way of thinking*.

As a mindset, it was not something that could simply be switched off, at least not easily. It was habitual, compulsive. Charles Babbage wrote of his "inveterate habit of contriving tools".[34] Herbert Spencer wrote of his father that "improvement was his watchword always and everywhere", and that this could even become debilitating, driving him to constantly amend everything he did, never quite reaching perfection, such that even the dictionaries he bought became smothered with revisions and emendations.[35] Henry Bessemer described how "the love of improvement . . . knows no bounds or finality"- it compelled ever more tweaks.[36]

Innovators thus everywhere saw room for improvement, but could also find it difficult to unsee. Bessemer complained that, even when trying to focus on other professional pursuits, "it was my misfortune that inventions sprung up in my mind without being sought".[37] John Baskerville described how, having in typefounding noticed "room for improvement" in founding types for book-printing, he "became insensibly desirous of contributing to the perfection of them". And Francis Pettit Smith, after his development of the screw propeller brought him only financial ruin, was understandably reluctant to invent again. But he reportedly could not help thinking about it: "if anything comes into my head, I give it a tap and say, 'Be off with you! I've suffered too much by such intrusions'".[38]

Crucially, the improving mentality spread from person to person, much like a disease – a spread that I will outline in detail below. Like a disease, it could infect anyone: the innovators in the sample included rich and poor, city-dwellers and rustics, Anglicans and dissenters, Whigs and Tories, skilled engineers and complete amateurs. Indeed, over a third

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32 Dircks, *Inventors and Inventions*, 9.
33 Baskerville, 'Preface', A3.
34 Babbage, *Passages from the Life of a Philosopher*, 2.
35 Spencer, *An Autobiography*, 60–61.
36 Bessemer, *Sir Henry Bessemer, F.R.S.*, 10.
37 Ibid., 128.
38 Berthon, *A Restrospect of Eight Decades*, 69.

of the sample (34%) innovated in areas for which they lacked the requisite education or training. Their skills, in other words, were irrelevant to their innovations. Edmund Cartwright, for example, famous for his invention of the power loom, was an Anglican clergyman, who at university studied only classics and poetry. And such a lack of expertise was not limited to wealthy hobbyists: Richard Arkwright, before inventing machines to improve the carding and spinning of textiles, had no experience of either process. He had a trade, but this was as a barber and a wigmaker – professional experiences that gave him no special tacit knowledge with which to make his improvements. Such cases, and the fact that they were so common, further suggest that what spread was a mindset, not any particular skill or understanding.

Indeed, Henry Bessemer recounted that when he started his career it was his “inventive turn of mind” that allowed him to overcome “the great disadvantage of not having been brought up to any regular trade or profession”.[39] When discussing his most celebrated work on steel, he even suggested that too much training could even be a barrier to innovation: “My knowledge of iron metallurgy was at the time very limited . . . but this was in one sense an advantage to me, for I had nothing to unlearn”. People could be skilled, but if they did not see room for improvement they could become complacent in their practical knowledge, sometimes believing that improvements were impossible, “having to stuggle against the bias which a lifelong practice of routine operations cannot fail to more or less create”.[40] In a letter to a friend, Cartwright complained of how the mechanics he had hired in Manchester to build his power loom had “not even begun upon” the machine because they “were not willing to consume their time upon a fruitless pursuit”.[41]

All innovations of course involve the application of *some* kind of knowledge or *some* kind of skill. And so where they lacked the relevant expertise to bring about an envisioned improvement, innovators either self-educated, or else relied upon the expertise of others. Patrick Bell, a farmer’s boy, noted that when he invented his widely-adopted reaping machine “no man could have been less slenderly furnished with books calculated to instruct him in the science and history of mechanical invention”.[42] Although he was able to do his

[39] Bessemer, *Sir Henry Bessemer, F.R.S.*, 9.
[40] Ibid., 136.
[41] Strickland and Strickland, *Edmund Cartwright*, 72.
[42] Bell, ‘Bell’s Reaping Machine’, 186.

own experiments and make his own working models, the creation of a full-sized machine required outsourcing its constructon to a foundry, a wheelwright, and two blacksmiths.[43]

As a mindset, separate from any particular skill or understanding, the improving mentality's emergence and spread can also account for how improvement accelerated simultaneously in industries as different as gardening, surgery, and engineering. After all, *anything* could be better. Lancelot Brown looked out over the gardens of the wealthy and declared them "capable" of improvement. He said it so often that he earned himself the nickname Capability Brown. The architect Robert Salmon suffered from a hernia and contrived a surgical truss to alleviate it. William Cecil, a country vicar who developed telescopes, ear trumpets, and a tool to draw teeth, even tried to apply the improving mentality to his work as a clergyman. He systematically categorised the quality of hymns, and constructed a "mechanical apparatus for teaching psalmody, to large assemblies of children", which consisted of a sort of sing-along chart suspended from the wall, to which he could pin notes and symbols of painted tin.[44] A young engineer, William Fairbairn, even got carried away and tried to apply the improving mentality to romance: by reverse-engineering the published correspondence of a pair of lovers in a magazine, he maintained that he had "inadvertently rendered one of the strongest passions of our nature subservient to the means of improvement".[45]

The improving mentality can, in the same way, account for the sheer breadth of industries that could be improved by even a single innovator. Edmund Cartwright, in addition to the power loom, also developed agricultural machinery; designed fireproof building materials; made medical discoveries; contrived a crank-operated, horse-less "centaur carriage"; and experimented with manures and potatoes as the superintendent of the Duke of Bedford's model farm. Of the sample of innovators such polymaths were not rare – in fact, they were in the majority (55%).

The educated often acquired the mentality when they read about and understood innovation in the abstract: they adopted accompanying beliefs about the acceptability of contesting tradition, and about the benefits of progress. And the educated could transfer these beliefs, along with the mentality, to those who were more practical. Both Margaret Jacob and

[43] Ibid., 191.
[44] Yule, 'In Memory of the Rev. William Cecil, M.A., Sometime Fellow of Magdalene College and Fellow of the Cambridge Philosophical Society', 10–11.
[45] Fairbairn, *Life of Sir William Fairbairn*, chap. 4.

