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What lessons, if any, does the evidence on technological innovation in the British Industrial Revolution provide for understanding the process of technological innovation more generally? Answer by referring to at least three theories of technological innovation.

2,477 words

Technological innovation in exogenous growth models is defined by the productivity residual.[1] Throughout the period referred to as the Industrial Revolution, evidence from Crafts (1985) shows that the growth rate of this residual was at most ~1% in 1830-1860, compared with a much lower 0.2-0.3% throughout the 18th century. This essay will argue that the theories explaining this phenomenon proposed by Crafts (1985), Wrigley (2010) and Allen (2009) are unconvincing on the basis of insufficient evidence, though carry major institutional implications and links. Moreover, this essay will postulate that the institutional view of technological innovation originally advanced by North (1991) is robust and provides notable lessons for understanding technological innovation more generally regarding political fragmentation and the guild, village and town systems. Nevertheless, the institutional story itself suffers from insufficient evidence to draw conclusive lessons regarding the patent system and property rights, as well as the role of human capital and literacy in technological innovation.

Crafts (1977) identifies technological innovation as essentially stochastic, suggesting that English innovations were fortuitously acquired and maintained through path-dependence (David, 2001). This is premised on France and England experiencing equivalent sets of initial feasible choices, which is disputed by Glaesar & Shleifer (2002). The differences in respective legal systems of England and France emerged as an efficient *"Coasian bargain"* establishing power relations between the monarch, the people and interest groups. As such, this set out the institutional framework which facilitated less efficient factor markets, stronger guilds, interest group privileges and turnpike prevalence in France to a greater extent than in England (Ogilvie, 2000). In his discussion, Crafts (1977) implicitly emphasises the role of macro-inventions, yet Allen (2011) disputes this in favour of incremental micro-inventions. This is evidenced by his data showing that as late as 1860, only ~30% of the labour force operated in sectors exhibiting substantial technological progress, and macro-innovations were predominant in "*metallurgy, textiles and energy"*. Indeed, numerous sectors faced minimal technological progress up until

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[1] Suppose an economy exhibits constant returns to scale with continuous-time technology $Y(t) = [K(t)]^{\alpha}[A(t)L(t)]^{\beta}[E(t)Q(t)]^{1-\alpha-\beta}$ with output Y, capital K, effective labour AL, effective land EQ, the respective output shares α and β (Solow, 1956). The economy has total factor productivity residual $\xi(t) = \frac{\frac{\partial Y}{\partial t}}{Y} - \left(\alpha \frac{\frac{\partial K}{\partial t}}{K(t)} + \beta \frac{\frac{\partial L}{\partial t}}{L(t)} + (1-\alpha-\beta)\frac{\frac{\partial Q}{\partial t}}{Q(t)}\right)$.

the mid-19th century, and deterministic micro-inventions facilitated by a favourable institutional framework in England appear to imply that Crafts' perspective is largely empirically unsupported. Furthermore, von Tunzelmann (1995) suggests that the replacement of the Newcomen steam engine by the Watts steam engine, enabled a mere one month of real GDP growth in 1800 terms compared to the counterfactual case. The macro-inventions of the Industrial Revolution appear to have exhibited a high degree of randomness, with France, the US and Germany all advancing revolutionary ideas (Allen, 2009). Yet, the British case implies the need for enabling markets. French and German institutional barriers led to extensive networks of internal tolls distorting market transactions. This is reinforced by French industrialisation occurring only after the weakening of village communities in the late 18th century, thereby facilitating incentives for agricultural innovation and labour release (Ogilvie, 2000). Institutions appear to be vital facilitators of both micro-inventions and country-specific differences, meaning that stochastic innovation remains unconvincing without adequate treatment of the role of institutions.

The micro-invention-centred approach of Allen (2014) is consistent with his factor price argument and that of David (2008). Similarly, technological progress through micro-inventions is reconcilable with the *"new carbonocentric theory"* of Wrigley (2010). These theories suggest that relative factor prices were conducive to British industrialisation. Allen (2009) uses real wage evidence to suggest that Britain was a comparatively high-wage economy by the turn of the 18th century, with London silver wages being almost double those for workers in Paris and Amsterdam. Allen uses a basket of goods as a real wage proxy for several European cities, finding that London diverges upwards compared to southern European cities between 1500-1750. Furthermore, Wrigley (2010) identifies that Britain's large endowment of inorganic coal compared with wood or peat generated an inclination for technological progress. Further lending support to the importance of micro-inventions is the notable lack of technological progress in coal mining itself, which was devoid of major macro-inventions for much of the Industrial Revolution period (Clark & Jacks, 2007). The relative factor price theory implies that labour-saving inventions were incentivised through cheap coal and expensive labour. This would suggest that technological innovation in general entails a need for wages to be sufficiently high to induce capital substitution and energy to be sufficiently cheap to fuel technological change in other sectors. Yet, the evidence on relative factor prices being necessary is questionable (Crafts, 2011). The next industrialising nations of Belgium and Switzerland did so without coal or iron. International trade also facilitated the exchange of

