REVIEWS IN ADVANCE

Precocious Albion: A New Interpretation of the British Industrial Revolution

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Abstract

Many explanations have been offered for the British Industrial Revolution. This article points to the importance of human capital (broadly defined) and the quality of the British labor force on the eve of the Industrial Revolution. It shows that in terms of both physical quality and mechanical skills, British workers around 1750 were at a much higher level than their continental counterparts. As a result, new inventions—no matter where they originated—were adopted earlier, faster, and on a larger scale in Britain than elsewhere. The gap in labor quality is consistent with the higher wages paid in eighteenth-century Britain. The causes for the higher labor quality are explored and found to be associated with a higher level of nutrition and better institutions, especially England's Poor Law and the superior functioning of its apprenticeship system.

INTRODUCTION

Why was Britain the cradle of the Industrial Revolution? The literature on the topic is quite substantial, and very little consensus has been reached since the survey in Mokyr (1999a). The dominant schools are divided among those who focus on geographic endowments (such as coal), those who focus on politics and institutions (including the Glorious Revolution), and those who stress the British empire and colonial successes.

In what follows, we present an argument that focuses on the quality of the British labor force. Although in the past claims for human capital as an explanation of Britain's leadership have been dismissed because of its mediocre schooling and literacy rates (Mitch 1999), we argue that this focuses on the wrong variables. Instead, we highlight two very different dimensions of human capital. One is the physical condition of the average British worker. We argue that better nutrition made British males grow up on average to be healthier and taller than their continental counterparts. Better health and increased height meant both more physical strength and, in all likelihood, higher cognitive ability, and hence higher labor productivity. As nutrition was costly, better health can be seen as an investment by parents in their children's human capital. The other dimension is that the distribution of productive ability and dexterity in Britain was more skewed than elsewhere, so there was a much larger density in the right tail, that is, a relatively large contingent of highly skilled and capable technical workers. That contingent may have contained a higher endowment of skills, through a more flexible and effective system of training young men in the apprenticeship system, but what counted above all was its highly skilled mechanics and engineers, who may not have been a large proportion of the labor force.

The net result is that on the eve of the Industrial Revolution, although Britain may have had more accessible coal and a larger overseas empire, the main reason for its precocity was its higher level of human capital. We do not dismiss other explanations, such as institutions. The contrast between institutions and human capital suggested by Glaeser et al. (2004) only exists if we employ a very narrow definition of institutions. If we include a wider definition of both formal and informal institutions, as well as distributional arrangements such as the Poor Law, we show how part of the comparatively high level of human capital was indeed rooted in Britain's institutions, but the mechanism we emphasize is a higher quality of the labor force triggered by these institutions.

INDUCED INNOVATION AND THE INDUSTRIAL REVOLUTION

An obvious implication of a higher productivity of British workers is that the observed wage level in Britain was higher than elsewhere. Allen (2009a,b; 2010), the leading collector and organizer of the wage data on which this observation is based, has suggested that the higher wages themselves may have been instrumental in bringing about the Industrial Revolution.

Allen has resuscitated the idea of induced innovation and reintroduced it into the literature on the origins of the Industrial Revolution. The argument builds on the literature that flourished in economic history in the 1960s on the effects of high wages on labor-saving innovation. He submits that the British Industrial Revolution was driven by a set of labor-saving and coal-using innovations, stimulated by the high cost ratio of labor to energy in Britain, relative to France (which is taken to be representative of the rest of Europe). Allen attributed the high level of British wages primarily to labor demand: the growing commercial and maritime sector and the growth of urban centers raised real wages in Britain, as it did elsewhere. This argument has obviously resonated with other scholars. For instance, Rosenthal & Wong (2011) adopted it wholesale in their account of the difference between nineteenth-century technological progress in China and Britain.

The induced innovation argument has a venerable pedigree in economic history as an explanation of why technological progress differed across economies. In the early stages of this literature, it was applied to explain the difference between American and British technology, with Britain cast in the role of the low-wage economy (Rothbarth 1946; Habakkuk 1962; Temin 1966, 1971). David (1975) attempted to resolve the issue of substitution versus technological progress and proposed a model that resembles Allen's framework. He assumed that innovation was mostly local (that is, the product of learning by doing) and that this learning was faster in the more mechanized techniques. If that was the case, the choice among existing techniques (substitution) would drive high-wage economies to choose labor-saving techniques, and these would generate further innovation in the neighborhood of high capital/labor ratios, leading to falling costs in those techniques. Eventually, the unit costs of the mechanized techniques became so low that even the relatively low-wage economies would mechanize, and thus the British Industrial Revolution spread to the Continent. In Allen's view, this model describes, roughly speaking, the history of the Industrial Revolution in Europe, although he was willing to leave some room for exogenous factors such as the Enlightenment and the Scientific Revolution.[1]

In more recent years, Acemoglu (2001, 2002, 2010) has shed further light on the economics of induced innovation. His research has recast the literature in terms consistent with endogenous growth, by postulating that innovation is brought about by profit-maximizing individuals or firms, who then become monopolistic sellers of the new technique or good. These models provide a more rigorous foundation for the induced innovation literature, but in the final analysis, this work has not helped cast much light on the role of high wages in the British Industrial Revolution.[2] All the same, in some historical situations, researchers have shown that when there is a strong unanticipated supply shock to factor prices, induced innovation can help to bring about adjustment. Good examples of such a phenomenon are the contributions of Hanlon (2013) on the British response to the Cotton Famine and that of Hornbeck & Naidu (2012) on the technological response to the Mississippi floods of 1927.

As an explanation for the British Industrial Revolution, an argument based on high wage levels relative to other economies needs to make strong assumptions, the most basic one being that higher British wages entailed higher unit labor costs for British employers. As shown below, it is far from clear that this assumption was met during the British Industrial Revolution. This is hardly a new idea. As Arthur Young (1929 [1790], p. 311) commented on the low cost of French labor, "labour is generally in reality the cheapest where it is nominally the dearest. The quality of the work, the skill and dexterity of performance come largely into account." In 1824, Thomas Malthus, testifying before a Parliamentary Committee, made the same point: "Generally, my opinion is, that the efficiency of labour in France is less than in England, and that that is one of the principle causes why the money price of labour is lower in France than in England" (Great Britain 1824, p. 600).

[1]Allen (2009a, pp. 52–56, 143) recognized the difference in human capital levels between Britain and the rest of the Continent but did not explore the implications for his interpretation.

[2]One implication of Acemoglu's model is that, because of the growth in the supply of unskilled labor in Britain (migrants, as well as women and children), technological progress might have been what he called "skill-replacing." Although the machines may have in some cases (especially in textiles) done that, changes in technology also increased the demand for very highly specialized skilled labor that could build, install, and maintain the new equipment. An increase in the supply of skills, he showed, can under certain conditions actually increase its price (that is, the skill premium). Elsewhere, Acemoglu (2010) specifically mentioned Habakkuk's and Allen's work as examples of labor-saving technological change that might have been induced by labor scarcity. Acemoglu (2010, p. 1071) concluded that "whether labor scarcity and high wages may induce innovation and technology adoption in practice is an open empirical question and is likely to depend on the specific application." Furthermore, in his model, biased technological progress is triggered, if at all, by a *rise* in wages (not a high level). There is little evidence that wages actually rose sharply before the Industrial Revolution, and after 1750, the growth in labor supply due to the acceleration in population growth makes this quite unlikely.