Joel Mokyr have stressed such linkages between *savants* and *fabricants*, between the learned and the makers.[46] But the mentality also spread without necessarily taking with it the ideals and beliefs that it originally rested upon; it could be transferred through emulation, from *fabricant* to *fabricant*. Edward Thomason recounted how "having been accustomed" during his apprenticeship to Matthew Boulton "to witness continual new inventions in mechanism and metallurgy, the mind became restless to produce some novelty or invention".[47] The tinkerers did not need to believe that their marginal improvements would help to fulfill some grand progressive vision; they simply needed to see that an existing product or process could be better.

What was transferred between the *fabricants* was not just useful knowledge – the understanding of regularities or techniques for applying them that Mokyr identifies.[48] In other words, they did not just imitate particular technologies, but emulated innovation *in general*. Useful knowledge spread too, but what the chapter identifies is the spread, alongside it, of a mentality that could be applied to anything: innovative potters of course inspired others to improve ceramics, but they also inspired others, like James Brindley, to improve steam boilers or canals.

Thus, once infected with the improving mentality, people everywhere saw room for improvement. It was not a technique, nor a skill, nor any special understanding, nor even an abstract idea – it was instead a mindset. In the following sections I will outline the mentality's origins, and the manner in which it spread. Most importantly, I will discuss why in the eighteenth century its spread accelerated.

THE IMPROVING MENTALITY'S ORIGINS, 1550-1700

Many innovations of course pre-date the period. But improvement is not always actively pursued. Technology can develop gradually, the product of an evolutionary process without purposeful direction. Joseph Henrich describes how indigenous Tukanoans of the Colombian Amazon developed a way to remove cyanide from manioc, one of their staple crops. It could take years or even decades before the effects of chronic cyanide poisoning

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[46] Jacob, *Scientific Culture & the Making of the Industrial West*; Jacob, *The First Knowledge Economy*. Mokyr, 'Long-Term Economic Growth and the History of Technology'; Mokyr, 'The Intellectual Origins of Modern Economic Growth'.
[47] Thomason, *Sir Edward Thomason's Memoirs during Half a Century*, 1:3.
[48] Mokyr, *Gifts of Athena*.

began to take effect, so they would have had no way of experimenting individually with how to process manioc. Instead, traditions built up over time, each of them seemingly obscure and none of them understood, but all essential to avoid chronic poisoning. When Portuguese colonists tried to transport manioc to West Africa without also adopting the traditions, cyanide poisoning became a problem there.[49] Like a language, technology can thus evolve without purposeful innovators, spontaneously. As Alfred North Whitehead put it, before the Industrial Revolution "change was slow, unconscious, and unexpected".[50]

Improvement as a purposeful activity does, however, pre-date the British Industrial Revolution: the Hellenistic Mediterranean had its Archimedes, the Medieval Islamic world its Banu Musa brothers, Song Dynasty China its Su Song, the Italian Renaissance its Leonardo da Vinci, Edo-era Japan its Hiraga Gennai, and the Dutch Republic its Christiaan Huygens. Britain, too, had innovators before the acceleration, many of whom are captured in the sample. But in these societies and in Britain before 1700, the improving mentality spread passively. Time spent with an innovator might inspire a person to improvement, but the innovators were, for the most part, not especially interested in sharing it. Da Vinci did not publish his designs, and even took active measures to keep them secret. Ralph Rabbards, in a 1574 list of inventions sent to Queen Elizabeth I, promised to reveal the details only in exchange for a "smalle chardge".[51] Hugh Plat, writing in 1592, would do exactly the same, offering inventions that "the author proposes to disclose upon reasonable considerations".[52]

From the late sixteenth century, however, this reticence to share gave way to a culture of openness, sharing, and then even active evangelism. We will probably never know who was the first to possess the improving mentality – indeed, it may have been independently adopted at various times throughout human history. Nonetheless, we may be able to identify the people who spread it to the British Isles, at least in the sense of sowing the seeds for the eighteenth century's acceleration. Among the very earliest was John Dee, today best known for becoming Elizabeth I's astrologer – an association with the occult that has inspired countless representations in fiction. In 1547, just a few months after the death of Henry VIII, the 19-year old Dee travelled to Leuven, in Brabant (in present-day Belgium), "to speak and conferr with some learned men, and chiefly Mathematicians, as Gemma Frisius, Gerardus

[49] I am grateful to the anonymous blogger "Pseudoerasmus" for bringing this example to my attention. Henrich, *The Secret of Our Success*, 97–99.
[50] Whitehead, *Science and the Modern World*, 96.
[51] Halliwell-Phillipps, 'Letters on Scientific Subjects', 7.
[52] Harkness, *The Jewel House*, 232.

Mercator".[53] Frisius was the inventor of triangulation, the fundamental principle of surveying, and consequntly of accurate map-making. And he had by then devised new navigational instruments, some of which Dee brought back with him to England. Dee would, however, become closest to Mercator, who was chief among Frisius's protégés. Mercator by the time of Dee's visit in 1547 was already constructing exceptional new globes, and in 1569 would develop the map projection that bears his name, which corrected for the curvature of the earth to depict sailing courses as straight lines.

Dee's personal contributions as a mathematician were modest, and he is only included as an innovator in the sample for introducing the major European navigational innovations to England – a border-line case that blurs the distinction between innovation and technological diffusion. But he appears to have been a significant vector for the spread of the improving mentality, often featuring in the early lives of many later English inventors, before they themselves apparently innovated. The sailor and privateer John Davis first described his newly invented backstaff in 1594 – a quadrant that allowed sailors to measure the height of the sun in the sky without having to stare directly at it – but had known Dee since at least the early 1580s. Leonard Digges, who developed the theodolite for surveying, was also one of Dee's closest friends: upon Digges's death, his son Thomas (yet another inventor of navigational instruments) was placed under Dee's foster care. Thomas Digges would refer to Dee as his "revered second mathematical father".