Swedish iron and other sources of cheap coal, allowing countries to specialise in other sectors. Moreover, industries which saw moderate technological change such as cotton with the development of the spinning jenny in 1764 and the spinning, carding, weaving and bleaching process in the late 18th century exhibited few backward linkages with the coal industry (Horrell, et al., 1994), conferring virtually no advantage to Britain in textiles due to cheap coal, with cotton being centred around water power. Allen (2014) lends support to this idea by suggesting that cotton experienced total factor productivity growth of 1.9% per annum in 1780-1860, the fastest of any major British industry, thereby reaffirming that the cotton industry was a key driver of technological progress despite its low reliance on coal. Mokyr (2009) argues that the technology in 1750 was "*most efficient for any realistic range of factor prices*" so irrespective of factor price differentials, incentives would have remained approximately constant. Mokyr (2007) also points to many of the greatest labour-saving inventions such as the Jacquard loom and De Girard's wet spinning process for linen being invented in France, where wages were much lower. In addition, Von Tunzelmann (1995) identifies the neutrality of technological change between labour and capital up to the early 19th century, implying that neither was employed to a significantly greater degree than the other, casting doubt on the notion that relative factor prices induced capital substitution. Nuvolari & Verspagen (2009) suggested that in Cornwall where coal was expensive, the steam engine was quickly developed and adopted as a form of fuel-saving. This implicitly refutes Wrigley by suggesting that in spite of high coal prices, engineering aptitudes generated innovation. A rebuttal of Allen (2009) by Stephenson (2016) argued that the emergence of structural changes in the 17th century such as building contractors in London was not considered by Allen. These structural changes affected the institutional records, with Stephenson concluding that Allen "*overestimated British wages by 20-30%*", thereby diminishing empirical support for relative factor price theory. One of the most prevalent empirical criticisms of Allen is that British labour productivity was sufficiently high to offset labour costs (Kelly, et al., 2014), thereby suggesting that it was effective labour rather than capital substitution that conferred an advantage to Britain. This is supported by data from Crafts (1985), Feinstein (1998) and Crafts & Harley (1992) which suggests that labour productivity growth was approximately 0.8% in 1760-1800 but 1.4% in 1831-1860. This would imply that capital would be more advantageously employed in 1760-1800 compared with 1831-1860 due to lower labour productivity growth, converse to the actual period in which capital substitution predominately occurred.

Aside from the empirical concerns with relative factor prices, there are institutional constraints on its effectiveness. Even if favourable factor prices induced labour-saving innovations, the incentives to develop these innovations and allow them to be employed in widespread sectors required a balance between securing entrepreneurial rents and facilitating knowledge diffusion. North & Thomas (1973) praise the British patent system for its flexibility and effective allocation of the returns to innovation. Since "*knowledge is a public good"*, the continental European approach of state-funded research was effective for diffusion though generated disincentive effects. Mokyr (2009) and Clark (2012) doubt the British patent system due to the uncertainty of patent value and high cost, such that patents were scarcely used even until 1851. Reconciling both perspectives implies that there is insufficient evidence for a consensus on the effectiveness of the British patent system (MacLeod & Nuvolari, 2006). As evidence for the institutional constraints on factor prices, Northern France, Northwest Germany, Belgium and Northern China all possessed sizeable endowments of coal, though Ogilvie (2000) argues that even with agricultural innovations releasing labour to industry and allowing for labour-saving innovations in the agricultural sector, occupational freedom and weak guilds were required, allowing a transition to industry. In light of disagreements regarding the patent system and reliability of real wage data, Allen and Wrigley's factor price argument appears highly contentious considering both the evidence and institutional constraint, implying that their explanation of the British experience of industrialisation, and technological progress more generally, is dubious.