Many other possible objections to the argument have been raised. For instance, Allen focused on process innovation (much of his writing concerns the textile industry), in which unit costs were reduced through mechanization. Although this is an apt description of some of the innovations we associate with the Industrial Revolution, we must keep in mind that new techniques were emerging along a broad front of production, and many are hard to classify as either labor or capital saving, as they involve entirely new or vastly improved products or services, from canned food to marine chronometers to vaccination. It also must be shown that London male wages relied on by Allen are representative of what textile mill owners expected to pay their workers [something strongly objected to by Humphries (2013)]. We stress that Allen focused primarily on the British cotton industry, by all accounts one of the most dynamic industries of the Industrial Revolution and often associated with it. Yet Meisenzahl & Mokyr (2012) demonstrated that in many respects, the inventive processes in the cotton industry were atypical and that in most other industries, such as engineering, the incentives and backgrounds of inventors were quite different. Hence, cotton was in some sense an outlier in the Industrial Revolution. Equally worrisome for Allen's argument is that he must show that the new capital-intensive techniques were profitable for Britain but that they could not be used in France for a long period because of its cheaper labor. At least one investigation has shown that the story may be problematic, even for the cotton industry. Gragnolati et al. (2011) demonstrated that on Allen's own numbers, the jenny, although more profitable in Britain than in France, would under reasonable assumptions also have been profitable in France from the onset (for a similar view, see Foster & Jones 2013, pp. 103–4).[3]

Moreover, Allen focused on the high cost of labor relative to the cost of energy. This is perfectly reasonable, given that in many of the British industrializing areas coal was abundant and cheap. However, steam power, the paradigmatic technology in which fossil energy supposedly replaced labor, was often used to replace horses or water mills. This indicates that the Industrial Revolution, rather than simply substituting resources for labor, replaced one form of resources by another. It is telling that in Cornwall, where coal was expensive, its high cost did not slow down technological progress, but simply reoriented it in another direction. Indeed, the high cost of coal has been cited as the stimulus for the development of fuel-saving technology in Cornwall (Nuvolari & Verspagen 2009, pp. 686–87). The success of Cornish engineers such as Arthur Woolf in developing fuel-saving engines wherever coal was expensive suggests that the driver of technological progress was something deeper and stronger than cheap coal and high wages, although the latter were affecting the direction in which innovation moved. Coal was important, but it was itself subject to technological progress, and its cost and availability were clearly endogenous to deeper forces. As E.L. Jones (2013, p. 186) remarked, "industry was growing in the North before any significant generation of power using coal, while trades vital for inventiveness—notably clock and watch-makers in South Lancashire—used little fuel."

Finally, there is mixed evidence at best for technological progress during the Industrial Revolution being on the whole labor saving, as the induced innovation hypothesis would contend. The macroeconomic record, questionable as the data are, has been summarized by von Tunzelmann (1994, pp. 289–91). Apart from a short period during the Napoleonic Wars, he found little evidence that technological change in Britain was on balance labor saving before 1830. Even after that year, in his view, when there was a clear-cut shift toward more labor-saving machinery, it

[3]Even in textiles, anecdotal evidence that high wages and cheap coal were the prime movers in mechanization is mixed. In 1807, Young reported from Witney (Oxfordshire) that it was a low-wage area, suffering from "the want of vicinity to coal"—yet it had introduced spinning jennies and "spring looms" (flying shuttles). The labor-saving innovations did not help raise local wages, and most of the local poor were denied a share in the increasing prosperity (Young 1809, p. 326).

was dampened by "the continuing labour-surplus of males" (von Tunzelmann 1994, p. 291). The microeconomic evidence from the patent records, assembled by MacLeod (1988), is equally troubling for the labor-saving inventions hypothesis. She calculated that labor saving was a stated goal of patentees in only 4.2% of all patents taken out between 1660 and 1800, whereas capital saving was the goal in 30.8% of all patents. Looking at what patents actually achieved, only 21% of all inventions can be said to have saved labor, compared to the 30.8% that were said to save on capital (MacLeod 1988, pp. 160–71).

Below we show that there is good reason to believe that there were far-reaching differences in the quality of labor between Britain and France on the eve of the Industrial Revolution that all point in the direction of British workers being more productive than their French colleagues. High wages were little more than a symptom of much deeper differences between Britain and the rest of Europe. The very factors that made Britain's workers more productive may have also been important in generating the inventions and (equally important) in disseminating and absorbing new knowledge and putting it to good use. We illustrate a number of things below. One is that the differences in productivity between British and French workers were sufficient to cast doubt on the assumption that unit labor costs in Britain were higher than in France. Another is that this higher quality of labor helps explain the British Industrial Revolution without having to rely on induced innovation. In this case, the high wage is not the cause of invention, but is a symptom of deeper factors that drive both wages and technological creativity.

A SIMPLE MODEL OF HUMAN CAPITAL AND THE INDUSTRIAL REVOLUTION

In what follows, we present the verbal and graphical outline of a simple dynamic model that captures the main features of our view of the Industrial Revolution. The formal model may be found in the **Supplemental Appendix** (follow the Supplemental Material link from the Annual Reviews home page at **http://www.annualreviews.org**). The historical reality reflected in the model is that technological ideas were generated by the Industrial Enlightenment, which redirected research efforts toward more pragmatic purposes and reorganized useful knowledge to make it more accessible (Mokyr 2009). But turning this knowledge into an Industrial Revolution required skilled and capable artisans who could build the new devices from blueprints, install, operate, and maintain them. These abilities required a large amount of training and adeptness, which we refer to as competence.

The importance of competence can be incorporated into a standard Phelps-Nelson growth model of human capital, in which productivity evolves as a function of human capital. Specifically, there is some maximum level attainable for productivity, and in each period, the economy gets closer to it as a function of its competence. Competence in the next period itself is a function of the existing stock of competence (reflecting that artisans were trained by other artisans) and the investment the artisans' parents make in their training (reflecting that apprentices had to pay a fee to their masters and that health depended on food consumption). The growth in productivity A is a function of past productivity and the level of competence in the economy. We then define a variable we term M (for misery), which is the reciprocal of both health and competence.

The model then solves for two log-linear difference equations that follow the trajectories of both A and M over time. This will be recognized as an adaptation of a linearized Lotka-Volterra dynamic system of two competing species (Hofbauer & Sigmund 1998, pp. 22–28). The two state variables M and A can be seen as two competing species in a finite environment. The growth of each species is retarded by the presence of the other. Four equilibria are possible. One is that conditions are so favorable to the first species, misery in our case, that its population will be high regardless of the second species, which it always drives to its minimum level. This corresponds to the Malthusian (dismal) equilibrium, with the population at the minimum of subsistence (maximum M), and A at its very minimum. The converse holds when A drives out M, meaning that M is minimized (high levels of health and human capital). In a third equilibrium, if the species have little impact on each other, both coexist at positive levels. Finally, if they have a strong effect on one another, it becomes indeterminate which of the two drives out the other, and the outcome depends on initial conditions: whichever species initially has a sufficiently large population to dominate the system will drive the other out.

The model then posits two economies that we call France and Britain. Each faces the same best-practice technological frontier $\tilde{A}$ that rises through time, reflecting the progress of Enlightenment scientific knowledge in Europe, which easily crossed national boundaries. France and Britain differ in only one way: initially disposable income is higher in Britain than in France. This historical development is illustrated in **Figure 1**. Our starting point (**Figure 1*a***) is a stark Malthusian world with little knowledge: log $\tilde{A}$ is arbitrarily small, and the knowledge isocline A_1 lies completely below the two misery isoclines pertaining to both countries. As a result, both economies are at an

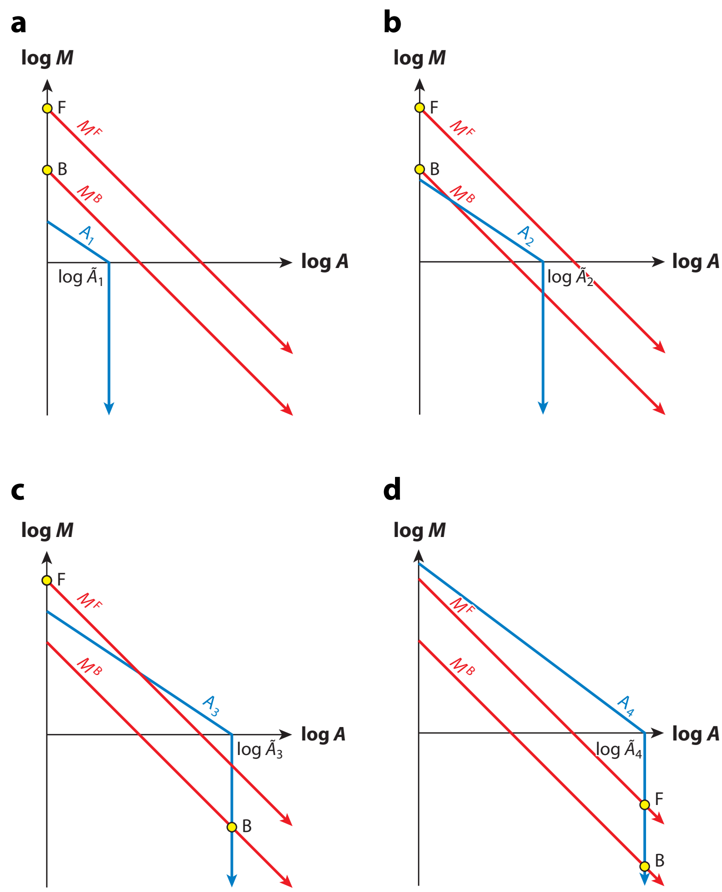

Figure 1

Impact of rising technological frontier $\tilde{A}$ on equilibrium in two economies, Britain and France, with different misery isoclines. (*a*) Both economics begin at the technological minimum. (*b*) A rising technological frontier has no initial impact. (*c*) Britain moves to the technological frontier. (*d*) France moves to the technological frontier.