Davis and Digges, like Dee, were interested in improving navigational instruments. But what Dee helped to introduce to England was not just useful knowledge – it was an improving mentality that could be applied to any other field. In 1582 one of Dee's friends introduced him to a son-in-law, Hugh Plat, a young lawyer who fancied himself a poet.[54] Ten years later Plat published a list of inventions that ranged from pasta-making machines and sweet-smelling oils, to methods of preserving food or rain-proofing garments. Some of Plat's reported inventions were related toinstruments, such as a perspective-drawing machine, but the rest covered everything from agriculture to weaponry. Similarly, Sir Robert Dudley, who was the son of Dee's patron the Earl of Leicester, would in the early seventeenth century develop an azimuth dial or "lunar computer", and complete the first English sea atlas to use the Mercator projection (particularly notable given Dee's close friendship with Mercator himself). Dudley, like Plat, did not restrict his innovation to navigational instruments: he also

[53] Dee, 'The Compendius Rehearsal of John Dee', 500–501.
[54] Thick, *Sir Hugh Plat*, 26.

proposed a new form of ship he dubbed the "Gallizabras" and developed a purgative medicinal powder. What Dee conferred was not just his mathematical expertise, but the verve for improvement in general.

The historian Paul Slack argues that over the course of the seventeenth century the word "improvement" emerged uniquely in England, particularly with its meaning as something that was generalisable to anything – even a hundred years later continental Europeans failed in their attempts to find a direct synonym.[55] But although the concept in the abstract was first described in English, the mentality itself was likely imported. We have already seen how Dee was influenced by Frisius and Mercator in the Low Countries – they had before 1547 already been making improvements to various instruments and navigational techniques. And for much of the late sixteenth century many of the sample's innovators were involved in catching up with continental advances as much as they were in originating new ones – England, after all, was in 1547 a technological backwater.

Matthew Baker, for example, picked up valuable knowledge of Venetian ship-building techniques during his time in the 1550s sailing in the Mediterranean. He also drew upon geometrical techniques developed by Albrecht Dürer.[56] From the 1570s Baker developed shallower and faster galleons, and in the 1580s he was the first English shipwright to apply mathematical techniques to ship design. Likewise, many of the innovators of the 1560s were German metallurgists, such as Burchard Kranich, Daniel Hoechstetter, and Christopher Schütz, who were recruited to introduce the brass industry to England. And on the site of Schütz's furnace in Dartford, the German jeweller Johann Spielman would introduce England's first successful paper mill.

Such European influences continued into the early seventeenth century. The Dutch merchant Thomas Rous and his English brother-in-law Abraham Cullen in 1626 tried to introduce Dutch techniques for producing stoneware ceramics. And Inigo Jones, on a trip to Italy in 1601, read the works of the Venetian architect Andrea Palladio, which prompted him to apply Vitruvian rules of proportion and symmetry first to the designs of theatre sets and masque costumes, and then, more famously, to architecture. Likewise, the Dutch-born civil

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[55] In the early sixteenth century the word meant, roughly, profitable agricultural management. Slack, *The Invention of Improvement*, 5–6.
[56] Johnston, 'Making Mathematical Practice: Gentlemen, Practitioners and Artisans in Elizabethan England', 153–54.

engineer Cornelius Vermuyden would from the 1620s introduce many of his country's techniques for land drainage.

Thus, over the late sixteenth and early seventeenth centuries, the improving mentality was gradually diffused to England along with European technologies: knowledge spread, along with the practice of applying it to improvement – the improving mentality. At the same time, improvement began to be theorised and abstracted, particularly by those who were learned, the *savants*. Dee's "worthy mathematical heir" Thomas Digges explained in 1579 how he turned away from the "Mathematicall Demonstrations" that had occupied his early life. It was in graduating from such musings in the abstract that Digges acquired an improving mentality (although at this early stage the word improvement was not yet used): "after I grew to yeares of riper judgement, I have wholly bent my selfe to reduce those Imaginative contemplations to sensible Practicall Conclusions". His learning in mathematics allowed him to see room for improvement, "finding the great imperfections in the Arte of Navigation". But Digges's improving mentality went beyond the application of just mathematics; he also sought to apply his understanding of ancient Roman military history to remedy the "ignorance and imperfection" in the "Arte of Discipline".[57]

As mentioned above, the *savants* held to ideas that accompanied the improving mentality. Two in particular are worth mentioning, as they appear to be the most common: a belief in the acceptability of contesting tradition; and a vision of the benefits of progress. On contesting tradition, Digges complains of how those with practical experience of soldiery refused to recognise the need for improvement, immediately dismissing anything that "should be desired in a Souldier that wanted in themselves"; his aim was "to awake our Nation out of that secure Dreame". As for the vision of progress, Digges echoed many of his contemporaries when he claimed that he was applying his knowledge "to the service of my Prince and Countrie" – in support, he recalled "that grave sentence of Divine Plato, that we are not borne for ourselves, but also for our Parents, Countrie, & Friends".[58] For the savants, acquiring both beliefs may have been necessary to their developing the improving mentality in the first place. But as stated before, the improving mentality could be transferred on without the accompanying beliefs.

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[57] Digges, *Stratioticos*, iv–v.
[58] Ibid., vii–viii, i–ii.