The importance of institutions in facilitating technological change was first identified by North (1991), who attributed the emergence of parliamentary sovereignty from the Glorious Revolution of 1688 as generating security of property rights and *"inclusive political institutions"* (Acemoglu, 2001). Since the 18th century, no major war has been fought on British soil, and aside from the Napoleonic Wars, Britain incurred comparatively minimal loss of the labour force and existing capital compared to France, the Netherlands and Belgium (Gates, 2011). In addition to facilitating relative political cohesion, the British state was also willing to allow for public good provision, though it largely refrained from provision itself, and provided the legal framework to guarantee property rights and enforce necessary contracts (Hoppit, 2014). The British state did grant specific privileges to merchants, craftsmen and noblemen, though comparatively few compared to the number of grants made in continental Europe (Ogilvie, 2000). Furthermore, the extent to which the British state practiced "*confiscatory government"* and the arbitrary infringement of property rights was notably low (North &

Weingast, 1989). As such, British institutional barriers were fewer in number and scale, thereby enabling British innovation to supersede that of continental Europe.

Mokyr (2009) argued that technological innovation derives from education and literary tradition. He places emphasis on the importance of British comparative advantage in highly skilled labour and posits that this is an overlooked factor in the country's technological innovation. This is reinforced by Humphries (2006) who argues that the immigration of skilled refugees such as the Huguenots from France augmented the technology of Britain, particularly in light of continental European persecution of Protestants, leading to mass inward migration to England. Further augmenting the human capital of the British economy was the apprenticeship scheme discussed by Meisenzahl & Mokyr (2011) which accommodated higher levels of labour productivity over time, allowing Britain to eclipse the Netherlands and Belgium in technological innovation. Mokyr argues that the mechanism through which highly skilled labour translates into technological improvement relates to Britain's tradition of *"practical science"* as opposed to *"theoretical science"* in France. Allen (2009) disputes that education was a major factor in explaining technological change due to equivalencies in English and northern French literacy rates in the early 18th century, also citing how Germany, the Netherlands and Scandinavia all possessed higher literacy rates albeit industrialised after Britain. Mokyr's argument is also heavily diluted by the lack of empirical backing for his claims, which may be regarded as highly subjective, particularly in light of the fact that a minority of entrepreneurs and industrialists were associated with Enlightenment thought (Allen, 2009). It also seems implausible that the Enlightenment, which began on continental Europe and prompted reactionary works from British scholars such as Burke (1790), spurred massive technological growth in Britain alone without diffusing across Western Europe. In spite of a deficiency in empirical evidence for or against Mokyr's perspective, the relevance to institutions is irrespective. Assuming that Enlightenment thought was indeed a driving force behind technological innovation, institutions which facilitated such development including the learned societies, apprenticeships and lack of political persecution vis-à-vis France stem from political unity and effective government. Conversely, the greater importance of micro-inventions implies the nature of technological innovation as deterministic, and hence susceptible to changes in the institutional structure, particularly the structure of communities and guilds which influence product and output markets.

In conclusion, it is infeasible that any substantial lessons without relevance to institutions can be derived from the evidence on technological innovation in the British Industrial Revolution.

This essay has suggested that the arguments of Wrigley (2010), Allen (2009) and Mokyr (2009) are evidentially inconclusive yet robust to the institutional perspective. Supposing that factor prices and Enlightenment thought were important factors in explaining technological innovation, Ogilvie (2000) discusses the importance of institutions in facilitating the markets and outcomes that would enable these factors to generate technological change. This essay has also considered the potential for stochastic growth as suggested by Crafts (1985). The institutional implications here are once again pertinent: the differences in legal institutions between France and Britain shaped the two countries' respective institutional climates and hence original possibilities; in addition, micro-innovations which are deterministic and dependent upon both political and educational institutions, play a greater role in the industrialisation process than more stochastic macro-innovations, as evidenced by the relative abundance of macro-inventions in France, Germany and the US, though with Britain being the first industrialiser (Allen, 2009). This essay argues that two key institutional lessons can be drawn. First, Britain was distinct from its European counterparts in the 18th century onwards due to its lack of major civil wars and relative political unity, as well as its lack of aristocratic and regional interest groups such as the noble classes, guilds and communities in France. There has never been a historical example of a society riddled by civil war and domestic unrest with strong technological innovation, and hence the British experience is informative of the nature of a society which is conducive to technological innovation as one that need not abstain from military activities, though must not experience war on the domestic territory which is a negative shock to the nation's production technology. Second, institutions can either facilitate or hinder the reasons for technological innovation discussed thus far: in the presence of strong guilds, sectoral shifts and a dynamic economy become hindered and less likely, preventing the possibility of technological innovation; and without weakening the power of town and village communities, price distortions and welfare losses can offset other favourable conditions for technological innovation. This essay argued that due to a lack of consensus on the patent system and the role of human capital, no general lessons can effectively be drawn from the British experience. However, it argued that these institutional factors remain robust irrespective of the evidence.

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