equilibrium at the lower bound of knowledge. As time passes, best-practice technology $\tilde{A}$ will rise exogenously, reflecting the progress of Enlightenment useful knowledge, and this will be the driving force behind the model. At some point, the A isocline rises enough to intersect with the British misery isocline, but it is still below the French one (**Figure 1*b***). What happens then depends on the parameters: under weak interaction, Britain may start moving to an interior solution at the intersection of the two; under strong interaction, the higher level of A starts kicking in only when the A isocline is entirely above it, as A_3 in **Figure 1*c***. At that time, Britain jumps to a new equilibrium at log $\tilde{A}_3$, at which its misery index is at the minimum and its productivity is high, whereas France remains in a Malthusian equilibrium until the A isocline has advanced sufficiently to make the transition possible there as well (**Figure 1*d***). Because British human capability is initially slightly higher than in France, Britain can start to apply technological knowledge to production earlier, giving rise to a cumulative process of rising living standards, rising human capital, and improving production technology. A gradual rise in knowledge above a critical level causes Britain to experience an industrial revolution, whereas France for a while appears mired in age-old backwardness.

Note that we need not assume that Britain is originally richer than France: the French M isocline would lie above the British one if Britain's elasticity of converting knowledge into productivity were higher, its ability to teach its apprentices were higher because the institutions governing apprenticeship worked better, or the elasticity of output with regard to human capital were higher, or some combination of those.

WAGES AND PRODUCTIVITY IN EIGHTEENTH-CENTURY BRITAIN AND FRANCE

There is no dispute regarding the main fact underlying this debate: British wages were considerably higher than French wages on the eve of the Industrial Revolution. Allen (2009a, chapter 2) calculated that the real wages of building craftsmen in London in 1780 were 83% higher than those in Paris, whereas the real wages of laborers were 80% higher. It is, however, invalid to conclude that British labor was therefore more expensive, until we compare productivity and can thus infer unit labor costs. Some indication of the differences in productivity can be attained from data in agriculture by comparing day rates and piece rates (**Table 1**). The average time needed to reap an acre

Table 1 Relative real wages and agricultural productivity, England and France, around 1780[a]

	England	France
Real wages		
Craftsmen	1.82	1.00
Laborers	1.80	1.00
Agricultural output per man-day		
Reaping	0.14	0.08
Threshing	1.54	0.93

[a]Data taken from Clark (1991, p. 449) and Grantham (1991, p. 363).

of wheat in early nineteenth-century England was 2.9 man-days per acre, or 7.2 days per hectare (Clark 1991, p. 449).[4] In France, the average cost ranged from 9.3 to 16.3 man-days per hectare, giving an average, weighted by regional output share, of 12.9 man-days per hectare (Grantham 1991, p. 362). Reaping and threshing were manual activities with almost no capital input and fairly little skill. Even allowing for considerable measurement error, the roughly 65–75% productivity advantage for English workers suggests a real difference in the physical quality of labor and one on the same order as the wage difference.

The exact reason why British workers were more productive than French ones is yet to be resolved. However, if income per capita affected labor productivity (instead of just the other way around), we are in an efficiency-wage world, in which employers will find it in their interests to pay workers more than the lowest wage possible because they increase their productivity by paying a higher wage. Employers will continue to do so until the increase in labor productivity is equal to the higher wage. A standard issue here is that coordination failure between employers may undermine this equilibrium. An employer may want to pay his workers a higher wage to elicit more work out of them. This could work fine if this efficiency wage engenders personal loyalty to the employer and thus reduces the effects of asymmetrical information. However, if it works through a mechanism of improved worker strength and energy owing to better nutrition or creates an intergenerational externality by improving the quality of workers available to the next generation of firms, other employers might free ride on the higher wage, and a coordination failure would result in a low-wage equilibrium. Arguably the British Poor Law could be seen as an attempt to prevent local free riding on improved worker quality.

Our argument then is that British workers were of higher quality than French ones. This not only would explain their higher wages, but also would provide a critical link that explains why British workers were able to take advantage of the technological opportunities emerging in the eighteenth century. This is not a traditional human capital argument: as is well known, in this period Britain led Europe neither in the quality and quantity of its educational system nor in observed literacy rates. Instead of human capital in its conventional, narrow sense of rates of literacy and schooling, we want to focus on the wider concept of what Heckman (2007) termed human capability. Human capability is the triad of cognitive skills, noncognitive skills (e.g., self-control, perseverance, time preference, risk aversion, preference for leisure), and health. These components of human capability in turn are strongly determined by the individual's nutritional and disease environment from conception to adolescence.

NUTRITION, HEALTH, AND PHYSICAL CAPABILITY

Perhaps the most obvious source of difference between British workers and French workers is that the former seem to have been fed better. There is a fair amount of anecdotal evidence that suggests that for the bulk of the population, Britons were better fed than Frenchmen. That said, estimates of the exact gap differ quite a bit. Fogel (2004) famously argued that English workers, by being better fed than their French counterparts, were capable of more work and estimated that the median French worker consumed approximately 2,200 kcal per day, considerably less than a median English diet of approximately 2,600 kcal. The amount of energy available for work (after the needs

[4]This estimate is consistent with Young's eighteenth-century observations. Dividing the median costs of reaping an acre of wheat (60d) by the median harvest wage (20–22d per day) on both Young's southern and northern circuits yields a rate just under three man-days per acre (Young 1771, pp. 293–96; 1772). Young (1793, pp. 315–16) wrote, "Strength depends on nourishment; and if this difference be admitted, an English workman ought to be able to do half as much work again as a Frenchman."

of basal metabolic demand) per capita in his estimate was about one-third higher in England than in France: 600 kcal in France in 1785 compared with 812 kcal in England in 1750 and 858 kcal in England in 1800 (Fogel 2004, pp. 9–11). The more recent calculations in Floud et al. (2011, p 99) are similar and put the English mean at 2,456 kcal around 1800 as opposed to the French mean of 1,847 kcal (computed from Floud et al. 2011, pp. 114–15), whereas Broadberry et al. (2013) estimated 2,100 kcal, more or less unchanged between the mid-thirteenth and mid-nineteenth centuries. At the other extreme, Muldrew (2011, p. 156) estimated average calories per capita in England at 5,047 kcal in 1770, falling to 3,977 kcal in 1800, although these estimates rely on an implausibly high output of coarse grains. In the middle is Allen (2005) with an estimate of 3,800 kcal for Britain in 1750, falling to 2,900 kcal in 1800.

In terms of the quality of the diet, the data suggest a much higher percentage of animal protein consumption in Britain than on the Continent. Muldrew's (2011, p. 153) claim that British adult laborers consumed approximately 0.7 pounds of meat a day around 1770 may err on the high side, but Floud et al.'s (2011, p. 210) estimates of a per capita consumption of 4.9 ounces in England in 1750 and 4.4 ounces in 1800 still compare favorably with Jean-Claude Toutain's estimates of France's per capita meat consumption of 0.1–0.13 pounds on the eve of the French Revolution. Meat consumption was low in Germany as well (see Blum 1974, pp. 413–15). Anecdotal evidence is abundant: many travelers visiting Britain commented on British carnivorous habits. For example, de Muralt (1726, pp. 39–40), a Swiss traveler, noted that "the pleasures of the table in this happy nation contained much roast beef which is a favorite dish as well at the King's table as at Tradesman." In 1748 Kalm (1892, p. 15), a Swede, similarly remarked that he did not believe that any Englishman "who is his own master, has ever eaten a meal without meat."