Almost immediately, the *savants* influenced the *fabricants*. The mariner and compass-maker Robert Norman, for example, in 1581 applied himself to improving the compass. Indeed, he felt the need to justify that practical men, with "Artes at their fingers endes", could engage in a common endeavour of improvement. Norman complained that some of the learned "would have all Mechanitians and Sea-men to be ignorant" of arithmetic and geometry, "alledging against them the latin Proverb of Apelles, *Ne sutor ultra crepidam* [shoemaker, not beyond the shoe]." And here also we see an early form of another idea, which in the eighteenth century would become so widespread: the commitment to spreading innovation further. Norman called upon "the learned in those sciences, being amongst their bookes" to make their knowledge more accessible so that the *fabricants* could "apply them to their severall purposes", all to "the benefitting of my Countrymen, in whom I wish continual increase of knowledge and cunning".[59] This approach would, famously, find its most influential expression in the early seventeenth century in the work of Francis Bacon. But as Mokyr and Slack both note, Bacon was merely the latest in a series of people to develop an explicit program for the *savants* to turn away from theory and understanding for its own sake, apply themselves to practical matters, and to make their knowledge more widely accessible. Among his English precursors were names we have already seen: John Dee, Leonard Digges, Thomas Digges, and Hugh Plat.[60] It was in this context that "improvement" began to emerge in the abstract.

Duing this early period Britain's innovators did not increase dramatically in number, and nor did they appear to be especially numerous relative to the rest of Europe. What made Britain special was not that it possessed people with the improving mentality; it was that British innovators in the mid-eighteenth century became uniquely committed to spreading innovation further. They, and others around them, became innovation's evangelists.

IMPROVEMENT'S ACCELERATION, 1700-1850

The importance of openness has been noted before, particularly as a norm of the scientific world and the wider Republic of Letters. [61] But I here explore the norm's adoption

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[59] Norman, *The Newe Attractive, Showing the Nature, Propertie, and Manifold Vertues of the Loadstone*, ii, iv.
[60] Mokyr, *A Culture of Growth*, 74; Slack, *The Invention of Improvement*, 74.
[61] Mokyr, *The Enlightened Economy*; Mokyr, *A Culture of Growth*; Jacob, *Scientific Culture & the Making of the Industrial West*; Jacob and Stewart, *Practical Matter*.

specifically by innovators (rather than scientists). They became more than just passively open; they and their associates became innovation's active evangelists. A growing number published about innovation, lectured on it, exhibited it, and funded it. They established and joined societies devoted to spreading it further, and they influenced existing institutions, such as the patent system, to become more conducive to sharing too.

Before 1700, Britain's innovators began to form into communities, organising institutions based around their common interests, and thereby laying the foundations for innovation's later acceleration. Many of the mid-seventeenth century innovators in the sample were active members of the Europe-wide Republic of Letters: Christopher Wren, William Petty, Robert Hooke, Robert Boyle. In 1660 these *savants* managed to place their network onto a formal footing, founding the Royal Society. Albeit primarily focused on advancing natural philosophy, the Royal Society's fellows still concerned themselves with improvement. Most importantly, it served as a conduit for the commitment to evangelising innovation.

Indeed, the foundation of the Royal Society was just the earliest of many similar institutions. As James Dowey has shown, the number of such learned societies, committed to the diffusion of innovation and scientific knowledge, increased dramatically: from 49 in 1750 to approximately 1,500 in 1850.[62] **[NB that results about innovators' sharing activities refer only to 675 innovators active 1651-1851. The data is still being collected for the subsequent additions].** Few records of societies survive, but at least 49% of innovators in the sample were members of such societies, rising from under a third before 1700, to over half in the early nineteenth century.

The growing commitment to spreading innovation was also reflected in the growing numbers who published books, journals, and article – the proportion rose from half in the early eighteenth century to two thirds in the early nineteenth. The publishing rate encompassed the writing of articles for encyclopaedias, and the translation of foreign works. The printer and coachbuilder Rudolph Ackermann translated Senefelder's work on lithography in 1818, thereby spreading the technique to Britain. He also published the *Repository of Arts, Literature, Commerce, Manufactures, Fashions, and Politics,* which between 1809 and 1828 sought to keep the public updated on current affairs and on new innovations. The Scottish clergyman Henry Liston, who improved musical instruments and

[62] Dowey, 'Mind over Matter: Access to Knowledge and the British Industrial Revolution'.

agricultural machinery, in 1812 published an *Essay on Perfect Intonation*, in which he described a euharmonic organ he had patented. Liston also contributed the section on "Music" to the *Edinburgh Encyclopaedia*, and even translated Book VI of Caesar's *Gallic Wars* for use in schools. Though the translation of Caesar was unrelated to innovation, it demonstrates his wider commitment to education and the diffusion of knowledge.

Innovators were also committed to evangelising innovation by other means. Just over a third (34%) were committed to education. Robert Willis, an inventor of musical and scientific instruments, in 1838 attracted an audience of some 3,000 people, who flocked to the Newcastle meeting of the British Association for the Advancement of Science to hear him describe advancements in weaving, rope-making machinery, and organs. In 1851, Willis published *A System of Apparatus for the Use of Lecturers and Experimenters in Mechanical Philosophy*, so as to equip others to further instil his passion for innovation. Those who did not teach, could fund it. The shipbuilding innovator Sir Robert Seppings donated to the Admiralty School of Naval Architecture (even though his own son failed to pass the entrance examinations). Richard Roberts, who applied steam power to the loom, in 1824 helped to establish the Manchester Mechanics' Institute.

Just under a third of innovators (31%) also shared their innovations directly. Many sent their improvements to the Society for the Encouragement of Arts, Manufactures, and Commerce (founded in 1754, usually called the Society of Arts, and continuing today as the Royal Society of Arts), which made the designs freely accessible to the public. Some even shared their innovations with societies of which they were not members. Patrick Bell was not a member of any society (that we know of), but submitted his improved reaper machine to the Highland Agricultural Society and to the Society of Arts. The Irish antiquarian and amateur innovator John Whitley Boswell from 1796 submitted some of his inventions to the Society of Arts, but was never formally involved (though in 1807 he unsuccessfully applied there for a job).

Some bypassed societies completely, exhibiting their innovations directly to the public. Thomas Drummond from 1830 arranged for public demonstrations of his improved limelight (as well as publishing descriptions of his inventions in the Royal Society's *Philosophical Transactions*). And a few innovators promoted not only their own improvements, but those of others: William Snow Harris, who developed lightning conductors, between 1829 and 1851 curated the Plymouth Institution's museum.

A tenth of innovators shared their improvements with the government or other official bodies. Henry Greathead constructed his lifeboat for a quasi-governmental organisation tasked with the maintenance of coastal safety, the Brethren of the Newcastle Trinity House. And the toolmaker Joseph Whitworth shared his designs for improved rifles and cannon with the Board of Ordnance. Of course, not all of these submissions were made out of patriotism or an altruistic concern for general welfare – many would have been motivated by the pursuit of personal glory or gain. But freely submitting a design to such organisations still involved the spilling of technological secrets.

15% of innovators consulted or otherwise assisted official bodies. The preacher and actuarial innovator Richard Price, perhaps more famous today for his works of moral and political philosophy, drew up actuarial tables for the Royal Society, compiled tables for insurance and annuity proposals that were submitted to Parliament, and advised on the implementation of the National Debt sinking fund. John Frederick Herschel prepared major reports on reforming constellations, advised James Ross's expedition to the South Pole, and consulted on efforts to establish a global network of magnetic and meteorological observatories. He was also a trustee of the British Museum, a visitor to the Royal Observatory, and sat on the Royal Commission on Standards, set up to try to recover the official imperial measurements lost in the 1834 fire that destroyed Parliament. It may be argued that such consulting activities merely reflected the demands of governments for expertise as technology became more complex. Yet the decision to assist official bodies ultimately rested with innovators themselves. Price turned down requests from Benjamin Franklin and John Adams to advise the United States Congress on financial matters, even despite his vocal support for the nascent republic.

Lastly, at least 18% of innovators are known to have actively assisted others informally. George Stephenson was renowned for being particularly generous with his advice. While waiting for a train at the platform he would offer tips to engineers to improve the efficiency of their locomotives, or show labourers how better to hold their shovels and barrows. The natural philosopher Stephen Hales, inventor of the ventilator, was seemingly incapable of holding a conversation without mentioning improvements. A friend described how "his whole mind seemed replete with experiment which of course gave a tincture and turn to his conversation often somewhat peculiar, but always interesting".[63] Hales offered

[63] Holt-White, *The Life and Letters of Gilbert White of Selborne*, 231.

casual tips to solve an astounding array of everyday problems, from ventilating houses and testing the water in wells, to advising housewives to place inverted teacups in their pies to prevent them boiling over.

In addition to such casual advice, some innovators financially supported other innovators. John "Iron Mad" Wilkinson (whose desk, chairs, and coffin were all cast in iron) supported Joseph Priestley, the dissenting preacher and chemist who first carbonated water, buying him a house in 1780, training his son, and giving him immediate aid in 1791 following the loss of his home and laboratory in the Birmingham "Church and King" riots. Particularly successful innovators also funded societies that disseminated innovations. Robert Stephenson, in addition to a number of other philanthropic and religious causes, bequeathed £7,000 to the Newcastle Literary and Philosophical Society, £2,000 to the North of England Mining Institution, and £2,000 to the Institution of Civil Engineers (altogether equivalent today to about £1million).

Taken together, at least 83% of innovators used one or more of these ways to share innovation – an overwhelming majority, and one that grew from about two thirds of the total in the late seventeenth century, to 90% in the early nineteenth century. And the proportion of innovators committed to sharing innovation may be higher still. Mokyr anecdotally identifies innovators who abstained from taking out patents, suggesting they did so for the good of society.[64] But the inclusion of such innovators should be treated with caution – it is not always clear exactly why some people chose not to patent. The druggist John Walker simply considered his invention of the friction match to be too trivial, and the ingenious carpenter John Wyatt, employed by Lewis Paul on his early spinning machine, seems to have failed to patent out of poverty rather than principle. It matters little to the total figure, in any case, as to whether non-patentees are included: a minimum of 83% is still an overwhelming majority.

But not all innovators shared. At least 12% did things to stifle innovation's spread, or at least hinder it: 5% are known to have been secretive, and the rest either lobbied Parliament to extend their patents beyond the usual terms, or enforced their patents through litigation. A case might also be made for patenting as being opposed to the diffusion of knowledge. But patents were used for a number of reasons. Patenting could be defensive rather than offensive, aimed at protecting innovators from litigation by more aggressive innovators,

[64] Mokyr, *The Enlightened Economy*, 91.

rather than being used to prevent others from adopting innovations.[65] Patents could also be used to merely signal a product's quality to consumers (sometimes even used to boost the sales of products that were fraudulent), rather than to prevent others from selling products that were similar.[66] Patents also became increasingly detailed, and accompanied by diagrams, thus enabling others to more easily take pre-existing innovations and improve upon them further.[67] So patents were not wholly opposed to the diffusion of innovation – they may even have aided its spread.

More obviously stifling of innovation than simply obtaining patents was to use them *aggressively*. By far the most celebrated and cited example of aggressive patenting activity was James Watt.[68] In 1775, he managed to obtain an astonishing 25-year extension on his 1769 patent for steam engine improvements, and then tracked down and prosecuted numerous alleged infringers. He threatened many more, such as the dissenting pastor Humphrey Gainsborough (brother of the artist Thomas), who was on the verge of patenting his own improvements as a defensive measure (rather than drag the dispute through the courts, Gainsborough was unfortunately forced to tend to his wife's last illness, and then to his own fatally deteriorating health).

Watt's aggressive stifling of innovation, however, was by no means the most extreme. The iron pioneer Isaac Wilkinson sued his old partners over patent infringement and the poaching of his workers, and on at least four separate occasions sued his own son. The innovative gun-maker Joseph Manton spent so much money prosecuting rivals for patent infringement in the 1820s that he continually went bankrupt, and was committed to debtors' prison at least five times. One of the rivals he prosecuted was his own brother.