The effects of better nutrition are most obviously visible in the differences in heights of adult males. **Figure 2** describes the average heights of English male convicts and French army recruits (Weir 1997, p. 191; Nicholas & Steckel 1991). Both sets of data refer to cohorts born between

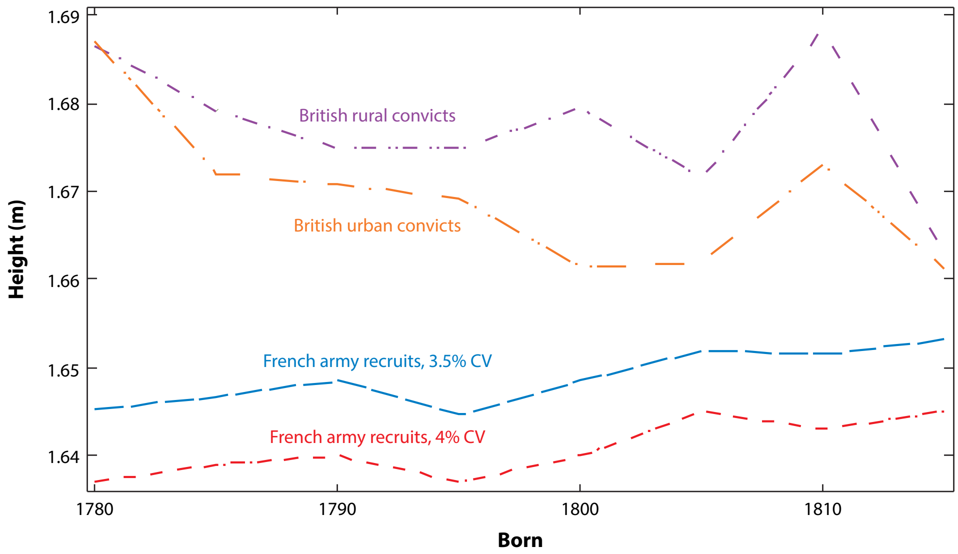

Figure 2

English and French adult male heights: cohorts born 1780–1815. Shown are heights for English urban and rural convicts and French army recruits from Weir's estimates with the original coefficient of variation of 3.5% and with a coefficient of variation of 4% implied by d'Angeville's data for 1825–1830.

1780 and 1815, and neither is likely to suffer from the kind of selection bias that compromises inferences drawn from the heights of recruits in volunteer armies (Mokyr & Gráda 1996).

The English heights shown in the figure distinguish between urban and rural convicts. The French heights include Weir's (1997) estimates, to which we have added 1 cm to reflect that they refer to recruits ages 20–21 and that in societies that are malnourished, adult males do not reach their terminal heights until age 23. Weir's estimates assume a coefficient of variation of 3.5% in heights, and the other set of French height data assumes a coefficient of variation of 4% implied by d'Angeville's data for 1825–1830.[5] The comparison suggests that the gap between French and English heights on the eve of the Industrial Revolution was considerable—about 5 cm. Moreover, if socially more representative data for England were available (i.e., not just data on transported convicts, who came disproportionately from poor backgrounds), the likelihood is that the gap would be somewhat wider still (compare with Fogel 2004, p. 13; Heyberger 2007). The gap for those born around 1810–1815 was lower but still significant, 3–5 cm.

Other data confirm these gaps. For 1825–1829, d'Angeville (1836, p. 322, table 3) reported the average height of accepted recruits by administrative department and the proportions rejected because of height or fitness. Under normality, d'Angeville's national average of 165.1 cm for accepted recruits, and 16% rejected for height, is consistent with a population mean of 163.8 cm and a coefficient of variation of 4%. Weir (1997) reported estimates of heights from 1804 onward based on the sample of accepted recruits but assumed a coefficient of variation of only 3.5%: the same as in modern Western populations, where the heights of the poor have more or less converged on those of the rich. This low coefficient of variation gives a 0.4-cm increase in average height for the late 1820s compared with our estimate but gives a very large gap for 1817: Weir estimated an average height of 163.2 cm compared with Villermé's (1829) reported value of 161.5 cm.[6] In any event, all those French estimates are substantially below the best British estimates, which are between 168 and 170 cm (Riley 1994).

The significance of height gaps is that above all they serve as the proverbial canary in a coal mine: they indicate that in childhood, much as in adulthood, the French were fed considerably more poorly than the British. But height was also an indication of physical strength, as modern studies indicate. The strength of a muscle is proportional to its cross section, which increases as the square of height, as shown in empirical studies. For example, a study of Indian female laborers implied an elasticity of approximately two between height and grip strength, whereas a study of champion weight lifters found that weight lifted "varied almost exactly with height squared" (Forde et al. 2000; see also Koley et al. 2008, 2009). It is telling, perhaps, that contemporary scientists tried to measure differences in physical strength and found that the strength of five Englishmen equaled that of a horse, as did the strength of seven Dutchmen or Frenchmen (Desaguliers 1734–1744, vol. 1, p. 254). Defoe (1728, pp. 38, 40) noted that a French worker may well be more diligent than his English colleague, but "the English Man shall do as much Business in the fewer hours as the Foreigner who sits longer at it" and added that "the English Man's work, according to his Wages, out-weigh the other; as his Beer is strong, so is his Work; and as he gives more Strength of Sinews to his Strokes in the Loom, his Work is firmer and faster, and carries a greater Substance with it." Moreover, childhood nutrition and health, which affect height, also had a strong effect on cognitive ability, as shown below.

[5]A case could be made for assuming a bigger coefficient of variation. Villermé (1829) reported that in 1817, the average height of all those measured was 161.5 cm, with 28% below 157 cm. That is consistent with a coefficient of variation of 4.75%.

[6]Assuming normality and a coefficient of variation of 4.75% implies that the average height of accepted recruits was 165.1 cm. Inferring average population height from this figure using Weir's assumption of a 3.5% coefficient of variation gives a value of 163.8 cm, close to his reported estimate.

What we are really interested in, however, is how much height mattered for productivity. There is no easy way to infer that information from eighteenth- or nineteenth-century data, but modern data give us something of a clue. In a series of studies of the impact of height on wages based on modern African and Brazilian individual-level data, Schultz (2002, 2005) reckoned that every additional 1 cm in height is associated with a gain in wage rates of "roughly 5–10 percent." Using contemporary urban Chinese wage data, Gao & Smyth (2009) found that each additional centimeter of adult height is associated with wage gains of nearly 5% for males and 11% for females. If a similar relationship between heights and productivity held two centuries ago, then the 4-cm gap between Englishmen and Frenchmen heights at the time implied a gap of 20–30% in wage rates. This would account for a significant proportion—although not all—of the gap in real wages. This finding also suggests that two centuries ago, the causation ran from nutrition and health to wages, and not just vice versa.

The other indicator of lower nutritional standards and lower child health is the difference in infant mortality between the two countries. If life expectancy was significantly longer in Britain due to lower infant mortality, this likely reflected an overall better nutritional and health status; moreover, it might be correlated with higher investment in human capital, because parents are more likely to invest in their children to the extent that their children had a better chance of surviving. The net effect of higher infant mortality on adult productivity depends, to some extent, on why infant mortality was so much higher in the first place. France's high infant mortality reflected to some extent its lower standard of living, and inferior diet probably had something to do with it. Matossian (1984) has linked higher French death rates to greater consumption of the wrong kind of food, whereas Fogel (2004) and B. Harris et al. (2010) emphasized the link between inadequate food consumption—hunger—and "premature death."

According to the Cambridge Group family reconstitutions, life expectation at birth (hereafter e_0) in England and Wales was 36.4 years in the first half of the eighteenth century and 40.3 years in the second half (Wrigley et al. 1997, p. 295). In France in the 1740s, e_0 was approximately 25 years; between 1750 and 1789, it averaged 28.1 years. The data are reproduced in **Table 2**.[7] Most of the gap between English and French e_0's on the eve of the Industrial Revolution resulted from the much higher survival rates of English infants and children, but the gap for adults exists as well, even if it is smaller.

Table 2 shows not only that life expectancy in Britain was higher on the eve of the Industrial Revolution, but also that apparently the damage of poor nutrition played itself out primarily among the young. This may turn out to be highly significant in determining the capabilities of the adult population, assuming that the selection effects (which weeded out the weakest youngsters in France more ruthlessly) did not dominate the deleterious effects of malnutrition on the surviving children. The height difference indicates that this was probably not the case.[8]

Other data on infant mortality and disease confirm the importance of childhood nutrition. For France, England, and Sweden during the nineteenth century, Crimmins & Finch (2006) found that childhood mortality rates, which reflect nutrition and environmental conditions, are strongly inversely related with subsequent old age mortality and adult heights, which they attributed to differing burdens of childhood infection and inflammation, whereas Bozzoli et al. (2009) showed

[7]Moreover, in 1750, the proportions of the population living in cities with at least 10,000 inhabitants were 16.7% in England and 9.1% in France; in 1800, they were 20.3% and 8.8%, respectively (De Vries 1984, p. 39). Given lower urban life expectancies, the gap between life spans in rural England and France must have been even higher than that reflected in **Table 2**.

[8]Some of the English advantage may have resulted from longer breast-feeding (Fildes 1986, p. 106; McLaren 1990, p. 163). It could also possibly be in part a result of a faster decline in smallpox owing to the application of pre-Jenner inoculation techniques, especially after the adoption of improved methods by Robert Sutton in the 1760s (Mokyr 2009, pp. 244, 285).

Table 2 Life expectancies in eighteenth-century England and France[a]

	e_0		e_1		e_{25}	
Years	England and Wales	France	England and Wales	France	England and Wales	France
1740–1749	37.3	24.8	46.2	34.0	34.5	31.3
1750–1759	42.1	27.9	50.5	37.4	36.6	33.7
1760–1769	39.0	27.7	47.2	37.4	34.4	33.8
1770–1779	39.4	28.9	47.3	38.6	35.3	34.9
1780–1789	39.2	27.8	47.4	37.4	33.9	33.5

[a]Data for England and Wales taken from Wrigley et al. (1997, pp. 224, 256, 291, 295) and data for France taken from Blayo (1975).

that postneonatal (between one month and one year after birth) mortality is a strong predictor of adult height in the United States and Europe from 1950 to 1980. In the public health literature for developing economies, Victora et al. (2008) found a strong connection between childhood malnutrition and shorter adult height, reduced schooling, and lowered economic productivity, whereas Walker et al. (2011) surveyed the biological mechanisms through which stunting, iodine deficiency, and iron-deficiency anemia inhibit brain development in children.

COGNITIVE EFFECTS AND SKILL DIFFERENCES

Were British workers more productive because they were smarter than French workers? Until recently, such a question would have been met with outrage, but recent work establishing correlations between height and various cognitive abilities points in this direction. Such a difference has nothing to do with any inherent genetic or cultural differences, but a lot with nutrition and health. Since the 1960s, a considerable body of literature has sought to identify and quantify the possible impact between malnutrition in the form of protein, iron, and other nutritional deficiencies in infancy and early childhood with weakened cognitive development (e.g., Scrimshaw & Gordon 1968, Scrimshaw 1998). Analysis is complicated by measurement difficulties and the likely influence of other variables correlated with malnutrition. In an early attempt at pinpointing the link between nutrition and brain development, Weidner-Williams (1988) pointed to the crucial importance of protein foods. Brain development in the first 18 months requires a number of amino acids, and a diet poor in protein foods can produce irreversible damage (as can a diet that is poor in carbohydrates and forces the body to burn proteins). Modern nutrition research (e.g., Whaley et al. 2003, Heys et al. 2010) has confirmed that higher consumption of animal-source food by children improves their cognitive abilities.

The fundamental mechanism is that the same factors determining height also influenced mental development. Case & Paxson (2008) found a strong connection between height and cognitive ability in the United States and Britain since the 1950s, with the strong impact of adult height on earning disappearing when childhood cognitive ability is controlled for. As noted above, there is strong reason to believe that British children had more access to meat than children on the Continent. For industrializing England, Baten et al. (2014) found that rising food prices are associated with lower numeracy for the cohorts born during food scarcity, with numeracy measured by the ability to recall one's age. Their study suggests that high food prices in Britain during the French and Napoleonic Wars led to nutritional deficiencies that resulted in some kind of cognitive insult and that can be measured by their lack of numeracy decades afterward. Although Baten et al. (2014) might have been the first to establish an unambiguous connection between nutrition and cognitive development in a historical environment, given much contemporary evidence, their finding cannot be said to be a surprise.

We are of course unable to measure average IQ rates for eighteenth-century societies. What we know, however, is that IQ measurements are strongly affected by nutritional intake, both quantitatively and qualitatively, which is associated with measured height, and that height (the output) and nutrition (the input) differed between France and Britain.[9] This is far from saying that France was behind Britain in productivity because of these cognitive factors; there are profound issues of endogeneity here that remain unresolved. Yet the evidence suggests that on the eve of the Industrial Revolution, French workers were in some definable ways less productive than British workers, and hence the gap in wages may have different implications than the ones drawn by Allen.

Were British workers also better endowed with human capital? This is much more difficult to document. Standard measures of schooling and literacy rates are hard to compare, as they are measured using different techniques and at different times. Reis (2005) estimated mail adult literacy in Britain around 1800 at 60% for males and 40% for females, slightly below northern France (71% and 41%, respectively) but above southern France (44% and 17%, respectively). It is, however, open to question whether literacy at this early stage of the Industrial Revolution mattered a lot for productivity; highly literate regions in Lutheran Baltic Scandinavia were latecomers to industrialization (Sandberg 1979). Mitch (1999) has specifically argued that by the early nineteenth century, Britain was, if anything, overeducated. School enrollment in the first half of the nineteenth century was not all that impressive in Britain either. By 1830, 28% of the male population ages 5–14 were enrolled in schools in England and Wales. The figure rose to 50% in 1850, but this was significantly less than in Prussia, where the percentages were 70% in 1830 and 73% in 1850, and even behind France (39% and 51%, respectively) (Lindert 2004, pp. 125–26). As McCloskey (2010, p. 162) noted, human capital so defined by itself had little effect: a miner at the coalface may have to be skilled, but the hewer's skill had nothing to do with formal education and book learning. The same was true for skilled textile workers, construction laborers, sailors, and so on. In a recent paper, Becker et al. (2011) established that literacy mattered a great deal for "catching-up" but not for the generation of new techniques, as was the case in the British Industrial Revolution. Standard human capital measures do not really reflect much advantage to Britain and do not explain its precocity.

Instead, we focus on a different form of human capital, namely the idea of competence introduced above. The basic idea is that technology, similar to the performing arts, is an implementable form of culture; much like music and theater, it takes one person to write the original, but another to be performed—that is, carried out or executed by competent individuals. Those skills, however, do not necessarily include creativity and originality. Both Britain and France could count on a considerable supply of original genius, as attested by the substantial number of great inventions made during the Industrial Revolution originating in France, even if they were first implemented on a large scale in Britain. Britain had an advantage in skilled artisans, what Meisenzahl & Mokyr (2012) have termed "implementer and tweakers." This was surely something that historians and contemporaries were convinced of.[10] A French visitor in 1704 noted that the English were "wanting in industry excepting mechanicks wherein they are, of all nations, the greatest improvers" (cited in Hollister-Short 1976, p. 159). The idea that the British were above all good imitators, thanks to their skilled labor force, was reiterated by no less than Hume (1985

[9]There is also an argument, made by Jones, that IQ correlates strongly with income per capita (Jones & Schneider 2006, 2010).

[10]As early as 1690, even Dutch travelers commented on the superiority of British artisans and their high level of skills, from furniture design to the casting of metal rollers (Dobbs & Jacob 1995, p. 74).

[1777], p. 328), who opined that "every improvement which we have made [in the past two centuries] has arisen from our imitation of foreigners.... Notwithstanding the advanced state of our manufacturers, we daily adopt, in every art, the inventions and improvements of our neighbours." Other such examples can be found (Mokyr 2009, pp. 107–8), and for a while, it became something of a consensus among British economists to attribute the country's technological leadership to its advantage in skills.[11] But is there systematic evidence to back up contemporary observations?