But such attempts to stifle innovation were rare. Only 3% either sought or obtained extensions for their patents, and only 7% were involved in suing others. The figure for suing is especially low considering it includes all those involved, such as Watt's innovative employee William Murdoch who, despite initiating no legal proceedings of his own, conducted the industrial espionage to build Watt's case for prosecution.

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[65] MacLeod, *Inventing the Industrial Revolution*, 73; Macleod and Nuvolari, 'Patents and Industrialisation', 11–12.
[66] MacLeod, *Inventing the Industrial Revolution*, 85–86.
[67] Bottomley, *The British Patent System during the Industrial Revolution 1700–1852*.
[68] For example, see Allen, *The British Industrial Revolution in Global Perspective*, 167; Mokyr, *The Enlightened Economy*, 92.

Activity that stifled innovation was not just rare – some even considered it unrespectable. Shortly before his death, Gainsborough wrote to Watt to complain about his aggressive behaviour and the extension of his patent:

> As you have been ungenteel enough to give me unnecessary trouble, I am only sorry that I did not endeavour to hinder your Bill passing in any form, which I have good reason to believe would have been in my power.[69]

Perhaps the fear of being seen to be "ungenteel" explains why so few innovators aggressively used the patent system or resorted to secrecy – another new institution that supported innovation's spread, albeit one that was informal. One possibility is that evolving ideas of dignity or respectability for commerce may have penalised overtly selfish or monopolistic behaviours rather than simply giving all commercial endeavours license, and thereby aided the acceleration of innovation.[70]

But opposing the spread of innovation in some contexts did not mean opposing it in *all* contexts. Many of the anti-sharing innovators were otherwise pro-sharing. Three quarters of the innovators who stifled innovation were *also* demonstrably committed to its spread, just in other ways. James Watt, despite his aggressively acquisitive and anti-sharing behaviour, otherwise favoured the dissemination of innovation. He was famously a member of the Birmingham Lunar Society, and financially supported an innovative pneumatic medical institute to combat tuberculosis. In later life too, he appears to have mellowed a little in his preference for appropriation over sharing: in 1811, aged 75, he refused all offers of payment for finding innovative solutions to Glasgow's problems of water supply.

Innovators were rarely straightforwardly either pro- or anti-sharing. The number of zealously self-interested innovators, without any countervailing commitment to sharing innovation, was vanishingly small – only 22 people, or 3% of the total. There were certainly zealots on the other end too, who apparently subverted their personal interests in pursuit of the ideal of innovation for all. But most innovators charted a course between the two extremes. They were nearly all committed to the dissemination of innovation, but to varying degrees, and for different reasons. Innovators, like anyone else, had complex motivations.

Richard Roberts, who applied steam power to the loom, was one such character. He was an extremist when it came to improvement: in 1842 after the death of his business

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[69] Tyler, 'Humphrey Gainsborough', 68.
[70] McCloskey, *Bourgeois Dignity*, 283–84.

partner, his obsession with tinkering and experimentation became unmoderated by business acumen and prudence, and he died in abject poverty as a result of his numerous costly experiments. He was also demonstrably committed to the wider proselytisation of improvement, in 1824 helping to establish the Manchester Mechanics' Institute, in 1839 co-founding the Royal Victoria Gallery, and in 1855 donating sixteen scientific models, of which only half were of his own invention, to the Salford Royal Museum. But Roberts also took out some 29 patents and even obtained a seven-year extension on his patent for a steam-powered spinning mule. Given his obvious commitment to sharing innovation, it seems he merely considered patents to be just another form of appropriation. Though he was an ideologically committed evangelist for innovation, he also felt it was perfectly legitimate to make money from inventions using available legal means.

Many innovators found ways to reap the rewards of innovation in a way that did not conflict with their ideological commitment to sharing innovation. The outright use of secrecy was extremely rare, but patents were used by 55% of innovators – a strategy to appropriate rewards that did not automatically stop the spread of invention, and that with detailed specifications could aid it. Innovators also submitted their innovations to societies such as the Society of Arts with the hope of winning honorary medals, or could pursue prestige by publishing their designs. Allen has also identified how, under certain circumstances, it could be in a person's self-interest to share information about improvements through a system of collective invention.[71] And Nuvolari and Sumner identify a strategy of selective revealing, particularly in the brewing industry,[72] whereby innovators could boost the sales of their products by publishing some details of their innovations or openly demonstrating them to the public. Thomas Savery extended the patent for his vacuum pump, yet also described its principles to the Royal Society, in 1702 published a description of a proposed steam engine, and later openly demonstrated how the engine worked to potential clients.

So a growing majority of innovators found a way to reconcile their diverse aims and values with the *norm* of sharing innovation. British innovators did not just improve things – they then tried to spread improvement further. And looking at innovators alone fails to take into account the many more people who were innovation's evangelists – the cheerleaders from the side-lines, who were not necessarily innovators themselves.

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[71] Allen, 'Collective Invention'.

[72] Nuvolari and Sumner, 'Inventors, Patents, and Inventive Activities in the English Brewing Industry, 1634–1850'. See also Henkel, 'Selective Revealing in Open Innovation Processes'.

Henry Brougham, for example, was a key evangelist for improvement, whose organisational energy led to the creation of the Society for the Diffusion of Useful Knowledge, and who helped George Birkbeck found the London Mechanics' Insitute (which survives today as Birkbeck, University of London). One inventor, John Condie, having once exhibited a model locomotive at the opening of the Carlisle Mechanics' Institution, over which Brougham presided, was reportedly "not a little proud" that Brougham recalled the model over three decades later.[73] In 1838 Brougham tried his own hand at innovation, designing a form of horse-drawn carriage that came to bear his name. But he was an important champion of the improving mentality long before he invented.