One piece of evidence suggesting that Britain collected some kind of rent from its higher level of skills is that the mercantilist policy makers of the eighteenth century felt that the exportation of machinery and the emigration of skilled artisans endangered these rents and passed laws prohibiting these acts first in 1696 and amended them repeatedly in the eighteenth century. They remained on the books until the mid-1820s, although enforcement was at best spotty (Jeremy 1977). The illegal export of machinery, for instance, was almost impossible to prevent; after all, customs officers lacked the technical expertise and the staff to inspect large cargoes (Jeremy 1981, p. 41). By the early nineteenth century, the laws against machinery exportation were weakened and after 1815 were barely enforced at all. All the same, they reflect a clear-cut view of the advantage Britain enjoyed in comparison with its main competitors. This view was shared by continental nations, who throughout the period sent a variety of industrial spies to Britain to try to transfer its expertise to the Continent (J.R. Harris 1998).

Decisive evidence on the relative quality of English workers comes from the direction of labor migration. If the expensive English labor hypothesis were true, we would expect the flow to have been from France to England, in the form of continental workers taking advantage of higher English wages. In fact, the flow was in the opposite direction and comprised English and Scottish skilled artisans. This flow of skilled artisans from Britain to France preceded the Industrial Revolution, implying that the advantage England enjoyed in the area of technical competence predated its technological achievements, strengthening the case for a causal connection. Thus, for instance, John Holker, an English mechanic and political refugee in France, set up a textile manufacturing plant in Normandy in 1752 and, despite the risks as a Jacobite refugee, returned to recruit many of his skilled workers in Britain. By 1754, he employed 20 English artisans, who were allocated among French workers so that skills could be disseminated in the most effective fashion (Henderson 1954, p. 16; J.R. Harris 1998, p. 60). The Industrial Revolution strengthened this connection, and after 1815, a large number of British technicians found their way to the Continent, where they installed, maintained, and managed new equipment and instructed local workers on its use. Such an advantage was to some extent fleeting: as a French memorandum of the late 1780s pointed out, when English experts and workmen had come over in recent times, the French soon became keen to emulate them in the machine and hand tools they used (J.R. Harris 1998, p. 413). As Fox (1984, pp. 142–43) has observed, the French learned quickly, and as soon as local workmen had acquired the basic skills, the senior British operative became more of a rarity. But the technology itself was changing rapidly, and the flow of high-skill emigrants had to continue until deep into the nineteenth century to work with more recent vintages of machinery.

How big were these flows? The laws prohibiting emigration resulted in a parliamentary investigation, which has yielded a rich, if largely anecdotal and impressionistic, body of evidence supporting the size of the flow due to the higher quality of British labor. A Mr. Alexander testifying in 1824 estimated that in the years 1822 and 1823 alone, 16,000 artisans moved from England to

[11]Marshall (1919, p. 62) asserted that "the English inventor . . . could afford to sink capital in experiments more easily that they [Germans and Frenchmen] could. For he had access to a great variety of highly skilled artisans, with a growing stock of engines . . . every experiment cost him less, and it was executed more quickly and far more truly than it could have been anywhere else."

France (Great Britain 1824, p. 108). This figure seems exaggerated; a year later, an engineer named Alexander Galloway estimated the stock of English workers in France at 15,000–20,000 workers (Great Britain 1825, pp. 37, 43).[12] In 1830, a report cited the number of English living in France at 35,695, of whom 6,680 were "mechanics" (Soc. Diffus. Useful Knowl. 1830, p. 217). Allowing for other skilled workers, this estimate seems to be in the right order of magnitude. Why they were there was quite clear: they were paid more. Thus, it was maintained that an English engineer, turner, or iron founder working in France would make twice as much as a French one. "The English workmen, from their better methods, do more work and better than the French . . . and though their wages are higher, yet their work does not cost more money in France than when done by Frenchmen, though their wages are lower" (Great Britain 1824, p. 106).[13] The great inventor and mechanical genius Bryan Donkin noted that a worker in the paper industry who might have made 18–20 shillings a week in Britain was hired at 50 shillings in France. Galloway felt that a person of similar qualifications would make 22 shillings in Paris and 36 shillings in London—but then added that English workmen in Paris would make twice what the locals would make (2 guineas), indicating the difference in the perceived quality of the workmen (Great Britain 1824, p. 24). John Martineau testified similarly (Great Britain 1824, p. 7) that a French blacksmith in France would make 4 francs a day, whereas an English smith in Paris would make 10–11 francs. Clearly, the much higher wages secured by skilled British workmen on the Continent provide a reflection of the different scarcities. Another witness who had spent time working in Alsace recounted that the British machine maker Job Dixon had to send to England for experts to set up the spinning machinery he had made. "Our spinners," he added, "will do as much in six hours as theirs in twelve" (Great Britain 1824, p. 580).[14]

Early continental adoption of the new techniques needed British skilled workmen in its beginning stages. Philip Taylor, an engineer, pointed out that in Wurzburg, the establishment of manufacturing ran into great difficulties because "things that would have come to the hands of workmen in this country instantly, were with great difficulty obtained" (Great Britain 1824, p. 34). In 1841, Grenville Withers, an engineer residing in Liège, testified that he had some self-actors at Verviers made by Sharpe and Roberts, the best he could find, and installed the same way as in Manchester, yet productivity was only two-thirds what he could get in Manchester (Great Britain 1841, p. 80). Clearly, the superior quality of English artisans, the complementarity of skilled workmen and machinery made or designed in Britain, and the need to teach local workers implied continuing migration of skilled workmen.[15] The higher competence of British workers is confirmed by the reverse flow of trained continental engineers who came to study with or spy on British engineers. Among the many Germans who came to Britain to acquire technical expertise, we mention Wilhem von Reden, sent to study British coal mining techniques in 1776; Johann Gottfried Brügelmann, who traveled to study Arkwright's famous Cromford Mill in 1794, before

[12]In 1841, a witness testified that in Liège, Mr. Cockerill had 2,000 men in his employment, "many of them Scotch and English" (Great Britain 1841, p. 20). Another witness reiterated that if five workmen were employed under identical circumstances in England and France, the English workers would do more work, the labor in England being more productive than in any other country (Great Britain 1841, pp. 27–28). Even in Belgium, where the quality of artisans was widely regarded as high, British engineers who worked there assured the members of the committee that "our artisans are a great deal superior than those in Belgium" (Great Britain 1841, p. 53).

[13]Similarly, a British engineer working in Belgium recounted in 1841 that he had hired an Englishman at 12 francs 50 cents, and a Belgian at 7–8 francs, "and the 12.50 man was a great deal the cheapest" (Great Britain 1841, p. 53).

[14]These numbers of course are anything but hard—the same witness (Adam Young) testified a few minutes later that "with one Englishmen I could have done more than with those eight Frenchmen."

[15]Withers attributed this difference to the comparative lack of dexterity among Belgian workmen, and their "nonchalance," and claimed that "as you place Belgian workers with English workers, they need the supervision—as soon as the British workers leave, the local workers fall back on their old ways" (Great Britain 1841, p. 80).

setting up his own mill near Düsseldorf; F.A.J. Egells, a Westphalian locksmith sent by the Prussian government to England in 1819 to study machinery engineering; and Jacob Mayer, who worked for a time at Sheffield before opening a cast-steel mill near Cologne (Henderson 1954, chapter IV).

A CROSS-SECTIONAL ANALYSIS

Wages differed not just between England and France; they also differed significantly within both countries. However, the gaps between wages in French regions were much greater (Chanut et al. 1995). Crébouw's (1986) analysis of official surveys conducted in the 1790s and 1800s suggested that interregional wage gaps across France were then considerable.[16] In the *départements* of Eure or Seine-Inférieure in approximately 1790, a worker might have earned enough to buy a quintal of wheat in what he or she earned in 6–6.5 days. Yet in the Breton *départements* of Morbihan or Ile-et-Vilaine, where wages were lower, it would have taken double the time to earn the same amount (Crébouw 1986, p. 740). In 1840, when data by *département* became available, agricultural wages in Breton *départements* were only 60% the national average, whereas in the *départements* surrounding Paris, they were 25% above the national average. Such gaps exceed those found in industrializing Britain (Chanut et al. 1995; Hunt 1986, pp. 965–66).

The internal variation within France and the availability of data by *département* can be utilized to test our hypothesis. **Tables 3** and **4** summarize some of Grantham's estimates. They show that, calculated in terms of man-days per hectare, labor productivity for wheat in approximately 1800 was highest in the Champagne, Lorraine, and Nord regions and lowest in Brittany and the West. One would expect workers in the former regions to have been taller and more productive than in the latter areas. Were they?

Data by *département* on the average height of conscripts recruited between 1819 and 1826 have been provided by Aron et al. (1972, pp. 92–93). We can use these data to look at the connection between height and wages, although of course the complex causal relation between the two cannot be identified. Still, the strong correlation between the two suggests that high wages in Britain should not be seen as the cause of high labor costs, because high wages were overall associated with high labor productivity.

More detailed departmental data on France in the mid-nineteenth century indicate a strong correlation between height (and other measures of physical well-being) and productivity or wage (**Table 5**). As **Table 6** shows, estimates relating wages and agricultural productivity (measured as wheat yield per hectare divided by man-days per hectare) in 1852 show that not only are the two highly correlated, they are by and large determined by the same variables: both are clearly positively influenced by factors determining physical well-being and by literacy. Urbanization, which is a proxy for Allen's argument about high wages in Britain, is also a factor (as would be expected), but measures of human quality still affect wages and productivity, holding urbanization constant. We include the only variable found in the data that is related to nutrition, namely goiter, the percentage of soldiers rejected from military service because they suffered from goiter, caused by iodine deficiency. Iodine deficiency is also associated with reduced mental capability (see *Lancet* 2008).[17]

[16]"The impression gained from uncertain data, not always easily to interpret, is of two Frances: one of low wages and payments in kind in the northwest, south, and southwest and another of middling or high wages in the north (dominated by Paris and the Normandy region), and even the center. . . . The north—with its combination of high wages, steady employment, and low grain prices—seems clearly privileged" (Crébouw 1986, pp. 733–39; our translation).

[17]Feyrer et al. (2013) found that adding iodine to cooking salt adds significantly to measured IQ and may well be responsible for a considerable part of the secular rise in IQ known as the Flynn effect.

Table 3 Harvest and threshing costs in man-days per acre for wheat in France around 1800[a]

Region	Preharvest (light)	Preharvest (stiff)	Manuring	Harvest	Threshing	Total (light)	Total (stiff)
Paris	24.7	13.6	7.4	12.9	13.5	58.5	47.4
West	31.5	18.0	3.5	14.0	12.5	61.5	48
Bretagne	33.5	20.0	4.7	16.3	15.0	69.5	56
Berri	32.0	18.5	3.0	13.8	11.25	60.05	46.55
Champagne	17.5	10.0	4.0	13.0	9.0	43.5	36
Lorraine	18.5	10.5	4.0	13.0	9.0	44.5	36.5
Nord	11.9	7.1	9.0	9.3	15.3	45.5	40.7

[a]Threshing costs estimated by multiplying yield by man-days per hectoliter. Data taken from Grantham (1993, p. 483).

Similar data for Britain for the nineteenth century are harder to come by, but the little there is confirms our hypothesis of a positive association between high wages and some measure of labor quality. One measure of human capital that seems to have withstood the test of time is an index of age heaping, which tends to be higher among less numerate and educated populations. **Table 7** produces some cross-sectional results for England at the county level. As our dependent variable, we use the wage level at the county level, as reported by Hunt (1986), although these are agricultural wages. The independent variables are a variety of measures of human quality. They include the literacy rate by county adapted from convict data (Nicholas & Nicholas 1992, p. 11) and two measures of nineteenth-century age heaping (Whipple indexes). We also utilize the data on the "quality of diet" developed recently by Horrell & Oxley (2012) and British army height data using the standard source based on the work of Floud, Wachter, and Gregory. All those data are flawed to some extent, yet they are consistent with the hypothesis that wages were associated with a higher quality of the average worker (although it is impossible to disentangle the exact causal relation with the data at hand). The results for the 1760 wage data are obviously weak, with both the height and the nutrition variables having the wrong signs. For the 1790 and 1840 wages, the signs are more reasonable, and perhaps most encouragingly, the wages are thoroughly negatively correlated with the degree of age heaping (which reflects numeracy, education, and innate cognitive ability, to some degree). All in all, the county-level regressions need more work and, in particular, a better measure of the dependent variable.

THE SOURCES OF BRITAIN'S HIGH-QUALITY LABOR

The account above may not solve the problem of British precocity as much as push it back. We need to know more about the deeper sources of British higher labor productivity before the Industrial Revolution. We must separate the underlying causes of better nutrition, leading to better health, strength, and cognitive ability, and those institutions that created the highly skilled artisans. Better nutrition in Britain was surely the result of its higher agricultural productivity, which has been abundantly documented. The debate today is between those who believe that there was an agricultural revolution in the eighteenth century (e.g., Overton 1996) and those who maintain that British agriculture was already quite advanced and productive before 1700. For the purposes of our argument, this matters little because what is necessary for our argument is that British agriculture was better able to feed the country's population than most continental countries. The adoption of convertible husbandry, and the successful breeding of bigger and fatter animals, surely

Table 4 Cost per hectare and per hectoliter in man-days for wheat in France around 1800

Region	Cost per hectare		Cost per hectoliter	
	Light	Stiff	Light	Stiff
Paris	58.5	47.4	3.01	3.63
West	61.5	48	5.17	6.67
Brittany	69.5	56	4.57	5.49
Berry	60.05	46.55	5.05	6.50
Champagne	43.5	36	3.48	4.19
Lorraine	44.5	36.5	3.08	3.69
Nord	45.5	40.7	2.34	2.62

increased the supply of high-protein foods. The exact size of the gap between Britain and France is hard to ascertain, given the fragile data and the strong assumptions needed. Allen's own data imply a ratio of 0.58–1 between France and England (Dennison & Simpson 2010, p. 150), whereas Brunt (2006 p. 15) suggested a ratio of 4.3:1 in favor of Britain. Computing caloric output per worker, England and Wales have an advantage of slightly better than 2:1.[18] A highly productive British agriculture was supplemented by its ability to import food, not just Baltic grains in times of harvest failure, but also a substantial amount of pork from Ireland (Thomas 1985).

Moreover, access to food in Britain was more equally distributed than in other countries. Whether income distribution in Britain was indeed less unequal on the eve of the Industrial Revolution, it clearly had one institution in place that made sure that the worst dangers of malnutrition would be cushioned: the English Poor Law, a unique institution in preindustrial European economic history. The possibility that the Poor Law had a salubrious effect on the Industrial Revolution has already been suggested by Solar (1995). More recent work (Kelly & Ó Gráda 2010, Greif & Iyigun 2013) has expanded on this suggestion through a number of mechanisms. This work suggests that, for example, the Poor Law weakened the Malthusian mechanisms, reduced population growth, and diminished rural unrest. The dimension we are adding here is straightforward: the Poor Law helped create a higher-quality labor force by making food more accessible to those who needed it most. Economic logic suggests that a small reduction in the inequality of income distribution would reduce the inequality of access to food more than proportionally. Moreover, the Poor Law provided a modicum of education and training, even to lads whose parents could not afford the often steep apprentice fees through parish (or pauper) apprenticeships. Whereas in the past pauper apprenticeship has been regarded as exploitative, recent research has taken a somewhat more favorable view of the institution (Humphries 2010, pp. 295–304). Although it rarely provided a very thorough training on the order of private apprenticeship, in many cases it provided a pathway toward useful employment.

[18]The calculation is as follows. For France, around 1785, Fogel (2004, p. 9) estimated a consumption of 1,848 kcal per person. The agricultural labor force is estimated at 61.1% of the population (Broadberry et al. 2013, table 8). These numbers imply an output of roughly 3,020 kcal per agricultural worker per day. For Britain, the calculation is for the year 1750. Kelly & Ó Gráda (2013) estimated the British caloric intake per capita at 3,150 kcal, which, with an agricultural labor force participation at 36.8% (Broadberry et al. 2013), implies an output of 8,560 kcal per worker, a productivity gap of 2.83:1. The actual food supply gap is much smaller, as England had proportionally 40% fewer workers in agriculture.