Another such evangelist for innovation was John Dalton. Although he does not appear to have innovated, Dalton was a significant scientist, famously responsible for developing atomic theory, and heavily involved in innovative circles, particularly as secretary of the Manchester Literary and Philosophical Society. As a tutor, he exerted a direct influence on several young men who would go on to innovate. His students included Samuel Clegg, one of the major pioneers of gas engineering; Eaton Hodgkinson, whose application of the science of tension and compression contributed to the development of cast-iron suspension bridges; James Prescott Joule, who developed electromagnetic engines and applied thermodynamics to brewing; and Bennet Woodcroft, an improver of screw propellers, textile printing machinery, and looms.[74] Dalton encouraged one of his students, the civil engineer Thomas Sopwith, from about the age of 13 to meticulously note down almost everything that he found interesting, antiquarian or scientific or otherwise.[75] The eventual effect was that Sopwith would come to be described by his acquaintances as a "cyclopaedia alive and kicking".[76] Dalton's influence could also apparently be felt at the meetings of the city's Quakers: many of his younger co-religionists would eventually become innovators too.

What is striking about the increase in the proportion of innovators who shared innovation, however, is that it occurred alongside another change in how the improving mentality spread: the influence of the learned, the *savants* of the ilk who founded the Royal Society, appears to have become less and less important. For 1,206 innovators (83% of the sample), I was able to identify connections they had with other innovators, or at least with

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[73] 'Sudden Death of a Glasgow Engineer'.
[74] Woodcroft's name is familiar to economic historians as the compiler of English patent records. He also founded the Patent Office Museum, which survives today as London's Science Museum.
[75] Richardson, *Thomas Sopwith*, 9–10.
[76] Ibid., 4.

prominent evangelists for improvement, prior to the date of their first known innovations.[77] The connections that I was able to find were not necessarily the ones that were influential in diffusing the improving mentality (although some undoubtedly were), but they allow us to identify whether or not innovators could *plausibly* have been influenced by the kinds of connections with scientific or Enlightened circles that both Jacob and Mokyr have emphasised.

For every innovator I first identified cases where their prior contact was with innovators or evangelists for improvement who were *savants*: fellows of the Royal Society, people in wider natural philosophical circles, and so on. Edmund Cartwright, for example, who in 1795 invented the power loom, had recited poetry at the house of the Edinburgh University medical lecturer John Rutherford; and in the 1770s had corresponded with the natural philosopher Thomas Beddoes (who was also a key influence on Humphry Davy).[78] If no *savants* were found among their prior connections, I determined whether or not they had had contact with other innovators who were the makers, artisans, or engineers: the *fabricants*. For example, John Broadwood, who in 1783 patented a pianoforte, was apprenticed to Burkat Shudi, who had also been an inventor of musical instruments. Some contacts, like James Watt, blurred the line between the two distinctions – but in cases such as these I categorised the individual according to the nature of their primary activities: Watt, as a skilled manufacturer, was thus classed as a *fabricant* (although note that he himself had had much early contact with *savants* – Joseph Black and John Robison, for example). Lastly, if no connections to either *savant* or *fabricant* innovators were found, I determined whether or not they had imported their innovations from abroad.

The results are shown in Figures 1 and 2. Innovators prior to 1700 had overwhelmingly had contact with *savants* (with a few of the earlier innovators importing innovations from abroad, as discussed in the previous section). *Savants* apparently continued to be influential, but from the eighteenth century a larger and larger proportion of innovators had seemingly only had prior contact with other *fabricants*. As such, the mentality

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[77] I erred on the side of assigning the earliest possible date, choosing the date at which they ostensibly began their experiments. For example, the celebrated railway pioneer George Stephenson became famous for inventing the mine safety lamp in 1815, but his first innovative activity appears to have been as early as 1808, when he unsuccessfully tried to improve the winding engines for mines. Smiles, *Lives of the Engineers: George and Robert Stephenson*, 49.

[78] Strickland and Strickland, *Edmund Cartwright*, 18, 28.

increasingly spread via emulation, from tinkerer to tinkerer, rather than necessarily via the inculcation of the other beliefs and ideas that had originally supported it among the educated.

As a child George Stephenson witnessed some of the very first steam locomotives constructed by William Hedley and Matthew Murray. He was also encouraged in his very first job by an inventive engineer Robert Hawthorn (whose son, another Robert, would also become an inventor). Stephenson reportedly obtained his schooling, late in life at the age of 18, because he wished to read about how the Boulton & Watt engines worked. And he was aware of the idea of perpetual motion, wasting his efforts in a scheme to achieve it – his son Robert claimed that he read about perpetual motion in a history of inventions.[79] Perhaps most importantly, Stephenson was mentored by another innovator in the sample, John Steele: "every word that came from Steele – Trevithick's pupil and workman . . . George Stephenson stored up in his memory".[80] As mentioned before, artisans with a machine in front of them did not need to believe that their marginal improvements would help to fulfill some grand progressive vision; young artisans and engineers like Stephenson simply needed to be shown that a given process or product could always be better.

CONCLUSION

The paper has charted the emergence and spread of an improving mentality, tracing its emergens and transmission from person to person. The mentality was not a technique, skill, or special understanding, but a frame of mind: innovators saw room for improvement where others saw none. The mentality could be received by anyone, and it could be applied to any field – anything, after all, could be better. But what led to innovation's acceleration was not just that the mentality spread: over the course of the eighteenth century innovators became increasingly committed to spreading the mentality further – they became innovation's evangelists. After all, for any mindset to become so widespread, it needs its preachers and proselytisers. Innovators thus new institutions and adopted social norms conducive to openness and active sharing, thereby ensuring the continued dissemination of innovation. Although in the late sixteenth century the improving mentality had mostly been spread by those who were educated, by the early nineteenth century it was spreading independently among the tinkerers and artisans too.

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[79] Ibid., 1–40.
[80] Jeaffreson, *Life of Robert Stephenson*, 1:28.