Table 5 Correlations between height and measures of labor productivity in seven French farming regions[a]

	Average height		Percentage "small"	
	Light	Stiff	Light	Stiff
Preharvest	−0.846	−0.812	0.847	0.810
Hectare	−0.780	−0.732	0.817	0.771
Hectoliter	−0.851	−0.885	0.857	0.891

[a]Data taken from Grantham (1993) and Aron et al. (1972, pp. 86–87, 92–93).

Access to food and the Poor Law may have shifted the entire distribution of labor quality to the right, but they cannot explain the unusual quality of the British skilled artisans. The main source of the high level of technical competence lay in Britain's system of professional training through apprenticeship: in 1700, over one-quarter of males aged 21 had completed an apprenticeship (Mokyr 2009, p. 118). As noted above, the English school system was not impressive by contemporary standards. However, the decisive group during the Industrial Revolution was artisans, and nearly all artisans were trained as apprentices by other artisans. The question is why the English system of apprenticeship worked better than elsewhere.

The importance of a successful system in which artisanal skills were transmitted and acquired cannot be overrated. We should keep in mind that much useful knowledge imparted on young lads was tacit knowledge, which could not be obtained from textbooks or encyclopedias. This was especially true for the coal-using industry, such as with iron, where experience and what J.R. Harris (1992, p. 33) called "unanalyzable pieces of expertise" and "the knacks of the trade" were especially important. But basically apprenticeship was at the core of human capital formation before the Industrial Revolution everywhere. Not all apprenticeships were the same, given that we deal with an institution that survived for centuries in many countries and trades. In some cases, apprentices would live with their masters, becoming part of the household, and were committed to obey and respect them like fathers. The training would be more than technical aptitude; it involved the many mysteries and secrets of the trade (Farr 2000, p. 34). The training took place through "observation, imitation and practice" over many years, during which acquiring human capital and providing labor services were jointly carried out (Wallis 2008, p. 849). For a variety of reasons, the institution of apprenticeship functioned better in Britain than elsewhere. It did so despite being largely an informal institution, that is, with little third party enforcement, although it operated "in the shadow of the law," and there was at least the possibility of going to court if all else failed, although such cases were rare.

In her work on childhood labor and training, Humphries (2003; 2010, pp. 282–83) stressed that, unlike across much of the Continent, apprenticeship in England was not normally enforced and monitored by a guild with coercive powers.[19] Instead, it was largely a self-enforcing institution in a repeated-interaction framework, relying on the capability of local networks based on kin, religion, and personal connections to create reputation effects that made the majority of both masters and pupils cooperate at a reasonable level, even when the contracts themselves were less than complete. This is especially true for the mechanical engineering profession, which, together with clockmakers and instrument makers, millwrights, ironmongers, and colliers, provided a great

[19]The traditional, negative view of European guilds has been disputed by Epstein (1998) but defended by Ogilvie (2008).

Table 6 Regressing 1852 wages in France on measures of labor quality[a]

Dependent variable	Wage (1852)					Agricultural productivity (1852)				
Constant	−20.39 (−5.32)	111.7 (12.83)	−1.316.5 (−2.45)	−1,445.0 (−3.76)	102.3 (13.02)	−10.72 (−5.49)	0.241 (5.85)	−3.99 (−1.53)	−10.12 (−4.76)	0.233 (5.55)
Height	1,322.2 (5.73)		873.1 2.65	954.2 (4.11)		6.76 (5.75)		2.59 (1.62)	6.39 (4.97)	
Literacy		0.867 (5.41)	0.438 (1.96)		0.799 (5.34)		0.0052 (6.88)	0.00395 (3.63)		0.00546 (6.84)
Urban				0.880 (3.96)	0.932 (4.63)				0.00088 (0.72)	
Goiter					−6.418 (−2.24)					−0.0348 (−2.40)
n	86	85	85	86	81	86	85	85	86	81
Adjusted R^2	0.272	0.252	0.303	0.38	0.455	0.274	0.356	0.368	0.27	0.453

[a]t-statistics are given in parentheses.

Table 7 Cross-sectional correlations for England at the county level[a]

Independent variable	Wage (1760)	Wage (1790)	Wage (1840)
Height	−3.78[b] (4.02)	6.92[b] (5.07)	6.48[c] (5.56)
Nutrition	−2.72[d] (0.903)	1.71[d] (1.14)	1.41[e] (1.36)
Whipple indexes[f]	−0.966 (0.41)	−0.669 (0.514)	−1.59 (0.58)
Literacy	−0.05 (0.20)	0.13 (0.25)	−0.05 (0.27)
Constant	472 (276)	−295 (348)	−149 (402)
n	35	35	37
R^2	0.42	0.30	0.25

[a]Standard errors are given in parentheses.
[b]1788–1805 average.
[c]1824–1844 average.
[d]1797.
[e]1834.
[f]Based on data generously provided by J. Voth (see Baten et al. 2014 for details).

deal of the inventive and technical competence of the British Industrial Revolution. In mechanical engineering, as MacLeod & Nuvolari (2009) have shown, would-be apprentices selected from a small number of closely connected firms for their training.

The 1563 statute that formally prohibited craftsmen to carry out their trade without completing their apprenticeship was not uniformly enforced, and after its final repeal in 1814, apprenticeship remained the main form for boys to acquire a professional training. Moreover, an examination of a large sample of indentures (formal contracts between masters and apprentices) reveals a substantial increase in the number of apprentices in mechanical and machine-related occupations in the early stages of the Industrial Revolution (Van der Beek 2010). This system of producing human capital was effective and adaptive and worked well as long as the importance of formal schooling remained limited. It remained largely a private order institution, very much part of a British institutional structure that stood at the center of its success in the early stages of the Industrial Revolution. This institutional structure represented a civil economy, one in which cooperative arrangements between individuals based on shared cultural norms and reputation mechanisms led to outcomes that elsewhere required direct state intervention. Most of Britain's skilled workers were hardly intellectuals, and even some of its most accomplished engineers and inventors often regretted their lack of formal education. But they tended to be well connected. James Watt, famously, was educated at a good grammar school but never had a formal education beyond that (although he networked with some of the best scientists at Glasgow University). John Smeaton, Watt's rival for the position of the best engineer of the age, was also largely self-taught in the art of what was known at the time as "philosophical instruments." He too cultivated friendships and correspondences with people from whom he felt he could learn (Skempton 2002, p. 619). To be sure, Smeaton made a number of important scientific contributions. George Stephenson was entirely self-trained in engineering skills and learned to read and write at age

18. His equally accomplished contemporary, Richard Roberts (inventor of the self-acting mule, among others), was in the understated description of one authority "more interested in making things than learning about them" (Hills 2002, p. 9). The kind of brilliant tinkerer with little formal education but with excellent mechanical intuition, good hands, and a quick mind did not dominate the technological stage for long, but while it lasted, he goes a long way toward explaining Britain's precocity.

CONCLUSIONS

Why was Britain the first industrial nation? Above, we argue that the observation that it was a high-wage nation, although correct, has been misidentified as a causal factor. Instead, high wages reflected the high quality of British labor. This quality took two dimensions: a physical-cognitive dimension and a human capital dimension. The result of the higher quality of its labor force was reflected in higher wages. But the higher quality of workers, especially in the right tail of the skill distribution, also meant that, although Britons may not have been all that much more inventive than their continental competitors, it was much easier for their engineers, technicians, and skilled workers to adopt the new techniques and install, operate, and maintain the equipment in which it was embodied.

The deeper causes of British precocity therefore have to be sought in the reasons for the higher quality of its workers. The physical-cognitive aspects are largely explained by better nutrition, for which there is ample evidence. A more productive agriculture, a better transportation system, and an ability to rely on imported food from the Continent and Ireland explain the well-documented better health and strength of British lads. The higher skills can be explained by better institutions, especially a well-working apprenticeship system and the absence of obstruction by guilds embodying entrenched interests. Another institution, peculiar to Britain, which may be responsible for both better physical quality and to some extent better education, is the Old Poor Law.

All in all, we propose a new narrative as to Britain's economic precocity in the eighteenth century. As such, this narrative is not a full explanation of the Industrial Revolution, because the latter was a European, not a purely British, phenomenon. Britain's advantages were important, but they were temporary. We do not mean to imply that they were a necessary condition for the Industrial Revolution to occur, but they do account for Britain being the lead car in a train that was gathering steam in the late eighteenth century and arrived at its full power after 1870.

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