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FIGURES

Figure 1 – Number of new innovators, by date of first innovation

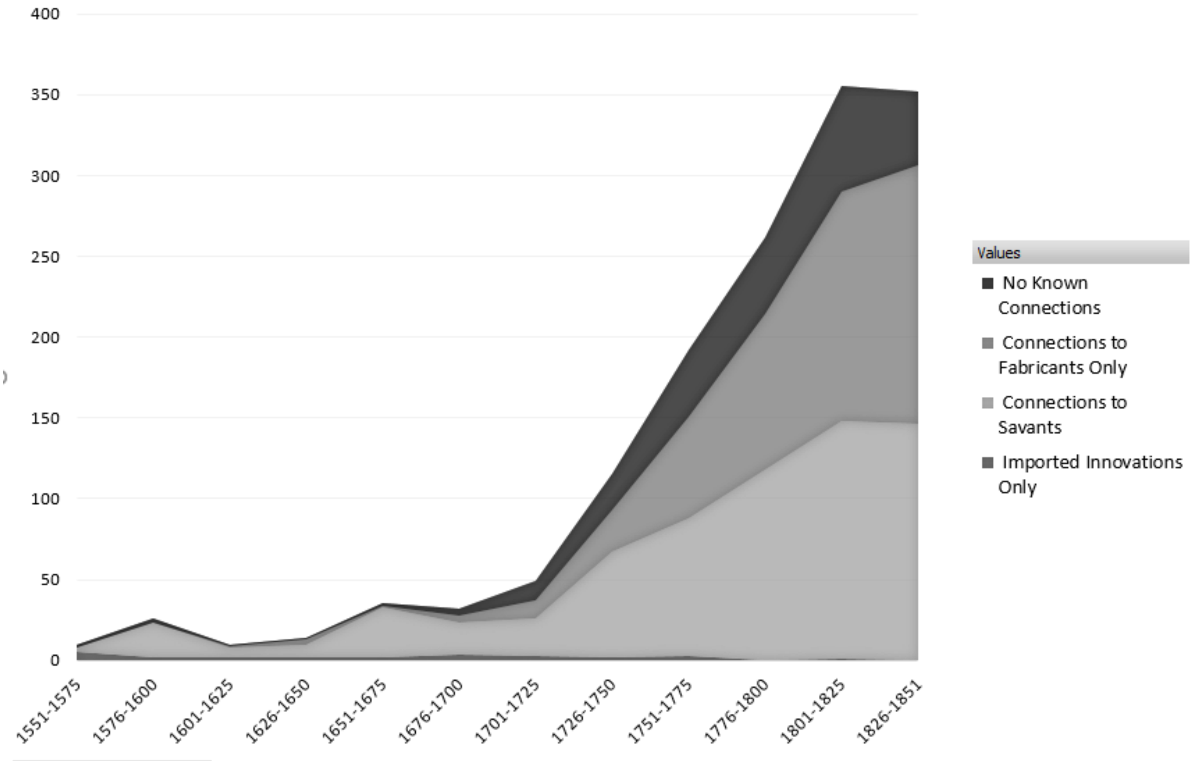
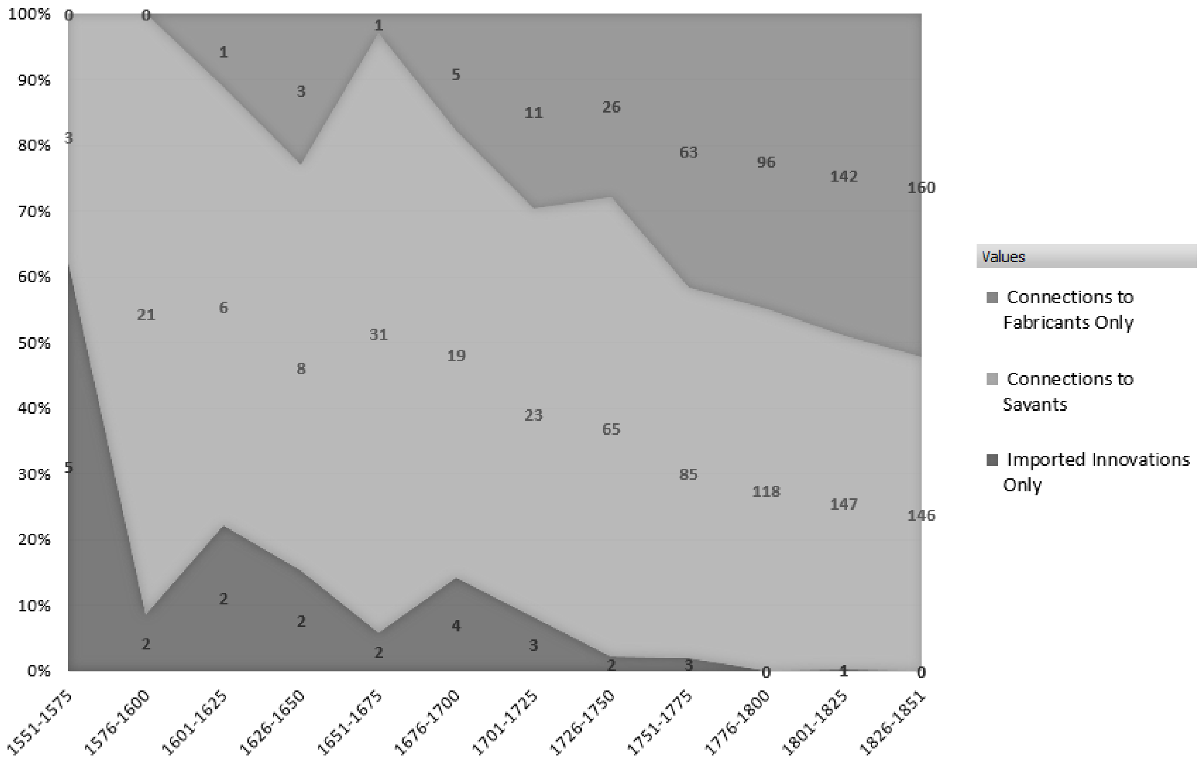


Figure 2 – Proportion of new innovators with prior connections, by date of first Innovation



Note: Figure does not include innovators with no known connections. n=1,206